Journal of Soil Science and Environmental Management Vol. 3(8), pp. 196-206, August 2012
Available online at http://www.academicjournals.org/JSSEM
DOI: 10.5897/JSSEM11.091
ISSN 2141-2391 ©2012 Academic Journals

Full Length Research Paper

Effect of heavy metal and nutrient uptake by soils in Indian Cardamom Hills

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Accepted May 28, 2012

Indian cardamom hill soils were studied to understand nutrient and heavy metal uptake and consequent fertility level changes. Extensive cultivation of cardamom and conversion of forest land to cardamom agriculture resulted in decline of OM and lower pH. Application of chemical fertilizers in the recent past helped enhance the available phosphorus (P). This is surprisingly contrary to the general observation of low P fertility and availability of tropical humid forest soils. Available nutrient concentrations with respect to potassium (K), magnesium (Mg) and sulphur (S) were low in cardamom soils while micronutrient concentrations were well above the proposed critical limits. Agricultural intensification through use of mercurial fungicides and other pesticides in Indian cardamom hill soils has resulted in continuous loading of heavy metals in leaves, seeds and rinds. Such a situation could soon lead to a level sufficient to cause serious fertility and environmental problems.

Key words: Nutrient and heavy metal uptake, soil fertility, tropical agro forest environment.

INTRODUCTION

The soil cover is a major interface between agriculture and environment. It represents the difference between survival and extinction for most land-based life (Doran et al., 1996). Tropical soils considered here are those with hyperthermic and isohyperthermic temperature regimes with mean annual temperatures 22℃ or higher (US, 1992). Strongly weathered soils predominate in the high rainfall areas of tropics where, due to high intensity rainfall and relatively high temperatures, the weathering reactions are rapid and strong leaching environment results in highly stable minerals such as kaolin and sesquioxides. Such minerals have a unique effect on the surface chemical and physical properties of soils. The quality and health of soil determine agricultural sustainability (Acton and Gregorich, 1995; Papendick and Parr, 1992) and environmental quality (Pierzynski et al., 1995) which jointly determines plant, animal and human health (Heberren, 1992). Current research shows that ability of crop plants to resist pests and diseases is due to optimal level of physical, chemical and mainly biological properties of soils. Fertility of soils has been shown to affect all three categories of resistance like preference, antibiosis and tolerance. Growth rate change and maturity are the obvious morphological responses of crops such as cardamom and banana to application of levels of fertilizers (Painter, 1951).

Indian cardamom hills in southern Western Ghats form part of global biodiversity hot spots where cardamom cultivation has been going on for many centuries. These hills (tropical mixed forest agroecosystem) are among the

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potential agriculture areas in India where traditional high value spices are being cultivated since centuries. An area of approximately 86,000 ha from Indian cardamom hills has been earmarked for the exclusive cultivation of small cardamom. The semi-protected soils have steep slopes that are intensively cultivated and highly degraded; these soils primarily koalinitic Ultisols, Oxisols and Inceptisols. Many of these soils are nutrient deficient and therefore crop production is usually enhanced by applications of rather large amounts of fertilizer nutrients. Recently, the system of cultivation has been towards more chemical fertilizer in pursuit of higher yields. Until 1990s, India used to export nearly 80% of its total production to particularly North America and Europe. Because of strict food commodity standards and stringent specifications, the country is unable to export even 10% of our past achievement. Such downtrend is attributed to reported presence of higher contents of heavy metals and pesticides in the cured cardamom. Heavy metals uptake resulting from application of fertilizers in soil and foliar region is found to be very high. Accumulation of lead, cadmium and copper in cardamom capsules causes worries among consumers. A recent survey during 2009 to 2011 revealed that the cardamom planters had applied fertilizers up to 6 to 7 rounds in 2010 and 2011 for both cardamom and coffee plantations in the Indian Cardamom Hills. Number of fungicide sprays (9 rounds) in cardamom had reached all time higher during 2011. Mercurial and copper based fungicides are most commonly used in cardamom plantations. Shetty et al. (2009) reported cardamom cultivation has had maximum amount of pesticides and other agrochemicals under intensive management. This can possibly lead to increased heavy metal concentrations in such soils. Cardamom varieties that are popular among the farmers are more responsive for applied fertilizers (350 kg ha^{-1} NPK in 1993 to 800 kg NPK ha^{-1} in 2007) and manures (3 t ha^{-1} in 1993 to 10 t ha^{-1} in 2007). As a result of such heavy application to monoculture cardamom ecosystem, the soils may pose sustainability threat. Periodic assessment of nutrient concentration and accumulation is imperative (Williams et al., 1982; Ndakidemi and Semoka, 2006; Gou et al., 2007). Hence, there is a growing need to study the above aspects of soil quality in various agroecosystems (Needleman, 1980; Mueller, 1994; McLaughlin et al., 1999; Schoenholtz et al., 2000) for sustainability.

The primary objectives of this study were to: (i) determine both primary and secondary as well as heavy metals concentration in forest and cardamom plantation soils to understand the status in the light of intensive cardamom cultivation; (ii) provide quantitative data on the concentration of heavy and rare metals by examining index leaf and harvested capsule at peak season; (iii) ascertain the sustainability of cardamom eco-system under the present practice of cultivation and fertilizer application.

MATERIALS AND METHODS

Study area

The study area (Figure 1) of cardamom hills (9°15′N to 10°0′N Lat. 76°45′E to 77°25′E Long.) is located in Idukki district, Kerala, southern India. The spread of cardamom hills is approximately 9º North and South of the equator with an altitude ranging from 600-1400 msl. Annual rainfall averages 1650-3000 mm/year and is concentrated between June and November. Annual minimum and maximum temperature varies from 12.5℃ in December to 33.2℃ in April. Soils in the cardamom hills are primarily Oxisols and Ultisols on granitic bedrock with loam to loamy sand surface texture. Argillic and, in some cases, lateritic horizons are present. Soils in valleys are deep (frequently more than 5 m) while on ridges and crest they are shallow up to 1 m. Until early 1950s, the cardamom hills had dense tropical mixed forest and shade pruning was infrequent. In the recent past decades regular and severe shade lopping has been practiced by almost all the growers of cardamom.

Soil sampling and analysis

One hundred and seventy seven composite soil samples from cardamom growing areas as well as undisturbed cardamom hills were collected during the first five months of 2008. Baring 10 from forest sites, rest of the samples were collected from farmers' field. Each composite sample was made up of 8 to 10 sub samples of top soil (0 to 30 cm) collected at random. Sub-samples were collected in a way that they represented the slope of cardamom hill terrain. The soil samples were air-dried, cleaned, pulverized and sieved to 2-mm. The sieved soil samples were properly stored in polyethylene flasks and immediately used for soil chemical analysis. Soil pH in water was determined by a pH meter using soil to water ratio of 1:1 following the procedure by Peech (1965). Organic carbon was estimated by Walkley and Black method (Allison, 1965) and total organic matter (OM) was calculated by multiplying the organic carbon by a factor of 1.72 (Walkley and Black, 1934). Available P was extracted following the Bray I procedure (Bray and Kurtz, 1945). The cation exchange capacity (CEC) was determined by the ammonium saturation method (Chapman, 1965); exchangeable bases (Ca, Mg, Na, and K) were determined by Flame photometry while micronutrients, that is, Cu, Zn, Fe and Mn were extracted using diethylenetriamine penta-acetate (DTPA) at pH 7.3 and determined by atomic absorption spectrophotometry".

Plant sampling and measurement of nutrient element concentration

Healthy panicle bearing tillers selected at random and index leaf (the 5th leaf from the top yielding tiller) were marked in each sampling point and 8 to 10 index leaves were collected to compose a sample. Totally 10 leaf samples were collected across main growing areas of cardamom. Six samples each of about 100 g of cured cardamom capsules were collected from six plantations spread out across the main cardamom growing areas. The leaf samples and cardamom capsules were first washed with tap water while rubbing softly by hand to remove dust and other contaminants and then rinsed in demineralized water acidified with hydrochloric acid (HCl) (0.01 M) before a final rinse in demineralized water. Seeds and capsule rinds were separated and washed carefully. After oven drying at 72℃, leaf samples were ground in a Wiley mill to pass through a 60-mesh stainless steel sieve. The ground leaf samples were digested in distilled concentrated nitric acid followed by hydrogen peroxide treatment. After digestion, the residue was dried and dissolved in 20% aqua regia solution and then analyzed (Jones, 1984) simultaneously for phosphorus (P), Potassium (K),

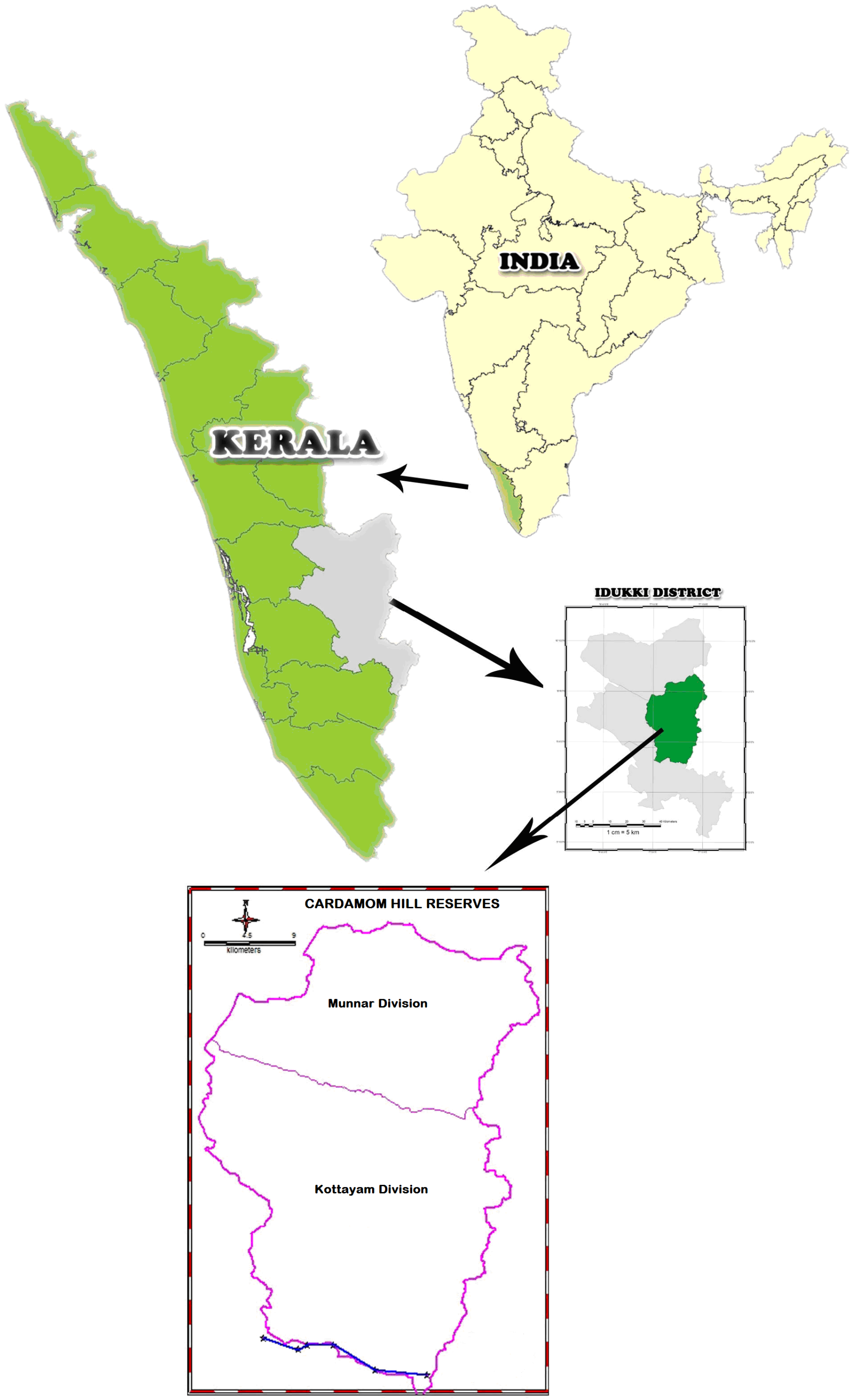

Figure 1. Map showing the study area of Cardamom Hill Reserves (shaded) in Indian Cardamom Hills, Kerala.

calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) on an inductively coupled argon plasma atomic emission spectrophotometer (ICAP-AES). The samples were analyzed on Thermo Electron Corporation's Emission Spectrometer, ICAP 6300 with an Echelle spectrometer covering wavelength range of 166 to 847 nm. It has solid state RF generator

Table 1. Statistical summary of selected chemical properties in top soil layer (0 to 30 cm) of cardamom plantation and undisturbed tropical humid forest (n=174).

Parameter	Cardamom soil							
	pH 1:1	EC m S cm^{-1}	OM %	CEC $Cmol_c kg^{-1}$	K Sat %	Ca Sat %	Mg Sat %	Na Sat %
Mean	4.6	0.1	3.5	6.7	12.7	64.2	19.9	3.0
>Mean %	40.7	38.9	52.6	49.1	47.3	44.9	43.7	38.3
<Mean %	59.2	61.0	47.3	50.9	52.6	55.0	56.2	61.6
Range	3.6-6.7	0.023-0.759	1.15-5.72	1.9-12.13	3.41-34.69	45.2-79.6	11.8-35.9	0.9-7.8
SD	0.60	0.12	0.82	1.93	4.74	6.16	4.27	1.44
CV	12.80	73.99	23.36	28.42	37.10	9.58	21.46	47.12
Skewness	0.91	1.98	-0.10	0.05	0.70	0.36	0.81	1.05
Kurtosis	0.44	6.70	-0.21	-0.09	1.90	0.54	0.65	1.07
	Forest soil							
Mean	4.6	0.1	4.9	13.1	12.1	58.4	22.8	2.8
> Mean %	57.1	28.5	42.8	42.8	71.4	57.1	57.1	42.8
< Mean %	42.8	71.4	57.1	57.1	28.5	42.8	42.8	57.1
Range	4.1-4.9	0.01-0.2	3.0-7.9	5.3-20.3	10.0-13.6	48.3-64.5	18.3-29.8	0.5-6.0
SD	0.30	0.09	1.76	6.13	1.49	5.64	4.44	2.25
CV	6.34	89.33	35.91	46.51	12.21	9.64	19.42	79.18
Skewness	-1.10	0.90	1.03	0.07	-0.86	-1.00	0.34	0.43
Kurtosis	1.53	0.09	-0.06	-2.04	-1.04	0.43	-1.19	-1.98

EC=Electrical Conductivity; OM=Organic Matter; CEC=Cation Exchange Capacity; KSat=Potassium Saturation; CaSat=Calcium Saturation; MgSat=Magnesium Saturation; NaSat=Sodium Saturation.

working at a frequency 27.12 mHz and charge injection device (CID) detector. Plasma ignition and operation are fully automated and controlled from computer using ITEVA Software.

RESULTS AND DISCUSSION

Soil pH and electrical conductivity (EC)

The soil pH of cultivated cardamom soils (Table 1) ranged from 3.6 to 6.7 with nearly 60% of samples (99 samples out of 167) having pH > 4.6 and about 40% of the samples (68 samples) having a pH value of <4.6. Approximately 20% of soil samples had pH values ranging from > 5.5 to 6.7 and this probably is the favorable pH range for spice crops like cardamom, black pepper and vanilla that were grown in the cardamom hills. Undisturbed forest soils showed narrow range of pH (4.1 to 4.9) (Table 1). However, the mean value of pH did not show much change between cardamom and forest soil. Greater soil pH variability was noticed for cardamom soils (CV 12.8%) than the forest soil samples (CV 6.3%), which was the lowest among all parameters analyzed. Although the highest pH values (up to 6.7) were reported for cardamom soil, the range was narrower for forest soil than cultivated cardamom soils. The lowest value of pH (3.6) was observed for cardamom soil. There has been a decrease of pH by 0.5 units in cardamom soils. Therefore, the cardamom agriculture in Indian cardamom hills has resulted n reduction soil pH. If the pH decreases below 4.0, the aluminum oxides will be increasingly susceptible to dissolution and the free aluminum ions in solution will be increased to levels toxic to crops and plants. This ion competes very successfully with other cations for remaining negative sites. Therefore the base nutrients depletion from the soils through tropical wet soil environment may take place. Soils with such low pH values could be associated with phosphorus fixation and some important bases besides the toxicity of some heavy metals (Sanchez and Uhera, 1980; McLaughlin et al., 1999). At the upper range, the difference is more than 1.5 units. Cardamom being a high value spice crop, consultants recommend maximum combination of fertilizer materials disregard to cardamom ecosystem environment and its sustainability. The findings of the earlier reports and published literatures (Korikanthimath et al., 2001) on soil pH status (4.8 to 6.5) of cardamom soils in Kerala are similar to the above results. Therefore, the decrease in pH of cardamom soils is due to the acidifying nature of fertilizers, manures and organic matter as well as other chemicals. Many forms organic matter have acidifying effect depending on the quantity of organic acids as well the quantity of bases they contain. If organic matter of particular plant origin does not contain enough bases to satisfy microbial needs of decomposition, it not only releases CO_2, but also removes calcium and magnesium from the soil. This causes further decrease of soil acidity. Since cardamom soils have lower pH than desired (about 5.5), application of lime with care is essential for healthy crop growth and yield. Variation in electrical conductivity between cardamom soils (0.16 $mScm^{-1}$) and forest soils (0.10 $mScm^{-1}$) was observed. However, the range for cardamom soils (0.023 to 0.759 $mScm^{-1)}$ has been wider than the forest soils (0.01 to 0.27 $mScm^{-1}$). It is well known that the electrical conductivity of soil is directly related to total soluble salt concentration in soil solution. Heavy application of fertilizer nutrients as high as 1000 kg NPK/ha/year (current practice) can increase the total soluble salt concentrations considerably, which might have resulted in increase in the electrical conductivity values of cardamom soils.

Organic matter and cation exchange capacity

Soil OM in agroecosystems is regarded as an important source of soil nutrients and determining factor in the availability of majority of nutrients to crops and plants (Agboola and Corey, 1973). The OM content of cardamom soils and forest soils under investigation, ranged respectively 1.1-5.7% and 3.0-7.9% (Table 1). The average OM values of cardamom soils and forest soils were 3.5 and 4.9% correspondingly. Cultivation of cardamom and conversion of forest to cardamom agriculture resulted in decline of OM. Among cardamom soils, more than 50% of soil samples (88 samples) had higher OM than the mean while 47% of samples (79 samples) reported to have lower than mean. Researchers (Moench, 1991; Murugan et al., 2009) have reported a change of OM in various systems where the average value for cardamom soils was 2.1% while pepper system registered 1.3% from same cardamom hills. This suggests that soil OM declines following conversion from forest or cardamom to pepper and appears to rebuild as mixed cropping replaces pepper even in the absence of soil erosion. Low organic matter levels in cardamom also indicate fertility problems. Soil temperatures measured in open areas were also higher than those under tree cover. This could have probably increased the rate of organic matter decomposition in cardamom soils than the undisturbed forest soils.

Soil OM is found to contain all the nitrogen and much of the phosphorus and sulfur capital of tropical soils (Sanchez and Uhera, 1980). OM is also known to increase CEC (Asadu et al., 1997) to improve soil aggregate stability to microbial population in the soil, and improve water holding capacity. Baruti (1997) found that heavy metals like Zn, Cu and Mn in selected acid soils, were positively correlated with soil OM. Therefore, practices that enrich soil OM should be encouraged mainly because as soil OM decreases, it would be increasingly difficult to get higher yields equivalent to those expected from organic rich soils.

The CEC of forest soils and cardamom soils respectively ranged from 5.3 to 20.3 and 1.9 to 12.1 $Cmol_c\ kg^{-1}$. Mean CEC (13.1 $Cmol_c\ kg^{-1}$) of forest soils were twice that of cardamom soils (6.7 $Cmol_c\ kg^{-1}$) (Table 1). In case of cardamom soils, approximately 50% (47 samples) of the samples analyzed had more than the mean (6.7 $Cmol_c\ kg^{-1}$). National Soil Services (1990) categorized soils having 6.0-12.0 $Cmol_c\ kg^{-1}$ as poor in exchangeable bases for similar soil in Tanzania. Our results compare well with the majority of upland farming systems in the tropics (Juo and Wilding, 1996; Ludwig et al., 2001). They have reported low CEC of < 12 $Cmol_c\ kg^{-1}$. Such low values are typical of weathered soils and have limited capacity to supply plants with nutrients such as Ca^{2+}, K^+ and Mg^{2+}. Because of high rainfall in cardamom hills, soils with low CEC were prone to leaching of nutrients like nitrogen, potassium and magnesium (Ludwig et al., 2001). Therefore, such soils have lower yield potential than those with higher CEC (Asadu et al., 1997). Higher levels of CEC ranging from 13.0 to 31.2 with an average 22.3 $Cmol_c\ kg^{-1}$ for Indian cardamom hill soils were also reported (Korikanthimath et al., 2001). The lower acidity of cardamom soils is mainly due to heavy and regular applications of compost manures up to 15 tons/ha, which equals to minimum 3.4 tons of organic matter addition. Apart from this, an average of 900 kg of NPK fertilizers has been applied every year to achieve higher yield of cardamom.

The above two factors are responsible for decrease in pH which favors higher availability of heavy metals in cardamom soils.

Available N (as nitrate) and P

The available N varied greatly in cardamom soils (1.4 to 83.4 ppm) as well as forest soils (8.2 to 64.4 ppm) with a corresponding mean value of 16.6 and 31.8 ppm (Table 2). Despite the greater diversity of available N in cardamom soils, 66% of samples had registered above mean level. Among the major nutrients investigated, the available N had recorded the second highest value of CV for both cardamom soils (85.7%) and forest soils (64.9%). Instantly the available N of forest soils was twice the mean of cardamom soils. This indicates the higher availability of nitrogen in forest soil systems than its counterpart cardamom soils. Earlier findings of available N in the same cardamom soils showed a range from 3.2 to 5.7 ppm. Higher available N value may be related to the application of nitrogen containing fertilizers which led to accumulation of nitrate nitrogen in cardamom soil systems. Such accumulation can have agronomical, environmental, social and economic implications.

The available P (Bray 1 P) in soils undisturbed forest varied considerably from 18.3 to 95.6 ppm; however, in cardamom soils up to 200 ppm had been reported in our survey (Table 2). Furthermore, the mean available P was

Table 2. Statistical summary of primary and secondary nutrients in top soil layer (0-30 cm) of cardamom plantations and undisturbed tropical humid forest (n=174).

Parameter	Cardamom soil (ppm)							
	N	P1 (Bray)	P2	K Ex	Ca Ex	Mg Ex	SEx	Na Ex
Mean	16.6	108.6	157.1	331.8	883.7	158.1	11.0	45.4
>Mean %	33.5	49.7	68.2	41.3	47.3	48.5	34.7	41.3
<Mean %	66.4	50.3	31.7	58.6	52.6	51.5	65.2	58.6
Range	1.4-83.4	0.09-200	1.9-200	47-785	223-1614	1.73-287	0.09-89.9	3-131
SD	14.24	78.54	64.43	145.43	297.82	48.40	13.26	21.91
CV	85.78	72.26	41.01	43.82	33.70	30.61	91.68	48.21
Skewness	2.05	-0.03	-1.15	0.83	0.26	0.12	2.41	0.90
Kurtosis	5.43	-1.68	-0.25	0.70	-0.42	0.33	8.20	0.67
	Forest soil (ppm)							
Mean	31.8	67.6	154.5	377.0	810.0	217.8	17.3	44.2
> Mean %	42.8	57.1	57.1	57.1	42.8	42.8	42.8	42.8
< Mean %	57.1	42.8	42.8	42.8	57.1	57.1	57.1	57.1
Range	8.2-64.4	18.3-95.6	67.8-200	28-490	485-1145	118-294	5.2-32	4-93
SD	20.70	27.03	58.21	80.00	221.48	61.75	9.11	40.73
CV	64.90	39.95	37.67	21.22	27.34	28.34	52.49	92.03
Skewness	0.62	-0.93	-0.58	0.04	0.11	-0.36	0.49	0.11
Kurtosis	-1.08	0.88	-1.99	-1.82	-0.45	-0.57	-0.41	-2.42

very high for cardamom soils (108.6 ppm) than the forest soils (67.6 ppm). Noticeably, the variability of available P was much higher for cardamom soils (CV 72.0%) than those of forest soils (CV 39.9%). Previous researchers have reported very low values of available P for the Indian cardamom hill soils (44.0 ppm) as well as forest soils (Korikanthimath et al., 2001; Moench, 1991). In accordance with levels given by FMANR (1990) for tropical upland soils of P (>15.0 ppm), most of these soils contain medium to high levels of available P. The recent increase of available P could be the result of application of inorganic and organic P sources to cardamom soils besides P cycling in cardamom agroforest system. In our recent survey in cardamom plantation, we observed farmers practicing 4-6 doses of P sources (10 to 15 t organic manures ha^{-1}) to cardamom soils in a year. In general the status of available P in cardamom soils has been enhanced which is contradicting to the general observation of low P fertility and availability of tropical humid forest soils.

Available K, Ca and Mg

Drastic variation in available K was noticed ranging from 47 to 785 ppm for cardamom soils and 28 to 490 ppm for forest soils. The available K (average) for forest soils (377.0 ppm) was higher than those for cardamom soils (331.8 ppm) (Table 2). Srinivasan et al. (1993) have reported he available K concentration ranging from 1050-2300 ppm in cardamom soils. The possible reason for poor status of available K in cardamom soils can be related to the crop uptake. Cardamom demands more potassium for maintaining its growth and development therefore K supplements become unavoidable in this cropping system. Table 5 shows the concentration of various essential and non essential nutrients in various parts of the crop. The highest concentration (43487 ppm) of K has been reported in cardamom capsule rind. Likewise the concentration of K in leaves also the highest (3.2%) (Table 6). The available Ca concentration was found to vary strongly related between the two soil categories studied. On comparison, cardamom soils (223 to 1614 ppm) had wider range than that of forest soils (485 to 1145 ppm). The mean available Ca for forest soils was 810 ppm while it was 883.7 ppm for cardamom soils (Table 2). Higher values of available Ca were observed for cardamom soils which may be due to the addition of lime stone and other liming materials as a general recommended practice to increase the soil pH range.

The mean available Mg content was higher for forest soils (217.8 ppm) (Table 2) than cardamom soils (158.1ppm). Similar trend was also noticed for available S also in which case the mean available S for forest soils ranged from 5.2 to 32 ppm while for cardamom soils, the concentration varied from undetectable level to 89.9 ppm (Table 2). Since the crop uptake of Mg and S is more than the regular supplements through fertilizers and manures, available S from soil pool has been used up resulting in a decreasing trend for these elements. The trends and status of available Na for the soils studied were, however, opposite of the available Mg and S. The

Table 3. Statistical summary of available heavy metals concentration in top soil layer (0-30cm) of cardamom plantations and undisturbed tropical humid forest (n=174).

Parameter	Cardamom soil (ppm)				
	Zn	Mn	Fe	Cu	B
Mean	3.8	47.1	207.6	17.4	0.3
>Mean %	36.5	39.5	32.3	37.1	40.7
<Mean %	63.4	60.4	67.6	62.8	59.2
Range	0.4-27.5	4.4-146.8	41.8-1378.4	1.1-97.1	0.09-1.1
SD	3.58	31.89	192.84	16.75	0.27
CV	93.44	67.60	92.89	96.16	82.52
Skewness	2.91	1.37	3.25	2.02	0.93
Kurtosis	13.26	1.62	14.04	5.00	-0.13
			Forest soil (ppm)		
Mean	4.3	43.5	104.6	3.9	0.3
> Mean %	42.8	42.8	28.5	57.1	57.1
< Mean %	57.1	57.1	71.4	42.8	42.8
Range	1.7-7.9	11.0-82.3	46.3-208.3	2.2-6.3	0.09-0.6
SD	2.30	23.97	67.89	1.33	0.18
CV	53.24	55.08	64.87	33.49	49.32
Skewness	0.63	0.36	0.99	0.67	-0.41
Kurtosis	-1.06	-0.28	-1.05	0.66	-1.03

cardamom soils (45.4 ppm) are found to have slightly more available Na than the forest soils (44.2 ppm). Upper limit of available Na was much higher for cardamom soils compared to forest soils. This had indicated that accumulation of available Na had occurred due to application of agrochemicals under intensive cardamom cultivation. Interestingly, the highest value of Ca was obtained for available Na (92.0%) in forest soils. Ratios of calcium, magnesium and potassium are very important nutritionally rather than their absolute contents in soil solutions. It is a general practice for cardamom planters to apply enormous quantity of bone meal and fish meal which contain large quantities of sodium and calcium. Liming is also an essential practice to alter the chemistry of soils.

Percent base saturation of Ca, Mg, K and Na

The percentage Ca saturation ranged from 45.2 to 79.6 in cardamom soils with a mean value of 64.2. The forest soils had a Ca saturation value between 48.3 and 64.5%. The cardamom soils showed higher saturation percentage of Ca than the forest soils (Table 1). Mg saturation varied from 11.8 to 35.9% for cardamom soils with an average of 19.9%. The mean value of the Ca saturation for forest soils (22.8%) was slightly higher than the cardamom soils. The range for forest soils (18.3-29.8%) was relatively smaller than for cardamom soils. K saturation values varied widely from 3.4 to 34.6 % for cardamom soils and 10.0 to 13.6% for forest soils. The average for both soil categories was approximately 12%. The variation was maximum for Na (CV 79%) when compared to other bases. The abundance trend of four nutrient elements in both forest and cardamom soils was in the order of Ca > Mg > K > Na. (Table 2).

Available micronutrients

Essential micronutrient concentrations for cardamom soils were in the following order: Fe (207.6 ppm) > Mn (47.1 ppm) > Cu (17.4 ppm) > Zn (3.8 ppm) > B (0.3 ppm). The forest soils also had a similar trend except the third placed Cu, which was replaced by Zn. However, there has been two and four fold increase respectively for Fe and Cu in cardamom soils. In case of B in forest soils, there was a slight increase noticed (Table 3). Owing to higher uptake and demand of cardamom, the available Zn is much lower in cardamom soils than in the forest soils. The abnormal increase in Cu and Fe in cardamom soils may be attributed to the application of several rounds of micronutrient mixtures and fungicides in cardamom agriculture. Substantial increase in the concentration of all the micronutrients between our results and previous reports (Srinivasan et al., 1993) has been observed for the same soils of cardamom ecosystem. This indicates definite accumulation of available form of micronutrients in delicate cardamom ecosystem. In majority of the soil samples studied under cardamom soils, the available micronutrient concentrations (for all the micronutrients) were well

Table 4. Correlation matrix of available heavy metals in top soil layer (0-30cm) of cardamom plantation and undisturbed tropical humid forest (n=174).

Element	Cardamom soil				
	Zn	Mn	Fe	Cu	B
Zn	1.00				
Mn	0.20	1.00			
Fe	0.26	-0.13	1.00		
Cu	0.41	0.40	0.17	1.00	
B	0.11	0.06	0.13	0.23	1.00
			Forest soil		
Zn	1.00				
Mn	0.02	1.00			
Fe	-0.13	0.34	1.00		
Cu	0.32	0.27	0.45	1.00	
B	-0.65	-0.62	-0.01	-0.53	1.00

Table 5. Cardamom leaf nutrients concentration (n=10).

Nutrient	Mean	Range	SD
N %	3.2	2.7-3.7	0.35
P %	0.1	0.09-0.1	0.01
K %	3.2	2.9-3.5	0.15
Mg %	0.4	0.3-0.4	0.04
Ca %	0.2	0.1-0.3	0.04
Cu ppm	19.1	15.0-26.0	3.33
Mn ppm	259.6	124.6-324.0	81.55
Zn ppm	2.1	1.1-3.04	0.73
Fe ppm	283.8	112.6-378.0	108.86

above the critical limits proposed by various authors (Lindsay and Cox, 1985; Hernandez et al., 2007) for tropical forest systems. Zn and Mn in cardamom soil bear a moderate positive correlation with Cu while Fe is positively correlated with Cu in forest soils. A weak correlation exists for Zn and Mn in these soils in contrast to cardamom soils. On the other hand, strong negative correlation is evident for Cu, Zn and Mn for Boron in undisturbed forest soils while the trend is mildly positive for cardamom soils (Table 4). However, Boron has been found to be conservative in both soil types irrespective fertilizer application.

Heavy metal and other nutrient concentrations in cardamom leaf, seed, capsule rind and whole capsules

Very high concentration of heavy metals in cardamom soils could be explained by the heavy application of fertilizers and manures, which contain lot of heavy metal impurities. In addition, Cu in the form of CuO and $Cu(OH)_2$ is applied to control various diseases of cardamom during the rainy seasons. Approximately, four rounds of Cu fungicides in a year adds 60 kg of Cu per ha. Similarly, Zn, Mn, and other fungicides are sprayed on regular basis in cardamom farming. Of all the heavy metals studied here, the most important to consider in terms of food chain contamination are Ar, Cd, Hg and Pb. Other heavy metals relatively pose minimum risk to soils and plant systems. In some of the soil samples the concentration of Hg ranges from 2-4 ppm which is very high and dangerous for soil micro organisms and health. Murugan et al. (2011) found up to 8 to 10% of the cardamom planters have been using mercurial fungicides (Emissan) to control clump-rot disease. However, this has resulted in contamination of cardamom soils with heavy metals.

Recent study reveals that the pesticide use has increased phenomenally because of high density and intensity of cultivation of cardamom. The number of plants/acre has doubled under intensive systems. So the quantity of dry and spray pesticide solutions has doubled accordingly. The survey by Murugan et al. (2011) also

Table 6. Heavy and rare metals concentration (ppm) in cured cardamom capsule (n = 8).

Element	Seed		Whole capsule		Rind	
	Range	Mean	Range	Mean	Range	Mean
As	0.2-0.3	0.3	0.18-0.26	0.2	0.15-0.18	0.16
Ba	18.4-33.2	23.6	42.8-68.1	51.7	224.6-263.5	241.5
Cd	0.03-0.07	0.05	0.03-0.04	0.03	0.07-0.09	0.08
Co	0.02-0.05	0.03	0.18-0.25	0.21	0.4-0.6	0.5
Cr	1.6-2.00	1.7	0.3-0.5	0.39	1.6-1.9	1.7
Cu	5.2-5.6	5.4	6.1-6.3	6.2	7.2-7.8	7.4
Fe	30.1-36.8	32.7	88.0-91.1	89.3	182.8-210.9	197.3
K	9811.2-11400.1	10538.8	16888.5-19235.1	17778.4	40682-47455.1	43487.9
La	0.4-0.7	0.6	0.8-1.09	0.9	1.0-1.4	1.2
Mg	1530.1-1740.3	1567.2	2244.5-2585.8	2384.9	5882.8-6175.3	5994.1
Mn	401.2-430.8	415.7	382.6-401.9	394.2	428.60-591.1	508.3
Na	82.1-107.0	93.8	282.5-302.8	289.8	862.50-1090.1	912.73
Ni	0.19-0.29	0.2	1.8-2.9	2.2	1.92-2.6	2.2
P	1828.5-1938.1	1884.9	1256.4-1272.7	1268.1	728.60-772.5	743.8
Pb	0.17-0.18	0.17	3.2-4.4	3.6	4.82-5.4	5.1
S	982.1-1055.3	1008.4	662.1-761.8	707.7	518.20-563.0	541.1
Se	0.5-0.7	0.6	0.22-0.25	0.2	0.5-4.6	3.3
Sr	8.2-13.1	9.9	22.8-33.1	26.8	88.2-90.3	89.4
Zn	35.1-37.3	36.2	36.6-46.5	40.3	80.2-89.4	84.1

showed that the intensity of pesticide use increased from 27.5 to 35 kg a.i/ha for the 2010 and 2011. Coincidentally, the number of fungicide sprays have been increased from 4 rounds to 9 rounds for the respective years 2009 and 2011.

The heavy metal and other major nutrient concentrations of leaf samples are given in Table 5. The concentrations varied greatly for both major and micronutrients. Among micronutrients Fe and Mn values ranged considerably and which were respectively 112.6 to 378.0 and 124.6 to 324.0 ppm. Corresponding values for Cu and Zn were 15.0 to 26.0 ppm and 1.1 to 3.0 ppm. Both N and K had the highest values in cardamom leaf samples which were in the order of 2.7 to 3.7% and 2.9 to 3.5%. P values (0.09 to 0.1%) were the lowest. A total of 19 essential and nonessential nutrient elements were quantified and the results were given in Table 6 (Figures 2 and 3). The highest concentration of K was reported in capsule rind (43487.9 ppm) followed by whole capsule (17778.4 ppm) and seed (10538.8 ppm). The concentration values for P, Mg and S in seeds were 1884.9, 1567.2 and 1008.4 ppm, respectively. S content of seeds (1008.4 ppm) was higher than those for capsule rind (541.1 ppm) and whole capsule (707.7 ppm). This indicates the higher demand of S for synthesizing amino acids and essential oils in cardamom seeds which are the main source of volatile oils and alkaloids in cardamom. Observed values of other heavy metal accumulation in whole capsules were 0.21 ppm for As, 51.7 ppm for Ba, 0.03 ppm for Cd, 0.2 ppm for Co, 0.3 ppm for Cr, 6.2 ppm for Cu, 89.3 ppm for Fe, 394.2 ppm for Mn, 289.8 ppm Na, 2.2 ppm for Ni, 0.2 ppm Se, 26.8 ppm for Sr and 40.0 ppm for Zn (Table 6). Higher concentration of some of the heavy metals in cardamom capsule rind were Ba 241.5 ppm, 1.7 ppm for Cr, 1.2 ppm for La, 1.7 ppm for Cr, 7.8 ppm for Cu, 197.3 ppm for Fe, 508.3 ppm for Mn, 5.1 ppm Pb, 3.3 ppm Se, 89.4 ppm for Sr and 84.1 ppm for Zn. This indicates that the metal concentration in leaves and capsules were a good reflection of high available metals in cardamom soils mainly through agricultural intensification. McLaughlin et al. (1999) and Loide (2004) have also sounded that such changes in chemical properties and metal uptakes by cardamom soils deserve reorientation of research on basic and applied aspect of “ecological intensive farming of cardamom”.

Conclusion

Sustaining and improving production capacity vis-à-vis inorganic fertilizer application has been found to be a major concern in cardamom soils. Measured data showed that pH of the cardamom soils has been significantly reduced which led to the increased concentration of heavy metals in cardamom soils. Metal concentration in leaves and capsules are a good reflection of high available metals in cardamom soils, mainly by agricultural intensification. The unscrupulous use of fertilizers and lime materials have caused nutrient imbalance and have been detrimental to cardamom production and soil system. Increase of available P was

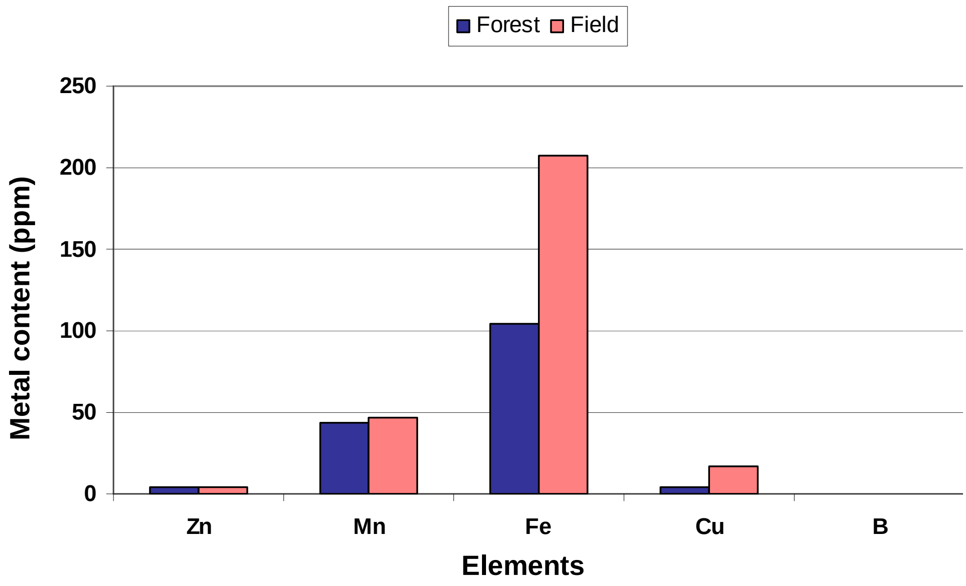

Figure 2. Available heavy metal concentrations (ppm) in forest and cardamom soils.

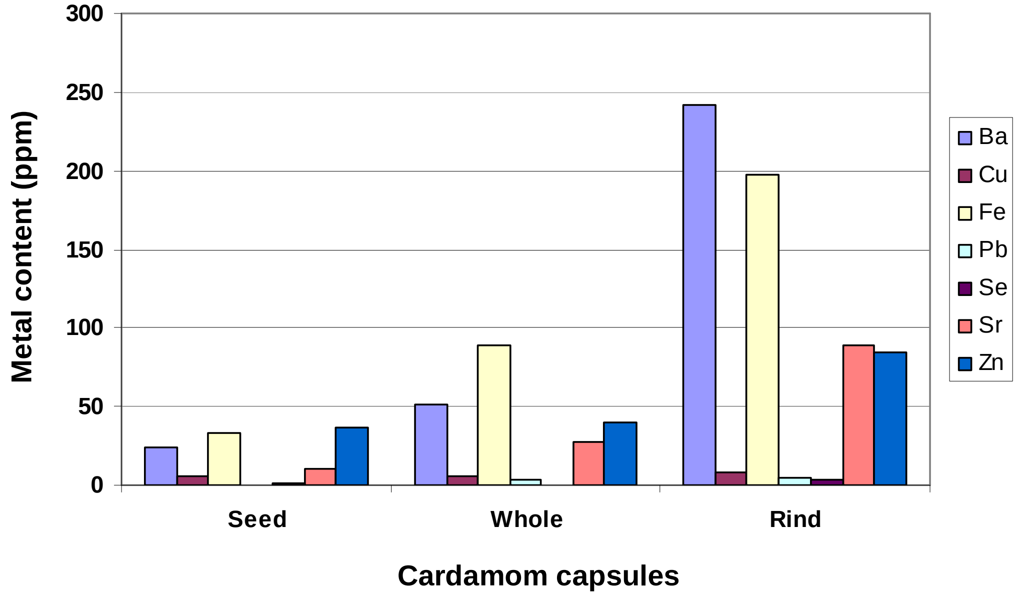

Figure 3. Heavy metal contents (ppm) of cured cardamom capsules.

found to be the result of application of inorganic and organic P sources besides cycling in cardamom agro forest system. This is in sharp agreement with findings of Sanchez and Uhera (1980) that soils with such low pH values could be associated with fixation of phosphorus and therefore, deserve careful investigation. High density and intensity farming of cardamom too has resulted in the accumulation of unwanted chemicals in the cardamom ecosystem which can pose serious social, environmental and health problems to inhabitants of cardamom hills andits overall sustainability.

ACKNOWLEDGEMENTS

The work was supported by National Institute of

Advanced Studies (NIAS), Indian Institute of Science Campus Bangalore in the form of Senior Research Fellowship to the first author. The authors thank the CHR forest officials and cardamom farmers for their co-operations during our soil sampling and survey.

REFERENCES

Acton DF, Gregorich LJ (1995). The health of our soils: toward sustainable agriculture in Canada. CDR Unit, 960 Carling Avenue, Ottawa, ON KIA 0 C6.

Agboola AA, Corey R (1973). The relationship between soil pH, organic matter, available P, exchangeable K, Ca, Mg and nine elements in the maize tissue. Soil Sci. 115:367-375.

Allison E (1965). Organic carbon. In Methods of Soil Analysis. Part 2. ed. C.A. Black, 1367-1378, Am. Soc. Agron. Madison, WI.

Asadu CLA, Diels J, Vanlauwe B (1997). A comparison of the contributions of clay, silt and organic matter to the effective CEC of soils of sub-Saharan Africa. Soil Sci. 162:785-794.

Baruti JHM (1997). Effects of fungicide use on coffee and vegetables on the status of copper and other heavy metals in soils of Lushoto district, M. S. Dissertation, Sokoine Univ. Agric. Tanzania p. 141.

Bray RH, Kurtz LT (1945). Determination of total organic and available form of P in soil. Soil Sci. 59: 39-45.

Chapman HD (1965). Cation exchange capacity. In: Methods of Soil Analysis. Part 2. ed. C.A. Black, 891-901. Am. Soc. Agron. Madison, WI.

Doran JW, Sarandon M, Liebig M (1996). Soil health its sustainability. Ad. Agron. ed. A.L. Sparks. 1-54. 56 Academic Press, San Diego, CA.

Gou X, Li Y, Wang G (2007). Heavy metal concentrations and correlations in rain-fed farm soils of Sifangwu village, central Gansu Province, China. Land Degrad. Dev. 18: 77-88.

Heberren J (1992). View point: a soil health. J. Soil Water Cons. 47:6.

Hernandez AJ, Alexis S, Pastor J (2007). Soil degradation in the tropical forests of the Dominican Republics, Pedernales Province in relations to heavy metal contents. Sci. Total Environ. 378:36-41.

Jones JB (1984). A Laboratory Guide of Exercises in Conducting Soil Tests and Plant Analysis, Benton Laboratories, Athens, Ga.

Juo ASR, Wilding LP (1996). Soils of the lowland forest of West and Central Africa. In: Essays on the ecology of Guinea-Congo rainforest, Proc. Royal Soc. Edinburgh, Scotland, UK, 10B:15-26.

Korikanthimath VS, Hegde R, Gaddi AV, Chandravanshi P (2001). Nutrient management in cardamom. Fert. News. 46:37-48.

Lindsay WL, Cox FR (1985). Micronutrient soil testing for the tropics. In: P.L.G. Vlek, (ed.) Macronutrients in tropical food crop production. International Fertilizer Development Centre, Muscle Shoals, pp. 169-200.

Loide V (2004). About the effect of the contents and ratios of soils available calcium, potassium and magnesium in liming of acid soils, Agron. Res. 2(1):71-82.

Ludwig B, Khanna BK, Anurugsa B, Folster H (2001). Assessment of cation exchange capacity and pH buffering in an Amazonian Ultisol. Geoderma. 102:27-40.

McLaughlin MJ, Parker DR, Clark JM (1999). Metals and micronutrient food safety issues. Field Crop Res. 60:143-163.

Moench M (1991). Soil erosion under successional agroforestry sequence: a case study from Idukki District, Kerala, India. Agrofor. Syst. 15:31-50.

Mueller M (1994). Distribution of cadmium in the food chain (soil-plant-human) of a cadmium exposed area and health risks of the general population. Sci. Total Environ. 156:151-158.

Murugan M, Paddu Shetty, Raju Ravi, Alappan S, Murigendra B (2011). Environmental impacts of intensive cardamom (small) cultivation in Indian cardamom hills: The need for sustainable and efficient practices. Recent Res. Sci. Tech. 3(2):09-15.

Murugan M, Shetty PK, Mukund V, Panigrahy BK, Josephrajkumar A (2009). Soil and surface air warming in cardamom ecosystem in southern Western Ghats, Kerala, India. Int. J. Agric. Rural De. 11(2):52-64.

Ndakidemi, P.A., Semoka, J.M.R. (2006). Soil fertility survey in western Usambara Mountains, northern Tanzania. Pedosphere 16(2):237-244.

Needleman HL (1980). Low level lead exposure- The clinical implications of current research. Raven Press: New York.

Painter RH (1951). Insects resistance in crop plants, University of Kansas Press, Lawrence, KS.

Papendick RI, Parr JF (1992). Soil quality – a key to a sustainable agriculture. Am. J. Alt. Agric. 7:2-3.

Peech M (1965). Hydrogen ion activity. In Methods of Soil Analysis. Part 2. (ed) C.A. Black, 914-926. Am. Soc. Agron. Madison, WI.

Pierzynski GM, Sims JJ, Vance GF (1995). Soils and environmental quality. Levis publishers, CRC press, Baca Raton, FL.

Sanchez PA, Uhera G (1980). Management consideration of acid soils with high phosphorus fixation capacity. (ed.) F.E.Khasawneh, 471-514. Am. Soc. Agron., Madison, WI.

Schoenholtz SH, Van Miegroet H, Burger JA (2000). A review of chemical and physical properties of forest soil quality: challenges and opportunities. For. Eco. Manage. 138:335-356.

Shetty PK, Hiremath MB, Sabitha M, Murugan M (2009). Integrated Pest Management strategies and agricultural sustainability in India. Int. J. Agric. Rural Dev. 11(2):45-51.

Srinivasan K, Vadiraj BA, Krishnakumar V, Naidu R (1993). Micronutrient status of cardamom growing soils of south India. Technical Report of Indian Cardamom Res. Institute, Myladumpara, Spices Board, Ministry of Commerce, Government of India.US Soil Survey Staff, Keys to soil taxonomy. 5th edition SMSS Technical Monograph No. 19. Pochantas Press, Blacksburg, VA, 1992.

Walkley A, Black IA (1934). An examination of Degtjareff method for determining organic carbon in soils: effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci. 63:251-263.

Williams DE, Vlamis J, Pukite AH, Corey JE (1982). Metal movement in sludge amended soils. A nine year study. Soil Sci. 143:124-131.

U.S. Dept. of Agriculture. Soil Conservation Service. Soil Survey Staff. 1992 (draft), 1983, 1972. National Soils Handbook. Washington, DC.

National Soil Service Report, 1990, Detailed Soil Survey Report D28, Agricultural Research Institute, Mingano, Tanga-Tanzania.

Federal Ministry of Agriculture & Natural Resources, FMANR 1990. Literature Review on Soil fertility investigation in Nigeria [In Five Volumes]. Federal Ministry of Agriculture and Natural Resources 281 Pp.