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Impact of Heavy Metals and Other Factors on Soil Acarines in Four Different Edaphic Habitats in and Around a Metropolitan Township

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ABSTRACT

Objectives: The objective was to examine the nature, the extent and the variation of the impact of edaphic factors and heavy metals (Pb, Zn, Cu) on soil acarine populations at different disturbed habitats and at a forest site in and around a metropolitan township.

Method: Four differently used edaphic habitats – a solid waste disposal site, a roadside area, sides of a sewage canal and a natural forest in and around Kolkata were selected for the study. Sampling was conducted for three years with 30 days interval.

Results: Soil moisture and organic carbon exhibited statistically significant and positive correlation with the mite population in all the sites ($p<0.05$), while soil temperature and heavy metals showed weak or strong negative effect in most instances. Solid waste disposal site appeared worst affected.

Conclusion: Edaphic factors and accumulation of heavy metals appeared to render more or less similar impact on acarine populations at the disturbed site irrespective of the nature of the habitats; at the forest site, the nature and the extent however differed.

Key Words: Soil mite, Edaphic factors, Heavy metals, Polluted sites

INTRODUCTION

Among soil mesofauna, Acari is one of the major microarthropod groups and is often found to constitute the largest fraction of them (Bhattacharya, 1979; Choudhuri and Pande, 1981; Sanyal, 1982). Their importance owing to their high numerical abundance and diversity in the context of edaphic environment is well established (Crossley, 1977; Heneghan et al., 1998). Population abundance of mites in soil vary in relation to various environmental factors like temperature, moisture, organic matters, nutrient availability etc. (Choudhuri and Pande, 1981; Sanyal, 1982; Ghatak and Roy, 1991; Tousignant and Coderre, 1992; Rutigliano et al., 2013; Bokhorst et al., 2014). The ecological study of soil microarthopods including mites in polluted or ecologically disturbed areas has drawn the attention of many researchers in different parts of the world (Russek, and Marshall, 2000; Zaitsev and van Straalen, 2001; Iloba and Ekrakene, 2008; Sarkar et al., 2015; Manu et al., 2017). In India however, a few studies on different groups of soil microarthropods in degraded and polluted areas have been attempted (Hazra et al., 1982; Hazra and Choudhuri, 1990; Bhattacharya and Chakraborti, 1994; Ghosh et al., 2007), but specific studies relating edaphic factors and abundance of acarines in degraded or polluted sites is limited when the magnificent variability of observations in their ecology is considered. The present work was therefore taken up to deal with this aspect and to add up to the information base necessary for future assessment of the environmental conditions and biomonitoring as well.

MATERIALS AND METHODS

Four differently used edaphic habitats – a solid waste disposal site, a roadside area, sides of a sewage canal and a natural forest in and around Kolkata were selected for the study. At

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each of the sites, five sub-plots of 1 m^2 area were marked for the collection. Three cores of samples up to 15 cm depth were collected from each of the sub-plots.

1. **Dhapa (Site-I):** This is a dumping ground of city wastes, located by the side of Eastern Metropolitan Bypass and is spread over an area of 35 hectares. Vegetation was sparse in the selected site. *Jacaranda mimosaefolia* (Bignoniaceae), *Calotropis procera* (Asclepiadaceae), *Datura metel* (Solanaceae) and *Lantana camara* (Verbinaceae) etc. were found in the area.
2. **Sides of VIP-Barasat road (Site-II):** VIP-Barasat road is one of the main arterial roads of North Kolkata connecting Ultadanga and Barasat and experiences heavy vehicular movement daily. The present site therefore has been considered as degraded. *Euphorbia hirta* (Euphorbiaceae)*, Colocasia esculenta, Datura metel* (Solanaceae)*, Amaranthus* sp. (Amaranthaceae)*, Acacia auriculiformis* (Mimoseae)*, Michelia champaka, Euphorbia* sp. (Euphorbiaceae)*, Saccharum spontaneum* (Poaceae)*, Calotropis* sp. (Asclepiadaceae) were among the common vegetation at the site.
3. **Tollygunj Nalah (Site-III):** Tollygunj Nalah or Tolly nullah is a remnant of 'Adi Ganga'. Nowadays this nulah receives a large amount of sewage daily from the adjoining human settlements as well as the small industries that have mushroomed around it. The sampling site selected for the present study was located in between Garia metro station and Garia rail station on the embankment of the nulah. *Poinciana regina* (Leguminosae), *Musa* sp. (Musaceae), *Tamarindus* sp. (Leguminosae), *Ricinus communis* (Euphorbiaceae) and *Saccharum* sp. (Poaceae) abounded the sampling site.
4. **Chintamani Abhyaranya, Narendrapur (Site-IV):** This abhayaranya is located near Narendrapur Ramkrishna Mission in south Kolkata. *Dalbergia* sp. (Papilionateae), *Saraca indica* (Annonaceae), *Terminalia arjuna* (Combretaceae), *Adina* sp. (Rubiaceae) *Tamarindus* sp. (Leguminosae), *Ricinus communis* (Euphorbiaceae), *Saccharum* sp. (Poaceae), and *Dryopteris* sp. (Polypodiaceae) constituted the dominant vegetation at the site.

Sampling:

A cylindrical steel holder, an iron rod and a stainless steel core with 5 cm internal diameter and 5 cm depth were used for sampling (Dhillon and Gibson, 1962). Sampling was conducted during three consecutive years (2007-2009) with a monthly interval. Three cores of samples from five subplots (of 1m^2 area) of each of the sites were collected.

Tullgren funnel apparatus modified by Macfadyen (1953) was used for the extraction of soil fauna from the samples in the present work.

Microarthropod groups were separated using needles and fine camel hair brush. They were preserved in tubes with 80% alcohol. Sorting and counting of the microarthropods was done using a wide field stereoscopic microscope with 70x magnification.

Physicochemical parameters:

Physicochemical factors investigated in the present study included soil moisture, soil temperature, organic carbon, pH and heavy metals - copper, lead and zinc.

Soil temperature was recorded at the sites during collection of samples using a soil thermometer. For other edaphic factors, soil samples were tasted in laboratory.

Soil temperature: Soil temperature was recorded from 3 cm depth of soil profile by inserting a mercury thermometer.

Soil moisture: Soil moisture was estimated by following the method suggested by Dowdeswell (1959).

Organic Carbon: Rapid titration method (Walkley and Black, 1934) was followed to estimate the organic carbon content of soil.

Hydrogen ion concentration (pH): The soil pH value was measured from soil suspension using a digital pH meter (Beckman).

Estimation of Heavy metals: Concentrations of three heavy metals– lead, zinc and copper in soil were estimated by atomic absorption spectroscopy using method based on ISO 11047 (1998) (ISO 11047: 1998: Determination of cadmium, chromium, cobalt, copper, lead, manganese, nickel and zinc: Flame and electrothermal atomic absorption spectrometric methods). Soil Analyst 700 atomic absorption spectrometer (Perkin Elmer make) was used for the purpose.

Statistical Analysis:

A natural log transformation of the data was made to meet the requirements of normality data sets whenever necessary in the application of parametric statistical methods that included linear correlation analysis, multiple regression analysis and analysis of variance (ANOVA) (Gerard & Berthet 1966). For statistical analysis, software Minitab, version 5.1.2600 service pack 2 was used.

RESULTS

Soil moisture and organic carbon exhibited statistically significant and positive correlation with the mite population in all the sites, while soil temperature and heavy metals showed weak or strong negative effect in most instances. Interrelations between edaphic factors were also studied along with mite population which indicated negative impact of moisture on metal content in many instances (Tables 1-4).

Site-wise observation on correlation between mite population and physicochemical factors:

Site-I: Soil temperature showed no significant correlation with the abundance, while moisture and organic carbon exhibited strong positive correlation ($p<0.05$). pH was also positively correlated with the abundance ($p<0.01$). Heavy metals (lead, zinc and copper) showed significant negative impact ($p<0.05$) (Table 1).

Site-II: Temperature exhibited no significant relationship with population. Soil moisture and organic carbon had positive correlation ($p<0.01$). Lead and zinc exhibited significant negative effect on abundance ($p<0.05$). pH and copper showed no significant correlation with the same (Table 2).

Site-III: Temperature exhibited strong negative correlation ($p<0.05$). Soil moisture ($p<0.01$) and organic carbon ($p<0.05$) exhibited significant positive effect on the abundance, whereas for pH, lead and zinc, negative correlations ($p<0.05$) were observed. Copper showed no significant correlation with the abundance (Table 3).

Site-IV: Soil temperature showed significant negative correlation ($p<0.05$) with the population abundance. Lead and zinc also exhibited significant negative impact ($p<0.05$). Soil moisture ($p<0.05$) and organic carbon ($p<0.01$) showed positive correlation with the abundance, while pH and copper showed no significant correlation with the same (Table 4).

Regression Analysis (Regression Lines and Multiple Regression):

Equations of regression lines depicting interrelationships between edaphic factors and population abundance of mites were worked out and lines were drawn to see the extent of impact of the factors separately (Figs. 1-4). Besides multiple regression analysis were also performed to investigate the collective impact of the factors (Table 5).

Site-wise observations on Regression Lines and Multiple Regression Analysis:

Site-I: The regression lines had negative slope for temperature, lead, zinc and copper and for the rest, the slope was positive. The adjusted R^2 (Coefficient of determination) ranged from 8.3% (organic carbon) to 48.5% (pH) (Fig. 1).

Multiple regression equation taking abundance of mites as response and seven physicochemical factors were prepared. R^2 value (Coefficient of determination) indicated that the predictors might explain up to 70.9% of variance of the response (mite population). The R^2 adjusted for the number of predictors in the model was 63.6% (Table 5).

Site-II: The slopes of regression lines were negative for temperature, pH, lead, zinc and copper and positive for the rests. The adjusted R^2 showed a range from 5.4% (copper) to 30.4% (moisture) (Fig. 2).

In multiple regression analysis, R^2 value indicated. It showed that the predictors might explain up to 43.3% variance of the abundance of mites, while, 36.6% was the adjusted R^2 (Table 5).

Site-III: Positive slopes of regression lines were noticed for soil moisture, organic carbon and copper. Individual factors could explain 1.9% (copper) to 48.5% (soil moisture) of variation of population as the adjusted R^2 suggested (Fig. 3).

In multiple regression analysis, R^2 value shows that the predictors may explain up to 66.7% of variance of the response while the adjusted R^2 was 58.4% (Table 5).

Site-IV: The slopes of regression lines were negative for temperature, lead, and zinc and positive for the rests. Selected factors, taken separately, could explain from 0.4% (copper) to 40.1% (organic carbon) of variance of abundance data as the adjusted R^2 showed (Fig. 4). R^2 value in the multiple regression analysis indicated that the predictors explained upto 59.5% variance of the response while the adjusted R^2 became 49.3% (Table 5).

DISCUSSION

Negative impact of temperature on mite population is a common observation in West Bengal and earlier reported by workers like Sengupta and Sanyal (1991), Sanyal (1996), Sanyal *et al*. (1999), Roy *et al*. (2004). In other parts of India, Singh and Yadava (1998) and Chitrapati and Singh (2006) recorded positive interaction in Manipur while negative correlation was observed by Tripathi *et al.* (2007) at Thar Desert, Rajasthan. Significant positive correlation with temperature however was reported by Choudhuri and Pande (1981) in Darjeeling Himalayas, while some workers reported the same in other parts of West Bengal (Sanyal, 1981b, 1982; Sanyal and Bhaduri, 1982; Sanyal, 1991a). Of them however, significant positive correlation was reported only by Sanyal (1981b). Negative correlation in Darjeeling was recorded by Choudhuri and Pande (1979, 1981) and Ghosh and Roy (2004).

Significant positive correlation between the soil moisture and the mite populations in the present study was in agreement with several studies conducted earlier (Choudhuri and Pande, 1979; Joy and Bhattacharya1981; Sanyal, 1981a, 1981b, 1982; Sanyal and Bhaduri, 1982; Banerjee, 1988; Sheela and Haq, 1991; Sanyal *et al*., 1999). Choudhuri and Pande (1979, 1981) and Ghosh and Roy (2004) however reported significant negative correlation with moisture in the Darjeeling Himalayas. Besides, Sarkar (1991), Sengupta and Sanyal (1991), Sanyal and Sarkar (1993) and Roy *et al*., (2004) also recorded similar observations in other parts of West Bengal. Singh and Yadava (1998) and Chitrapati and Singh (2006) recorded positive interaction in Manipur and Tripathi *et al.*

(2007) observed the same at Thar Desert, Rajasthan.

Impact of organic carbon on mite populations was significantly positive at all sites. This is in conformity with the earlier observations made in this region (Choudhuri and Pande, 1979, 1981, 1982; Ghosh and Roy, 2004) and other places in West Bengal (Banerjee, 1974b; Bhattacharya and Raychaudhuri, 1979; Joy and Bhattacharya, 1981; Sanyal, 1981a, 1981b, 1982, 1991b; Sanyal *et al*., 1999; Roy *et al*., 2004). Chitrapati and Singh (2006) recorded positive correlation in Manipur and the same was observed at Thar Desert, Rajasthan by Tripathi *et al.* (2007). Negative impact of carbon on acarines however was reported by Chattopadhyay and Hazra (2000) at a few sites in Kolkata when studying the effect of sewage effluents on arthropods.

pH exhibited a varying relationship with mites in the present work. At Site-I the effect was strongly positive, at Site-III significant negative interaction was observed for total mites, correlation was weak at other sites. Different mode of interactions between the mite populations and soil pH has also been reported from various other studies. Bhattacharya and Raychaudhuri (1979), Sanyal (1981b), Sanyal and Sarkar (1993), Sanyal *et al*., (1999), Roy *et al*. (2004) and Tripathi *et al*., (2007) observed negative correlation, while Joy and Bhattacharya (1981), Sanyal (1981a) and Sarkar (1991) reported either weak or significant positive impact of pH. Choudhuri and Pande (1979, 1981, 1982), and Ghosh and Roy (2004) reported negative correlation with pH at different sites in the Darjeeling Himalayas, West Bengal.

Negative impact of heavy metals on the diversity and the abundance of soil organisms including mite is a common observation as it is evidenced from various studies (Dindal *et al*., 1975; Hazra and Choudhuri, 1990; Posthuma and van Straalen, 1993; Gergocs and Hufnagel, 2009; Tyokumbur, 2016; Skubala et al., 2016; Manu et al., 2017). There are however some different observations too (Denneman and Van Straalen, 1991; Gackowski *et al*., 1997; Skubala and Kafel, 2004). Lead and zinc rendered significant negative impact in almost all the instances in the present study while copper exhibited only weak correlation in many cases. Hazra and Choudhuri (1990) reported detrimental effect of lead and copper on mites in West Bengal. Negative effect of lead and copper on the acarine populations was reported by Chattopadhyay and Hazra (2000) at various sites at Kolkata. Hågvar and Abrahamsen (1990) showed that although increasing lead concentration decreased species richness, there were only slight changes in total abundance because the density of several species had grown. High Cu concentration has adverse effects on abundance, growth, and activity of soil fungi which are an essential trophic resource for soil microarthropods including various taxa of mites (Siepel and De Ruiter-Dijkman, 1993; Kuperman and Carreiro, 1997; Gadd *et al*., 2001) and the negative impact of copper on mites may be functional in this way.

Zaitsev and van Straalen (2001) observed that the mite community as a whole was tolerant to the contamination of heavy metals like lead, zinc and copper by a metallurgical plant. Skubala and Kafel (2004) observed that despite the high Zn concentrations, there was no significant decrease in density compared to the control and thus it could be concluded that Zn does not have a significant effect on this group. Similar result was obtained by Hågvar and Abrahamsen (1990). Skubala et al. (2016) observed positive correlation between the Zn content of oribatid mites and their microhabitat which indicate that the group is prone to bioaccumulation of this metal. Other edaphic factors like moisture, pH etc. are also important and should be taken into consideration while investigating the effects of heavy metals on mite population (Steiner, 1995).

For all the edaphic factors cited above, there should be an optimum range favourable for soil organisms including mites, below or above of which the factor may render detrimental effect on the organisms. Different species have their respective physiological needs and range of tolerance for those factors. The qualitative or quantitative characters of the factors at a given site however, may not always develop as per the biological need. Different studies with same components (either organisms or environmental factors or both remaining same) at different time and place may produce different outcome for the above uncertainty. Further, the factors may or may not remain interlinked and may produce combined effect with greater impact of some more important factors.

CONSLUSION

In the control site, i.e., the forest floor, the mode and the extent of impact of the selected factors differed conspicuously from rest of the sites. The acarine community of the sites with polluted or disturbed habitats however appeared to be affected in a more or less similar pattern in spite of their differentiable mode of perturbations.

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Table 1: Correlation analysis between the abundance of soil mites (individuals / month) and the physicochemical parameters at Site-I. TM= Number of total mite, T= Soil temperature, M= Soil moisture, OC= Organic carbon, pH= Soil pH, Pb= Lead, Zn= Zinc, Cu= Copper, * = significant correlation. (Pearson correlation and p-value are mentioned).

	TM	T	M	OC	pH	Pb	Zn
T	-0.325						
	0.053						
M	**0.655***	-0.212					
	0.000	0.214					
OC	**0.331***	-0.296	**0.404***				
	0.049	0.080	0.014				
pH	**0.707***	-0.172	**0.494***	0.115			
	0.000	0.316	0.002	0.506			
Pb	**-0.415***	0.315	**-0.620***	**-0.395***	-0.312		
	0.012	0.062	0.000	0.017	0.064		
Zn	**-0.483***	0.106	**-0.368***	-0.029	-0.277	0.273	
	0.003	0.539	0.027	0.867	0.101	0.107	
Cu	**-0.442***	0.149	**-0.438***	-0.149	**-0.364***	**0.413***	**0.365***
	0.007	0.387	0.008	0.385	0.029	0.012	0.029

Table 2: Correlation analysis between the abundance of soil mites (individuals / month) and the physico-chemical parameters at Site-II. TM= Number of total mite, T= Soil temperature, M= Soil moisture, OC= Organic carbon, pH= Soil pH, Pb= Lead, Zn= Zinc, Cu= Copper, * = significant correlation. (Pearson correlation and p-value are mentioned).

	TM	T	M	OC	pH	Pb	Zn
T	-0.317						
	0.060						
M	**0.569***	-0.177					
	0.000	0.301					
OC	**0.562***	-0.313	**0.568***				
	0.000	0.063	0.000				
pH	-0.286	-0.248	**-0.368***	**-0.411***			
	0.090	0.145	0.027	0.013			
Pb	**-0.347***	0.234	-0.123	-0.189	-0.144		
	0.038	0.169	0.474	0.270	0.404		
Zn	**-0.343***	0.178	**-0.538***	**-0.486***	0.178	0.077	
	0.041	0.300	0.001	0.003	0.300	0.654	
Cu	-0.284	-0.179	-0.276	**-0.360***	0.183	**0.410***	0.210
	0.093	0.297	0.103	0.031	0.285	0.013	0.219

Cell Contents: Pearson correlation
P-Value

Table 3: Correlation analysis between the abundance of soil mites (individuals / month) and the physico-chemical parameters at Site-III. TM= Number of total mite, T= Soil temperature, M= Soil moisture, OC= Organic carbon, pH= Soil pH, Pb= Lead, Zn= Zinc, Cu= Copper, * = significant correlation. (Pearson correlation and p-value are mentioned).

	TM	T	M	OC	pH	Pb	Zn
T	**-0.338***						
	0.044						
M	**0.704***	-0.221					
	0.000	0.194					
OC	**0.353***	-0.134	0.261				
	0.035	0.435	0.124				
pH	**-0.338***	**-0.421***	**-0.396***	-0.218			
	0.044	0.011	0.017	0.202			
Pb	**-0.396***	**0.490***	-0.194	-0.231	-0.200		
	0.017	0.002	0.256	0.176	0.242		
Zn	**-0.443***	0.091	**-0.500***	-0.163	0.111	-0.070	
	0.007	0.598	0.002	0.342	0.519	0.685	
Cu	0.217	0.214	0.239	0.159	-0.325	0.065	-0.042
	0.204	0.210	0.160	0.355	0.053	0.706	0.807

Cell Contents: Pearson correlation
P-Value

Table 4: Correlation analysis between the abundance of soil mites (individuals / month) and the physico-chemical parameters at Site-IV. TM= Number of total mite, T= Soil temperature, M= Soil moisture, OC= Organic carbon, pH= Soil pH, Pb= Lead, Zn= Zinc, Cu= Copper, * = significant correlation. (Pearson correlation and p-value are mentioned).

	TM	T	M	OC	pH	Pb	Zn
T	**-0.333***						
	0.047						
M	**0.534***	-0.174					
	0.001	0.310					
OC	**0.647***	-0.246	**0.603***				
	0.000	0.149	0.000				
pH	0.132	0.107	0.264	0.172			
	0.442	0.535	0.120	0.317			
Pb	**-0.382***	0.180	**-0.452***	**-0.343***	-0.299		
	0.022	0.292	0.006	0.041	0.076		
Zn	**-0.394***	**0.395***	-0.069	**-0.404***	0.080	0.253	
	0.017	0.017	0.689	0.014	0.642	0.137	
Cu	0.063	-0.140	**-0.403***	-0.173	-0.277	0.299	0.115
	0.716	0.416	0.015	0.313	0.103	0.077	0.504

Cell Contents: Pearson correlation
P-Value

Table 5: Multiple regression equations taking the monthly abundances of soil mites as the response and the selected edaphic factors as the predictors.

Site-I

TM = -2.14 -0.357T +0.574M +0.183 OC +3.19 pH +0.200Pb -1.70 Zn -0.335 Cu

R^2 = 77.7% R^2(adj) = 72.1%

Site-II

TM = 12.4 - 0.760 T + 0.830 M + 0.207 OC - 0.655 pH - 0.631 Pb + 0.048 Zn - 0.081 Cu

R^2= 55.4% R^2(adj) = 44.2%

Site-III

TM = 17.5 - 0.808 T + 0.911 M + 0.156 OC - 1.15 pH - 1.20 Pb - 0.709 Zn + 0.440 Cu

R^2= 64.3% R^2(adj) = 55.4%

Site-IV

TM = 2.63 - 0.096 T + 1.17 M + 0.310 OC + 0.47 pH - 0.412 Pb - 0.965 Zn + 0.441 Cu

R^2= 61.0% R^2(adj) = 51.2%

TM= Number of mites/ month, T= Soil temperature, M= Soil moisture,
OC= Organic carbon, pH= Soil pH, Pb=Lead, Zn= Zinc, Cu= Copper
R^2 = Coefficient of determination, R^2(adj)= Coefficient of determination adjusted for the degree of freedom

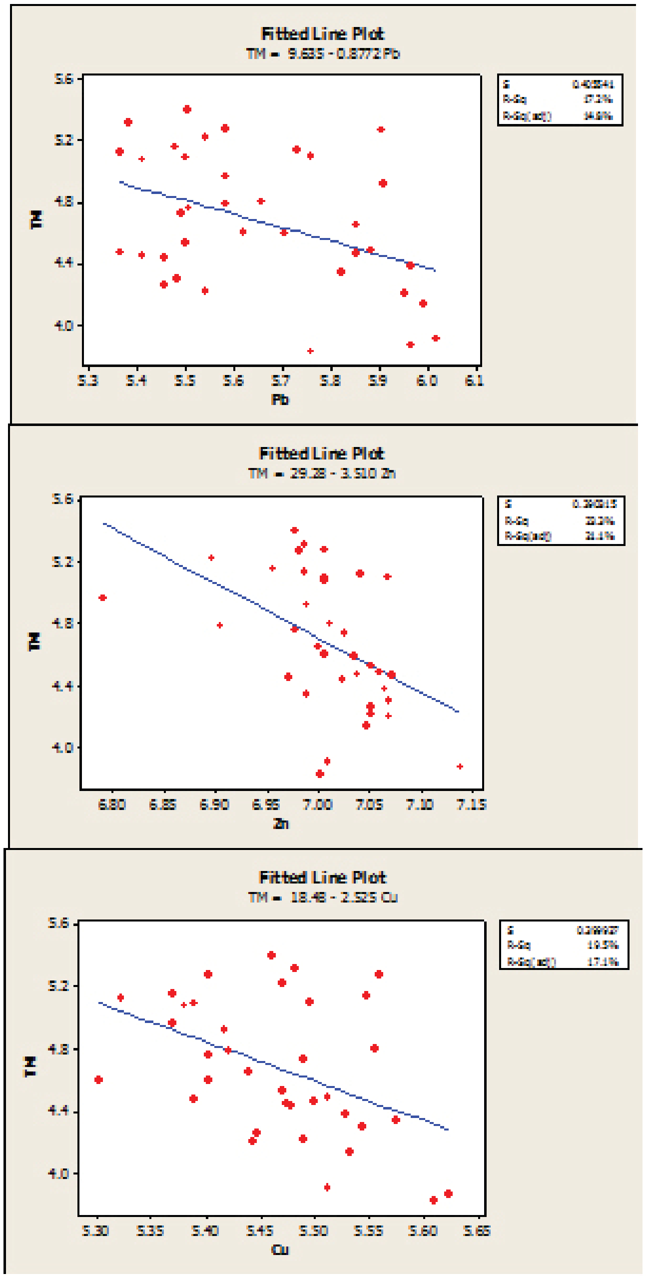

Figure 1: Regression line for the population abundance of total mites and lead (Pb), zinc (Zn) and copper (Cu) at Site-I. (S = Standard distance of data values from regression line. R-Sq = Coefficient of Determination. R-Sq (adj) = Coefficient of Determination adjusted for the number of observations. TM= Total mites.

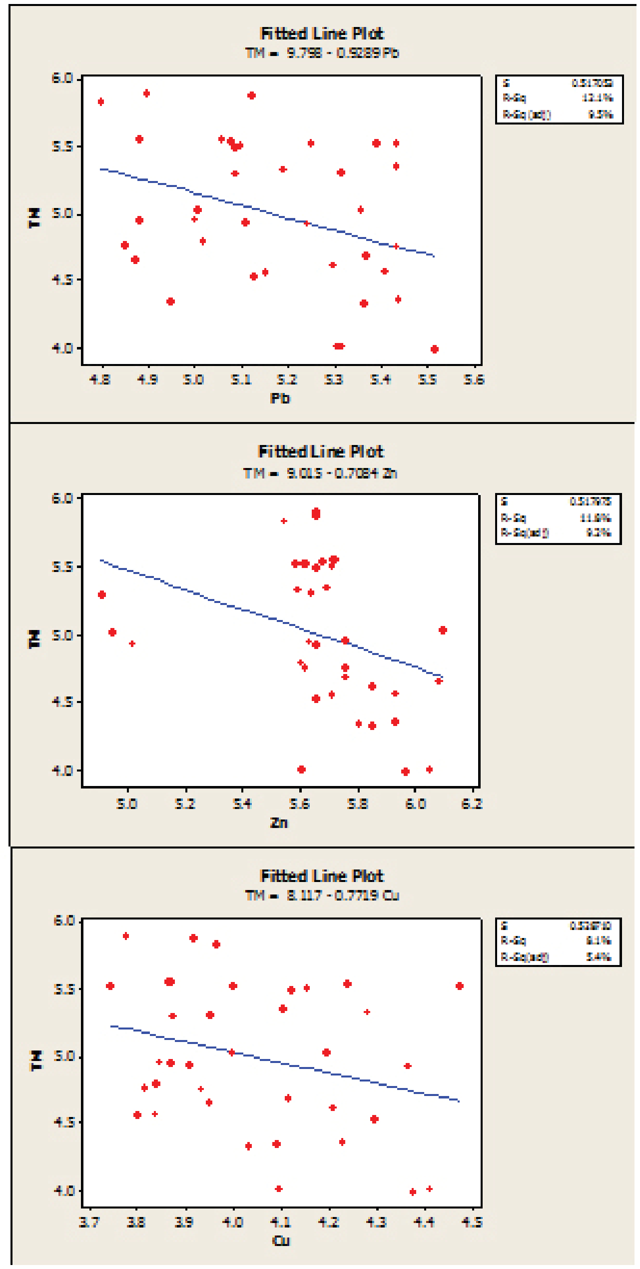

Figure 2: Regression line for the population abundance of total mites and lead (Pb), zinc (Zn) and copper (Cu) at Site-II. (S = Standard distance of data values from regression line. R-Sq = Coefficient of Determination. R-Sq (adj) = Coefficient of Determination adjusted for the number of observations. TM= Total mites.

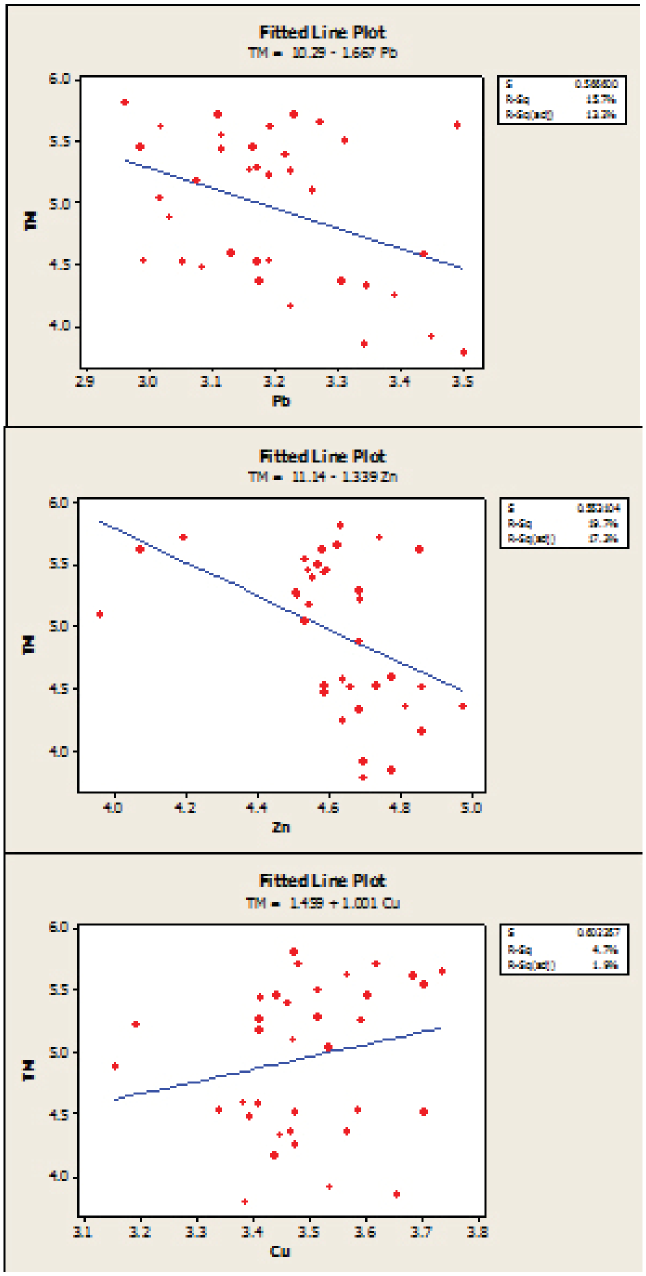

Figure 3: Regression line for the population abundance of total mites and lead (Pb), zinc (Zn) and copper (Cu) at Site-III. (S = Standard distance of data values from regression line. R-Sq = Coefficient of Determination. R-Sq (adj) = Coefficient of Determination adjusted for the number of observations. TM= Total mites.

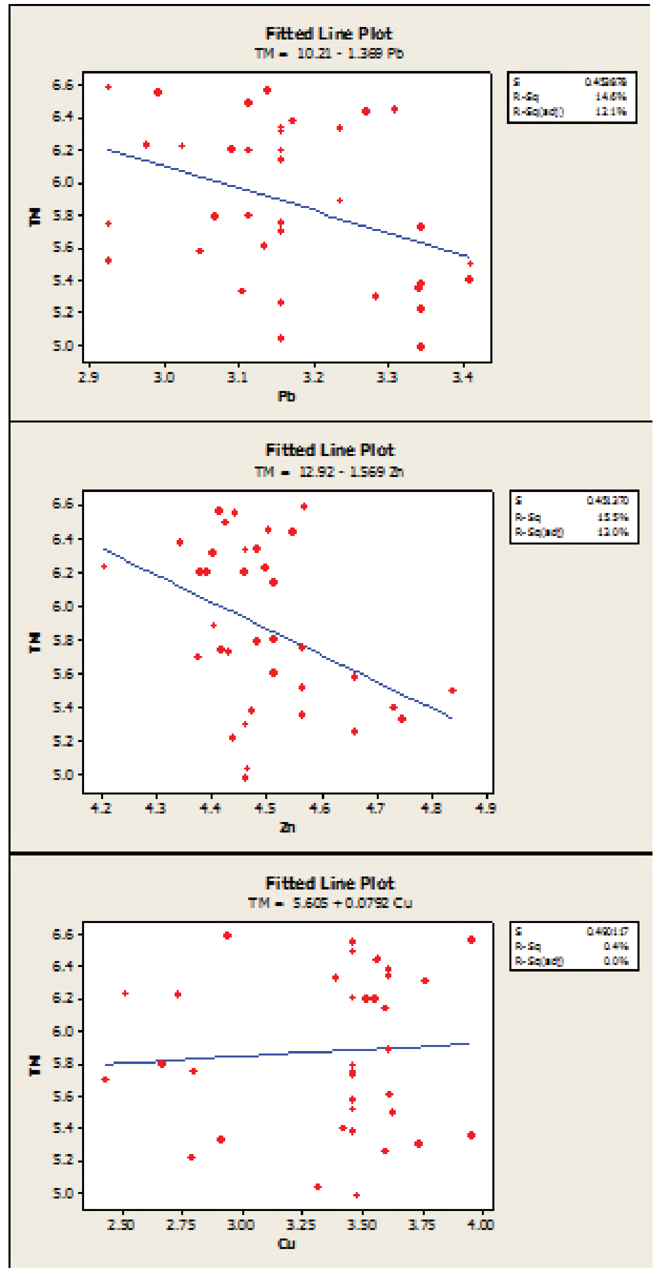

Figure 4: Regression line for the population abundance of total mites and lead (Pb), zinc (Zn) and copper (Cu) at Site-IV. (S = Standard distance of data values from regression line. R-Sq = Coefficient of Determination. R-Sq (adj) = Coefficient of Determination adjusted for the number of observations. TM= Total mites.