RESEARCH ARTICLE

# Assessment of Essential Nutrients in Soil with Litter Chemistry of Tropical Deciduous Forest, India

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## Abstract

We investigated assessment of essential and non-essential nutrients in soil along with litter chemistry in the tropical deciduous forest at Katerniaghat Wildlife Sanctuary, India. Three forest communities in teak plantation (TP), sal mixed (SM) and dry mixed (DM). The factors examined were nutrients contents chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel(Ni), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), molybdenum (Mo), cadmium (Cd), lead (Pb) and carbon in soil and litter. Majorly of essential nutrients levels were higher in the DM followed by SM and TP in soils. Zn was increased in TP, while Cu in SM soils at the depth of 0-15cm. Overall litter nutrients, concentration was maximum in DM. But some litter nutrients as like Ni and Zn maximum in the SM and TP. TOC was maximum in SM (19.23 g $kg^{-1}$) followed by DM (17.74 g $kg^{-1}$) and TP (13.62). Litter C was also increased in DM followed by SM and TP.

**Keywords:** Litter chemistry, Nutrients, TOC, Tropical deciduous forest.

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## Introduction

In forested ecosystems, litterfall represents the main pathway of nutrient transfer from the plants to the soil through the process of primary productivity (Vitousek, 1982; Vitousek and Sanford, 1986; Clark *et al.,* 2001). Forest litter plays an important role in determining nutrient cycling, balance and maintaining ecosystem function. Plant uptake the nutrients found as soluble components in the soil solution or easily solubilized by root exudates (Blaylock and Huang, 2000). The influences of nutrient supply on litter substrate quality is unpredictable because the internal concentration nutrient in live leaves and aging leaves absorb different nutrients, litter leaf nutrient leaching, and species with maximum nutrient content accompanied soil nutrient cycling (Aerts *et al.,* 1997). The nutrients Cr, Cd, Ni, Cu, Zn takes part in the biological turnover and their excess or lack presence cause disturbances in the vegetation growth and productivity (Jaakkola *et al*., 1994; Adomaitis *et al.,* 2003). Essential nutrients such as Co, Cu, Fe, Mg, Ni, and Zn play a significant role in plant development. León and Osorio (2014) provide the litter nutrient content and decomposition in process different land uses in Colombia. They observed that the return of organic matter and nutrient from litter fall depend on the environmental factor that influences the decomposition process. The litter nutrient, changes with plant community impact the structure and activity of microbial community inhabiting in the soil (Kutsch and Dilly, 1999). Soil aeration, microbial activity, and mineral composition also affect the availability of nutrients in soils (Magnuson *et al.,* 2001). Nutrients also modify soil properties, especially soil biological properties (Friedlova, 2010). Hernandez *et al.* (2003) observed the higher concentration of nutrients Cd, Cr, Cu, Zn and Ni in the soil of natural forests. Nutrients have been found to aggregate in surface organic layers and as a result, affect the biological activity in forest soils because of their strong congeniality with organic matter. The standard ratio of nutrients in soil has been provided in the report of (NJDEP, 1996). Cd in quantity 1 mg $kg^{-1}$ soil, Pb 150 mg, Zn 100 mg and Cu 20 mg $kg^{-1}$ (Wilson, 1979; Berg *et al.,* 1989; Atanassov *et al.,* 1999), do not have so far adverse effect soil organisms. A soil nutrient is a significant factor controlling litter decomposition because of the essential nutrients in the soil or litter material impact community and activity of decomposers (soil organisms). Such complexity and interrelationship justify the need for further studies in tropical soils because of contrasting chemical, physical and mineralogical characteristics (Soares *et al.,* 2005; Fontes and Alleoni, 2006). The scientific literature poorly addressed the subject of soil nutrients levels in tropical countries (Davies, 1997, Naidu *et al.,* 1998; Kookana and Naidu, 1998; Campos *et al.,* 2003; Udom *et al.,* 2004). In this study, assess attended to of essential nutrients of soil with litter chemistry in three forest communities tropical deciduous forest, which will in helping us to understand forest soil nutrient dynamics and soil carbon sequestration.

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## Materials and methods

### Study Area

The study was conducted in the Katerniaghat Wildlife Sanctuary (KWLS) in tropical deciduous forest, North India (Fig. 1). According to Rodgers and Panwar (1988) the area falls under the Terai Bhabar biogeography sub-division of the upper Gangetic plain. The geographically located between 27°41′ and 27°56′ N latitude and 81°48′ and 81°56′ E longitude and the area is 409 $km^2$ (Jha, 2000). This area experiences a tropical monsoon climate. An annual temperature at the KWLS a range between 40.5°C to 3.5°C, with an average annual rainfall of 1495 mm (Behera *et al.,* 2012).

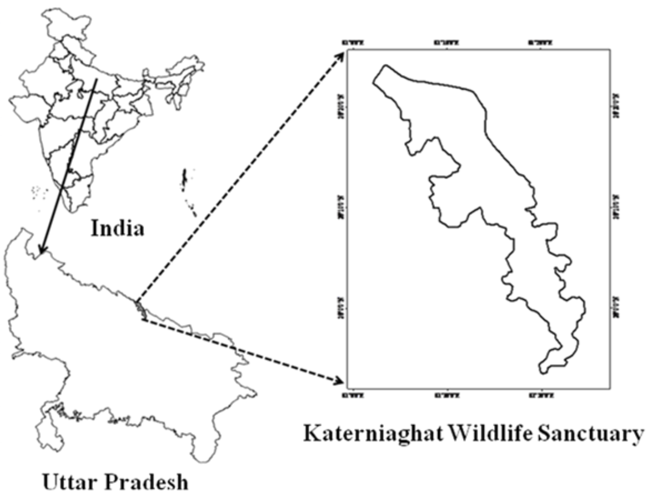



**Fig. 1:** The study area of Katerniaghat Wildlife Sanctuary in tropical deciduous forest from North India

## Soil and Litter Collection

The sampling (i.e., soil and litter) was done based on soil homogeneity and ground vegetation. The sample was collected during June 2016 in three forest communities, i.e., Teak plantation (TP), Sal mixed (SM) and dry mixed (DM). From each forest site randomly soil samples were collected from two soil depth (i.e., 0–15 and 15–30 cm) because the most changes are expected in these regions. The sample of 200 g from the pooled samples was taken, air dried and sieved to pass through 2 mm mesh sieves before analysis. The quantification of litter production was estimated by randomly placing the 10 litter traps (each 1 $m^2$ area) by Hughes *et al.* (1987) with a perforated plastic sheet wrapping the base bottom under the canopy of each tree species in all the three permanent plots. The litter samples were air dried in the laboratory and samples were kept at 80°C for 48 h to prepare the dry mass (Swamy and Proctor, 1994).

## Analysis of Soil and Litter Nutrients

The soil sample was air dried, sieved through 2 mm governorates sieves for analysis. Litter parts segregated into different parts as like leaves, branch, seed and miscellaneous. The sample of soil and litter parts was chemically analyzed for detection of nutrients (Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Cd, Pb). Accurately 0.5 gm of dry powder of sample was weighted and digested with concentrated $HNO_3$, $H_2SO_4$ and $H_2O_2$ (1:3:3) (Mishra *et al.,* 2014). The blanks were run with the set, and the sample was analyzed in inductive coupled plasma mass spectrometer (ICP-MS). Total organic carbon (TOC) of soil was measured by TOC analyzer malty N/C 300 analytic Jena AG, Germany. Carbon content was measured by isotope ratio mass spectrometer (IRMS).

## Statistical Analysis

Analysis of variances (ANOVA) was used to do statistical assess in the different forest communities on nutrients of soil and litter. Statistical analysis was conducted using Sigma Plot 11.0 version (Systat Software, Inc. USA) and Microsoft Excel 10.0 version. Pearson correlation was also used to check for correlation between different nutrients. PCA (principal component analysis) was used against different nutrients and forest communities (PAST 2.00; Hammer *et al.,* 2001).

# Results and Discussions

## Nutrients concentration in soil

Nutrients occur in the environment in two forms as essential and non-essential, and they come in soil biota from different origins like a natural process and anthropogenic activities. Essential nutrients concentrations in soils have been used as an indicator for soil carbon sequestration. Soil nutrients like Cr, Mn, Fe, Zn, Co, Cu, and TOC were higher in the DM followed by SM and TP at the depth of 0–15 cm (Table 1). Hou *et al.* (2014) observed maximum essential nutrient comparison in the natural forest plantation in Remnant forest China. Nutrients like Cr, Ni, Fe, Zn, Co, Cu, Cd, and Pb with maximum TOC were observed in the temperate forest (Hernandez *et al.,* 2003).

**Table 1:** Soil nutrients (mean value) at the depth of 0–15 cm and 15–30 cm in tropical deciduous forest from north India, total organic carbon (TOC), carbon (C), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel(Ni), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), molybdenum (Mo), cadmium (Cd), lead (Pb)

| *Forest type* | *Site* | *Cr* | *Mn* | *Fe* | *Co* | *Ni* | *Cu* | *Zn* | *As* | *Se* | *Mo* | *Cd* | *Pb* | *TOC g kg$^{-1}$* | *References* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Southern China forest | Dashanchong (Changsha) | | | | | | 33 | 243.5 | | | | 1.2 | | | Liao *et al.* (2007) |
| | Shizhuyuan (Chenzhou) | | | | | | 21.2 | 289.4 | | | | 1.9 | | | |
| Tropical dry evergreen forest, Coromandel Coast, India | Puthupet | 67 | | | 5 | 13 | 8 | 24 | 5 | | | | 14 | 16 | Sudhakaran and Ramamoorthy (2014) |
| | Oorani | 26 | | | 4 | 9 | 5 | 25 | 5 | | | | 12 | 11.2 | |
| | Vadaagram | 38 | | | 5 | 13 | 9 | 21 | 6 | | | | 11 | 11.55 | |
| | Palvathunan | 37 | | | 5 | 14 | 13 | 36 | 4 | | | | 9 | 20.25 | |
| | Sendrakillai | 35 | | | 5 | 12 | 6 | 30 | 3 | | | | 11 | 18.2 | |
| Moist deciduous forest, Tamil Nadu, India | Siruvani hills | | 418.75 | 9747 | | | 15 | 35.46 | | | | | 44.29 | 15.1 | Mohanraj *et al.* (2000) |

*(Cont...)*

(Cont...)

| *Forest type* | *Site* | *Cr* | *Mn* | *Fe* | *Co* | *Ni* | *Cu* | *Zn* | *As* | *Se* | *Mo* | *Cd* | *Pb* | *TOC g kg$^{-1}$* | *References* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nigeria | EGASPIN, Department of Petroleum Resources, Lagos, Nigeria. | 20 | | | | 140 | 0.3 | | 200 | | | 100 | 35 | | DPR-EGASPIN (2002) |
| | Proposed Cleanup Standards for Contaminated Sites | 100 | | | | | | 1500 | | | | 100 | 600 | | NJDEP (1996) |
| Remnant natural and plantation forests, China | Natural | 1.5 | 4.1 | | | 2.5 | 17 | 1.1 | | | | | 25.1 | | Hou *et al.* (2014) |
| | Plantation | 0.4 | 7.7 | | | 1.8 | 23.3 | 1.8 | | | | | 12.6 | | |
| French Forest | Haute Vienne (10-30) | 14.35 | | | 1.36 | 4.12 | 3.05 | 67.04 | | | | 0.17 | 23.83 | | Hernandeza *et al.* (2003) |
| | Seine Maritime (6–15) | 25.8 | | | 0.87 | 2.24 | 3.94 | 12.19 | | | | 0.14 | 11.41 | | |
| | Vosges (12–17) | 14.82 | | | 1.13 | 4.49 | 2.5 | 24.67 | | | | 0.11 | 12.04 | | |
| | HautesAlpes (0–15) | 102.77 | | | 15.92 | 52.75 | 29.45 | 116.6 | | | | 0.26 | 27.67 | | |
| | Loir et Cher (15–30) | 37.77 | | | 6.27 | 8.05 | 10.41 | 61.87 | | | | 0.17 | 17.96 | | |
| Tropical deciduous forest, North India | Teak plantation (0–15) | 13.9 | 171.7 | 487.0 | 0.8 | 2.9 | 1.6 | 89.1 | 8.0 | 0.1 | 0.1 | 1.0 | 17.2 | 13.6 | Present study |
| | Sal forest (0–15) | 22.9 | 218.9 | 743.9 | 3.4 | 7.5 | 12.6 | 40.8 | 0.4 | 0.1 | 1.8 | 1.0 | 25.1 | 19.4 | |
| | Dry mix forest (0–15) | 35.4 | 296.3 | 1158.0 | 4.8 | 8.1 | 8.9 | 48.7 | 0.6 | 0.1 | 0.9 | 2.6 | 25.5 | 18.4 | |
| | Teak plantation (15–30) | 8.5 | 124.9 | 287.9 | 0.0 | 0.5 | 1.5 | 83.7 | 2.0 | 0.0 | 0.7 | 0.4 | 12.0 | 13.0 | |
| | Sal forest (15–30) | 25.4 | 199.7 | 767.5 | 3.9 | 23.7 | 10.7 | 66.1 | 3.2 | 0.0 | 1.9 | 0.2 | 21.3 | 17.44 | |
| | Dry mix forest (15–30) | 33.9 | 323.9 | 1081.7 | 5.7 | 5.3 | 16.4 | 52.5 | 2.5 | 0.0 | 0.3 | 0.8 | 29.8 | 17.74 | |

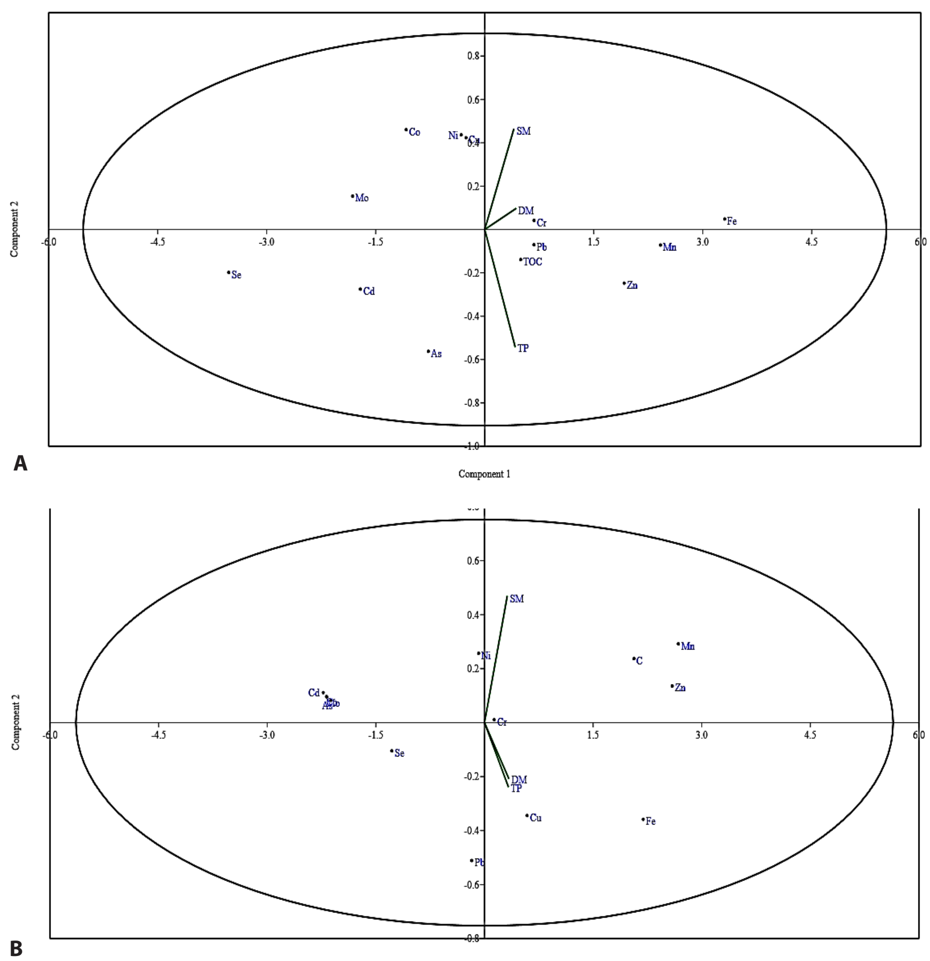
Sudhakaran and Ramamurty (2014) observed the Cr, Co, Ni, Cu, Zn, Pb with TOC in tropical dry evergreen forest, India (Table 1). Mohanraj *et al.* (2000) reported a concentration of Mn, Fe, Cu, Zn, and Cd with maximum TOC. Maximum Ni was found in SM at the depth of 15-30 cm. Table 2 showed the Pearson correlation was established between nutrients and TOC. TOC positively correlated with Cr, Mn, Fe, and Co. Some nutrients have stabled correlated with Cr/Mn/Fe/Co. Akoto (2016) also established a strong correlation between Pb/Cu, Cu/Zn, Fe/Pb, and Cr/Co. Eigen values in three axis were observed 3.51, 0.09 and 0.029. PCA analysis showed that TOC is closely associated with Cr, Zn Mn and Fe (Fig. 2A). DM is mainly affected by Cr and TOC. Figure 4A cluster analysis showed the TOC close with Cr and Pb and also positively correlated with Pb, Fe, Cu, Ni, Mn and Co (Table 2). Foster and Bhatti (2006) discussed the wind deposited soils, which support mixed and hardwood forest, are likely to be fine textured with high nutrient supplying capacity.

The nutrients in different litter parts collected from different forest communities are given in (Fig. 3). The nutrients are essential for plants, playing significant roles in plant metabolism and biosynthesis, both as cofactors for enzymes and as metabolic consequences (Rattan *et al.,* 2005). For example, Zn, Fe, Cu, Cr, and Co are essential nutrients. Maximum nutrients concentration was observed in seed, leaves and miscellaneous parts. Cr, Mn, Fe, Cu, and Co observed maximum in seed at DM and Ni maximum in TP. In leaves Cr, Mn, Fe, Co, and Cu was increased at DM, Ni in SM and Zn and Fe in TP (Fig. 3). Bai (2013) discussed the role of Ni in the metabolic processes of plants has not been identified as greatly as other elements such as Mn or Cu; it is a key factor in the activation of the enzyme urease, which is essential for N metabolism. Moreover, it plays a part in seed germination and iron uptake (Poonkothai, 2012). Overall maximum essential nutrients of litter were observed in DM followed by SM and TP. Table 3 showed the maximum carbon content was found in a DM followed by SM and TP. Carbon content was maximum observed in the miscellaneous part from DM (45.54) followed by SM (40.53) and TP (33.52). In seed, carbon content was higher in DM (42.33) and TP (40.56). In branch, carbon content was higher in DM (43.54) and SM (41.57). Carbon content was reported in tropical forest discussed by a different author (Singh and Mudgal, 2000; Kraenzel *et al.,* 2003; Petsri *et al.*, 2007; Guendehou *et al.,* 2014; Paudel *et al.,* 2015). Eigen values in three axes were observed 3.66, 0.65

**Table 2:** Pearson correlation ratio between TOC, litter C and nutrients in the tropical deciduous forest from north India.

| | *TOC ($g\ kg^{-1}$)* | *(L) C %* | *Cr* | *Mn* | *Fe* | *Co* | *Ni* | *Cu* | *Zn* | *As* | *Se* | *Mo* | *Cd* | *Pb* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (L) C % | 0.88* | 1 | – | – | – | – | – | – | – | – | – | – | – | – |
| Cr | 0.87* | 0.99** | 1 | – | – | – | – | – | – | – | – | – | – | – |
| Mn | 0.76 | 0.97** | 0.98* | 1 | – | – | – | – | – | – | – | – | – | – |
| Fe | 0.84* | 0.99** | 0.99* | 0.99* | 1 | – | – | – | – | – | – | – | – | – |
| Co | 0.93* | 0.99* | 0.99* | 0.94* | 0.98* | 1 | – | – | – | – | – | – | – | – |
| Ni | 0.81* | 0.44 | 0.41 | 0.22 | 0.36 | 0.53 | 1 | – | – | – | – | – | – | – |
| Cu | 0.99* | 0.94* | 0.93 | 0.84* | 0.91* | 0.97* | 0.72 | 1 | – | – | – | – | – | – |
| Zn | 0.34 | 0.74 | 0.76 | 0.87 | 0.80* | 0.67 | –0.28 | 0.46 | 1 | – | – | – | – | – |
| As | –0.94* | –0.67 | –0.65 | –0.48 | –0.60 | -0.74 | –0.96* | –0.88* | 0.01 | 1 | – | – | – | – |
| Se | 0.74 | 0.97* | 0.97* | 0.99* | 0.99* | 0.94* | 0.20 | 0.82* | 0.89* | –0.46 | 1 | – | – | – |
| Mo | 0.64 | 0.22 | 0.18 | -0.02 | 0.12 | 0.31 | 0.97* | 0.53 | -0.50 | –0.87* | -0.04 | 1 | – | – |
| Cd | 0.36 | 0.75 | 0.77 | 0.88** | 0.81* | 0.68 | -0.26 | 0.48 | 0.99* | –0.01 | 0.90* | –0.49 | 1 | – |
| Pb | 0.92* | 0.99* | 0.99* | 0.95* | 0.98* | 0.99* | 0.52 | 0.97* | 0.68 | –0.73 | 0.94* | 0.30 | 0.69 | 1 |

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)




**Figs 2A and B:** Diagram of the principal component analysis (PCA) of soil nutrients against TOC (A) and litter nutrients against litter C; (B) in tropical deciduous forest from North India [dry mixed (DM), teak plantation (TP), sal mixed (SM); total organic carbon (TOC), carbon (C), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel(Ni), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), molybdenum (Mo), cadmium (Cd), lead (Pb)].

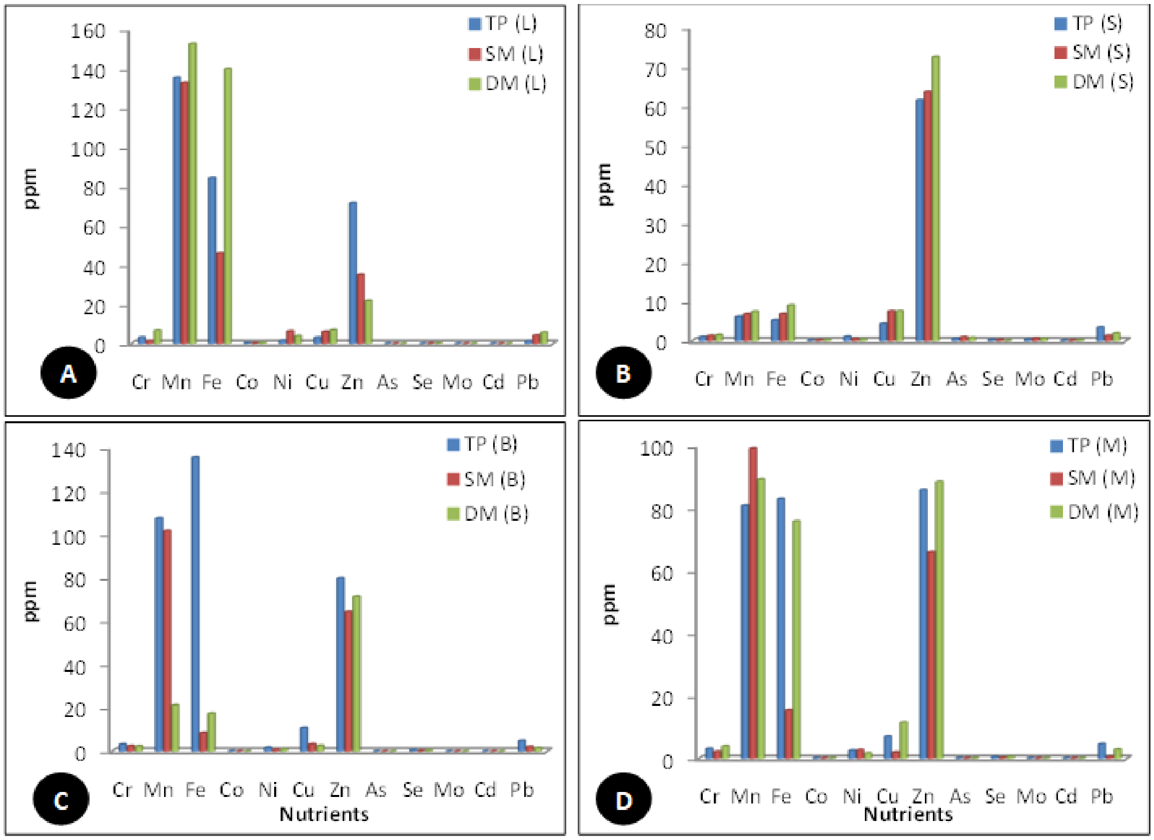



**Fig. 3:** Nutrients concentration of litter collection in different part leaf (L); seed (S); branch (B); miscellaneous (M) in the tropical deciduous forest from north India

**Table 3:** Litter carbon (%) in tropical deciduous forest form north India, *C (t ha$^{-1}$).

| *Forest* | *Site* | *Samples* | *Carbon %* | *References* |
|---|---|---|---|---|
| Teak plantation | Panama (Tranquella) | Litter | 43.90 | Kraenzel *et al*. (2003) |
| Hauy Kha Kaeng Wildlife Sanctuary | Teak plantation | Litter | 1.56* | Petsri *et al*. (2007) |
| | Mixed deciduous forest | | 0.68 * | |
| Nokrek Biosphere Reserve, Meghalaya | | Litter | 34.20 | Singh and Mudgal (2000) |
| West African tropical forest | Forest | Litter | 49.5 | Guendehou *et al*. (2014) |
| Tropical forest | Dry season | Litter | 41.85-45.86 | Paudel *et al*. (2015) |
| | Wet season | | 41.61-46.94 | |
| Tropical deciduous forest | Teak plantation | Leaf | 41.43 | Present study |
| | | Seed | 40.56 | |
| | | Branch | 31.56 | |
| | | Miscellaneous | 33.52 | |
| | Sal mixed | Leaf | 45.43 | |
| | | Seed | 39.52 | |
| | | Branch | 41.57 | |
| | | Miscellaneous | 40.53 | |
| | Dry mixed forest | Leaf | 40.45 | |
| | | Seed | 42.33 | |
| | | Branch | 43.54 | |
| | | Miscellaneous | 45.54 | |

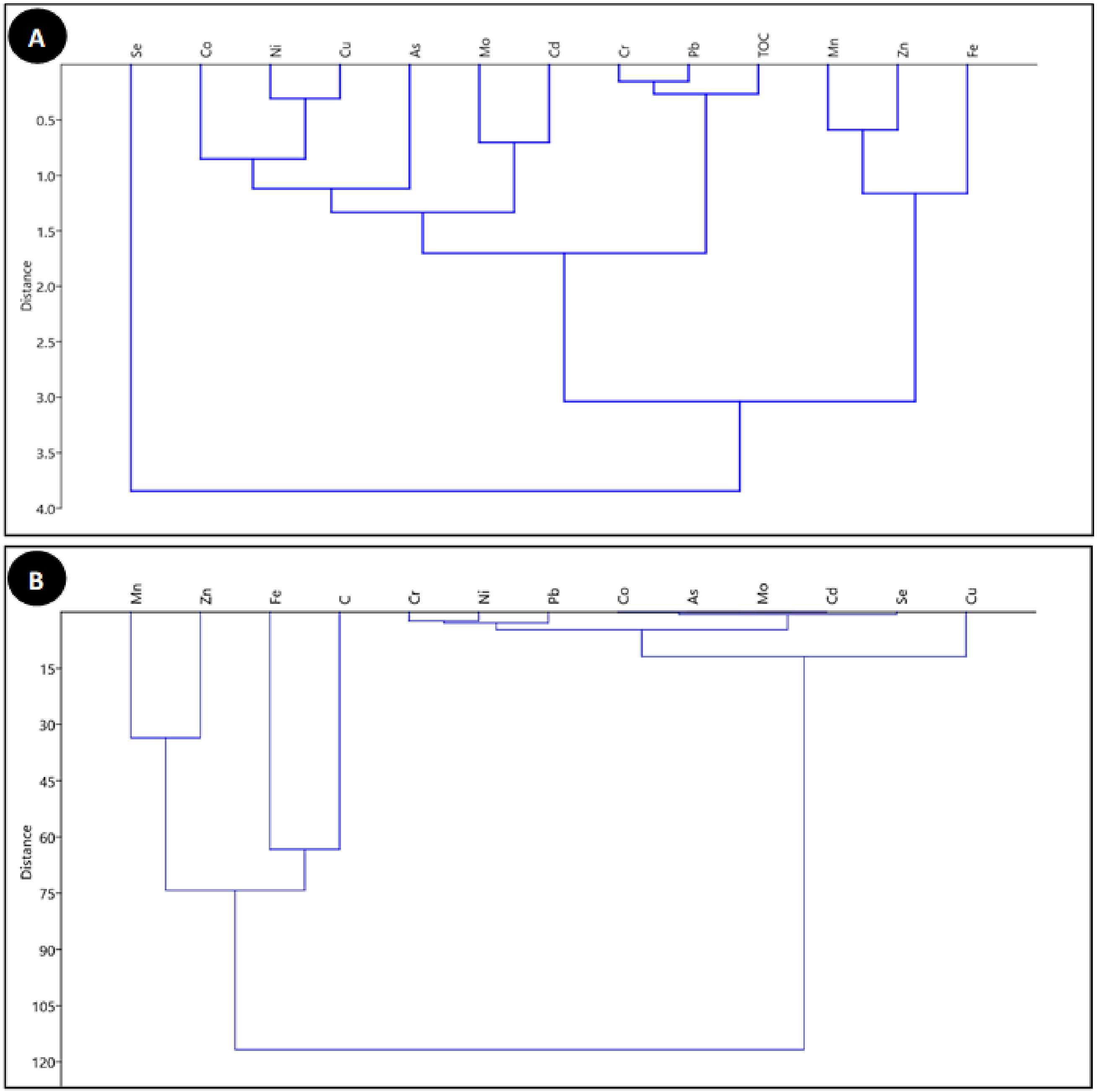



**Fig. 4:** Diagram of the cluster analysis of soil nutrients (A) and litter nutrients (B) in the tropical deciduous forest from North India [total organic carbon (TOC), carbon (C), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), molybdenum (Mo), cadmium (Cd), lead (Pb)

and 0.007. PCA analysis showed that C is closely associated with Cr, Zn, and Mn. DM and TP are mainly affected by Cr, Cu, and Fe (Fig. 2B). Figure 4B cluster analysis showed the Fe, Mn, and Zn is close with carbon and these nutrients essential for plant growth. This nutrient maximum observed in litter different parts. So we can say that these nutrients help of carbon sequestration and increases plant growth.

## Conclusion

The results conclude here clearly soil nutrients with litter's chemistry differ in forest communities on different soil depth. DM maximum fertile soils support productive forests and quantities of nutrient. Zn, Mn, Cu, Ni, and Fe are higher in among all forest communities. Finally, the tropical deciduous forest is in generally low observed non-essential. These nutrients affect the soil fertility, community ecology, soil carbon sequestration and plant richness of tropical forests.

## References

1. Adomaitis, R. 2003. A reduced-basis discretization method for chemical vapor deposition reactor simulation. Mathematical and Computer Modelling 38:159-175.

2. Aerts, R. 1997. Climate, leaf litter chemistry and leaf litter decomposition in terrestrial ecosystems: A triangular relationship. Oikos 79:439-449.
3. Akoto, O., Nimako, C., Asante, J. and Bailey, D. 2016. Heavy metals enrichment in surface soil from abandoned waste disposal sites in a hot and wet tropical area. Environmental Processes 3:747-761.
4. Atanassov, I., Vassileva, V. and Shegunova, P. 1999. Applications of data for background concentrations of Pb, Zn, Cu and Cd in soils for calculating critical loads. Gregor et al(1999):137-140.
5. Bai, Y., Tao, T., Gu, C., Wang, L., Feng, K. and Shan, Y. 2013. Mudflat soil amendment by sewage sludge: soil physicochemical properties, perennial ryegrass growth, and metal uptake. Soil Science and Plant Nutrition 59:942-952.
6. Behera, S.K., Mishra, A.K., Sahu, N., Kumar, A., Singh, N., Kumar, A., Bajpai, O., Chaudhary, L.B., Khare, P.B. and Tuli, R. 2012. The study of microclimate in response to different plant community association in tropical moist deciduous forest from northern India. Biodiversity and Conservation 21:1159-1176.
7. Berg, B., Jansson P.E. and McClaugherty C. 1989. Litter mass-loss rates in a climatic transect in north-western europe-effects of climate and substrate quality. EällASA, pp. 49.
8. Blaylock, M.J. and Huang, J.W. 2000. Phytoextraction of metals. Phytoremediation of toxic metals: Using plants to clean up the environment, pp. 53-70.
9. Campos, M., Pierangeli, M., Guilherme, L., Marques, J. and Curi, N. 2003. Baseline concentration of heavy metals in Brazilian Latosols. Communications in Soil Science and Plant Analysis 34:547-557.
10. Clark, D.A., Brown, S., Kicklighter, D.W., Chambers, J.Q., Thomlinson, J.R.J. and Holland, E.A. 2001. Net primary production in tropical forests: an evaluation and synthesis of existing field data. Ecological Applications 11:371-384.
11. Davies, B.E. 1997. Deficiencies and toxicities of trace elements and micronutrients in tropical soils: limitations of knowledge and future research needs. Environmental Toxicology and Chemistry 16:75-83.
12. DPR-EGASPIN, 2002. Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN). Department of Petroleum Resources, Lagos, Nigeria.
13. En-Qing, H., Xiang, H.-M., Jian-Li, L., Jiong, L. and Da-Zhi, W. 2015. Soil acidification and heavy metals in urban parks as affected by reconstruction intensity in a humid subtropical environment. Pedosphere 25:82-92.
14. Fontes, M.P.F. and Alleoni, L.R.F. 2006. Electrochemical attributes and availability of nutrients, toxic elements, and heavy metals in tropical soils. Scientia Agricola 63:589-608.
15. Foster, N.W. and Bhatti, J.S. 2006. Forest ecosystems: nutrient cycling. Encyclopedia of soil science New York: Taylor and Francis Group, pp. 718-721.
16. Friedlova, M. 2010. The influence of heavy metals on soil biological and chemical properties. Soil Water Research 5:21-27.
17. Guendehou, G.S., Liski, J., Tuomi, M., Moudachirou, M., Sinsin, B. and Makipaa, R. 2014. Decomposition and changes in chemical composition of leaf litter of five dominant tree species in a West African tropical forest. Tropical Ecology 55:207-220.
18. Hammer, Ø., Harper, D.A.T. and Ryan, P.D. 2001. Paleontological statistics software: Package for education and data analysis. Palaeontologia Electronica (4).
19. Hernandez, L., Probst, A., Probst J.L. and Ulrich, E. 2003. Heavy metal distribution in some French forest soils: evidence for atmospheric contamination. Science of the Total Environment 312:195-219.
20. Hou, E., Xiang, H., Li, J., Li, J. and Wen, D. 2014. Heavy metal contamination in soils of remnant natural and plantation forests in an urbanized region of the Pearl River Delta, China. Forests 5:885-900.
21. Hughes, J.W., Fahey, T.J. and Browne, B. 1987. A better seed and litter trap. Canadian Journal of Forest Research 17:1623-1624.
22. Jaakkola, T., Jordan, M.I. and Singh, S.P. 1994. Convergence of stochastic iterative dynamic programming algorithms. In: Advances in Neural Information Processing Systems, pp. 703-710.
23. Jha, R. 2000. Management Plan of Katerniaghat Wildlife Sanctuary (2000-2001 to 2009-2010). Wildlife Preservation Organisation. Forest Department, Uttar Pradesh.
24. Kookana, R.S. and Naidu, R. 1998. Effect of soil solution composition on cadmium transport through variable charge soils. Geoderma 84:235-248.
25. Kraenzel, M., Castillo, A. Moore, T. and Potvin, C. 2003. Carbon storage of harvest-age teak (Tectonagrandis) plantations, Panama. Forest Ecology and Management 173:213-225.
26. Kutsch, W.L. and Dilly, O. 1999. Ecophysiology of plant and microbial interactions in terrestrial ecosystems. Okophysiologiepflanzlicher Interaktionen. Bielefelder Okologische Beitrage 14:74-84.
27. León, J.D. and Osorio, N.W. 2014. Role of litter turnover in soil quality in tropical degraded lands of Colombia. The Scientific World Journal, 2014.
28. Liao, Q.-l., Evans, L.J., Gu, X., Fan, D.-F., Jin, Y. and Wang, H. 2007. A regional geochemical survey of soils in Jiangsu Province, China: Preliminary assessment of soil fertility and soil contamination. Geoderma 142:18-28.
29. Magnuson, M.L., Kelty, C.A. and Kelty, K.C. 2001. Trace metal loading on water-borne soil and dust particles characterized through the use of split-flow thin-cell fractionation. Analytical Chemistry 73:3492-3496.
30. Mishra, S., Upadhyay S.K. and Singh T. 2014. Heavy metal recovery by native macrophytes from Subarnarekha river-India. International Journal of Environmental Sciences 5:634.
31. Mohanraj, R., Mahajan, M.V. and Azeez, P. 2000. Heavy metals in the moist deciduous forest soils of Siruvani Hills, Tamil Nadu, India. Indian Journal of Forestry 23:262-267.
32. Naidu, R., Sumner, M.E. and Harter, R. 1998. Sorption of heavy metals in strongly weathered soils: an overview. Environmental Geochemistry and Health 20:5-9.
33. NJDEP 1996. New Jersey Statewide Water Supply Plan. New Jersey Department of Environmental Protection, Trenton, NJ.
34. Paudel, E., Dossa, G.G., de Blécourt, M.P. Beckschäfer, J. and Harrison, R.D. 2015. Quantifying the factors affecting leaf litter decomposition across a tropical forest disturbance gradient. Ecosphere 6:1-20.
35. Petsri, S., Pumijumnong, N., Wachrinrat, C. and Thoranisorn, S. 2007. Aboveground carbon contern in mixed deciduous forest and teak plantations.
36. Poonkothai, M. and Vijayavathi, B.S. 2012. Nickel as an essential element and a toxicant. International Journal of Environmental Sciences 1:285-288.
37. Rattan, R., Datta, S., Chhonkar, P., Suribabu, K. and Singh, A. 2005. Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. Agriculture, Ecosystems and Environment 109:310-322.
38. Rodgers, W. and Panwar, H. 1988. Planning wildlife protected area network in India.
39. Singh, J. and Mudgal, V. 2000. Assessment of mineral content of tree leaf litter of Nokrek Biosphere and its impact on soil properties. Journal Tropical Ecology 4:225-235.
40. Soares, M.R., Alleoni, L.R., Vidal-Torrado, P. and Cooper, M. 2005. Mineralogy and ion exchange properties of the particle size fractions of some Brazilian soils in tropical humid areas. Geoderma 125:355-367.
41. Sudhakaran, M., Ramamoorthy, D., Swamynathan, B. and Ramya, J. 2014. Impacts of soil microbial populations on soil chemical and biological properties under tropical dry evergreen forest, Coromandel Coast, India. Journal of Forest and Environmental Science 30:370-377.
42. Swamy, H.R. and Proctor, J. 1994. Litterfall and nutrient cycling in four rain forests in the Sringeri area of the Indian Western Ghats. Global Ecology and Biogeography Letters ***Vol***:155-165.
43. Udom, B., Mbagwu, J., Adesodun, J. and Agbim, N. 2004. Distributions of zinc, copper, cadmium and lead in a tropical ultisol after long-term disposal of sewage sludge. Environment International 30:467-470.
44. Vitousek, P. 1982. Nutrient cycling and nutrient use efficiency. The American Naturalist 119:553-572.
45. Vitousek, P.M. and Sanford, R.L. Jr. 1986. Nutrient cycling in moist tropical forest. Annual Review of Ecology and Systematics 17:137-167.
46. Wilson, D.O. 1977. Nitrification in three soils amended with zinc sulfate. Soil Biology and Biochemistry 9:277-280.