International Journal of Environment and Climate Change

10(1): 62-73, 2020; Article no.IJECC.54438
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Vertical Distribution of TOC, TN and Other Important Soil Attributes and Their Relationship in Alfisol and Entisol of West Bengal

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Authors' contributions

This work was carried out in collaboration among all authors. Authors SR and AKS designed the study, wrote the protocol and wrote the first draft of the manuscript. Author SR managed the analyses and performed the statistical analysis of the study. Author PM managed the literature searches and finalized the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2020/v10i130176
Editor(s):
(1) Dr. Isidro Alberto Perez Bartolome, Associate Professor, Department of Applied Physics, Faculty of Sciences, University of Valladolid, Spain.
Reviewers:
(1) Elilson Gomes De Brito Filho, Universidade Federal do Amazonas, Brasil.
(2) Oľga Šestinová, Slovak Academy of Sciences, Slovakia.
Complete Peer review History: http://www.sdiarticle4.com/review-history/54438

Original Research Article

Received 06 December 2019
Accepted 12 February 2020
Published 18 February 2020

ABSTRACT

A study to assess the profile distribution of important soil attributes in Alfisols and Entisols of West Bengal was conducted during 2016-17. Purposefully selected random sampling was carried out to collect the soils from different locations of two study sites, viz., Kalinagar (25º27'33.9"N, 88º19'10.2"E) from Malda district and Durganagar (26º09'62.7"N, 89º53'51.7"E) from Cooch Behar district of West Bengal at 0-15, 15-30, 30-45 and 45-60 cm depths. Understanding of vertical distribution of soil fertility indicators like soil organic carbon (SOC), total nitrogen (TN) and other important properties in two different soil and climatic conditions will provide an insight regarding the behaviour of soil with the change in environmental conditions. Soil bulk density (BD), porosity, pH, SOC, TN, C:N ratio and texture were determined using standard laboratory procedures and computations. Obtained results were subjected to statistical analyses. Soils of Kalinagar sites were slightly acidic in nature while soils of Durganagar were neutral in nature. Kalinagar soils were silt clay loam in texture where Durganagar soils classified as loam to sandy loam. Soil BD values increased with depth in both Kalinagar (Alfisol) and Durganagar (Entisol). The porosity percentage

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progressively decreased with an increase in depth. Soils of Durganagar reported higher soil porosity at all the depths studied. An increase in soil pH with increasing depth was observed in both the sites. The mean total organic carbon (TOC) content recorded maximum in surface soil and its concentration decreased with the depth. Kalinagar soils observed 7.63% higher TOC (17.94 g kg^{-1}) content than Durganagar (16.57 g kg^{-1}) at surface depth (0-15 cm) and its accumulation at the lower depths was also maximum in former soil. Mean TN values were also found to decrease by increasing the depth. The accumulation of total nitrogen at the subsequent depths was relatively higher in Kalinagar than Durganagar. Increase in C:N ratio with increasing depth was noticed in Kalinagar site but the opposite trend was accorded in case of Durganagar. Accumulation of SOC and TN throughout the soil depth was found to be greater in Alfisol (Kalingar) due to higher clay and silt fractions as compared to Entisol (Durganagar). There was a significant positive relation of TOC with clay and silt (r = 0.285, p<0.05, r = 0.314, p<0.01, respectively) and of TN with clay and silt (r = 0.328, p<0.01, r = 0.262, p<0.05, respectively) irrespective of soil orders. Alfisols with high bulk density have a greater capacity to accumulate SOC and TN throughout the soil profile due to higher clay and silt fractions in comparison to Entisols with loose textural properties.

Keywords: Alfisol; entisol; total organic carbon; total nitrogen; physicochemical properties; depth-wise distribution.

1. INTRODUCTION

Soil is a life-supporting natural resource which accomplishes diverse functions that are crucial for sustainable crop production [1,2]. The physicochemical properties of soil, viz., pH, bulk density (BD), porosity, total organic carbon (TOC), total nitrogen (TN), C:N ratio, and texture are key indicators of fertility and physical stability of soil [3]. Any degradation in these properties can significantly affect the soil quality by creating an imbalance in soil processes (nutrient cycling). Soil pH has a great impact on solute concentration and absorption in the soil [4]. It is also an indicator of available soil nutrients [5]. Soil texture directly influences the aeration, root penetration, and soil-water retention. It also affects the nutrient supplying capacity of the soil [6].

Soil organic carbon (SOC) playing a significant role in global C cycling, is often used as an indicator of soil quality [7,8]. It plays important agronomic and environmental functions [9] associated with soil fertility [10], aggregation [11], and biological process [12]. Soil nitrogen (N) affects phytomass production and microbial metabolism [13], in turn regulating the SOM dynamics. The C:N ratio in the soil is an indicator of N retention by the microbial communities [14]. A high C:N ratio indicates the presence of excess organic C which may lead to immobilization of N. Whereas, a low ratio is an indication of excess N which may result in mineralization of N.

Alfisol is a soil order form in semi-arid to humid tropics, clay-enriched subsoil and relatively high fertile. Because of their abundance and productivity alfisol is considered as the most important order for food and fibre production, easier to keep fertile than other humid climate soils, widely used in agriculture and forestry. Higher SOC was recorded in silt plus clay fraction than the coarser size fractions in sandy Alfisols of USA [15]. Entisol is a very diverse group of soil with little profile development (recently deposited material-alluvial type) which includes the soils of floodplains, sand dunes, etc. occur in very cold or dry climates. Highly productive alluvial soils are found on floodplains whereas low productive soils are found in sandy areas. The Entisols of Cooch Behar fall under *Terai* agro-ecological region [16]. Here, organic C lies between 0.30-1.69% [17]. A clear understanding of the depth-wise distribution of soil fertility indicators like TOC, TN, and other important properties and their relationship is imperative in these soils. West Bengal soils comprise both types of soil orders with a wide range of soil characteristics and climatic conditions provide an opportunity to study the variation in soil fertility with respect to the change in climatic conditions.

Therefore, the present investigation was carried out to assess the depth-wise distribution of important soil attributes and their relationship in Alfisol and Entisol of West Bengal.

2. MATERIALS AND METHODS

2.1 Design and Sampling

Purposefully random sampling was followed to collect the soils from both the sites during March-April of the year 2017. GPS coordinates were recorded to map the study area. Samples (from 10 locations in each site) were collected separately for bulk density and other physicochemical analyses from 0-15, 15-30, 30-45, and 45-60 cm soil depths using bulk density sampler and 1-meter tube core sampler, respectively.

2.2 Site Description

To study the vertical distribution of soil attributes under varying climatic conditions and soil types, two soil orders from Eastern Ganga Alluvial Plains were selected, viz., Kalinagar (25º27'33.9"N, 88º19'10.2"E) from Malda district belonging to the order Alfisol and Durganagar (26º09'62.7"N, 89º53'51.7"E) from Cooch Behar district (Fig. 1) belonging to the order Entisol. Soils of Kalinagar sites were slightly acidic in nature while soils of Durganagar were neutral in nature. The study areas fall under sub-humid (moist) to humid climate. However, the annual rainfall is considerably higher in Durganagar. The meteorological data of the selected sites shown in Table 1.

2.3 Soil Analysis

Soil pH was estimated by the soil: solution ratio of 1:2.5 is stirred continuously for 15 minutes using a glass rod and the suspension was measured with the help of a pH meter with a glass electrode as described by Jackson [18]. The actual bulk density of the soil was estimated with the help of 5 × 5 cm (height × diameter) core rings; sampled with the help of a 20 cm length core sampler. The proportion of sand, silt, and clay in soil was determined by the Bouyoucos hydrometer method [19].

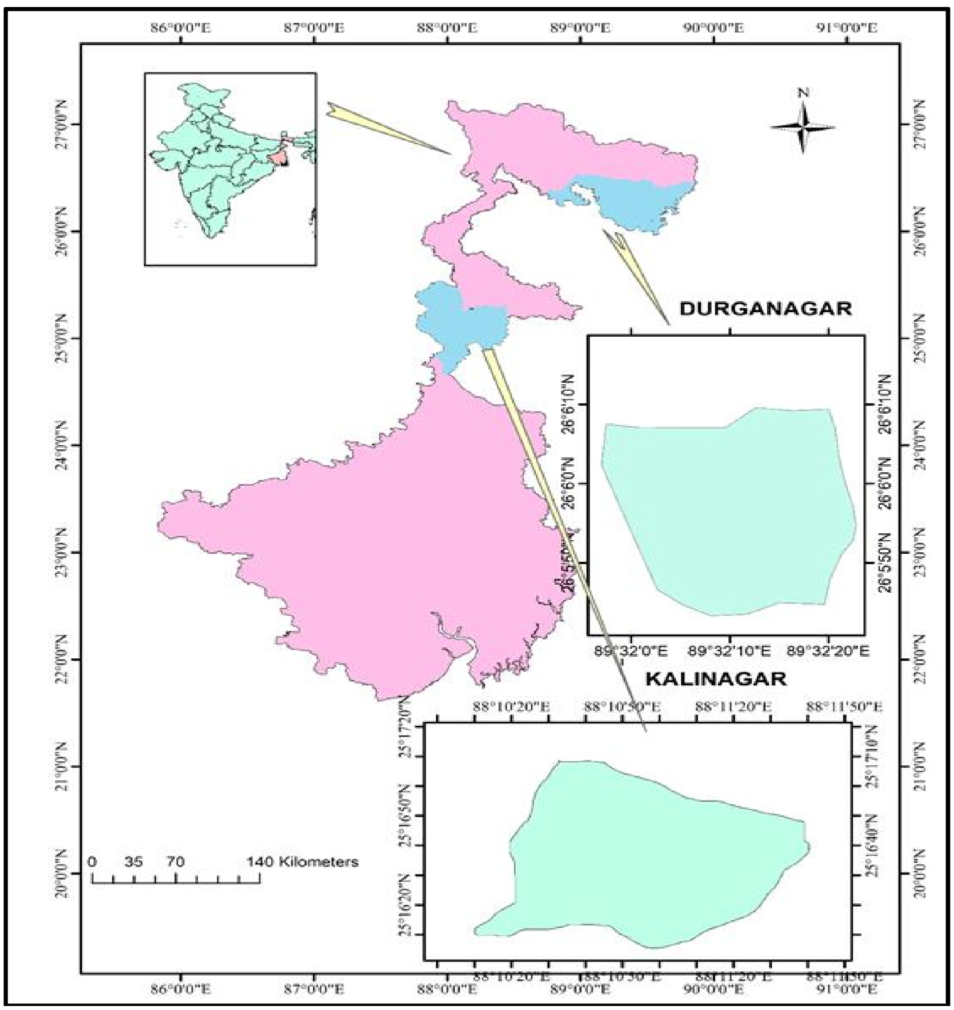

Fig. 1. Location map of the study area

Table 1. Annual meteorological data of Kalinagar and Durganagar sites

Site	Min. Temp.	Max. Temp.	Humidity	Wind	Sun	Radiation	ETo	Rainfall	Effective rainfall
	°C	°C	%	Km day^{-1}	hours	MJ m² day^{-1}	Mm day^{-1}	mm	mm
Kalinagar	20.2	30.6	69	152	6.7	17.1	3.97	1358	857.7
Durganagar	20.0	28.2	85	103	7.1	17.6	3.37	2357	1126

Source: CLIMWAT 2.0 for CROPWAT software package

The texture of the soils was then ascertained from the particle-size distribution of sand, silt, and clay using the soil texture triangle. A modified Walkley and Black method developed by Baker [20] for the analysis of TOC in soil determined by a colorimetric method by oxidizing 1 g soil sample with 10 ml of 5% potassium dichromate ($K_2Cr_2O_7$) and 20 ml of concentrated sulphuric acid (H_2SO_4). After cooling 50 ml of 0.4% barium chloride ($BaCl_2$) solution was added and allowed for overnight; used sucrose as a standard and read the absorbance at 600 nm wavelength as described in Tropical Soil Biology and Fertility Manual. Content of total N in soil was analysed by the Kjeldahl method after digesting the sample with 10 ml H_2SO_4 and a catalyst mixture at 370ºC; finally titrating the absorbed ammonia in boric acid against 0.05 N H_2SO_4 until it turns from green colour to pink [21].

2.4 Data Analysis

A standard deviation test was performed to ensure the variability between the sample locations. Duncan's test was carried out to differentiate the various soil attributes among different depths based on DMRT results using SPSS 17.0 version software package.

3. RESULTS AND DISCUSSION

3.1 Bulk Density

Bulk density (BD) was found to increase with an increase in depth (Fig. 2a). Higher BD was recorded in the soils of Malda (Kalinagar) in comparison to Cooch Behar (Durganagar). At the plough layer (0-15 cm), a BD value of 1.55 g cm^{-3} was observed in Kalinagar soil and for Durganagar, it was 1.09 g cm^{-3} (Table 2). We noticed no significant variations of BD in the subsequent depths (15-60 cm) of the study. A similar trend was also reported by Liu, et al. [22] where there were no statistical differences in BD among treatments below 40 cm depth. The higher values of BD figured as 1.77 and 1.32 g cm^{-3} was observed at the lowermost depth (45-60 cm) in Kalinagar and Durganagar sites, respectively. These results were consistent with the observation of other works in Ghana [23-26]. Bulk density typically increases with soil depth since subsurface layers are more compacted and have less organic matter, less aggregation and less root penetration compared to surface layers, therefore contain less pore space (www.nrcs.usda.gov). Location to location variability in the data was determined by the standard deviation values (Table 2) indicating that Durganagar soils recorded the highest variability (±0.076 to ±0.086) at all the depths except at 30-45 cm (±0.040) as compared to Kalinagar.

The correlation study (Table 3) between BD and other soil attributes indicated the dry BD was correlated positively with clay and silt contents (r = 0.867 and 0.741, respectively, p<0.01) implying that higher amount of clay and silt in the soil increased the BD. The increase in BD in high clay and silt soils is due to the compaction phenomenon. Soil compaction leads to increased bulk density [27,28]. Thus, the significantly higher bulk density up to 70 cm soil depth can be attributed to the direct effect of soil compaction due to compression of overburden substrates with heavy machinery during the reclamation process. High clay content and the introduction of farm machinery cause compaction of the subsurface layer, which increases BD. In our study, a negative correlation (r = -0.12) observed between BD and TOC indicated that increasing TOC in soil decreases the BD. Higher SOC will impact in lowering the BD [29,30].

3.2 Porosity

The porosity percentage was noticeably decreasing with increasing depth in both the investigated sites (Fig. 2b). Porosity percentage was reportedly higher at all the depths in Durganagar soils of Cooch Behar district. At the surface soil layer (0-15 cm), the highest porosity of 41.44 and 58.56% was recorded in Kalinagar and Durganagar soils, respectively (Table 1). Minimum porosity percentage was noted in Kalinagar at the lower depth (45-60 cm) because of the highest soil bulk density (1.77 g cm^{-3}) and clay content (321.5 g kg^{-1}) as showed in Table 1. A strong negative correlation (r = -1.00, p<0.01) observed between soil porosity and bulk density. Similarly, Tanveera, et al. [31] reported a significant negative correlation (r = -0.67) between soil porosity and bulk density. However, a significant positive correlation (Table 2) was recorded with sand content (r = 0.836, p<0.01) indicated that an increase in sand content of the soil increases the soil porosity. The standard deviation in soil porosity was noted to be relatively similar in both the soils among all the studied depths.

3.3 Soil pH

Increase in soil pH with increasing depth observed in both the sites (Fig. 2c). The soils of Kalinagar sites were relatively acidic in nature than Durganagar soils. The pH value of 5.90 at the surface layer recorded in Kalinagar, where the value of 7.25 noted in Durganagar which was 11.22% higher than the former. Soils of Cooch Behar and Malda are alkaline and neutral in nature, respectively beyond 15 cm depth. Maximum pH values of 7.19 and 8.42 were recorded in Kalinagar and Durganagar soils, respectively at 45-60 cm depth. Soil pH increased with soil depth in all land use/cover types [32,33]. A strong negative correlation (Table 3) observed between TOC and soil pH (r = –0.756, p<0.01) indicating that an increase in TOC decreases the soil pH. A similar trend also reported by Bhattacharyya, et al. [29]. Leaching of base salts from the surface layer and accumulation.

3.4 Soil Texture

There was no significant variation of the amount of clay throughout the depths observed in two different sites but the sand and silt contents were varied significantly among all the depths (Fig. 3). Kalinagar soils are rich in clay (>300 g kg^{-1}) and silt (>500 g kg^{-1}) at all the four studied depths (Table 2) comes under the textural class "silt clay loam"; wherein Durganagar, the soil was high in sand (>400 g kg^{-1}) and silt (>300 g kg^{-1}) content with low clay (<150 g kg^{-1}) classified as "loam to sandy loam". Sand correlated negatively (r = −0.310, p<0.01) with TOC implying that, where sand is high, clay is expected to decrease resulting in decreased TOC (Table 2). Similar results were also found by Hairiah and van Noordwijk [32].

The variability of soil pH at lower depths was more in Kalinagar than Durganagar, where the latter soil showed maximum deviation (±0.22) at 0-15 cm depth against the former (±0.13).

3.5 Total Organic Carbon (TOC)

The mean TOC content found to be maximum in surface soil and its concentration decreased with the depth (Fig. 2d). At surface depth (0-15 cm) Kalinagar soils recorded 7.63% higher TOC (17.94 g kg^{-1}) than Durganagar (16.57 g kg^{-1}) and its accumulation at the lower depths was also maximum in former soil (Table 2). The non-significant values of TOC in the subsequent layers were evident in Kalinagar soil but the same trend was true only at 30-45 and 45-60 cm depths in Durganagar. The least amount of TOC (3.79 g kg^{-1}) was noted in Cooch Behar soil at 45-60 cm depth. Overall, the TOC concentration was decreased with increasing depth. These findings were consistent with the following studies [23,24,34,35]. Variability of TOC was found to be higher in Kalinagar soils at all the depths except at 15-30 cm, where the standard deviation at this depth was maximum (±1.08) in Durganagar. A positive correlation (Table 3) of TOC with clay and silt (r = 0.314 and 0.285, p<0.01 and p<0.05, respectively) revealed that these two fractions played a significant role in enhancing TOC content in the soil. Bhattacharyya, et al. [29] also reported a highly significant correlation between TOC and clay (r = 0.616**). Positive linear correlations between TOC concentrations and either soil clay or silt + clay content of surface soils have been found in both temperate [36] and tropical environments [37]. Higher TOC content in fine-textured compared to coarse-textured soils may be ascribed to the fact that differences in C input, rather than long-term decomposition dynamics, since fine-textured soils tend to be more fertile than coarse-textured soils due to likely differences in water storage capacity [38]. In any given environment the amount of TOC increases as soil texture becomes finer. Clay particles are believed to protect some of the more easily decomposable organic compounds from rapid microbial breakdown through encrustation and entrapment [39].

3.6 Total Nitrogen

Significant (p<0.01) variation in the vertical distribution of TN was noted across the study sites (Table 3). The mean TN values were found to decrease with an increase in depth (Fig. 2e) for both the sites. This decreasing trend was consistent with the results obtained by Zhao, et al. [40]. The comparison of TN concentration at the interval of 0-15 cm depth between two sites showed that Kalinagar soil is 35% higher (2.40 g kg^{-1}) than Durganagar (1.56 g kg^{-1}). Accumulation of TN at the lower layers (15-30, 30-45 and 45-60 cm) was relatively more in Kalinagar than Durganagar. The latter soils are sandy loam in texture and highly prone for leaching, which is the main cause behind low N status as compared to former. Moreover, the annual rainfall (2357 mm) in Durganagar (Table 1) is 42.3% higher than Kalinagar (1358 mm), further leading to percolation losses. The maximum variation was found in Kalinagar at all the four depths. In correlation study (Table 2), TN showed high relationship with TOC (r = 0.898, p<0.01). A recent meta-analysis conducted for multiple terrestrial ecosystems also indicated that increased N availability may augment short term

Table 2. Status of important soil properties studied in Malda and Cooch Behar soils at 0-15, 15-30, 30-45 and 45-60 cm depths (n=10)

Site	Order	Depth (cm)	BD ($g\ cm^{-3}$)	Porosity (%)	pH	TOC	TN	C:N Ratio	Texture			Textural class
									Sand	Silt	Clay	
						($g\ kg^{-1}$)			$g\ kg^{-1}$			
			Mean (Std. Dev) DMRT									
Kalinagar (Malda)	Alfisol	0-15	1.55 (±0.059)b	41.44 (±2.21)a	5.9 (±0.13)b	17.94 (±2.14)a	2.40 (±0.15)a	7.47 (±0.59)c	92 (±13.17)b	576 (±14.49)b	332 (±7.15)a	Silt Clay loam
		15-30	1.72 (±0.058)a	35.18 (±2.19)b	7.07 (±0.28)a	8.12 (±0.65)b	1.25 (±0.14)b	6.78 (±0.81)c	122 (±9.78)a	547 (±12.06)c	331 (±3.94)a	Silt Clay loam
		30-45	1.71 (±0.091)a	35.31 (±3.43)b	7.192 (±0.45)a	7.09 (±0.87)b	0.69 (±0.09)c	10.56 (±2.17)b	67 (±21.88)c	604.5 (±21.66)a	328.5 (±6.69)a	Silt Clay loam
		45-60	1.77 (±0.055)a	33.18 (±2.06)b	7.19 (±0.31)a	7.43 (±1.13)b	0.44 (±0.12)d	20.02 (±7.16)a	67 (±12.52)c	611.5 (±9.73)a	321.5 (±8.51)b	Silt Clay loam
Durganagar (Cooch Behar)	Entisol	0-15	1.09 (±0.076)b	58.56 (±2.88)a	7.25 (±0.22)c	16.57 (±1.05)a	1.56 (±0.06)a	10.51 (±0.81)a	434.5 (±30.95)c	445 (±31.0)a	120.5 (±4.38)a	Loam
		15-30	1.29 (±0.086)a	50.90 (±3.41)b	8.04 (±0.21)b	6.33 (±1.08)b	0.76 (±0.13)b	8.77 (±1.91)bc	405 (±58.93)c	478 (±62.99)a	117 (±10.85)a	Loam
		30-45	1.31 (±0.040)a	50.29 (±1.49)b	8.30 (±0.19)a	3.99 (±0.60)c	0.53 (±0.06)c	7.47 (±1.65)c	566.5 (±26.98)a	336 (±22.09)c	97.5 (±13.79)b	Sandy Loam
		45-60	1.32 (±0.076)a	50.53 (±2.88)b	8.42 (±0.15)a	3.79 (±0.64)c	0.43 (±0.05)d	9.05 (±1.59)b	523.5 (±63.12)b	378 (±63.52)b	98.5 (±5.30)b	Sandy Loam

Note: n= No. of sampled spots. The alphabets in same letters indicates no significant difference among depths at P≤0.05 level (ANOVA)

Table 3. Pearson correlation (r) result between different soil properties (n=80: 2 sites, 4 depths, 10 sampling locations)

	BD	Porosity	pH	TOC	TN	C:N ratio	Sand	Silt	Clay
BD	1	-1.00**	-0.447**	-0.120	-0.060	0.295**	-0.837**	0.741**	0.867**
Porosity			0.446**	0.120	0.060	-0.295**	0.836**	-0.741**	-0.866**
pH				-0.756**	-0.773**	-0.030	0.744**	-0.682**	-0.751**
TOC					0.898**	-0.020	-0.310**	0.314**	0.285*
TN						-0.352**	-0.307**	0.262*	0.328**
C:N ratio							-0.279*	0.335**	0.210
Sand								-0.961**	-0.966**
Silt									0.858**
Clay									1

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

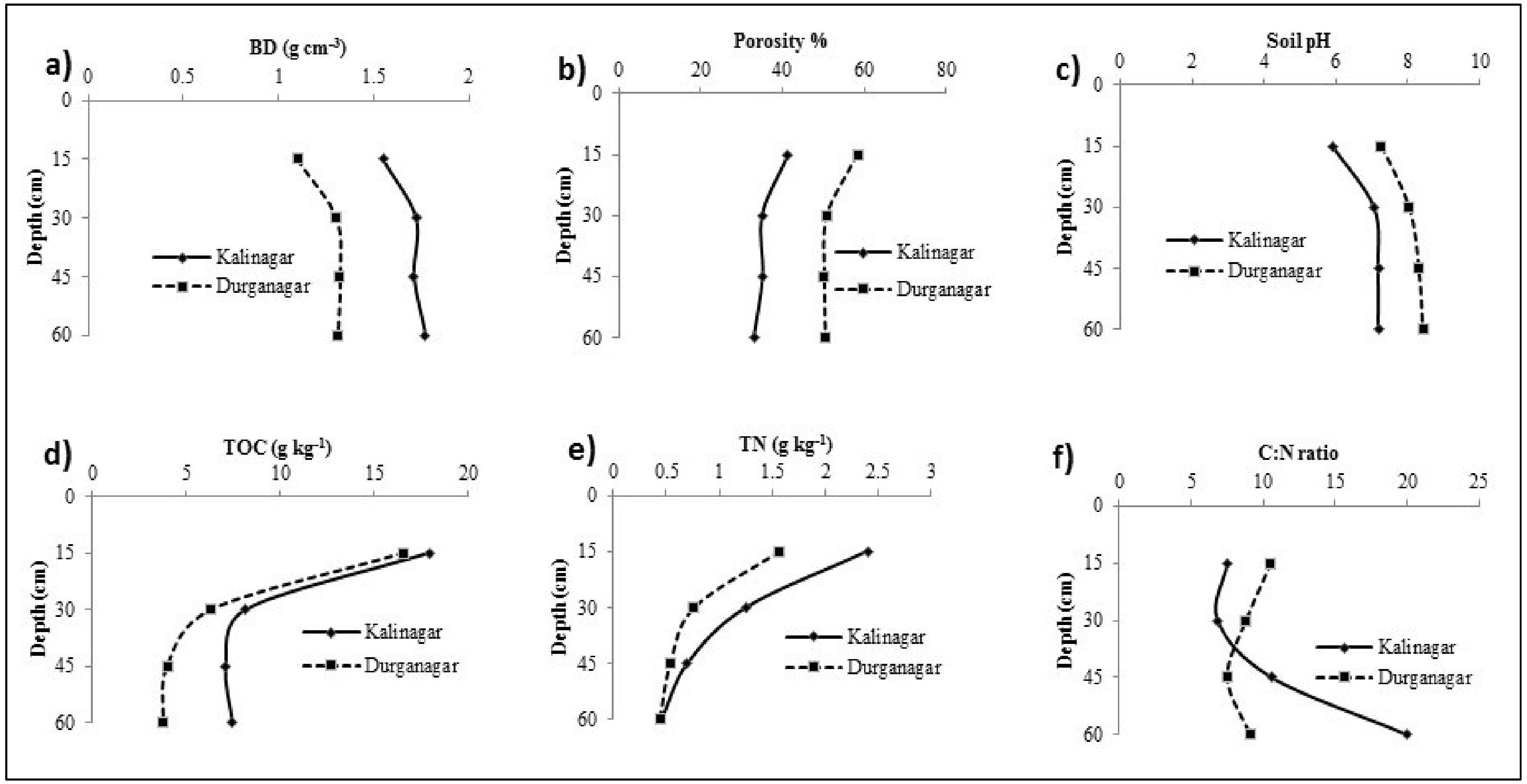

Fig. 2. Soil properties: (a) BD, (b) Porosity, (c) pH, (d) TOC, (e) TN and (f) C:N ratio at 0-15, 15-30, 30-45, and 45-60 cm depths under Kalinagar and Durganagar sites

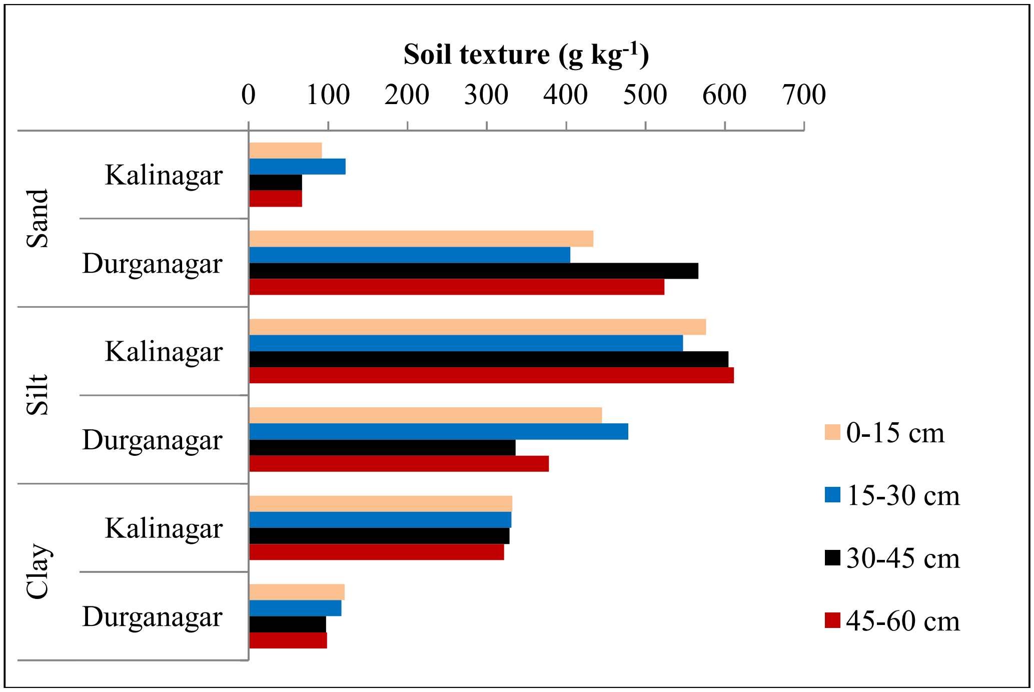

Fig. 3. Mean values of sand, silt and clay at 0-15, 15-30, 30-45 and 45-60 cm depths under Kalinagar and Durganagar sites

soil C storage by increasing the C content of the organic layers [41]. A negative correlation was noticed (r = -0.352, $p<0.01$) between C:N ratio and soil TN indicating that nitrogen content of the soil is not completely related to C:N ratio rather it also depends on soil physical characteristics like texture responsible for the leaching process. In some ecosystems, soil C:N ratio can also be an indicator of nitrate leaching [42,43].

3.7 C:N Ratio

The increase in C:N ratio with increasing depth was evident in Kalinagar site but the opposite trend was recorded in Durganagar (Fig. 2f). The lowest value (7.47:1) observed in Kalinagar at the uppermost layer (0-15 cm) as against the highest value of 10.56:1 noted in Durganagar soil. At the lowermost depth (45-60 cm), a large C:N ratio of 20.02:1 recorded in Kalinagar soil; where at the same layer the ratio of 9.05:1 resulted in Durganagar. Higher standard deviation of ±7.16 was noted at 45-60 cm depth in Kalinagar. The decrease in C:N ratio with increased soil depth in Durganagar is due to the humification process. Organic matter in subsoil layers is older and more humified than that in topsoil layers, and thus it is frequently observed a decreasing soil C:N ratio with soil depth [44]. As decomposition proceeds, easily decomposed material disappears and nitrogen is immobilized in microbial biomass and decay products, leaving behind more recalcitrant material with slower decomposition rates and lower C:N ratio [45]. Soils of Kalinagar reported to be increased in C:N ratio by increasing depth may be explained by the accumulation of soil carbon source (crop residue) in subsoil layers due to high silt and clay content. It was further corroborated from the correlation study; a strong correlation (Table 3) of C:N ratio with silt content (r = 0.335, $p<0.01$) noticed in these soils.

4. CONCLUSION

As hypothesized, investigating the profile distribution of important soil attributes under varying environmental conditions and soil characteristics provides an insight into the positive/negative link between each other. From the present investigation, we conclude that soil physicochemical properties varied significantly with the soil depth and their concentrations depend on the land use type and environmental factors. The depth-wise distribution of the chemical properties, viz., TOC, TN, pH, and C:N ratio were greatly influenced by soil texture and bulk density. We observed, there was variation in location to location in the status of studied soil characters which was evident from the standard deviation analysis. Correlation study confirmed the strong relation of TOC and TN with soil clay and silt particles showing its crucial role in accumulating the same. In our study, Entisol contained less amount of clay, and therefore, a lesser amount of carbon and nitrogen was found throughout the soil depth as compared to Alfisol. Conclusively, Alfisols with high bulk density have a greater capacity to accumulate TOC and TN throughout the soil profile due to higher clay and silt fractions compared to Entisols with loose textural properties.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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