

## Clay carbon pools and their relationship with short-range order minerals: avenues to mitigate climate change?

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**The relationship of short-range order (SRO) minerals, their role in carbon sequestration capacity and its relation with clay carbon was studied in three soils with contrasting characteristics. The study was carried out in two phases, viz. sorghum–sudangrass depletion experiment and test crop experiment with maize using three levels of fertility status (depleted, original and fertilized with 40 ppm P and K) and two levels of rhizospheric status (rhizosphere and non-rhizosphere). After crop harvest, the clays were separated and fractionated into fine and coarse clay humus complexes and SRO minerals, total organic carbon (TOC) and labile carbon (LC) contents were estimated in them. In fine clay humus complex, mean TOC was significantly higher in Vertisol (3.01%), depleted fertility (2.96%) and rhizosphere (2.87%) samples. LC was significantly higher in depleted fertility status (1.74%), Vertisol (1.72%) and non-rhizosphere (1.82%) samples. In coarse clay humus complex, mean TOC was significantly higher in depleted fertility status (2.33%), Vertisol (2.71%) and rhizosphere (2.30%) samples, whereas for LC only significant difference was observed in soil. TOC showed significant and positive correlation with amorphous ferri-alumino silicate (AFAS) content and allophane content in fine and coarse clay humus complexes respectively. Non-labile carbon showed significant positive correlation with AFAS in both the clay humus complexes and allophane content in coarse clay humus complex. Fine clay humus in any soil is most important in terms of total amount of sequestered carbon. In coarse clay humus fraction, the role of Al and Fe compound is more prominent. Alfisol is the most potential soil for sequestering carbon; rhizosphere sequestered more carbon than non-rhizosphere.**

**Keywords:** Amorphous ferri-alumino silicate, labile carbon, short-range order minerals, total organic carbon.

ABOUT 5–21% of all photosynthetically fixed carbon, which is equivalent to 20–50% of plant biomass transfers to the rhizosphere through root exudates<sup>1</sup>. The root exudates contain more than 200 carbon compounds<sup>2</sup> and on

the basis of molecular weight they are classified into high molecular-weight compounds such as mucilage and ectoenzymes, and low molecular-weight compounds such as organic acids, sugars, phenolics, amino acids, phyto-siderophores, flavonoids and vitamins. This diverse array of compounds adds substantial amount of organic carbon into the soil. For instance, maize transfers 0.5–10% of fixed carbon into the soil<sup>2</sup>. Among these root exudates, low molecular-weight organic acids (LMWOAs) play an important role in transforming crystalline clay minerals by the dislodging of cations (Al<sup>3+</sup>, Si<sup>4+</sup>) in the moiety of the minerals through the formation of chelate. Thus short-range order (SRO) minerals having high capacity to sequester carbon may be formed by this process.

Allophane-containing soil like Andosol exhibits high soil organic carbon (SOC) concentrations compared to other soils<sup>3</sup>. It has been observed<sup>4</sup> that with increasing soil allophane content, there is less transformation and decomposition of organic matter into CO<sub>2</sub>. High C accumulation in allophanic soils can be attributed to the presence of stable SOC protected from microbial degradation. The protective effect of SRO minerals was thought to result from the flocculation of initially soluble organo-Al complexes, and the binding of organic molecules within either the inter-tubular spaces of imogolite threads or the inter-spherular spaces of allophane aggregates. Organic matter is not only chelated to poorly crystalline material, but it may also limit the polymerization of mineral phases to a stage between proto-imogolite and proto-imogolite allophane<sup>5</sup>. Studies indicate that SRO minerals have a large specific surface area by which they are capable of adsorbing organic molecules<sup>6</sup>. On the contrary, several other reports indicate non contribution of SRO minerals in the stabilization of soil organic matter<sup>7,8</sup>.

Many studies have been conducted on whole soil, instead of its clay fractions; therefore, as yet the data generated do not reflect the real situation. The data do not reveal the importance of field crops like maize in mineralogical transformation in clays, which ultimately induces carbon sequestration. Moreover, the involvement of SRO minerals in carbon sequestration is still a matter of debate and its association with colloidal (<0.2 µm) and non-colloidal (0.2–2 µm) clay humus complexes has not been addressed so far. Keeping these facts in view, under controlled condition a greenhouse pot culture experiment was conducted to identify the actual relationship of SRO minerals with clay carbon.

Soils representing three orders, viz. Alfisol (Typic Haplustalfs), Inceptisol (Typic Haplustept) and Vertisol (Typic Haplustert) from Parvathipuram (Andhra Pradesh), Indian Agricultural Research Institute Research Farm (New Delhi) and Rajahmundry (Andhra Pradesh) respectively, were used for the present study. The surface (0–15 cm) soil samples were collected, ground and passed through 2 mm sieve and characterized for physico-chemical properties and mineralogical compositions.

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The soils were analysed following standard methodologies. Basally oriented clay samples (Mg–air, Mg–glycerol, K–air-dried, K heated to 300°C and 550°C) were subjected to XRD analysis. The X-ray diffractograms were recorded (Philips diffractometer, model 1710) using Ni-filtered Cu-K $\alpha$  radiation at a scanning speed of 1.5°2 $\theta$ /min and subsequently identification and semi-quantitative estimation of clay minerals was also carried out using standard procedure.

A controlled greenhouse experiment was conducted with the soils collected during 2010–11 at IARI, New Delhi. The experiment was conducted in two phases. In the first phase, i.e. sorghum–sudangrass depletion experiment, an exhaustive crop, multicut ‘GSC-40’ sorghum–sudangrass hybrid was grown during *kharif* for 100 days in one part of the soil to deplete it from P and K. Immediately after harvesting, the soil was processed for sowing of the next crop, i.e. maize. In the second phase, i.e. test crop experiment with ‘HPQM-1’ maize during winter (*rabi*), in each pot, 2 kg of soil was taken and healthy seedlings were grown up to 60 days after germination. Nitrogen fertilization was given @ 80 mg N/kg to all the treatments in two splits. Thus, three levels of nutrient status were used, viz. ‘depleted’ (sorghum–Sudan grass pre-depleted soil), ‘original’ (initial soil) and ‘fertilized’ (original soil + 40 mg/l P + 40 mg/l K). Similarly, treated soil without any plant was kept as non-rhizospheric soil. Thus, two levels of rhizospheric status were used, viz. ‘rhizosphere’ and ‘non-rhizosphere’. Another factor, soil, as already described contained three levels (Alfisol, Inceptisol and Vertisol) and the experiment was replicated thrice.

Fractionation of soil samples was done by ultrasonic vibration technique<sup>9</sup> for dispersion and finally clay was separated out following Stokes’ law. The collected soil suspension was centrifuged at 5000 rpm for 12 min (calculated using Stokes’ law average specification data of the Remi centrifuge, C-24) to separate fine (<0.2  $\mu$ m) and coarse (0.2–2  $\mu$ m) fractions and used for further analysis. Selective dissolution of SRO minerals in clay and clay–humus complex was performed by boiling NaOH, acid ammonium oxalate (in dark), citrate-bicarbonate-dithionite (CBD) and Na-pyrophosphosphate. Different parameters, viz. amorphous ferri-alumino silicate (AFAS), allophane plus imogolite, ferrihydrite, crystalline iron, poorly ordered iron, poorly ordered aluminium, organically bound aluminium and organically bound iron were calculated from Al, Si and Fe concentrations measured in the aliquot from above selective dissolution procedures. Total organic carbon (TOC) was determined by oxidation with 0.4 N chromic acid in the presence of external heat supply<sup>10</sup>. Labile carbon (LC) was estimated<sup>11</sup> in clay humus complex oxidized by 333 mM KMnO<sub>4</sub>. The change in KMnO<sub>4</sub> (Mn<sup>7+</sup>  $\rightarrow$  Mn<sup>4+</sup>) concentration was used to estimate the amount of carbon oxidized.

The data were processed for analysis of variance for factorial CRD to test differences among the treatment means. Means were compared by LSD multiple range tests using MSTATC software. Results were considered statistically significant at  $P < 0.05$  level. Correlation coefficients were computed using SPSS program.

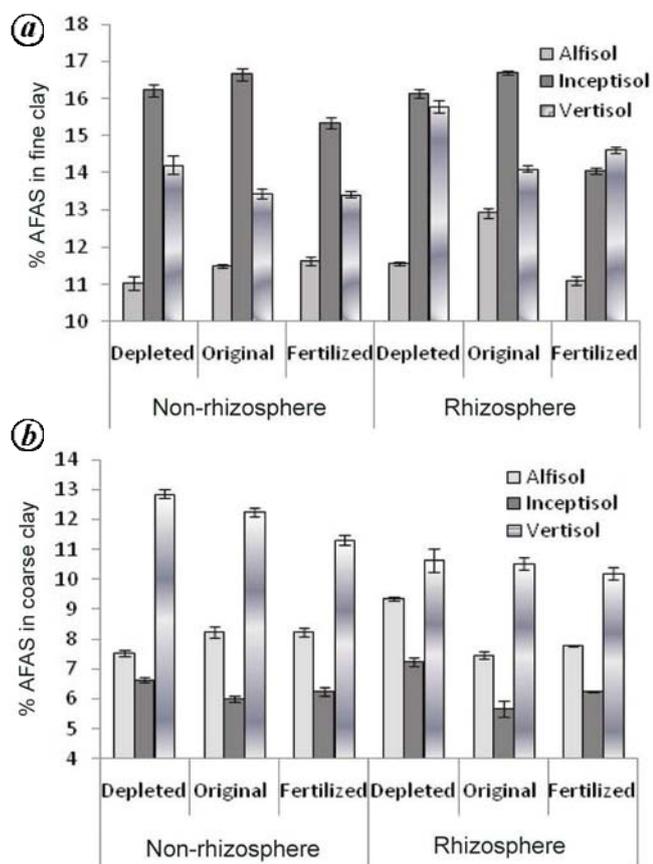
Table 1 indicates that Alfisol was acidic in nature, whereas Inceptisol and Vertisol showed alkalinity. There is no problem of high salt concentration as evidenced by low electrical conductivity value of the soils. Cation exchange capacity was lowest in Alfisol, medium in Inceptisol and highest in Vertisol. Oxidizable organic carbon content was low in Alfisol, whereas it was medium in Inceptisol and Vertisol. Mineralizable nitrogen content was medium for all the soils. Olsen’s P ranged from low to high in these soils and it was maximum in Vertisol followed by Inceptisol and Alfisol. Ca-P was the dominant fraction among different pools of P and higher in Inceptisol and much lower in Alfisol. Available K content was medium to high. Maximum non-exchangeable potassium was observed in Inceptisol, which was 4–5 times higher than Alfisol and Vertisol. Textures of Alfisol, Inceptisol and Vertisol as observed from textural triangle were sandy clay loam, sandy loam and clay respectively. The content and composition of crystalline clay minerals revealed that the major mineralogical composition for Alfisol was kaolinitic (76–81%) in both the fractions. Both Inceptisol fine clay and coarse clay were micaceous (71–76%). Vertisol fine clay was smectitic (60%), whereas coarse clay showed mixed smectite (35%) and mica (46%) mineralogy. Mica was present in all soils and fractions. Inceptisol contained vermiculite (13% in fine clay and 1% in coarse clay). Kaolinite content in Inceptisol and Vertisol was higher in coarser fraction than in the finer fraction.

In fine clay, depleted and original fertility status showed high mean AFAS content (%) over fertilized treatments (Figure 1a). Mean AFAS content was found to be highest in Inceptisol followed by Vertisol and Alfisol. Average AFAS content of rhizosphere was significantly higher than non-rhizosphere. In coarse clay, mean AFAS content (%) of depleted fertility status was significantly higher than original and fertilized fertility status (Figure 1b). Highest mean AFAS content was observed in Vertisol followed by Alfisol and Inceptisol. Average AFAS content of non-rhizosphere was higher than rhizosphere. In addition to AFAS, some other parameters were also measured. A perusal of data in Table 2 indicated that mean allophane plus imogolite content was maximum in Inceptisol fine clay and Vertisol coarse clay, whereas ferrihydrite, crystalline iron, poorly ordered iron and organically bound Fe were highest in Alfisol. In both fractions of clay, organically bound Al content was almost similar in Alfisol and Vertisol samples.

Depletion caused more TOC pool to be stored in the soil, which was evidenced by higher TOC in depleted

**Table 1.** Physico-chemical properties of initial soil samples

Parameter	Alfisol	Inceptisol	Vertisol
pH (1 : 2.5)	5.16	8.32	8.30
EC (dS/m)	0.08	0.35	0.37
CEC cmol (p <sup>+</sup> )/kg	6.4	10.5	24.5
Oxidizable organic C (%)	0.35	0.5	0.62
Mineralizable N (kg/ha)	527.0	539.0	351.0
Available P (kg/ha)	3.4	46.6	58.6
Ca-P (kg/ha)	22.7	433.1	530.9
Non-occluded Al and Fe-P (kg/ha)	228.5	375.1	486.7
Available K (kg/ha)	269.9	355.0	420.0
Non-exchangeable K (kg/ha)	576.8	2494.2	561.1
Mechanical analysis (%)	Sand: 64.3 Silt: 9.3 Clay: 26.4	Sand: 54.4 Silt: 31.8 Clay: 13.8	Sand: 11.2 Silt: 23.9 Clay: 64.9
Crystalline minerals in fine clay (%)	Kaolinite: 81 Mica: 19	Kaolinite: 11 Mica: 76 Vermiculite: 13	Kaolinite: 10 Mica: 30 Smectite: 60
Crystalline minerals in coarse clay (%)	Kaolinite: 76 Mica: 24	Kaolinite: 28 Mica: 71 Vermiculite: 1	Kaolinite: 19 Mica: 46 Smectite: 35



**Figure 1.** Amorphous ferri-alumino silicate (AFAS) content (%) in (a) fine clay humus complex and (b) coarse clay humus complex.

fertility status (Table 3). It may be due to the released organic acids from plant roots under P and K stress. Among the soils, Vertisol had the maximum TOC indi-

cating higher release of organic acids in Vertisol followed by Inceptisol and Alfisol (Table 3). On the contrary, AFAS and allophane plus imogolite contents in the fine clay fraction were higher in Inceptisol followed by Vertisol and Alfisol. From this it can be referred that Vertisol may have alternate mechanism to protect additional carbon in soil. Since this soil contains lesser amount of free Al and Fe oxides and hydroxides, the high TOC may be due to inter-layer adsorption of carbon or chelate formation of humic substances and organic acids with the broken edges of highly charged mineral surface. The binding of the aromatic acids in dissolved organic matter to reactive mineral surfaces was resulted in long-term soil carbon stabilization<sup>12</sup>. Averaging the effect of fertility status, it was observed that rhizosphere contained higher mean TOC than non-rhizosphere and Vertisol rhizosphere stored maximum. Rhizospheric soils contain much higher TOC than non-rhizosphere soils because of carbonaceous compound addition through root exudates. Depleted rhizosphere contained higher amount of TOC than all other combinations (Table 3). Owing to the similarity with TOC content, depleted fertility status contained higher mean LC content than original and fertilized fertility status. Among the soils, Vertisol contained maximum amount of LC. The LC contents of depleted Inceptisol and depleted Vertisol were significantly higher than other combinations. Unlike TOC, rhizosphere possessed lesser mean LC content than non-rhizosphere. Non-rhizospheric soil with all three combinations of fertility status contained significantly higher amount of LC than similar combinations with rhizospheric soil (Table 4). The lability of the released carbon in rhizosphere was less due to conversion of labile pool to non-labile form (NLC) in SRO minerals of the finer fraction. The SRO minerals

**Table 2.** Content of short-range order (SRO) minerals (%) in soil clay humus complexes averaged over fertility and rhizospheric status

SRO minerals (%)	Formula	Fine clay humus complex			Coarse clay humus complex		
		Alfisol	Inceptisol	Vertisol	Alfisol	Inceptisol	Vertisol
Allophane + imogolite	% Si <sub>o</sub> × 7.1	1.06–2.88 (1.73)	2.65–7.13 (4.15)	2.10–3.60 (2.60)	1.17–2.52 (1.70)	4.44–5.93 (5.00)	4.45–6.12 (5.43)
Ferrihydrite	% Fe <sub>o</sub> × 1.7	0.63–0.73 (0.66)	0.48–0.63 (0.53)	0.38–0.43 (0.40)	0.69–0.75 (0.72)	0.44–0.50 (0.47)	0.50–0.53 (0.52)
Crystalline Fe	Fe <sub>d</sub> –Fe <sub>o</sub> (%)	5.61–9.15 (7.39)	1.57–1.93 (1.79)	1.74–2.61 (2.08)	7.24–9.46 (8.35)	1.93–2.18 (2.06)	1.84–2.68 (2.40)
Poorly ordered Fe	Fe <sub>o</sub> –Fe <sub>p</sub> (%)	0.19–0.34 (0.25)	0.15–0.25 (0.18)	0.08–0.14 (0.11)	0.21–0.31 (0.26)	0.09–0.17 (0.13)	0.16–0.21 (0.18)
Organically bound Al	Al <sub>p</sub> (%)	1.05–1.70 (1.42)	0.77–1.41 (1.20)	0.99–1.91 (1.46)	1.17–1.65 (1.33)	0.86–1.76 (1.25)	0.76–1.68 (1.33)
Organically bound Fe	Fe <sub>p</sub> (%)	0.09–0.19 (0.14)	0.11–0.15 (0.13)	0.10–0.15 (0.12)	0.11–0.21 (0.16)	0.11–0.17 (0.15)	0.11–0.15 (0.13)

Numbers within parenthesis indicate the mean value. o, Oxalate extractable; d, CBD extractable; p, Pyrophosphate extractable.

**Table 3.** Total organic carbon content (%) in fine clay humus complexes in rhizosphere and non-rhizosphere soils

Fertility status	Soil			Mean
	Alfisol	Inceptisol	Vertisol	
Depleted	2.55e	3.05ab	3.26a	2.96A
Original	2.12f	2.78cde	2.94bc	2.62B
Fertilized	1.99f	2.60de	2.83bcd	2.47C
Mean	2.22C	2.81B	3.01A	
LSD ( <i>P</i> = 0.05)	Soil ( <i>S</i> ) = 0.14		Fertility status ( <i>F</i> ) = 0.14	
Soil				
Rhizospheric status	Alfisol	Inceptisol	Vertisol	Mean
Non-rhizosphere	2.09e	2.61c	2.78c	2.49B
Rhizosphere	2.35d	3.02b	3.25a	2.87A
Mean	2.22C	2.81B	3.01A	
LSD ( <i>P</i> = 0.05)	Soil ( <i>S</i> ) = 0.14		Rhizospheric status ( <i>RH</i> ) = 0.11	
Soil				
Rhizospheric status	Depleted	Original	Fertilized	Mean
Non-rhizosphere	2.64bc	2.49cd	2.35d	2.49B
Rhizosphere	3.27a	2.75b	2.59bc	2.87A
Mean	2.96A	2.62B	2.47C	
LSD ( <i>P</i> = 0.05)	Fertility status ( <i>F</i> ) = 0.14		Rhizospheric status ( <i>RH</i> ) = 0.11	
				<i>F</i> × <i>RH</i> = 0.19

Means followed by the same capital letter or interactions followed by the same small letter in each row or column are not significantly different at 0.05 level of probability by LSD range test.

such as allophane, imogolite and ferrihydrite have a tendency to form complexes with humic substances through ligand exchange between mineral hydroxyl groups and humic substance functional groups<sup>13</sup>. Similar kind of mechanism is expected to occur in the present study.

The NLC/LC ratio is considered as an index of carbon sequestration. Higher the ratio, more will be the carbon sequestration. In rhizospheric soils this ratio is > 1, which suggests that majority of TOC is non-labile or inactive and less susceptible to microbial degradation. The

rhizospheric soils (average 1.31, > 1) had higher NLC/LC ratio (Figure 2a) than non-rhizospheric soils (average 0.38, < 1). Alfisol in depleted rhizosphere, Inceptisol in original and fertilized rhizosphere and Vertisol in fertilized rhizosphere contained more NLC as evidenced by high NLC/LC ratio. Alfisol has high NLC/LC ratio, it can sequester more carbon in fine clay humus complex of depleted rhizosphere. However, SRO minerals content in this soil is much less than the others. Therefore, this can be explained by the formation organo-metallic (Al/Fe-SOM)

**Table 4.** Labile carbon content (%) in fine clay humus complexes in rhizosphere and non-rhizosphere soils

Fertility status	Soil			Mean
	Alfisol	Inceptisol	Vertisol	
Depleted	1.34d	1.91ab	1.97a	1.74A
Original	1.70c	1.31d	1.75bc	1.59B
Fertilized	1.41d	1.46d	1.43d	1.43C
Mean	1.48B	1.56B	1.72A	
LSD ( $P = 0.05$ )	Soil ( $S$ ) = 0.11		Fertility status ( $F$ ) = 0.11	$S \times F = 0.18$

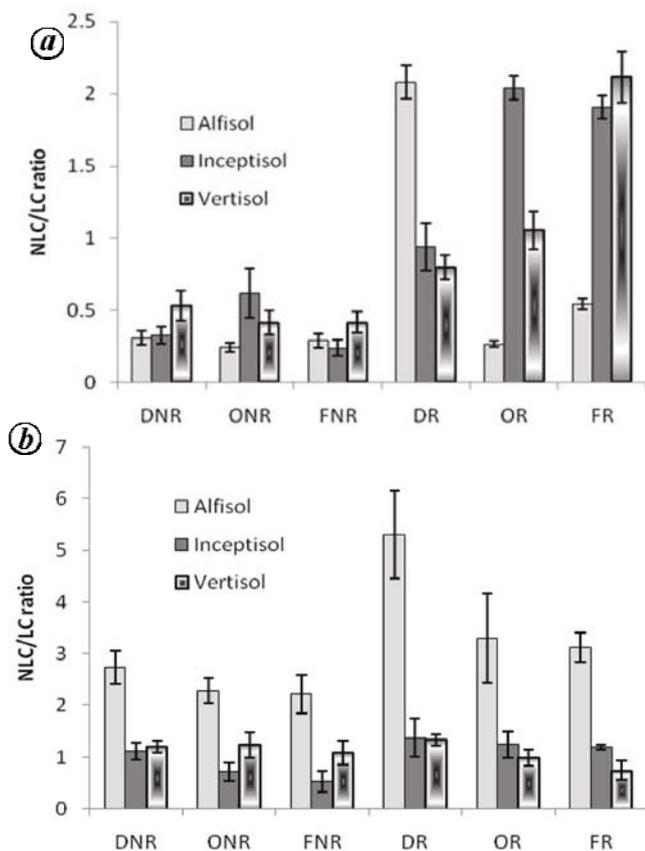
  

Rhizospheric status	Soil			Mean
	Alfisol	Inceptisol	Vertisol	
Non-rhizosphere	1.64b	1.89a	1.93a	1.82A
Rhizosphere	1.33c	1.22c	1.51b	1.35B
Mean	1.48B	1.56B	1.72A	
LSD ( $P = 0.05$ )	Soil ( $S$ ) = 0.11		Rhizospheric status ( $RH$ ) = 0.09	$S \times RH = 0.15$

Rhizospheric status	Fertility status			Mean
	Depleted	Original	Fertilized	
Non-rhizosphere	1.91a	1.76b	1.79ab	1.82A
Rhizosphere	1.57c	1.41d	1.08e	1.35B
Mean	1.74A	1.59B	1.43C	
LSD ( $P = 0.05$ )	Fertility status ( $F$ ) = 0.11		Rhizospheric status ( $RH$ ) = 0.09	$F \times RH = 0.15$

Means followed by the same capital letter or interactions followed by the same small letter in each row or column are not significantly different at 0.05 level of probability by LSD range test.



**Figure 2.** Non-labile carbon/labile carbon (NLC/LC) ratio of (a) fine clay humus complex and (b) coarse clay humus complex. D, Depleted; O, Original; F, Fertilized; R, Rhizosphere; NR, Non-rhizosphere.

complexes formation mainly with aluminum ions, but also with iron ions<sup>7</sup>.

Similar to fine clay humus fractions, depleted fertility status significantly stored higher TOC than original and fertilized fertility status. Vertisol had the highest amount of TOC followed by Inceptisol and Alfisol. The rhizosphere contained significantly higher amount of mean TOC than non-rhizosphere. Rhizospheric condition with different combinations of fertility status showed significantly higher TOC than those of non-rhizosphere and fertility status combinations (Table 5). This result follows the similar trend as observed in fine clay, but TOC content associated with this fraction is smaller than that of the finer fraction. Mean LC content over different fertility status and rhizospheric conditions were non-significant. Mean LC content of Inceptisol and Vertisol was significantly higher than Alfisol (data not shown).

NLC/LC ratio was higher in case of Alfisol in both rhizosphere and non-rhizosphere soil than Inceptisol and Vertisol. This ratio for rhizospheric Alfisol was significantly higher than non-rhizospheric Alfisol, whereas for Inceptisol and Vertisol the differences were non-significant (Figure 2b). This attributes more importance of organo metallic complexes than organo-mineral complexes in carbon sequestration, especially in coarse clay humus fraction. The organo-mineral complex is formed by the valence unsatisfied hydroxyl groups of Al, Si and Fe hydroxides, which have the ability to adsorb ions and compounds of opposite charge specifically and the mechanism is the linking of soil organic matter (SOM) to

**Table 5.** Total organic carbon content (%) in coarse clay humus complexes in rhizosphere and non-rhizosphere soils

Fertility status	Soil			Mean
	Alfisol	Inceptisol	Vertisol	
Depleted	1.31e	2.75b	2.93a	2.33A
Original	0.94g	2.55cd	2.66bc	2.05B
Fertilized	1.13f	2.41d	2.54cd	2.03B
Mean	1.13C	2.57B	2.71A	
LSD ( $P = 0.05$ )	Soil ( $S$ ) = 0.10		Fertility status ( $F$ ) = 0.10	$S \times F = 0.17$

Rhizospheric status	Soil			Mean
	Alfisol	Inceptisol	Vertisol	
Non-rhizosphere	1.07d	2.31c	2.53b	1.97B
Rhizosphere	1.19d	2.82a	2.89a	2.30A
Mean	1.13C	2.57B	2.71A	
LSD ( $P = 0.05$ )	Soil ( $S$ ) = 0.10		Rhizospheric status ( $RH$ ) = 0.08	$S \times RH = 0.14$

Rhizospheric status	Fertility status			Mean
	Depleted	Original	Fertilized	
Non-rhizosphere	2.09b	1.91c	1.91c	1.97B
Rhizosphere	2.57a	2.19b	2.14b	2.30A
Mean	2.33A	2.05B	2.03B	
LSD ( $P = 0.05$ )	Fertility status ( $F$ ) = 0.10		Rhizospheric status ( $RH$ ) = 0.08	$F \times RH = 0.14$

Means followed by the same capital letter or interactions followed by the same small letter in each row or column are not significantly different at 0.05 level of probability by LSD range test.

clay particle (CL) through polyvalent cations and is represented as  $[(CL-P-SOM)_x]_y$ , where  $x$  and  $y$  are whole integers depending upon the size of clay particles<sup>14</sup>. Similarly, a study revealed that the influence of clay content on maximum adsorption capacity of dissolved organic carbon was of secondary importance and was largely masked by the dominant influence of sum of poorly crystalline Fe and Al<sup>15</sup>.

In fine clay humus complex, TOC showed significant and positive correlation with AFAS content (0.63\*\*). Highly significant, positive correlations were shown to increase with increasing SRO minerals content<sup>16</sup>. NLC showed high significant positive correlation (0.40\*\*) with AFAS content. In coarse clay humus complex, significant and positive correlation was observed between TOC and allophane plus imogolite (0.93\*\*). Similarly, there are several reports on positive correlation between carbon and allophane contents<sup>4,17</sup>. For LC, significant negative correlation was observed with ferrihydrite (-0.84\*\*), poorly ordered iron (-0.67\*\*) and organically bound iron (-0.34\*). Actually free or bound short-ranged aluminium and iron compounds are involved in transforming the labile pool of carbon to NLC. Decrease in carbon adsorption capacity was found for illite and kaolinite minerals compared to ferrihydrite, a SRO Fe oxyhydroxide<sup>18</sup>. Furthermore, following adsorption, illite and kaolinite samples demonstrated greater mineralization of adsorbed carbon relative to ferrihydrite samples. Significant positive correlation between NLC and AFAS in both

the fractions (0.40\*\* and 0.29\*) and allophane plus imogolite in coarse clay humus complex (0.63\*\*) confirms the role of SRO minerals in carbon sequestration. The relationship can be expressed in terms of equations by considering TOC as a dependent variable and different iron pools (eqs (1) and (3) below) or allomino-silicates (eqs (2) and (4) below) as independent variables.

In fine clay:

$$\text{TOC} = 2.138^{**} + 0.906 \text{ AFAS}^* - 2.392 \text{ FERRI}^{**} + 0.013 \text{ CRYFE} + 3.303 \text{ ORFE}^{**} \quad (1)$$

$$(R^2 = 0.645),$$

$$\text{TOC} = 1.203 + 0.163 \text{ AFAS}^{**} - 0.041 \text{ KAO} - 0.721 \text{ FERRI} - 0.065 \text{ ALIM} \quad (2)$$

$$(R^2 = 0.625).$$

In coarse clay:

$$\text{TOC} = 2.178^{**} + 0.049 \text{ AFAS}^* + 0.469 \text{ FERRI} - 0.258 \text{ CRYFE}^{**} + 2.481 \text{ ORFE} \quad (3)$$

$$(R^2 = 0.864),$$

$$\text{TOC} = 5.465 + 0.050 \text{ AFAS}^{**} - 0.128 \text{ KAO} - 3.528 \text{ FERRI} - 0.324 \text{ ALLO} \quad (4)$$

$$(R^2 = 0.797).$$

where FERRI is ferrihydrite; CRYFE is crystalline iron; ORFE is organically bound iron; KAO is kaolinite and ALIM is allophane + imogolite.

Released carbonaceous exudates influence carbon sequestration in two ways: (i) partially breaking the crystalline structure to form SRO minerals having high carbon sequestering potential and (ii) acting as a source of carbon. From the present study, the following important conclusions can be drawn: (a) Carbon sequestration is a function of soil mineralogical constituents. It is governed not only by SRO aluminosilicates present in the soil, but also short-ranged iron and aluminium oxides and oxyhydroxides. (b) Fine clay humus in soil is most vital in terms of total amount of sequestered carbon, as higher amount of all the forms are being associated with that fraction. (c) In coarse clay humus fraction, role of Al and Fe compounds is more prominent. (d) Alfisol is the most potential soil for sequestering carbon than Vertisol and Inceptisol, and rhizosphere sequestered more carbon than non-rhizosphere.

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## Electrical resistivity tomography for groundwater exploration in a granitic terrain in NGRI campus

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**Rapid growth of residential colonies around the campus of the CSIR-National Geophysical research Institute (NGRI), Hyderabad during the last two decades has resulted in either disappearance or drastic reduction in size of open space and ponds for groundwater recharging. Withdrawal of groundwater for domestic uses has increased several fold causing continuous lowering of the water table in and around the campus. Due to this changed scenario, availability of groundwater to meet the requirement of CSIR-NGRI is drastically reduced. This communication presents the results of electrical resistivity tomography (ERT) carried out in the CSIR-NGRI premises to locate potential groundwater resources as well as choose suitable sites for artificial recharging of aquifer. Groundwater potential zone identified by ERT is verified at one site by drilling a bore well.**

**Keywords:** Artificial recharging, granite, groundwater resources, electrical resistivity tomography.

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