ISSN 0255-7193

CLAY RESEARCH

Vol. 37, No. 2

December, 2018

IOS Press

Overseas distribution
IOS Press, The Netherlands

THE CLAY MINERALS SOCIETY OF INDIA
Division of Soil Science and
Agricultural Chemistry
Indian Agricultural Research Institute
New Delhi-110 012, India

Overseas subscribers may send
their queries to IOS Press, Nieuwe
Hemweg 6B, 1013 BG Amsterdam,
The Netherlands, orders@iospress.in:
URL: http://www.iospress.nl

THE CLAY MINERALS SOCIETY OF INDIA

(Registered under Act XXI of 1860)
Registration No. S/13028 of 1982

Annual Institutional Subscription Rates Inclusive of Air Mail and Handling Charges :

Subscription Rates (Year 2011)	Indian (INR)	Overseas (USD)
Print + online access	Rs. 1,800.00	$ 350.00
Online access	Rs. 600.00	$ 150.00
Print	Rs. 1,200.00	$ 200.00

All payments should be sent to **"The Clay Minerals Society of India"** Division of Soil Science and Agricultural Chemistry, I.A.R.I., New Delhi-110 012

Clay Research, Vol. 37, No. 2, pp. 41-49 (2018)

Ceramic Potential of varying Trinidad Clay-Based Soils

STEPHAN SIEUNARINE[A], CHRIS MAHARAJ[A], REAN MAHARAJ*[B]

[a] *Department of Mechanical and Manufacturing Engineering, The University of the West Indies, St. Augustine Campus, St. Augustine, Trinidad.*
[b] *Process Engineering, The University of Trinidad and Tobago, Point Lisas Campus, Brechin Castle, Trinidad.*

Abstract–*As the Government of Trinidad and Tobago seeks to diversify the economy away from oil and gas, opportunities arise for value added products, made from indigenous raw materials. The traditional ceramic industry, based on clay products can be a growth pole in the medium to long term as products are developed for both local consumption and export. The main clay deposit currently exploited for heavy industrial production is in the geographic regionof Longdenville, situated in central Trinidad. This deposit consists ofkaolinitic clay mineral; presently extensively utilized in the production of clay blocks, bricks, and tiles. This study examines samples of kaolinitic claysfrom other sources including Rio Claro, Valencia, Cocoloco, and Caparoalong with the Longdenville clay. A 70:30clay: sand ratio was used as a baseline, as well as formulations with 2.5% more clay and 2.5% less clay than the baseline. All samples were fired to 1075 °C and then subjected to compressive strength, modulus of rupture(MOR) and water absorptiontests. Within the composition range tested, the Rio Claro, Cocoloco, and Caparoclay sources yielded maximum compressive strengths, (MOR) in excess of 10 MPa and water absorption between 3.7% and 9.4%. These exceed the TTBS requirements and can be substitutes for the Longdenville clay in the manufacture of construction products. The estimated acreage of the Cocoloco clay is approximately 10 times that of the Longdenville clay and its close proximity to Longdenville can make ita good substitute.*

Key words: Ceramic, Clay, Compressive strength, Modulus of rupture.

Introduction

Clay is a naturally occurring material found in soil and consists of hydrous aluminum silicates containing small amounts of contaminants such as sodium, potassium, calcium, magnesium and iron. Clay exhibits plastic behavior when wet, can be easily molded. It loses plasticity becominghard when subjected to heat (Guggenheim and Martin, 1995). Industrially, clays are typically blended with sand and lime or cement and fire hardened to produce clay bricks which typically consist of Silica (sand) – 50% to 60%, Alumina (clay) – 20% to 30%, Lime – 2 to 5%, Iron oxide – ≤ 7% and Magnesia – less than 1% (Punmia and Jain, 2003; Maharaj *et al.*, 2014). Trinidad and Tobago is an oil and gas based economyand is one of the largest producers of clay blocks in the region. Blocks are manufactured by Trinidad Aggregate Products (TAP) and Alston's Building Enterprises Limited (ABEL) in the Longdenvilletown, utilizing mainly the Grey Gumbo and Red Mottle clay types (Ramdath, 2012). These companies mine their clay from an area spanning approximately 300 acres as shown in Figure 1.

Based on current consumption and available acreage, the current life expectancy of the clay pits is finite expecting to last a further 50 to 80 years. As Trinidad and Tobago embarks on economic diversification away from oil and gas exports, focusing more on manufacture and export of non-oil products such as clay blocks, the demand for clay will increase resulting in the need for source similar type of clay to sustainthe

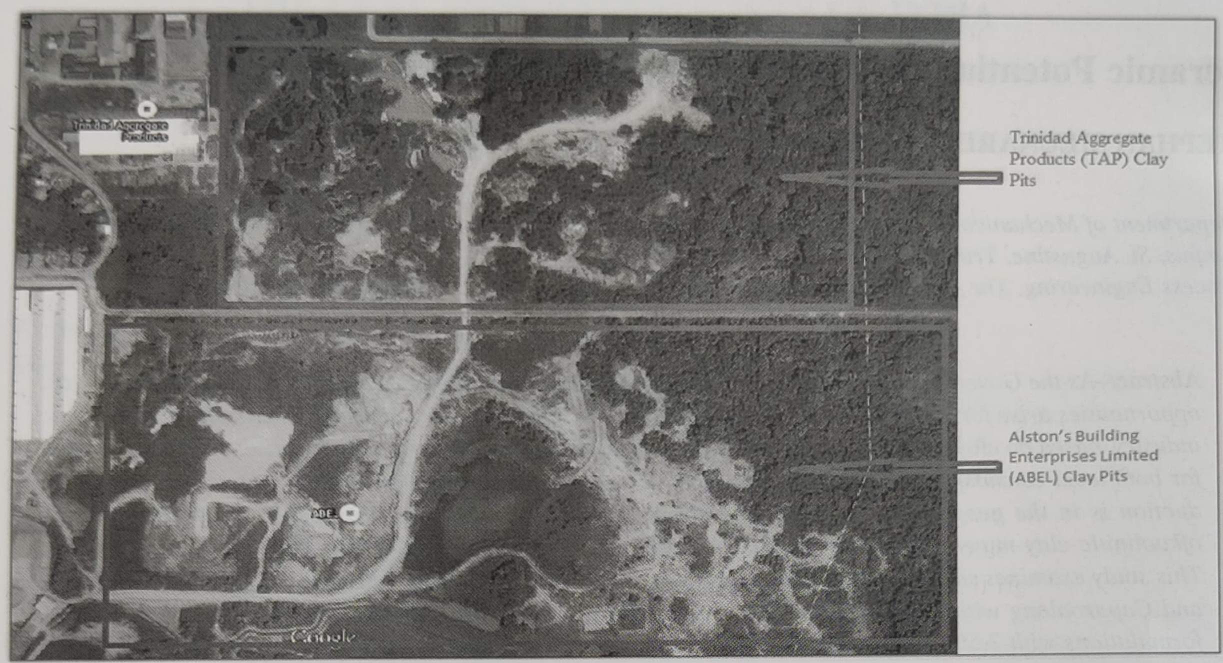

Fig. 1. *Location of (TAP) and (ABEL) clay pits in Longdenville, Trinidad. Adapted from Google Earth (cited 2015 July 8th).*

clay block manufacturing industry. There exist other sources of clay in Trinidad, some of which have ceramic producing potential (Knight, 1996; Knight *et al*., 2006; Knight and Hosein, 2007) however these alternative clay materials cannot be simply substituted within the existing clay block formulation as the source of the clay together with the relative proportions of the ingredients used in the block mixing formulations, play a critical role in the determination of the required physical and performance specifications of the end product. The source's inherent mineral and chemical constituents are not inert materials but functional within the clay system anddeterminethe clay's plasticity, drying, unfired and fired characteristics (Murray, 2000; Aras, 2004; Onal and Sarýkaya, 2009).

The ceramic potential of some Trinidad clays, from the localities of Valencia, Caparo, Longdenville, Cocoloco and La Brea were evaluated to determine its chemistry and mineralogy (Knight, 1996). The results of this study shown in Table 1 revealed that these were all predominantly Kaolinitic clay and the major oxides were those of silica and aluminium.

The study also investigated the fired

Table 1. *Chemical analysis and loss on ignition (LOI) (Weight %)*

	Weight Percentage (%)							
Clay	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	LOI
Valencia	71.8	16.9	1.5	-	4.1	-	-	1.24	4.5
Caparo	73.0	11.0	4.5	-	3.9	-	-	0.60	7.0
La Brea	58.0	17.8	5.4	-	3.8	0.1	0.5	0.78	13.7
Cocoloco	66.3	14.1	4.1	-	4.1	-	-	1.56	9.8
Longdenville	68.0	15.5	5.8	-	3.8	-	-	0.90	6.0

characteristics of the aforementioned clays, without the addition of sand. The Valencia clay has a near white fired color, relatively high porosity, and low density making it a worthy candidate for refractory and ceramic applications such as wall tiles and domestic wares. The Caparo and Longdenville clays showed low strength and toughness, orange to reddish color, relatively high porosity, and minimal linear shrinkage; however useful strength and toughness renders these clays promising for possible refractory applications. The Cocoloco and La Brea clays exhibited good strength and toughness that renders these promising for ceramic and refractory application however the La Brea clay formed a scum on the outer surface due to the presence of soluble salts (Knight, 1996).

The formulation of clay blocks from Alston's Building Enterprises Limited (ABEL) was optimized by varying therelative proportions of the Longdenville clay, sand and water (Maharaj *et al*., 2014). The effects on the green mechanical properties such as compressive and flexural strengths, and the physical properties of extruded surface finish, density, extrusion pressure and rheology were investigated. For the various properties and characteristics,a weighting system was developed to evaluate the formulations. It was found that the addition of 5% more clay to the existing formulation, at 16% water content, produced the best result. A similar study by (Mylan *et al*., 2016) into the optimal clay block formulation for Trinidad Aggregate Products (TAP) was also conducted. The weighting system used to evaluate the optimal fired clay block formulation consisted of the highest compression strength, highest modulus of rupture and most attractive colour for the various formulations. The most favorable product was produced by adding 2.5% clay to the original TAP formulation.

In Trinidad and Tobago the two clay block manufacturers Trinidad Aggregate Products (TAP) and Alston's Building Enterprises Limited (ABEL) utilize the same raw material mined from the same geographic region of the country. The concentration of the source and the apparent lack of proven alternatives, is not an issue presently, however it may present it self as one in future. The current situation also reduces physical and economic feasibility of a new manufacturer being able to enter the market unless a viable alternative source of raw material is found. Clays from different sources in Trinidad vary in chemical composition and cannot be substituted to manufacture clay blocks because the chemical composition influences the fired properties such as compressive strength and modulus of rupture strength. This research will be focused on determining alternative sources of raw materials to be used as a substitute for Longdonville clay, with optimized mix proportions, that can be used to manufacture products that meets or exceeds the local standards, yet yielding consistent quality independent of the source.

Method

Raw Materials Collection and Preparation

Global Positioning System (GPS) coordinates of the sample locations were taken and soils were identified according to conventional soil taxonomy according to Brown and Bally (1967). A program called Agri Net. TT developed by the University of the West Indies was used to identify the various soil codes and series. Once the soil series was identified, the quantity available in terms of acreage was determined using available data fromthe Food and Agriculture Department at the University of the West Indies. Table 2 shows the soil names that were identified according to its proper soil taxonomical name and the quantity available in terms of acreage.

Disturbed sampling of the clay was carried out consistent with Roopnarine *et al*., (2012) was carried out at the locations listed above. Ten to twelve inches (10-12) of soil was removed to eliminate the high concentration of organic matter. A garden fork was then used to extract

Table 2. *Soil name and commercial availability*

Location of Clay source	GPS Coordinates	Soil series	Total acreage In Trinidad
Guayaguayare Road Rio Claro	10.29194 N, -61.16892 E	L' Ebranche series (35b1)	62971
CocolocoEstate Todd's Road	10.47356 N -61.32128 E	Talparo series (177bc2)	276112
TurureRoad Valencia	10.619541 N, -61.14746 E	Valencia scl (255)	12541
Caparo Valley Road	10.46625 N, -61.32774 E	Arena sand (261c1)	7922
Longdenville	10.51107 N -61.36672 E	Cunupia series (33a1)	24895

the clay and transfer it to a crocus bag. The raw material was then stored at the foundry of The University of the West Indies for air drying.

Dried clumps of clay were crushed into less than 12 mm particle size in a Braun chipmunk crusher and further reduced in size by blending in a Hamilton beach blender. The raw material was then passed through a 0.212 mm sieve. The samples were then placed in the dehumidification chamber until constant mass was achieved. The Ravine Sable sand was passed through the 0.5 mm sieve and the 0.2 mm sieve, and the portion retained on the 0.2 mm sieve utilized.

Particle size analysis of the crushed clays passed through the 9.5 mm sieve was performed in accordance to ASTM D421- Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants.

Chemistry and Mineralogy Five (5) 12 mm by 12 mm by 50 mm specimens were similarly produced for MOR evaluations.

Specimen drying was conducted in two stages, as used byVieira *et al.*, (2008).

1. The specimens were placed in a holding area and subjected to atmospheric conditions and intermittent streams of air for 48 hours.
2. These were then transferred to a Thermo Scientific oven for 24 hours at a temperature of 110 °C.

The dried specimens were fired in atunnel kiln at a clay block manufacturing facility. The kiln was operated on a controlled firing profile from starting from 150 °C to a maximum firing temperature of 1075 °C.

Water Absorption

Specimens were subjected to water absorption test consistent with Khalaf and Devenny (2002). The mass of each specimen wasrecorded after heating for 24 hours at a temperature of 110 °C in a Thermo Scientific oven. The mass was retaken after immersion in water for 24 hours. The percentage water absorption was calculated based on the difference in mass with respect to the initial mass.

Mechanical Properties

The flexural strength of the specimens was determined in accordance to ASTM C674 - 13 - Standard Test Methods for Flexural Properties of Ceramic Whiteware Materials

Compressive strength testing was donein accordance to ASTM C773 - 88(2016) - Standard Test Method for Compressive (Crushing) Strength of Fired Whiteware Materials

The aforementioned tests were conducted

using an Hounsfield model H25KStensometer.

Results and Discussion

Particle Size Analysis

Particle size distribution data for the clay soil samplesis depicted in Figure 2. All of the samples were mainly sand, silt and clay by particle size as over 90% of the material passed through the 850 μm sieve. The Cocoloco clay was the finest, with the highest proportion passing through, the 75 μm sieve. The Caparo clay turned out to be the coarsest, retaining significant material on all the sieves from No. 4 downwards. However, the rest have similar fineness, with over 80% passing the 75 μm sieve.

Chemistry and Mineralogy

The chemistry in terms of oxide contents of the clay soils used is presented in Table 3. As expected, from clay minerals, Alumina and silica would be dominant oxides, as clays are alumino-silicate minerals. The high silica content alludes to the presence of sand. Iron oxide is responsible for the reddish coloration of most fired clays. The relatively low iron oxide content of the Valencia clay is responsible for its light color on firing. Additionally, iron oxide acts as a flux, and lowers, the firing temperature required for vitrification of iron containing clays. Consequently, Valencia clays require a firing temperature of about 1300°C to attain its full strength (Knight and Hosein, 1997). Cocoloco clay has the highest LOI suggesting high organic matter content. Thus the lowLoss on Ignition (LOI) of the Rio Claro Clay indicate a low organic content.

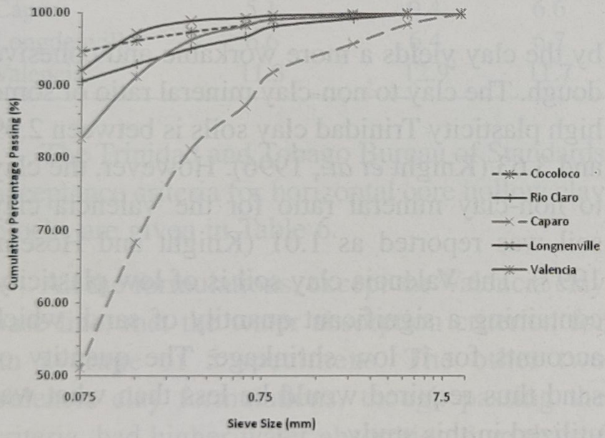

Fig. 2. *Sieve analysis of the selected clays*

The chemistry of the sand soil utilized is shown in Table. This sand is free of organic matter and clays as there is no LOI and the particle size used is greater than the 2 μm of clay. This sand is almost entirely silica (97%), with1% alumina.

The XRD profile of the Rio Claro clay soil can be seen in Figure 3. Figure 4 shows the XRD profiles of five other Trinidad clays, including Caparo, Cocoloco, Longdenvile and Valencia. A comparison of Figure 3 with Figure 4 reveals that the Rio Claro clay is the only one in this study that possesses, three clay minerals, namely: Kaolinite, Montmorillonite and Illite. As kaolinite is the mineral in common with all the clay soils sampled, its properties can be viewed as the baseline for comparison. Montmorillonite is a smectite clay, known as an expensive clay,

Table 3. *Chemical composition and Loss on Ignition (LOI).For Rio Claro clay soil, with Valencia, Caparo,Cocoloco,and Longdenvilledata from Knight et al., (1996) included for comparison.*

Clay soil source	Weight Percentage (%)								
	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	LOI
Valencia	71.8	16.9	1.5	-	4.1	-	-	1.24	4.5
Caparo	73.0	11.0	4.5	-	3.9	-	-	0.60	7.0
Cocoloco	66.3	14.1	4.1	-	4.1	-	-	1.56	9.8
Longdenville	68.0	15.5	5.8	-	3.8	-	-	0.90	6.0
Rio Claro	74.2	12.7	4.7	-	4.3	-	-	0.80	3.3

with significant volumetric changes with respect to water content. The obvious effect on ceramic green ware is excessive drying shrinkage and cracking. Illite is a non-expansive clay, that can occur interlaid with montmorillonite, reducing its expansive potential as expansion can only occur between the montmorillonite-montmorillonite layers (Maio, 2002). The relative effects of combining these three clay typeswas not investigated.

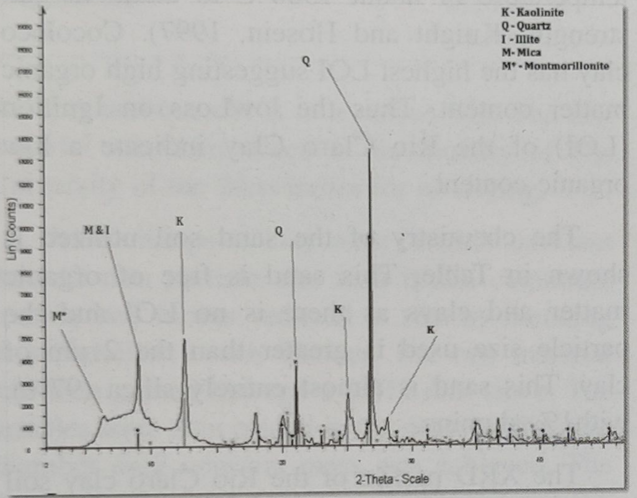

Fig. 3. *XRD Profile of Rio Claro Clay*

Quartz is present in the entire clay sample tested, indicating that these have considerable quantities of sand mixed in with the clay as can be seen from the particle size distribution of Figure 2. Potash Feldspar is a precursor to clay formation and its presence is not surprising. Additionally, potash feldspar acts as a flux and aids in vitrification.

Micasare present in most Trinidad clays tested and generally account for a very small proportion of the minerals within the sample. Illite is a mica-type clay mineral thatcontains more water and less potassium than true micas.

Sample Preparation

Samples with higher clay content extruded better than those with lower clay content. This was expected as the increased plasticity imparted by the clay yields a more workable and cohesive dough. The clay to non-clay mineral ratio of some high plasticity Trinidad clay soils is between 2.09 and 3.63 (Knight *et al.*, 1996). However, the clay to non-clay mineral ratio for the Valencia clay soil was reported as 1.01 (Knight and Hosein, 1997). The Valencia clay soil is of low plasticity, containing a significant quantity of sand, which accounts for it low shrinkage. The quantity of sand thus required would be less than what was utilized in this study.

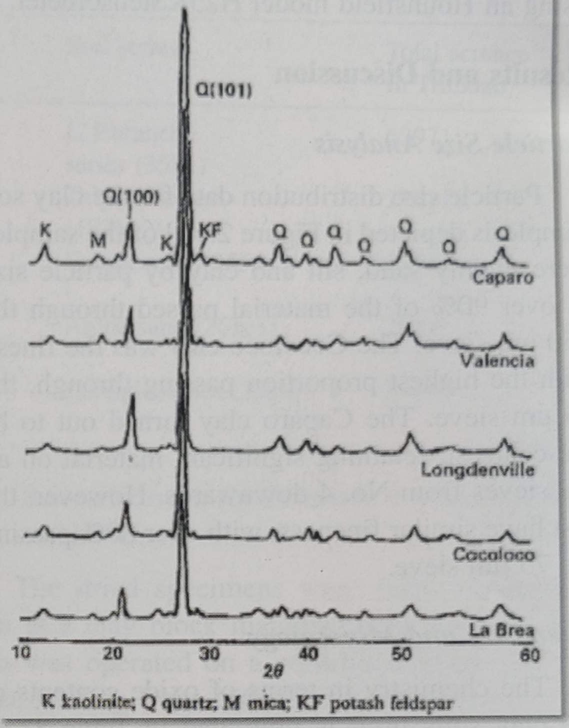

Fig. 4. *XRD Profile of Five Trinidad Clays fromKnightet al., (1996).*

Fired color ranged from light orange for the Valencia clay soil, through orange–brown for the Caparo, Cocoloco and Longdenville clay soils. The Rio Claro clay soil fired to a dark red-brown color. The fired color is mainly due to the presence of iron oxide and the removal of organic matter that gave the soils their unfired color.

Water absorption

The acceptable water absorption for clay

Table 4. *Chemical Composition and Loss on Ignition (LOI) of the sand used (Ramdath, 2012).*

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	K_2O	Na_2O	CaO	MgO	LOI
Ravine sable sand %	97.38	1.05	0.01	0.14	0.2	0.61	0.13	0.01	-

bricks is important to obtain a proper bond between the mortar and the bricks. Highly porous bricks might rapidly absorb moisture from the mortar especially so in hot climates resulting in a rapid stiffening of the mortar resulting in a decrease in the plasticity, poor adhesion and low compressive and flexural strengths. Table 5 shows the percentage water absorption for the clay briquettes of the various formulations studied.

Table 5. *Water absorption percentages (%) for the various clay briquettes*

Clay formulation	2.5% Less Clay	Baseline	2.5% More Clay
Rio Claro.	3.9	3.7	4.0
Cocoloco	3.7	7.5	8.0
Caparo	5.1	9.4	6.6
Longdenville	6.6	6.4	6.7
Valencia	11.3	12.9	11.7

The Trinidad and Tobago Bureau of Standards acceptance criteria for horizontal core hollow clay blocks are given in Table 6.

All the formulations, except the Valencia clay base line, met the water absorption criterion for an average of 5 specimens. The other two Valencia clay formulations, though passing the criteria, had higher water absorption than that of the other clay soils. This is mainly due to the fact that Valencia clay properly vitrifies at about 1300°C, and thus would have high porosity and thus high water absorption at the firing temperature employed. The Rio Claro clay soil consistently had the lowest water absorption, indicating that vitrification maybe complete at this firing temperature. Like the Rio Claro, the Longdenville clay soil also had consistent water absorption with respect to formulation. The Caparoand the Cocoloco clay soils had wide swings in their water absorption, but had formulations that met or exceed the performance of the Longdenville samples.

Mechanical Properties

Figure 5 shows MOR or flexural strength versus formulations with standard deviation as error bars for the five soils. The Rio Claro and Longdenville clay formulations achieved the

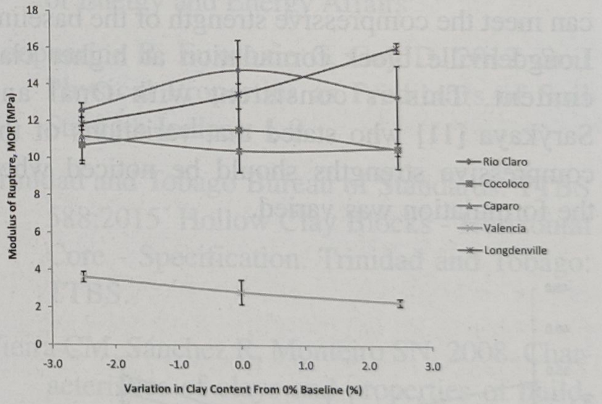

Fig. 5. *Modulus of rupture strength versus variation in clay percentage*

Table 6. *Acceptance criteria for clay blocks (TTBS 588:2015).*

Property	Number of samples to be tested	Acceptance criteria
Individual compressive strength (MPa)	1	More than 3.4 MPa
Average compressive strength (MPa)	5	More than 4.8MPa
Individual water absorption (%)	1	Absorption for each block in sample <14 %
Average water absorption (%)	5	Average absorption < 12 %

highest values of over 13 MPa. The Valencia clay soil having the lowest strengths, consistently less than 4 MPa. Low MOR is directly attributable to the high porosity of the Valencia clay soil and is consistent with the findings of Baccour, Medhioub (Bacchour, 2009). The Caparo and Cocoloco clay soils produce similar MOR values of above 10 MPa that are not affected by clay content.

Compressive strength versus Clay block formulations along with standard deviation as error bars is depicted in Figure 6. The Trinidad and Tobago Bureau of Standards acceptance criterion on compressive strength cannot be applied to these specimens as the standard applies to complete hollow clay block units. However as, blocks made from the baseline Longdenville clay block exceeds the standard, clay soils that meet or exceed its compressive strength will pass this criterion. The Longdenville and Caparo formulations produced the highest compressive strengths whilst the Valencia clay soil produced the lowest. Cocoloco and Rio Clario clay soils can meet the compressive strength of the baseline Longdenville block formulation at higher clay content. This is consistent with Onal and Sarýkaya [11] who stated that variations of the compressive strengths should be noticed when the formulation was varied.

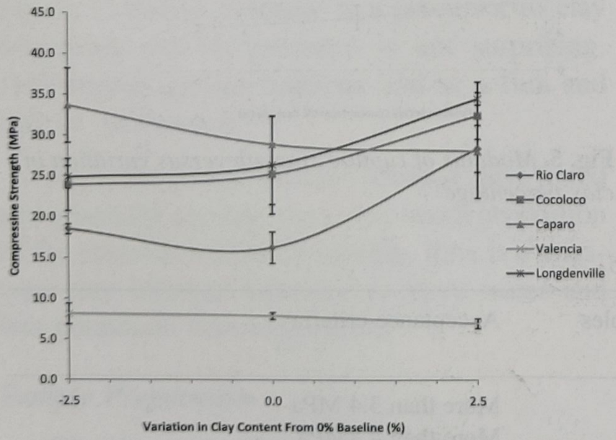

Fig. 6. *Compressive strength versus Clay block formulation*

Conclusion

The high plasticity clay soils of Caparo, Cocoloco and Rio Claro are comparable to the clay soil from Longdenville in terms of replicating the requisite physical and mechanical properties. These clay soils can substitute for the highly utilized Longdenville clay soil, without significant differences in strength and appearance. Consequently, these sources of raw materials can possibly be commercialized as a site for new investment or as a supplement / alternate source for the current facilities.

The estimated quantity of material in the Cocoloco estate is an order of magnitude greater than the figures quoted for the depleting Longdenville clay soil. Additionally, based on the its geographic location and close proximity to the Longdenville area, transportation would not a significant barrier to exploitation. The Caparo clay soil is also within close proximity of the Longdenville ceramic industry, but has an estimated acreage of about 1/3 that of the Longdenville clay soil.

The estimated Rio Claro clay soil acreage is more than 2X larger than that of Longdenville. The relatively long road journey between Rio Claro and Longdenville requires the re-establishment of a ceramic industry in that area for the exploitation of this resource.

The Valencia clay soil with its low iron oxide content, and high firing temperature can be utilized as a clay base for the production of white ware, porcelain tiles, and slip for artisan use. Again, due to geographic considerations, a ceramic plant may have to be set up in that area. Additionally, Valencia clay can be used to reduce the plasticity of high plasticity clays to make them it more amenable to slip casting (Knight and Hosein, 1997).

References

Aras A. 2004. The change of phase compositionin kaolinite and illite-rich clay-based ceramic bodies. *Applied Clay Science.* **24**: 257-269.

Baccour H, Medhioub M, Jamoussi F, 2009. Influence of firing temperature on the ceramic 2812-2817.

Brown C, Bally G. 1967.Land Capability Survey of Trinidad and Tobago. No. 4. Soils of the Northern Range Trinidad. Port of Spain: Government Printery.

Google Earth. Longdenville, Trinidad. 10.519 N and -61.375 E: Google Earth; 2015 [cited 2015 July 8th].

Guggenheim S, Martin RT. 1995. Definition of clay and clay mineral: Joint report of the AIPEA nomenclature and CMS nomenclature committees. Clay and Clay Minerals. **43**(2) : 255-256.

Khalaf FM, Devenny AS. 2002. Test for Porosity and Water absorption of Fired Clay Bricks. *Journal of Materials in Civil Engineering.* August;14.

Knight JC. 1996. Ceramic potential of some Trinidad clays:Fired Characteristics. *British Ceramic Transactions.* **95**: 162-167.

Knight JC, Grierson H, Hosein A. 1996. Ceramaic potential of some Trinidad clays: Chemistry and mineralogy. British Ceramic Transactions. **95**(3): 121-123.

Knight JC, Hosein A. 1997. Ceramic characteristics of the White-Burning Valencia Clay of Trinidad. *West Indian Journal of Engineering.* **20**(1): 76-84.

Maharaj R, Maharaj C, Penjilia C, 2014. Optimization of Ingredients for Clay Block Manufacture:Unfired Characteristics. *Trends in Applied Science Research.* 574-587.

Maio CD, Hueckel T, Loret B. 2002. Chemo Mechanical Coupling Clays. 1st ed. Maio CD, Hueckel T, Loret B, editors.: CRC Press.

Mylan R, Maharaj C, Maharaj R. 2016. Creating the optimal formula for use by a heavy clay block manufacturer. *Clay research.* **35**(2): 17-29.

Murray HH. 2000.Ullmann's Encyclopedia of Industrial Chemistry. 6th ed. Weinheim, Germany: Wiley-VCH VerlagGm BH.

Onal M, Sarýkaya Y. 2009. Some physicochemical properties of a clay containing smectite and palygorskite. Applied Clay Science. **44**(1-2): 161-165.

Punmia BC, Jain. AK. 2003.Basic Civil Engineering. Vol. 442. New Delhi: Firewall Media.

Ramdath H. 2012.Economic Minerals. Ministry of Energy and Energy Affairs

Roopnarine R, Euxdoxie G, Gay D. 2012. Soil Physical Properties as Predictors of Soil Strength Indices: 1-9.

Trinidad and Tobago Bureau of Standards. TTBS 588:2015 Hollow Clay Blocks - Horizontal Core - Specification. Trinidad and Tobago: TTBS.

Vieira CM, Sánchez R, Monteiro SN. 2008. Characteristics of clays and properties of building ceramics in the state of Rio de Janeiro, Brazil. *Construction and Building Materials.* **22**(5).

(Received January, 2019; Accepted June, 2019)

Clay Research, Vol. 37, No. 2, pp. 50-57 (2018)

Effect of Rhizosphere on Labile Carbon Pool and its Stability with Clay

SANGITA MOHANTY AND *SAMAR CHANDRA DATTA

Division of Soil Science & Agricultural Chemistry
ICAR-IARI, New Delhi

The release of organic compounds from plant roots into soil brings about remarkable changes in chemical and physical environment and also in growth, activity and composition of microbial population in rhizosphere (Lynch 1990). These changes may effect key processes such as the mineralization of native soil organic matter and nitrogen transformation in rhizosphere (Kuikiman, 1990; Robinson *et al.,* 1989). Understanding of rhizosphere induced modification of carbon mineralization is very much essential to develop nutrient uptake model for precision agricultural practice.

As far as carbon and nitrogen dynamics in rhizosphere is concerned it has been studied much but least understood. There are lots of discrepancies regarding the effect of roots.

There are reports of rapid rate of mineralization of organic matter due to rhizosphere priming effects (Van Veen *et al.,* 1991; Liljeroth *et al.,* 1994). At the same time suppression of decomposition of soil organic matter due to root activity has also been reported (Reid and Gross, 1982). Rhizosphere priming effect is also observed to vary according to plant species and soil conditions.

Maize and wheat, two high nitrogen demanding crops are grown extensively in India. It is essential to improve our understanding of the effects of roots of these plants grown in different soils, in order to promote efficient use of plant nutrients. In this context the present experiment is designed mainly to test some of the findings regarding rhizosphere priming effect.

The objective of the present study is to evaluate the effect of rhizosphere on different 'C' pools and their stability of complex formation with clay.

Materials and Methods

In order to achieve the objectives of the study, a series of laboratory and greenhouse experiments were conducted on three soils. A brief description of materials used and methods employed is given below

Bullk surface soil samples (0-0.15 m) classified as Inceptisol, Alfisol and Vertisol were collected from IARI research farm (New Delhi), Bhubaneshwar (Orrisa) and Raipur (Chhatisgarh), respectively.

Details of the soils and green house experiment have been described in another communication (Mohanty and Datta, 2018)

Collection and Processing of Soil and Plant Samples

Starting from the day of emergence, five periodic samplings were done at an interval of one weak. Destructive sampling was done and on each sampling event, sampled pots were discarded. Entire soil of cropped pot was taken as rhizosphere soil and that of non-cropped pot was taken as non rhizosphere soil. The soils were

---

***Corresponding Author Email :** samar1953@yahoo.com

separated from the root manually by carefully shaking the plants over a paper sheet. Immediately after sampling, moisture content was determined by using oven dry method.

Total soil organic carbon

Total soil organic carbon was determined by the method of Schollenberger (1927) of chromic acid oxidation and application of external heat.

Labile carbon (LBC)

Labile carbon in soil sample was determined by 0.333 M KMnO4 oxidation method as described by Blair *et al.* (1995). Five gram air dried sample was taken in a centrifuge tube, 25 ml of 0.333 M KMnO4 solution was added and shaken for 1 hour. The samples were centrifuged for 5 min at 2000 rpm and supernatant was diluted 250 times with distilled water. The absorbance of diluted samples and standard KMnO4 solution were read on a spectrophotometer at 565 nm. The change in the concentration of KMnO4 was used to determine the amount of carbon oxidised, assuming that 1 m M KMnO4 is consumed (Mn VII ® Mn IV) in oxidation of 0.75 mM or 9 mg of carbon.

Separation of Clay Organic Complexes

The soil samples in distilled water (soil : water :: 1 : 2) were subjected to ultrasonic vibrations using a SONIPROBE (Type 1130 A DAWE Instruments Ltd.) The < 2 µ fractions of the clay-organic complexes were isolated by gravity sedimentation method.

Stability of Clay-organic Complex against chemical extraction

One g each of clay treated with 250 ml 0.1 N Na4P2O7 - 0.1 N NaOH were taken in 7 separate conical flasks of 500 ml capacity. Flasks were shaken for different time periods, *viz.*, 1/2 hr, 1 hr, 2 hr, 4 hr, 8 hr, 12 hr and 24 hr. After each designated period of shaking, specified flask was removed, suspension was filtered and organic carbon content in the filtrate was measured by Walkley and Black (1934) method. Thus organic carbon released at time intervals of 1/2 hr, 1 hr, 2 hr, 4 hr, 8 hr, 12 hr and 24 hr was determined. Data were fitted to Elovich equation. From the coefficient of equation, rate of release of carbon and the stability of clay-organic complex was assessed.

Results and Discussions

Total organic carbon

Total organic carbon as measured by chromic acid oxidation and application of external heat remained constant without showing any change over the period in all soils. This was observed under both the crops (Fig. 1)

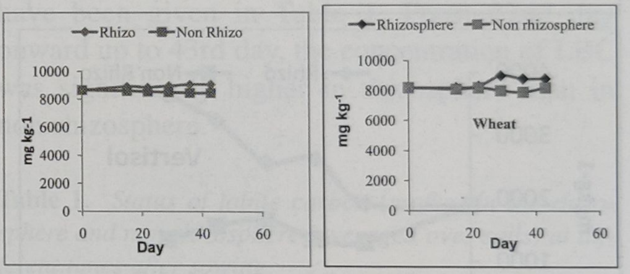

Fig 1. *Status of total organic C(mgkg^{-1}) over the period of 43 days under maize and wheat rhizosphere in Inceptisol*

Labile carbon

Labile carbon (LBC) represents the fraction oxidized by 0.335 M KMnO4 as described by Blair *et al.* (1995). Being a much milder oxidising agent compared to combined use of sulphuric acid, phosphoric acid, potassium dichromate (Walkley and Black, 1934), it primarily consists of soluble and easily oxidizable fraction of soil C. The trends of the change in concentration of LBC under different crops and in different soils have been observed as follows

Maize crop

In case of Inceptisol sample the initial concentration of LBC in rhizosphere and in non-rhizosphere was 1384 mg kg^{-1}. On 15th day the value was reduced to 1241 mg kg^{-1} in rhizosphere and to 1191 mg kg^{-1} in non-rhizosphere (Fig. 2). Further on 22nd day there was sharp increase of LBC to 2491 mg kg^{-1} in rhizosphere. After a slight fluctuation, rhizosphere exhibited an increasing trend in the concentration of LBC throughout the period. Whereas in case of non-rhizosphere, after an initial decrease, the concentration remained almost constant around a value of 719 mg kg^{-1}.

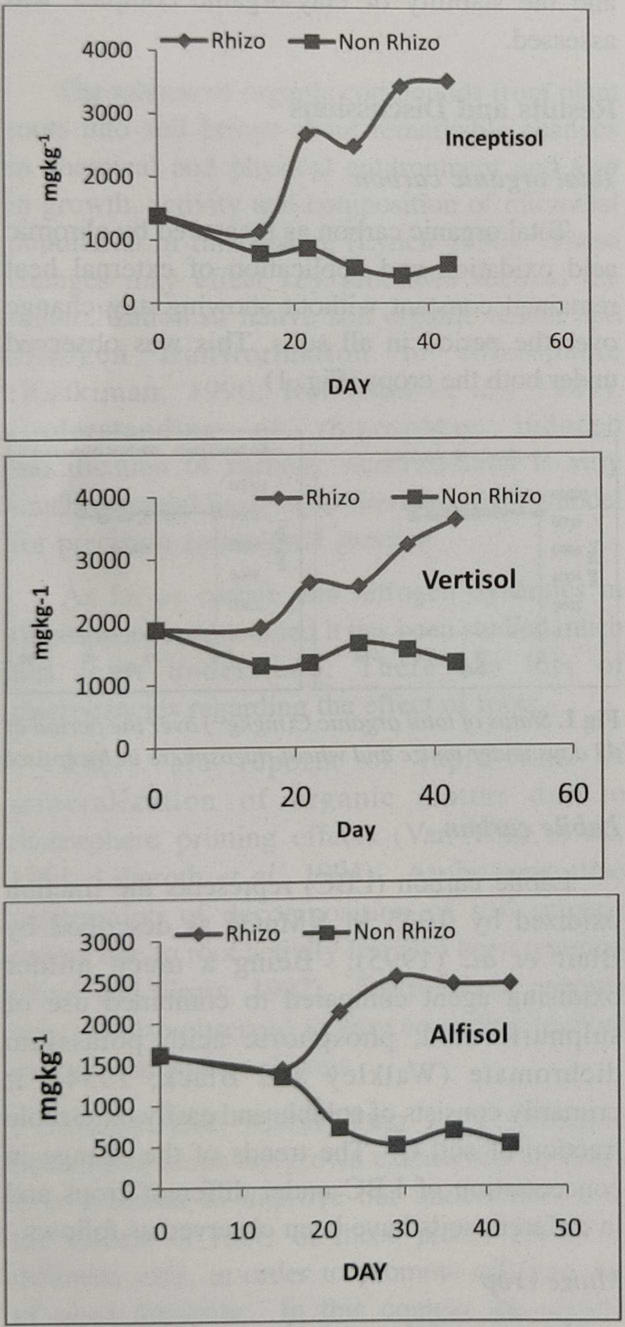

Fig. 2. *Changes in labile carbon in the rhizosphere during maize cropping in different soils*

Initial concentration of LBC in rhizosphere and in non-rhizosphere in case of Vertisol was 1618 mg kg^{-1}. On 15th day the concentration declined to 1527 and 1468 mg kg^{-1} in rhizosphere and non-rhizosphere respectively (Fig. 2). 15th day onward, rhizosphere soil showed an increasing trend in the concentration of LBC. The concentration attained a value of 3886 mg kg^{-1} on 43rd day. Whereas in non-rhizosphere, the LBC after showing slight increase, maintained an almost constant level between the range of 800 - 900 mg kg^{-1}.

For Alfisol sample the initial concentration of LBC in rhizosphere and non-rhizosphere was 1151 mg kg^{-1}, which decreased slightly to 1080 and to 1133 mg kg^{-1} (Fig. 21) in rhizosphere and non-rhizosphere, respectively on 15th day. From 22nd day onward up to 43rd day, concentration increased steadily and attained a value of 2721 mg kg^{-1} on 43rd day. In case of non-rhizosphere, beyond 15th day there was a clear cut fall in the concentration of LBC to a value of 987 mg kg^{-1} on 22nd day. Throughout the remaining period the value remained constant within range of 700 - 800 mg kg^{-1}.

Wheat crop

In case of Inceptisol sample the initial concentration of LBC in rhizosphere and non-rhizosphere was 1250 mg kg^{-1}. It remained almost constant in both the cases up to 15th day (Fig. 3). From 15th day onward there was an increase in the concentration of LBC in rhizosphere, whereas in non-rhizosphere, the concentration steeply decreased to 888 mg kg^{-1} on 22nd day and beyond which there was further reduction in the concentration and on 43rd day the value reached at 721 mg kg^{-1}. In rhizosphere, barring some fluctuations the concentration exhibited an increasing trend and on 43rd day concentration was 3624 mg kg^{-1}.

For Vertisol sample the initial concentration in the rhizosphere and non-rhizosphere was 1425 mg kg^{-1} (Fig. 3). It increased to 1615 mg kg^{-1} and to 1512 mg kg^{-1} in rhizosphere and non-rhizosphere, respectively, on 15th day. From 22nd day onward, LBC concentration started to increase in the rhizosphere. Over all, rhizosphere showed a marked increasing trend in the concentration of LBC throughout the period. On 43rd day the concentration was 3874 mg kg^{-1} in rhizosphere, whereas in non-rhizosphere the concentration of LBC remained almost constant throughout the period and on 43rd day, the value was 807 mg kg^{-1}.

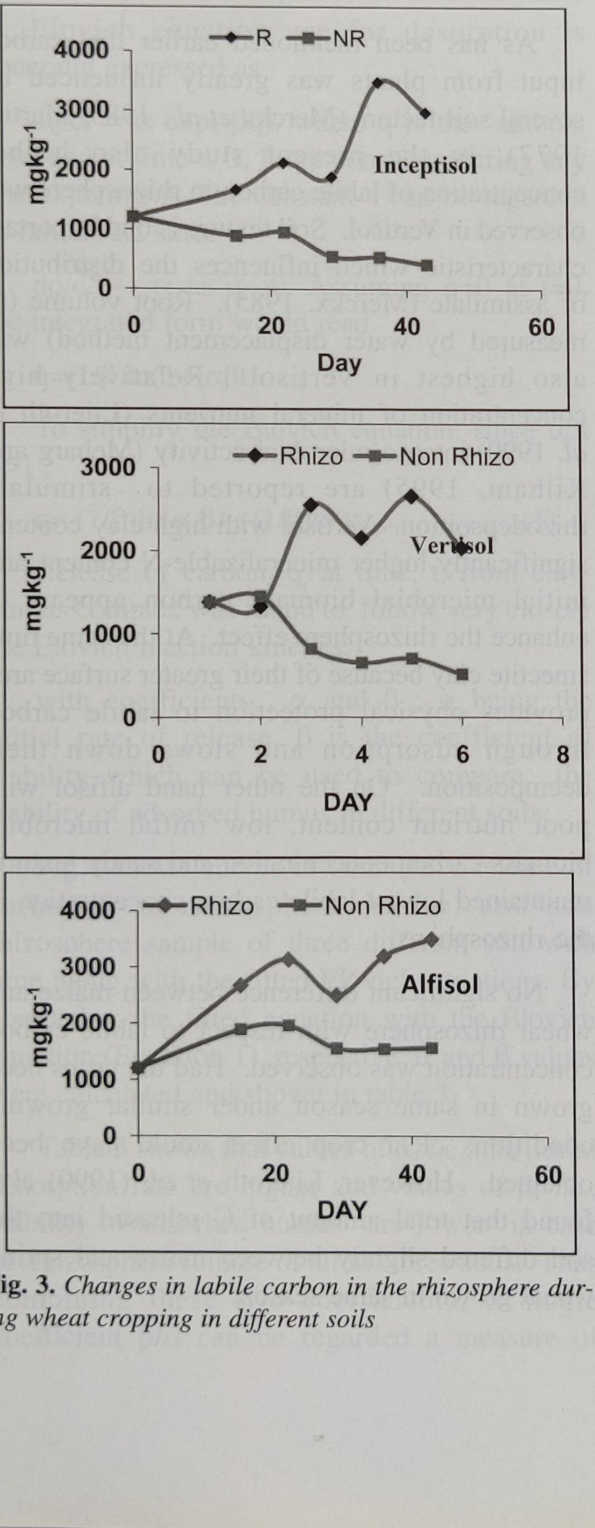

Fig. 3. *Changes in labile carbon in the rhizosphere during wheat cropping in different soils*

For Alfisol sample the concentration of LBC remained almost constant both in rhizosphere and non-rhizosphere up to a period of 15th day (Fig. 3). Then it slowly increased in rhizopshere and reached at a value of 2613 mg kg^{-1} on 43rd day. On the other hand, in non-rhizosphere LBC concentration decreased very slowly to a value of 807 mg kg^{-1} on 43rd day.

The statistical comparisons between LBC concentrations in rhizosphere and non-rhizosphere (values are averaged over the soils) have been given in Table 1. From 22nd day onward up to 43rd day, the concentration of LBC was significantly higher in rhizosphere than in non-rhizosphere.

Table 1. *Status of labile carbon (mg/kg) in the rhizosphere and non rhizosphere (averaged over soils) at different times after sowing*

Day	Rhizosphere	Non rhizosphere	C.D . $p<0.05$
15th	1084	1136	804
22nd	2437	849	496
29th	2749	876	544
36th	2651	820	589
43rd	3427	935	551

The interaction effect of rhizosphere and types of soil on concentration of LBC has been presented in the table 2. Though initially rhizosphere labile carbon was not significantly different in three soils but 29th day onward the labile carbon concentration was significantly higher in the Vertisol samples than the other two soil samples

According to the model structure given by

Table 2. *Status of labile carbon (mg/kg) in the rhizosphere (averaged over crops) in different soils at different times*

Day	Inceptisol	Vertisol	Alfisol	C.D. <0.05
15th	1139	1419	1079	401
22nd	2327	2874	2408	484
29th	2747	3136	2667	544
36th	2231	3576	2923	523
43rd	2514	3325	2658	531

Parton *e al.* (1988) soil organic carbon is divided into five different pools, on the basis of their turn over time viz. metabolic (0.5 yr), active (1.5 yr) structural (3 yr) slow (25 yr) and passive (1000 yr). It is the metabolic pool which includes labile soil organic matter fractions generally being affected by root activity through rhizodeposition, secretion and exudation. Besides this because of its rapid turn over rate this pool greatly influences the carbon and nitrogen dynamics in rhizosphere. Labile carbon, carbohydrate carbon microbial biomass carbon and amino acid are part of this metabolic pool so their status in rhizosphere soil and non rhizosphere soil was monitored for a period of forty three days.

This was the fraction of soil organic carbon with most rapid turnover time. It is generally accepted that labile constituents decompose within a few weeks or months. It includes part of the dissolved organic carbon (Christensen, 1986), microbial biomass carbon (Sparling, 1992), mineralizable carbon (Yoshikawa and Inubushi, 1995), carbohydrates and enzymes (Deng and Tabatabai, 1997). This fraction is highly responsive to changes in the carbon inputs to the soil.

In the present experiment labile carbon concentration, as determined by 0.33 M potassium permanganate oxidation method was found to increase with time in the rhizosphere, because of increased root activity and subsequent root secretion, exudation and lysis of root walls. This was the reason why from 22nd day onwards upto 43rd day rhizosphere exhibited significantly higher concentration of labile carbon than the non rhizosphere. This was observed under both maize and wheat crop. This finding is in agreement with that of Whitebread *et al.* (2000), who observed an increase in the labile carbon concentration in soil after a field trial with lucerne and wheat. Similar results were also obtained by Blair and Crocker (2000) and Blair *et al.* (1999).

As has been mentioned earlier that carbon input from plants was greatly influenced by several soil factors (Merckx *et al.,* 1985; Martin, 1977), in the present study also higher concentration of labile carbon in rhizosphere was observed in Vertisol. Soil texture is one important characteristic which influences the distribution of assimilate (Merckx, 1985). Root volume (as measured by water displacement method) was also highest in Vertisol. Relatively high concentration of mineral nutrients (Lijeroth *et al.* 1990) intense microbial activity (Meharg and Kilham, 1995) are reported to stimulate rhizodepsoition. Vertisol with high clay content, significantly higher mineralizable-N content and initial microbial biomass carbon appears to enhance the rhizosphere effect. At the same time smectite clay because of their greater surface area provides physical protection to labile carbon through adsorption and slows down their decmposition. On the other hand alfisol with poor nutrient content, low initial microbial biomass carbon concentration and sandy texture, maintained lowest labile carbon concentration in the rhizosphere.

No significant difference between maize and wheat rhizosphere with respect to labile carbon concentration was observed. Had the crops been grown in same season under similar growing conditions clear crop effect could have been obtained. However, Lijeroth *et al.* (1990) also found that total amount of C released into the soil differed slightly between maize and spring wheat grown in same season.

Stability of Clay Organic Complex Against Chemical Extraction

Here a new chemical index of humus stability is proposed from the results of an experiment on kinetics of carbon release from naturally occurring clay-humus complex in rhizosphere and non rhizosphere by sodium hydroxide-sodium pyrophosphate extractant using Elovich equation.

Elovich equation use for desorption is generally expressed as

$dq/dt = \alpha \exp(-\beta q)$, where q is the amount desorbed at time t, α, β are constants during any one experiment. The constant a can be regarded as initial rate since

$dq/dt \rightarrow \alpha$ as $q \rightarrow 0$. Assuming q=0 at t=0, the integrated form would read

$q=(1/\beta)\ln(1+ \alpha\beta t)$.

To simplify the Elovich equation, since $\alpha\beta t >> 1$,

$q= (1/\beta)\ln(\alpha \beta) +(1/\beta)\ln t$ ....(1)

Release of carbon, q_t at time, t, from clay-humus complex was found to follow very closely the Elovich reaction kinetics,

with coefficients , α and β ; α being the initial rate of release, β is the coefficient of stability which can be used to compare the stability of adsorbed humus in different soils.

Fig 4 shows curves of cumulative release of carbon from rhizosphere (maize) and non rhizosphere sample of three different soil with time along with the fitted Elovich equations. By comparing the fitted equation with the Elovich equation (Equation 1), respective, α and β values were calculated and shown in table 3

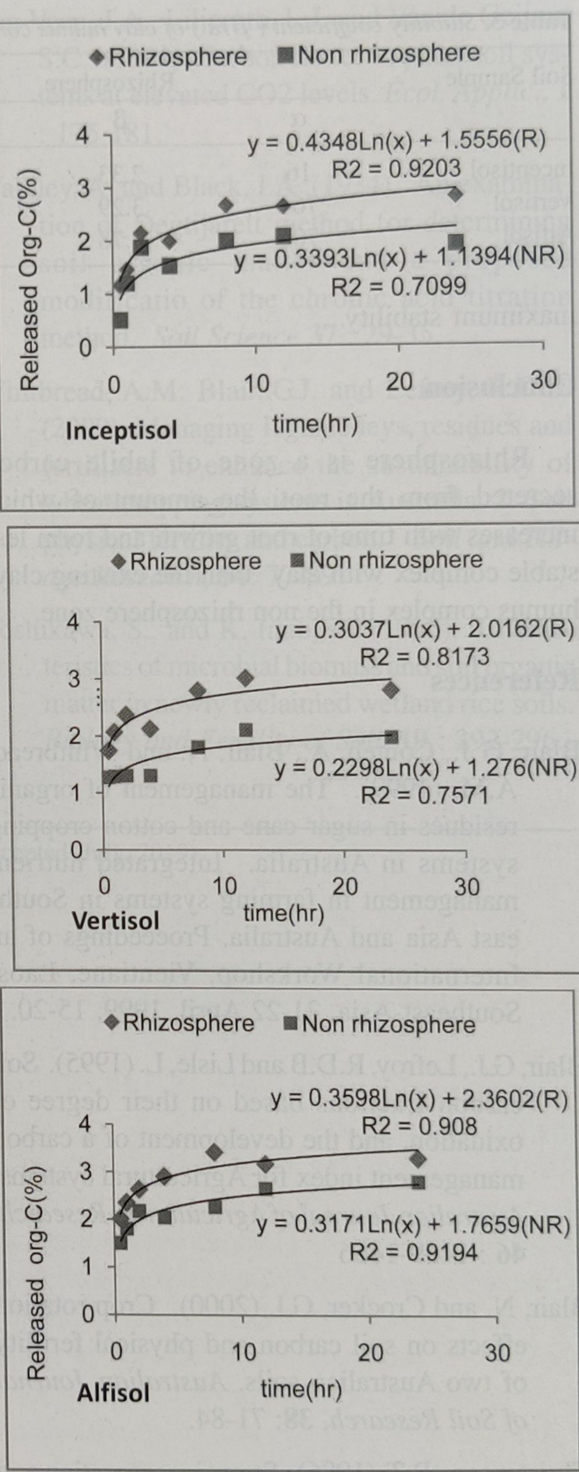

Fig. 4. *Release of organic carbon from clay-humus complex of rhizosphere and non rhizosphere sample*

Table 3 shows that values of α, i.e., the initial desorption rate are higher and values of β, i.e., stability of adsorbed humus are lower in case of rhizosphere sample of all the three soils. Thus combining these two coefficients, α single coefficient β/α can be regarded a measure of humus stability. Table 3 shows these lower β/α for rhizosphere sample of all the three samples. Among the three soil, the Inceptisol sample show

Table 3. *Stability coefficient (β/a) of clay humus complex in rhizosphere and non rhizosphere.*

Soil Sample	Rhizosphere			Non rhizosphere		
	α	β	β/α	α	β	β/α
Inceptisol	16	2.33	0.146	10	3.03	0.29
Vertisol	764	3.29	0.004	257	4.35	0.017
Alfisol	706	2.78	0.004	262	3.15	0.012

maximum stability.

Conclusion

Rhizosphere is a zone of labile carbon secreted from the root, the amount of which increases with time of root growth and form less stable complex with clay than the existing clay-humus complex in the non rhizosphere zone.

References

Blair, G J., Conteh, A., Blair, N. and Whitbread, A.M. (1999). The management of organic residues in sugar cane and cotton cropping systems in Australia. Integrated nutrient management in farming systems in South-east Asia and Australia. Proceedings of an International Workshop, Vientiane, Laos, Southeast-Asia, 21-22 April, 1999, 15-20.

Blair, G.J., Lefroy, R.D.B and Lisle, L. (1995). Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for Agricultural systems. *Australian Journal of Agricultural. Research,* **46** : 1459-1466

Blair, N. and Crocker, G.J. (2000). Crop rotation effects on soil carbon and physical fertility of two Australian soils. *Australian Journal of Soil Research,* **38**: 71-84.

Christensen,, B.T. (1986). Straw incorporation and soil organic matter in macro-aggregates and particle size separates. *Journal of Soil Science,* **37** : 125-135.

Deng, S.P., and M.A. Tabatabai (1997). Effect of tillage and residue management of enzyme activities in soils. III, Phosphatases and anysulfatase. *Biology and Fertility of Soil,* **24** : 141-146.

Kuikiman, P. J. (1990). Mineralization of nitrogen by protozoan activity in soil. Dissertation. Agricultural University, Wageningen, The Netherlands, 105p.

Liljeroth E, Van Veen, J.A. and Miller, H.J. (1990) Assimilate translocation to the rhizosphere of two wheat lines and subscequent utilization by rhizosphere microorganisms at two soil nitrogen concentrations. *Soil Biology and Biochemistry,* **22** : 1015-1021.

Liljeroth, E., Kuickman, P. and Van Veen, J.A. (1994). Carbon translocation to the rhizosphere of maize and wheat and influence on the turnover of native soil organic matter at different soil nitrogen levels. *Plant and Soil,* **161** : 233-240.

Lynch, J.M. (1990). The Rhizosphere. John Wiley and Sons Ltd., Chichester, England, 458 p.

Meharg, A.A. and Killham, K. (1995). Loss of exudates from the roots of perennial ryegrass inoculated with a range of micro-organisms. *Plant and Soil*, **170**: 345-34

Merckx, R., den Hartog, A. and Van Veen, J.A. (1985). Turnover of root derived material and related microbial biomass formation in soils of different texture. *Soil Biology and Biochemistry*, **17** : 565-569.

Mohanty, Sangita and Datta, Samar Chandra. (2018). Effect of rhizosphere on release of fixed ammonia. *Clay Research,* **37**(1), 1-7.

Parton, W.J., J.W.B. Stewart, and C.V. Cole.

(1988). Dynamics of C, N, P and S in grassland soils: A model. Biochemistry, **5** : 109-131.

Reid, J.B. and Goss, J.M. (1982). Suppression of decomposition of 14C labelled plant roots in the presence of living roots of maize and perennial rye grass. *Journal of Soil Sci*ence, **33** : 387-395.

Robinson, D., Griffiths, B., Ritz, K. and Whiteley, R. (1989). Root-induced nitrogen mineralization : a theoretical analysis. *Plant and Soil,* **117** : 185-193.

Schollenberger, C.J. (1927). A rapid approximate method for determining soil organic matter. *Soil Science,* **24** : 65-68.

Sparling, G. P. (1992). Ratio of microbial biomass C to soil organic C as a sensitive indicator of changes in soil organic matter. *Australian Journal of Soil Research,* **30** : 195-207.

Van Veen, J.A., Liljeroth, L.J. and Van de Geijnm S.C. (1991). Carbon fluxes in plant soil systems at elevated CO2 levels. *Ecol. Applic.*, **1** : 175-181.

Walkley, A. and Black, I.A. (1934). An examination of Degtijarett method for determining soil organic matter and a proposed modificatio of the chronic acid titration method. *Soil Science* **37** : 29-35.

Whitbread, A.M; Blair,.G.J. and Lefroy, R.D.B. (2000). Managing legume leys, residues and fertilisers to enhance the sustainability of wheat cropping systems in Australia. 2. Soil physical fertility and carbon. *Soil and Tillage Research*, **54**: 77-89

Yoshikawa, S., and K. Inubushi (1995). Characteristics of microbial biomass and soil organic matter in newly reclaimed wetland rice soils. *Biology and Fertility of Soil,* **19** : 292-296.

(Received May, 2019; Accepted July, 2019)

Clay Research, Vol. 37, No. 2, pp. 58-66 (2018)

Evaluation of Total and Matric Suction of Clayey Soil by Filter Paper Method

P. B. PANDE [1,*], S.R. KHANDESHWAR[1] AND S.P. BAJAD [2]

[1] *Department of Civil Engineering, Yeshwantrao Chavan College of Engineering, Nagpur, India*
[2] *Department of Civil Engineering, Government Polytechnic, Amravati, India*

Abstract–*Suction is the most important parameter required to study the soil in unsaturated condition. Filter paper method is the easy and economical method for suction measurement in which the calibration of filter paper is indispensable.The total suction calibration curve is not applicable for measuring suctions less than 1000 k Pa. Thus it is necessary to develop separate calibration curves for measuring matric suction. It is convenient to develop total suction calibration curve from filter paper technique but for matric suction calibration curve is quite difficult. Normally the pressure plate and pressure membrane were preferred fordeveloping calibration curves, neverthelessthese methods are having some limitations such as time consuming, skill and unavailability of equipment. The objective of this paper is to sidestep those limitations by adopting the prescribed procedure of establishing both total and matric suction calibration curves from filter paper method. In this paper, thetotal suction calibration equation was obtained by developing wetting calibration curve for Whatman No. 42 filter papers and compared with calibration equations developed by several other researchers. Thetotal suction calibration equationwas so selected that percentage error between obtained and selected must be less than 5%. Then the drying calibration curve developed by the same researcher for the same filter paper was used for measuring matric suction of clayey soil used in this study. The prescribed procedure reduces the efforts and additional time required for developing drying calibration curves. This technique can be appropriate in case of unavailability of equipment required for constructing drying calibration curve.*

Keywords: *Filter paper method, Calibration, Total suction, Matric suction, Clayey soil*

Measurement of soil suction is the challenging task for geotechnical engineers. Various methods are available for measuring suction of unsaturated soil. Filter paper has proven to be low cost, precise and simple in terms of test setup and procedures (Bulut *et al.,* 2011; Nam *et al.,* 2009). Filter paper method has been widely used to evaluate soil suction which covers entire range of suction (zero to 1,000,00kPa) (Houston *et al.,* 1994). This is the only method that evaluates both matric and total suction at the same time. Total suction measured in terms of vapour transfer and matric suction measured in terms of liquid transfer (Fredlund *et al.,* 2012). The filter paper method confirmed that the matric and osmotic components are additives of total suction (Krahan and Fredlund, 1971). The "non-contact" and "contact" filter paper technique are used to measure total suction and matric suction respectively.

Calibration of filter paper is necessary for measuring both the suction. While measuring suction using filter paper, it is necessary to develop at least one point of calibration for the particular batch to verify the calibration equation (Oliveira and Marinho, 2006). This is the major drawbacks of the filter paper method of generating one data point in the developing SWCC, needs lot of time and effort. Distinct

---

***Corresponding Author Email :** pbpande@ycce.edu

calibration curves are necessary to be used because the total and matric suction calibration curves are not similar (Greacen *et al.*, 1987). Therefore two separate calibration curves are required to develop, one by wetting the filter papers through vapor flow and other by drying the filter papers through fluid flow. The wetting curve is established by use of salt solutions and the drying curve can be established by employing both pressure plate and pressure (Al-Khafaf and Hanks, 1974; Bicalho *et al.*, 2007; Bulut *et al.*, 2001). It is very difficult, time consuming and required skill for establishing both the curves at a time (Bicalho *et al.*, 2007; Bulut, 1996).

There are still controversies identified associated with the calibration methods (Lang, 1967). Developing wetting calibration curve using salt solution is easy because salt required for wetting process is easily available. Suction plate and pressure plate are equipment for developing drying calibration curve which are not easily available (Bulut *et al.*, 2001). Due to non-availability and lack of knowledge about thisequipment, it is difficult to perform drying process for calibrating filter paper. In this research an attempt has made for measuring matric from readily available drying calibration curves by comparing the developed wetting curves for the same filter paper with the wetting curves developed from the same salt solution (Bicalho *et al.*, 2007).

This study is undertaken to simplify the methodology of measuring both total and matric suction. The linear equation obtained from the developed wetting curve was used to estimate total suction. The estimated total suction values were compared with the total suction calculated from the equations developed by the other researchers. The calibration equation obtained in this study was found similar to the equation (Bicalho *et al.*, 2013) developed by wetting process as it gives similar total suction values. Therefore, the equation developed by (Bicalho *et al.*, 2013) from the drying process was adopted to evaluate matric suction which was found within the range of suction for the soil used in this study. The tests were conducted on 30 numbers of identical clayey soil samples measuring total suction and matric suction. The range of the filter paper gravimetric water content (w_f) is between 17 to 36% hence the study is limited to the curves within this range. The identical clayey soil samples used in this study were prepared by compacting with machine developed by the author. The proposed wetting calibration equation was used to determine total suction of soil and thereafter drying calibration equation obtained by (Bicalho *et al.*, 2013) was used to determine for matric suction. From the results presented in this paper it is suggested to perform calibration of filter paper at least once for verifying the developed. The contact filter paper method was used to measure the matric suction of clayey soil specimens over a range of 20 to 300 kPa. This range of suction was usually chosen to understand the performance and sensitivity of the filter paper method in the low suction range. A comparison of published calibration equations was also undertakenby to study variation in matric suction estimation (Power *et al.*, 2008).

Materials and Methods

Filter Paper Method

The filter paper method for estimating soil suction consists of placing a small piece of filter paper either in direct contact with the soil, or in the atmosphere directly above the soil, in airtight jars, which are then placed in a constant temperature container. The filter paper water content is then used in respective calibration equations to measure the soil matric suction in the case of the contact filter paper or the soil total suction in the case of non-contact filter paper.

In this study both non-contact and contact filter paper methods were performed simultaneously. In non-contact method, only vapor flow can occur, a dry filter paper was placed above a soil specimen in a sealed container to reach vapor equilibrium with the soil specimen. Wherein, dry filter paper was sandwiched between the soil specimens, water from the soil sample transfers to the filter paper in contact with the soil specimen by capillary flow in contact filter paper method. The whole assembly of filter paper and soil was positioned in closed jar sealed with electrical tape and placed in a constant temperature for the equilibration period of seven days. After achieving equilibrium, the filter paper is removed and filter paper water content determined within few second. The filter paper water content enables to measure the total and matric suction from established calibration curve (Houston *et al.,* 1994). In present study wetting calibration curve was developed by performing calibration process which is discussed in next section.

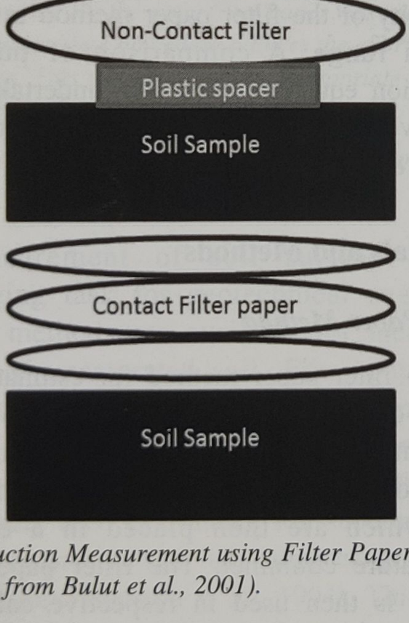

Fig. 1. *Suction Measurement using Filter Paper Method (Adapted from Bulut et al., 2001).*

Calibration of filter paper

The filter paper method is a simple means of measuring suction only the calibration part is time consuming and somewhat tiresome, nonetheless it is the essential part of this method. The equipment like pressure plate and pressure membrane was generally used for constructing the drying filter paper calibration curves. When transfer of soil water is allowed only through fluid flow, dissolved salts will move with the soil water, and the measuring device will not detect the osmotic suction component. In pressure plate type devices the filter papers holds large extent of water at low suctions during the drying or wetting process. At lower suction range, pressure plate type devices should be investigated consciously. Table 1 represents the suction range with respect to equipment used for calibration.

Table 1. *Equipment required for calibration of filter paper with respect to suction range (Adapted from Fawcett et al., 1967)*

Equipment	Suction (k Pa)
Suction Plate	10, 20 and 30
Pressure Plate	70, 100, 200, 300 and 400
Salt solution	500, 1000, 2000, 3000, 4000 and 5000

In this study, NaCl salt solution has been used for constructing wetting calibration curve of filter paper which is commonly applicable for measuring total suction. One of the most commonly used filter papers; Whatman No. 42 was used and calibrated. The calibration of filter paper for obtaining the suction wetting curve by using salt solutions is based upon the thermodynamic relationship between total suction, ψ_t (or osmotic suction) and the osmotic coefficients resulting from a specific concentration of a salt in distilled water. Combining procedures described in ASTM D5298 (1997) and Bulut (1996) calibration of filter paper was measured.

The objective of the calibration of the filter paper for total suction is to place the filter paper above the distilled water in such a way that transfer of water to the filter paper takes place only by vapor absorption. All the items related to filter paper testing were cleaned carefully. Gloves and tweezers were used to handle the materials in nearly all steps of the experiment. The filter papers, plastic cups that were used as support the filter papers, glass jars, and aluminum cans were never touched with naked hands, because using oily hands may cause the filter papers to absorb more water. The procedure that was adopted for the experiment is as follows:

Representative filter papers are initially oven-dried to constant mass at 105⁰C and then allowed to cool to room temperature in a desiccator. NaCl solutions having concentrations ranging between 0.003 to 2.7 molality (Hamer and Wu, 1972) were prepared in 30- to 50-ml distilled water and dispensed into small the glass (nonreactive container). Two paper were suspended above the salt solution so that the paper does not touch the sides or top of the jar with the help of perforated plastic supports as shown in Fig. 1. The jar containing the paper and salt solution were sealed and placed in constant temperature container for an equilibration period of seven days. The temperature fluctuations during equilibration were maintained to ±0.10C because temperature fluctuations influenced on the predicted soil water potential (Al-Khafaf and Hanks, 1974). After seven days filter papers were removed and immediately weighed to the nearest 0.0001 g with an electronic balance to avoid the rapid evaporation laboratory air. Then the papers were placed in aluminum cans and kept for oven drying for overnight. After oven drying the filter paper reweighed by placing cans over aluminum block for 30 seconds to determine filter paper water content.

The filter paper method was performed by following the procedure described above for obtaining the total suction calibration curve. From the obtained filter paper water content and total suction values with respect to salt solution used the calibration curve was developed (Fig. 2). Fig. 2 shows the result of calibration performed for filter paper Batch no. 9850766 (CAT No. 1442-125) used in this study. Linear equation (1) obtained from the proposed calibration curve is represented by line in Fig. 2.

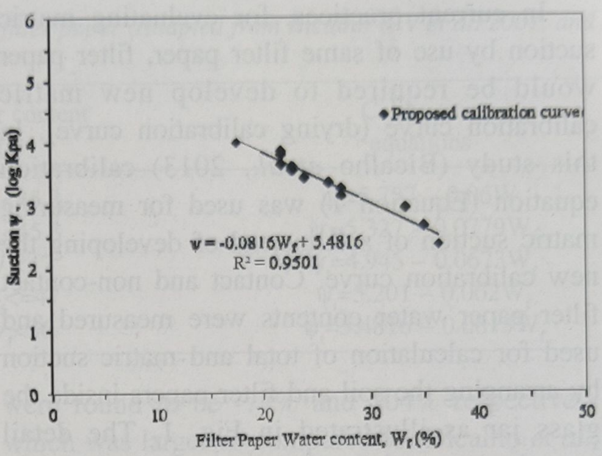

Fig. 2. *Proposed Calibration curve for Whatman 42 Filter paper*

For w_f<=36%

ψ_t= 5.4816–0.0816w_f, $R^2 = 0.9501$ .. (1)

The calibration equations obtained by other researchers can be used for Whatman No. 42 filter paper (Hamblin, 1981). Proposed equation has been compared with the equations obtained by various researchers summarized Table 2. Very closed equations in the view of a and b parameters were included in this paper for comparison. All the equations (Table 2) were total suction calibration equations developed from the wetting calibration method for the filter paper water content less than 47%.

The total calibration curves for Whatman 42 filter paper developed by (Fawcett R G and Collis-George N, 19679) and (Greacen *et al.*, 1987) are presented in Table 2. ASTM D5298 adopted the equations proposed in (Greacen *et al.*, 1987) which was developed using the data originally presented in (Fawcett R G and Collis-George N, 19679).

For w_f<=47%

$\psi_t = 5.201–0.062\ w_f$, $R^2 = 0.976$ .. (2)

For w_f>47%

$\psi_t = 2.909 – 0.021\ w_f$, .. (3)

where, R^2=Coefficient of corelation.

In current practices, for evaluating matric suction by use of same filter paper, filter paper would be required to develop new matric calibration curve (drying calibration curve). In this study (Bicalho *et al.*, 2013) calibration equation (Equation 1) was used for measuring matric suction of soil instead of developing the new calibration curve. Contact and non-contact filter paper water contents were measured and used for calculation of total and matric suction by arranging the soil and filter papers inside the glass jar as illustrated in Fig. 1. The detail procedure is explained in next section followed from Bulut *et al.* (2001) and is based on ASTM D5298 (1997).

Soil suction measurement

Series of tests were performed on identical clayey soil samples. The preparation process of samples is the same for all the tests. The soil sieved through 2 mm sieve mixed with the required quantity of water and it was placed for 24 hours in the specially designed tank to establish the hydraulic equilibrium. Then it was compacted with the mechanized compaction machine developed by the author. The compactive energy used was same as standard proctor test described by ASTM D2216. Average compaction water content is 36 %. The liquid limit of the clayey soil used is 68.5 %, the plastic limit is 29.1%, and specific gravity is 2.61. The clayey soil exhibits the maximum dry unit weight (γ_{dmax}) 14.4 kN/m^3 with optimum moisture content 25 %. Figure 4 illustrates the compaction curve obtained for soil in this study.

Previously very some researchers had measured the suction of highly plastic clay suction using Whatman 42 filter paper (Chandler and Gutierrez, 1986; Oloo and Fredlund, 1995). Both non-contact and contact filter paper methods were performed on soil specimens by extracting the soil sample with sampler of size 55mm diameter and height 150 mm. The test procedure involves placing a filter paper of 55 mm diameter of initially air dry filter paper against the compacted soil specimen whose matric suction is required to be determined. After achieving equilibrium, the filter paper is removed from the soil specimen and filter paper water content determined carefully within few second. The measurement of the water content of the filter paper enables the total and matric suction to be obtained from a previously established calibration curve.

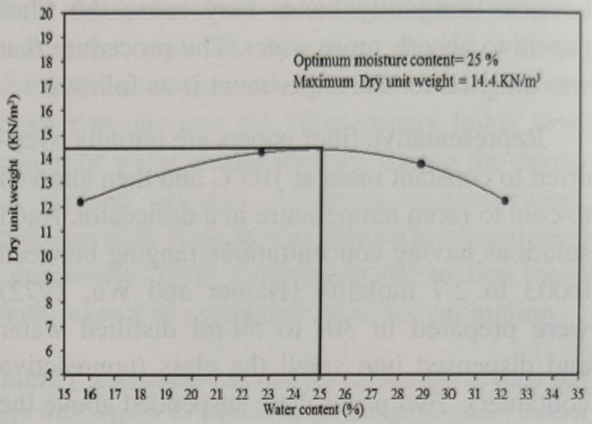

Fig. 3. *Compaction curve obtained for soil*

The total suction was measured from (Equation 1) obtained from the calibration curve developed in this study and matric suction was measured from the (Equation 3) taken from Bicalho *et al.*, (2013) whose total suction curves were very similar.

Results and Discussion

The equation developed by Bicalho *et al.*, (2013) was found to be much closed to the proposed calibration equation (see Table 2).

The total suction obtained from the proposed developed equation involved in this study was compared with the total suction measured from the readily available equations in literature summarized in Table 2. Fig. 4 shows the curves between total suction (kPa) and filter paper water content (w_f) obtained by using equations involved in this study (Table 2). The Coefficient of

ψ_t

Table 2. *Equations for Calibration curves for Whatman 42 filter paper (Adapted from Bicalho K V et al. 2007, and Oloo and Fredlund, 1995)*

Reference	Water content (%)	Calibration equations
Fawcett *et al.*, (1961)	$W_f<45.3$	$\psi_t=5.777 - 0.06W_f$
ASTM D5298 (1997) and Greacen *et al.* (1987)	$W_f<45.3$	$\psi_t=5.327 - 0.0779W_f$
Leong *et al.* (2002)	$W_f<47$	$\psi_t=4.945 - 0.0673W_f$
Bichalo *et al.* (2013)	$W_f<=47$	$\psi_t=5.201 - 0.062W_f$
Author (2018)	$W_f<36$	$\psi_t=5.4816 - 0.0813W_f$

determination (R^2) values for the curves obtained from the proposed and other included equations was found to be 0.99. Out of all the curves the total suction curve obtained from proposed calibration equation curve represented by solid filled dots found to be much closer to Bicalho et al., (2013) and ASTM D5298. Authors have compared four total calibration curves proposed in various literatures (Bicalho *et al.*, 2013; Fawcett and Collis-George, 1967; Leong *et al.*, 2002). The method includes measurement of total suction from non-contact filter paper gravimetric water contents obtained for the soil used in this study (16% $<w_f<$ 43%). To interpret the measured total suction error has been calculated and explored the well agreed calibration curve with the proposed one. Error measured in total suction estimates from the ASTM D5298 calibration curve and the proposed calibration curve is 24% & when compared with (Bicalho *et al.*, 2013) it was only -6%. Errors observed from Fawcett and Collis-George, (1967) and Leong *et al.* (2002) were found to be -77% and 104% respectively which was larger as compared to (Bicalho *et al.*, 2013) and ASTM D5298.

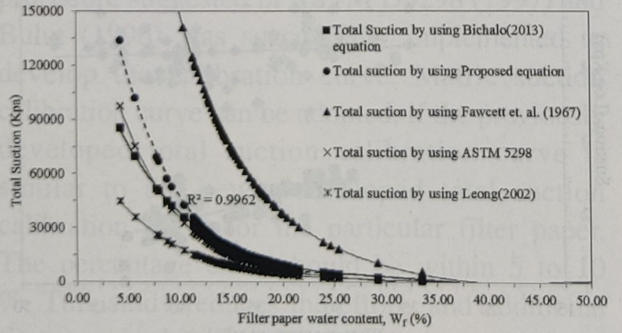

Fig. 4. *Total Suction values obtained by using various calibration equations with respect to Filter paper water content*

Fig. 5, Fig. 6, Fig. 7 and Fig. 8 shows results of total suction (Log Kpa) from various equations at various gravematric water content (%) for the

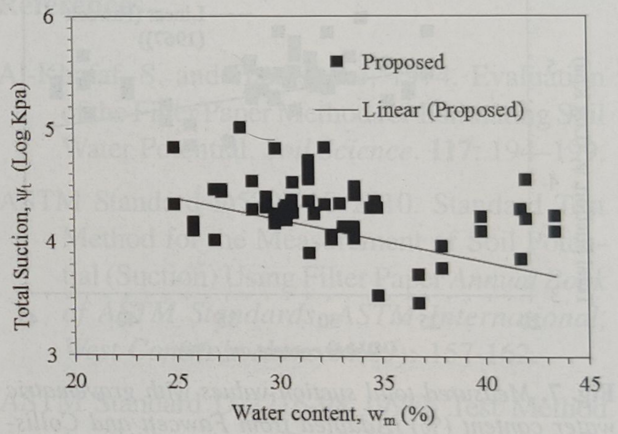

Fig. 5. *Measured total suction values with gravematric water content (%) from proposed equation*

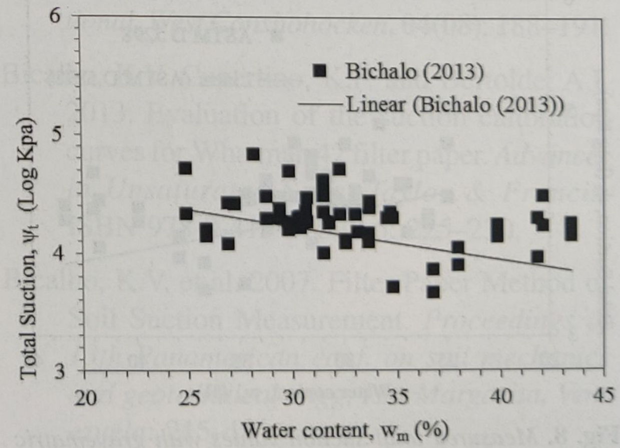

Fig. 6. *Measured total suction values with gravematric water content (%) from Bichalo (2013) equation*

soil used in this study. Filter paper total suction was plotted against the gravimetric water content to compare the data obtained from the four wetting calibration equations and proposed equation. These results were obtained for the clay used in this study at the average dry density of 13.09 KN/m^3 and 36% moisture content. Each figure shows data for filter paper method performed and developed water retention curve. Each water retention curve is defined by total suction and gravimetric water content. Many of these figures show the magnitudes and trends in the filter paper data are generally consistent with the water retention curves. However, several disagreements were observed. Fig. 7 shows the trend line obtained from Fawcett (1967) which is observed somewhat above the trend line observed in proposed Fig. 5, wherein the trend line obtained from ASTM D5298 (Fig. 8) is observed below. Fig. 5 and Fig. 6 shows trend lines are at same level which are obtained from proposed and (Bicalho *et al.,* 2013).

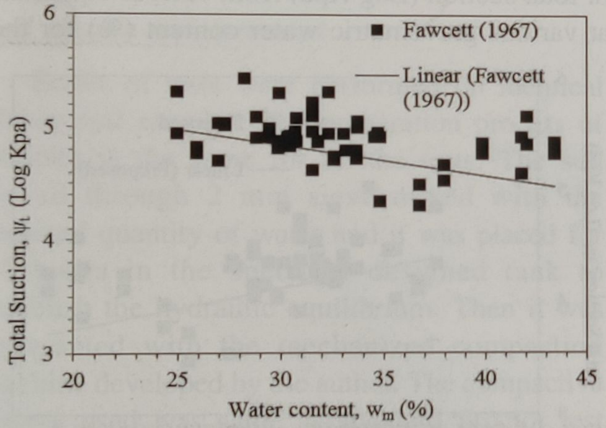

Fig. 7. *Measured total suction values with gravematric water content (%) (Adapted from Fawcett and Collis-George, 1967)*

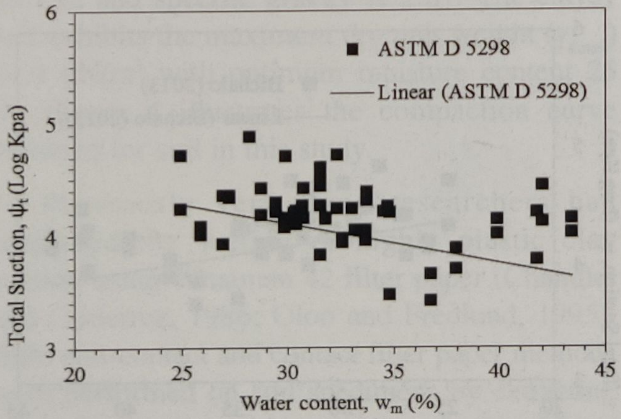

Fig. 8. *Measured total suction values with gravematric water content (%) (Adapted from ASTM D5298*

From the above results and discussion, it has been observed that (Bicalho *et al.,* 2013) wetting calibration curve is well agreed with the proposed curve. Therefore drying calibration curve developed by (Bicalho *et al.,* 2013) for measuring matric suction of soil has been used in this study with conformity.

The total suction measured from the (Bicalho *et al.,* 2013) wetting calibration curve and the total suction measured from the proposed wetting calibration curve is found to be very similar. Another similarity was both the curves were developed for Whatman No. 42 in the range of filter paper water content less than 47%. Therefore matric suction values of compacted clayey soil can be evaluated by the drying calibration equation established by the (Bicalho *et al.,* 2013).

Laboratory results of total and matric suction with respect to soil water content was plotted as shown in Fig. 9. Due to large difference in the range of total and matric suction logarithmic scale

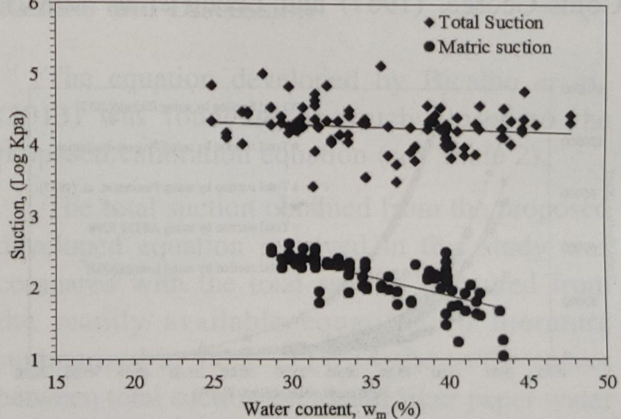

Fig. 9. *Relation between Suction (Total Suction and matric suction vs. Gravimetric water content)*

was used for plotting the relationship. The total and matric suction curves for the clayey soil are expressed in linear form. These suction relationships were developed using the filter paper method. The range of Total suction measured for the soil used in this study is 3.41 log kpa to 5.01 log kpa (2500 Kpa to 1,00,000Kpa). Matric suction for same soil is ranges between 2.00 log kpa to 2.60 log kpa (10 Kpa to 500 Kpa). From the nature of trend line of both the suction it was observed that the total suction decreases gradually with increase in water content. The results for the compacted soils show a linear decrease of matric suction with water content. The matric suction significantly decreases though it does not cover the wide range of suction. At higher soil water contents, this procedure will measure matric suction, and, as sample dries, there will be a gradual transition to a measurement of total suction. It is observed that at very high level of suction the suction measured might be a combination of matrix and total suction which was also observed by the other researchers (Fredlund *et al.,* 2012). The non-linearity between filter paper gravimetric water content and Log (suction) is observed but some scatter was evident that the trends are clear.

Conclusions

A total suction calibration curve was developed for Whatman 42 filter papers using sodium chloride salt solutions. Combination of procedure suggested in ASTM D5298 (1997) and Bulut (1996) was successfully implemented to develop the calibration curve. Matric suction calibration curve can be adopted, if the previously developed total suction calibration curve is similar to the newly developed total suction calibration curve for the particular filter paper. The percentage error should be within 5 to 10 %. This study reduces the efforts and additional time required for developing drying calibration curves.

In order to improve suction predictions, a methodology was proposed in this paper based on a trial and error (regression analysis) on already established total suction calibration curves. Approach adopted in this paper for measuring matric suction is more reliable as the satisfactory results of soil water retention curves were obtained.

List of notation

ψ_t	is the total suction (kPa)
w_f	is the gravimetric filter paper water content (%)
w_m	is the gravimetric water content of soil (%)
γ_d	is the dry unit weight of soil (KN/m^3)

References

Al-Khafaf, S. and Hanks, R.J. 1974. Evaluation of the Filter Paper Method for Estimating Soil Water Potential. *Soil Science*. **117**: 194–199.

ASTM Standard D5298-10 2010. Standard Test Method for the Measurement of Soil Potential (Suction) Using Filter Paper *Annual Book of ASTM Standards, ASTM International, West Conshohocken.* **04(09):** 157-162.

ASTM Standard D 2216-98 1998b Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock. *Annual Book of ASTM Standards, ASTM International, West Conshohocken*. **04(08)**: 188–191.

Bicalho, K.V. Cupertino, K.F. and Bertolde, A.I. 2013. Evaluation of the suction calibration curves for Whatman 42 filter paper. *Advances in Unsaturated Soils, Taylor & Francis.* ISBN 978-0-415-62095-6: 225–230.

Bicalho, K.V. et al. 2007. Filter Paper Method of Soil Suction Measurement. *Proceedings of 13th Panamerican conf. on soil mechanics and geotechnical engg, Isla Margarita, Venezuela*: 215–19

Bulut, R. 1996. A Re-Evaluation of the Filter Paper Method of Measuring Soil Suction. *Civil Engineering Master of Science, Thesis, Civil Engineering Graduate Faculty of Texas Tech University.*

Bulut, R., Lytton, R. and Wray, W. 2001 Suction measurements by filter paper method. *American Society of Civil Engineers Geotechnical Special Publication* No.**115**: 243-261.

Chandler, R.J. and Gutierrez, C.I. 1986. The filter paper method of suction measurements. *Geotechnique*. **36**: 265–268.

Fawcett, R.G. and Collis-George, N. 1967. A filter-paper method for determining the moisture characteristics of soil. *Aust. J. Exp. Agric. Anim. Husb.* **7**: 162–167.

Fredlund, D.G., Rahardjo, H, and Fredlund, M.D. 2012 *Unsaturated Soil Mechanics in Engineering Practice*. John-Wiley, New York.

Greacen, E.L., Walker, G.R. and Cook, P.G. 1987. Evaluation of the filter paper method for measuring soil water suction. *International Conference on Measurement of Soil and Plant Water Status:* 137–143.

Hamblin, A. 1981. Filter-paper method for routine measurement of field water potential. J. Hydrol. **53** :355–360.

Hamer, W.J. and Wu, Y.C. 1972. Osmotic coefficients mean activity coefficients of uni-univalent electrolytes in water at 25°C. *Journal of Physics and Chemistry Reference Data.* **1(4)**: 1047–1099.

Houston, S.L, Houston, W.N. and Wagner, A.M. 1994. Laboratory Filter Paper Suction Measurements. *Geotech. Test. J.* **17(2)**: 185–194.

Krahan, J. and Fredlund, D.G. 1971 On Total, Matric and Osmotic Suction. *Soil science,* **114**: No. 5

Lang, A.R.G 1967 Osmotic Coefficients and Water Potentials of Sodium Chloride Solutions from 0 to 40^{0}C. *Australian J. Chem.* **20**: 2017–2023.

Leong, E.C., He, L. and Rahardjo, H. 2002 Factors Affecting the Filter Paper Method forTotal and Matric Suction Measurements. *Geotech. Testing J.* **25(3)**: 322–333.

Nam, S., Gutierrez, M., Diplas, P. and Petrie, J. 2009. Comparison of testing techniques and models for establishing the SWCC of Riverbank soils. *Engineering Geol.* **110(1–2)**: 1–10.

Oliveira, O.M. and Marinho, F.A.M. 2006. Evaluation of filter paper method. *Unsaturated soils ASCE.*1845–1851.

Oloo, S.Y. and Fredlund, D.G 1995. Matric suction measuring in an expansive soil subgrade in Kenya. *Proceedings of 1st international conference on unsaturated soils, Paris.*

Power, K.C., Vanapalli, S.K. and Garga, V.K. 2008 A revised contact filter paper method. *Geotech. Testing J.* **31(6)**: 461–69.

(Received: 08 June 2019; Accepted: 16 July 2019)

Clay Research, Vol. 37, No. 2, pp. 67-73 (2018)

Optimization of Soil Organic Carbon through Particle Size Fractions and Cation Exchange Capacity in Humid Sub-Tropical Climate of Eastern India for Land Use Planning

B.N. GHOSH [1,*], SILADITYA BANDYOPADHYAY[1], SUBRATA MUKHOPADHAYA [1], KRISHNENDU DAS[1]. D.C. NAYAK[1] AND S.K. SINGH [2]

[1] ICAR-National Bureau of Soil Survey and Land Use Planning, Regional Centre, Sector-II, Block-DK, Salt Lake, Kolkata-700091, India
[2] ICAR- National Bureau of Soil Survey and Land Use Planning, Amravati Road, Nagpur- 440010, India

Abstract–*Critical value of soil organic carbon, a range of threshold to optimum is determined from the relative yield/soil quality index with soil organic carbon (SOC) content of soils and affected by pedogenic processes, land use and input management. But optimization of SOC is related to dominant clay minerals in soils. Here, we attempted to determine the optimum soil organic carbon through CEC /particle (clay, silt) ratios and SOC pool for land use planning. The study area comprised of Maynaguri block, Japaiguri district, West Bengal, India (Agro-Ecological Sub-Region 15.3), where details soil survey had been conducted for soil resource mapping. Horizon wise soils sample were collected from fifteen modal soils profiles upto a depth of 150 cm in seven established land management units (LMU) through soil survey database representing Indo-Gangetic Alluvial plains soils at the Maynaguri block of Jalpaiguri district, West Bengal having three land uses (field crops, forest and tea plantation). The SOC chemical pools of very labile (P1), labile (P2), less labile (P3) and non-labile (P4) in different LMUs varies from 24-34,14-20,19-24 and 26-38 % of total soil organic carbon, respectively in the above root zone depth (ARZD) while it varies from 24-31, 12-22, 20-22 and 26-34% of total soil organic carbon, respectively in the below root zone depth (BRZD) following the order of P4>P1>P3>P2. The labile pool was highest (14.69 g kg^{-1}) in LMU1 having forest land use and lowest (1.61 g kg^{-1}) in LMU3 in single cropping in the ARZD and the same trend followed at BRZD. The recalcitrant pool is also highest (14.13 g kg^{-1}) in LMU1 and lowest (2.05 g kg^{-1}) in LMU3 but the same trend did not follow in BRZD. The recalcitrant pool is also highest (14.13 g kg^{-1}) in LMU1 and lowest (2.05 g kg^{-1}) in LMU3 but the same trend did not follow in BRZD. Relationship among the soil particles with different C polls showed significant positive correlation with clay, fine silt, fine silt +clay and their ratios but not significant with silt fraction indicating very initial soil aggregation process. It has been observed that the CEC/clay+fine silt ratios (Illite dominant in clay fraction; Mica and Feldspars in fine silt fraction) showed exponential relationship with labile (L) and recalcitrant (R) pools. The recalcitrant pool in BRZD, SOC pools maxima and its derived priority class will guide selection of root zone depth basis crop suitability, cropping intensity and input management practices for long-term soil carbon restorative land use plan.*

Keywords: SOC pools, CEC, soil particles, crop choice and LUP

Soil Organic Carbon stock and pools are manifestation of the combined impact of decadal pedogenesis, land use and land management practices. Its range between optimum to threshold value estimation is important for appropriate soil and input management for planning long term land use as well as carbon input requirement to arrive at optimum value. The amount of carbon present in the soils is the function of land use change, soil type, climate (rainfall and temperature) and management practices (Bhattacharya *et al.*, 2008). The maximum

---

***Corresponding Author Email :** bnghsoh62@gmail.com

capacity of a soil to store organic matter is related to the association of soil organic matter with clay and clay plus silt (2-20 μm) and macro-aggregates (20-250 μm) and the fraction of sand size (250- 2000 μm) macro-aggregates. Once the clay and silt is saturated with organic matter, the additional SOM would be found in macro-aggregates probably as sand size macro- organic matter (Tong *et al.*, 2014). Again, oxidizable SOC (Walkley-Black) is considered as one of the key parameters for assessing soil health/ quality. Maintenance of SOC at a reasonable level is thus essential for up keeping the soil health. Conceptually the critical limit of SOC is the desirable range of its values required for normal functioning of soil and maintaining its health for sustainable crop production (Biswas, 2012). It is generally been determined with the relationship between relative yield (RY)/ relative soil quality (RSQ) and oxidizable SOC content in soil. In a study in Alfisols of West Bengal, Mandal *et al.* (2011) reported 7.3 and 4.4 g kg^{-1} the optimum and threshold values of SOC, respectively. Most of the studies following this procedure identified constrains of relative yield determination and soil quality index which require measurements of numbers of parameters in a fixed plot study over the years. Another constrain of this method is non-consideration of below root zone SOC which significantly contribute to nutrient supplying capacity and structural developments of soils. Several studies (Benbi *et al.*, 2015, Mandal *et al.*,2011) reported that one or more labile SOC pools could be more sensitive to management than TOC and may, therefore, be used as a sensitive indicator to characterize management induced changes in SOM in rice-wheat system. But none of the studies utilized the concept of ratios of recalcitrant to labile ratios for maximization of SOC in varied mineralogical soils as both the fractions were required for maintaining soil health and sustained higher productivity. The labile pools were responsible for nutrient cycling and recalcitrant pools for SOC stabilization and quality enhancement (Six *et al.* 2002). It is presumed that their ratios could be better parameters for estimation of optimum level. It is always better to understand the optimal level of SOC to optimize costly external inputs of organic source and its management. It is hypothesised that in a set of conditions depends on soil aggregation stages, soil particles distribution and CEC ratios can predict SOC optimum which is useful for land use plan and its sustainability. Keeping all the background research in view, the following objectives were set in: i) to estimate the SOC pools of soils, ii) to determine the relationship between ratios of CEC, clay and silt with labile and recalcitrant and iii) to estimate the optimum level in an alluvial soils of *terai* region of West Bengal.

Materials and Methods

Study area and site details

The study has been conducted in Maynaguri block (Agro-Ecological Sub-Region 15.3) of Jalpaiguri District, West Bengal, India (26^{0}22'42" to 26^{0}47'40" N latitude and 88^{0}44'30" to 88^{0}58'34" E longitude) covering an area of 55000 ha land at 84 m amsl. Geologically, it is quaternary deposits; mainly fluvial origin forms alluvial fans. The soils of the block is very deep (>150 cm), less soil erosion, moderate to well drain, 50% irrigated area with cropping intensity of 141%. The major phygiography of land forms in the study area consist of Indo-Gangetic alluvial plain, sub-phygiography of alluvial plain and five landforms of upper piedmont plain, lower piedmont plain, old alluvial plain, young alluvial plain and active alluvial Plain. The major field crops commonly grown in the study areas were rice, jute, potato, green gram, black gram, mustard and home stead tea garden in the upslope. These soils were mapped in 1:10000 scale using details soil survey data base and finally classified into seven land management units (LMU) using remote sensing and GIS tools (Ghosh *et al.*, 2017).

Soil Sampling and Processing

In March, 2017, after the harvest of winter crops the details soil survey was conducted in the block using GIS developed LEUs maps and soils sample was collected horizon wise from about fifty eight soil profile from which fifteen modal profiles were selected and composite samples were prepared for laboratory analysis. Two sets of triplicate undisturbed soil cores were collected soil horizon wise with a core sampler (7.5 cm diam). Bulk density was determined from oven-dried core mass divided by the core volume using one sample set. Samples from individual composite profile (the second set) were thoroughly mixed, air-dried, and passed through a 0.2-mm sieve. A soil subsample was taken from layer wise and analyzed for soil SOC as well as labile and recalcitrant pools.

Soil Organic Carbon pools

Soil organic carbon (SOC) of soil samples that were ground to pass through a 0.2-mm sieve was determined following Walky and Black, 1934 and subsequently total SOC was determined multiplying the factor developed by Ghosh *et al.*, 2001; and Bhattacharyya *et al.*, 2012) for different soil texture class. Since the samples were free of inorganic C (carbonates), the total soil C measured was taken as equivalent to the SOC. The SOC content was apportioned into different pools by the modified Walkley–Black method as described by Chang *et al.* (2001) using 5, 10, and 20 mL of 36.0 M H2SO4 that resulted in 12.0, 18.0 and 24.0 M H_2SO_4, respectively. Hence, it involves mixing 1M dichromate solution with H_2SO_4 in different proportions. Total SOC was, thus, divided into four different pools according to their decreasing order of stability (Chang *et al.*, 2001). Soil organic C oxidized by 12.0 M H_2SO_4 was termed very labile pool (Pool I), the difference in SOC oxidizable by 18.0 M H_2SO_4 and that by 12.0 M H_2SO_4 was labile pool (Pool II), the difference in SOC oxidizable by 24.0 M H_2SO_4 and that by 18.0 M H_2SO_4 was less labile pools (Pool III), and the difference between total SOC and SOC oxidizable by 24.0 M H_2SO_4 was termed non labile pool (Pool IV). Pool I and II together constitute the labile pool, while Pool III and IV constitute together the recalcitrant pool (Chang *et al.*, 2001; Bhattacharyya *et al.*, 2012). The above root zone depth (ARZD)) SOC pools were considered as the A horizon occurrence (0- to 25 cm max.), whereas the below root zoon depth (BRZD) upto >25 cm to <150 cm as the case in profile. CEC of the soil was determined by Chapman *et al.* (1965) and particle size (sand, silt and clay) by International pipette method (Piper,1966). Recalcitrant and labile maximum and their ratios were determined from the exponential curve as Y= a e^{bx} by plotting CEC/clay+ fine silt in X axis and labile and recalcitrant pools in Y axis.

Statistical analysis

Correlation coefficient as well as exponential functions of the parameters was conducted using excel and Fisher's T test to find out the level of significant.

Results and Discussion

SOC pools in above and below ground root zone depth

It is evident from the table1 that soil organic carbon (SOC) pools varied significantly in different land management unit and highest was observed in *Typic Humudepts* (LMU1) and lowest in *Typic Udifluvents* (LMU3) in both the above and below ground root zone depth. The different pools of SOC, very labile (VL), labile (L), less labile (LL) and non-labile (NL) ranges from 20.0 to 33.1 in ARZD whereas 18.0 to 33.9 % of TOC in BRZD in different LMUs. The different pools followed the order of P4>P1>P3>P2 in both the root zone depths. This indicates that very labile pools were very significant pools which generally changes very early stage of input management (Mandal *et al.*, 2001). It is observed

Table 1. *SOC pools in above and below root zone depth in different LMUs*

Soil order	Soil taxonomy	LMU	Soil depth (cm)	TOC	VL (P1)	L (P2)	LL (P3)	NL (P4)	Labile (L)	Recalcitrant (R)
							(g kg^{-1})			
Inceptisol	*Typic Humudepts*	LMU1	ARZD	28.25	9.04	5.65	4.78	9.35	14.69	14.13
			BRZD	16.55	4.97	2.98	3.31	5.96	7.95	9.27
Inceptisol	*Humic Dystrudepts*	LMU2	ARZD	14.42	5.48	2.02	2.74	4.18	7.50	6.92
			BRZD	4.31	1.55	1.52	3.11	1.34	2.07	5.64
Entisol	*Typic Udifluvents*	LMU3	ARZD	3.66	0.95	0.66	0.81	1.24	1.61	2.05
			BRZD	0.86	0.26	0.19	0.19	0.22	0.45	0.41
Inceptisol	*Humic Endoaquepts*	LMU4	ARZD	17.59	4.57	3.17	3.87	5.98	7.74	9.85
			BRZD	3.55	0.92	0.78	1.03	1.10	1.70	2.13
Entisol	*Typic Fluvaquents*	LMU5	ARZD	9.18	2.39	1.65	2.02	3.12	4.04	5.14
			BRZD	2.11	0.63	0.46	0.46	0.55	1.10	1.01
Inceptisol	*Typic Dystrudepts*	LMU6	ARZD	10.63	2.76	1.91	2.34	3.61	4.68	5.95
			BRZD	3.86	1.00	0.85	0.85	1.20	1.85	2.05
Inceptisol	*Typic Endoaquepts*	LMU7	ARZD	7.92	2.06	1.43	1.74	2.69	3.48	4.44
			BRZD	3.30	0.86	0.73	0.73	1.02	1.58	1.75

ARZD- Above root zone depth, BRZD- Below root zone depth, TOC- Total Organic Carbon, VL-Very labile, L-labile, LL- Less labile and NL-non-labile

that the major chemical fraction as labile and recalcitrant ranges from 45-52% and 50-56% of TOC in the ARZD whereas 48-52 and 47-56% in BRZD, respectively. The recalcitrant pools were significantly higher in LMU2, 4, 6 and 7 at the BRZD. The soils of LMU1 which represents as *Typic Humudepts* showed higher fraction of both the pools in both the layers than LMU3, representing *Typic Udifluvent* because of presence of less amount of clay and silt fraction. The higher amount of both the pools of SOC in LMU1 because of receiving continuous leaf litter deposition as forest land use compared to other LMUs which represents single or double field crops. Of the major soil SOC pools, the labile and recalcitrant pools were more in all the LMUs in ARZD whereas recalcitrant pools were more in LMU2, 4, 6 and 7 in BRZD indicating significant eluviation of clay and continuous cultivation of deep rooted crops receiving more external C input addition over the years. As recalcitrant pools is considered as long-live C pools, so land management should be in such a way that these pools will be protected and had the potential to sequester higher SOC in below depth and these kinds of soils were most suited for deep rooted intensive crops of cereals.

Correlation among different pools and soil particles

Correlation coefficients among the different C pools (Table 2) showed significant positive correlation. Similar findings have also been reported by Mandal *et al.* (2011) and Ghosh *et al.* (2017) for Alfisols and Entisols, respectively for the terai regions India. Of the soil separates, clay particles showed significant correlation with non-labile pools whereas fine silt showed correlation with very labile pools indicating that their association with in the soil matrix. It is observed that coarse silt faction of the separates showed non- significant relation with all the pools; however clay plus fine silt showed significant relationship with all the pools of SOC (Table 2). This indicates that soil aggregation process is very initial stages and requires restoration of these fine silt particles. It has been observed that CEC by clay+ fine silt particles

Table 2. *Correlation coefficient among different SOC pools and soil particles*

Soil fraction	SOC pools			SOC pools		
	P1	P2	P3	P4	Labile	Recalcitrant
P1	-	0.925**	0.886**	0.825**	0.845**	0.786**
P2	0.845*	-	0.812**	0.874**	0.905**	0.845**
P3	0.785*	0.824**	-	0.807**	0.945**	0.814**
P4	0.797*	0.846**	0.804**	-	0.854**	0.960**
Clay	0.314	0.210	0.286	0.765**	0.815**	0.890**
Fine silt	0.768**	0.425	0.346	0.512	0.725**	0.812**
Silt	0.348	0.210	0.120	0.045	0.345	0.145
Fine+Clay	0.785**	0.714*	0.786*	0.846**	0.912**	0.980**
CEC/Clay	0.718*	0.705*	0.719*	0.758*	0.820**	0.912**

**% 1 and *5% level of significance

showed positive significant correlation with all the SOC pools. Similar observations have also been reported by Benbi *et el.* (2015) in rice growing Inceptisols of Punjab. It is observed from the table 3 that the labile and recalcitrant pool carbon can be optimised upto 1.03% and 2.0% of R/L ratios to attain to 1.51 in these pedogenic processes of soil formation, land use and prevalent input management practices. These correlations help in development of carbon management priority zone (Table 3) and the level can be enhanced up to saturation level. The higher capacity of these soils is attributed to the presence of Illite dominant clay as evident from the CEC/clay ratios (Smith, 1986).

Carbon management priority zone

It was observed that the major carbon pools in the profile as labile and recalcitrant varied from 2.06 to 22.64 g kg^{-1} with highest in *Typic Humudepts* (LMU1) and lowest in *Typic Udifluvents* (LMU3). The R/L corresponding ratios varied from 1.05 to 1.31 highest in *Humic Dystrudepts* and lowest in *Typic Udifluvents.* It is to mention that none of these soils SOC level happens to be closer to C saturation including forest land use (LMU1) representing *Typic Humudepts.* To attain the near C saturation, it has been observed that there is scope to increase R/L$_{max}$. level to the tune of 15.1 to 44.0% for increasing the maximum SOC level (Table 4). The priority class (1- 4) of SOC develop will help in guiding the cropping intensity and input management practices to be followed for developing C restorative land use plan (Table 4).

Conclusions

The soils were developed with the deposition of alluvial materials and were at initial soil aggregation stages as evident from SOC pools. The distribution of clay and fine silt particles in the soil profiles and their ratios to CEC showed Illite dominant soil mineralogy in the clay fraction. The higher below root zone depth (BRZD) recalcitrant pool as determinant of deep rooted crops, the derived recalcitrant and labile maxima from CEC to clay ratios will guide to

Table 3. *Relationship between CEC/ (clay+ fine silt), X with labile (Y1) and recalcitrant pools (Y2)*

Pools	Exponential equation	R^2	Y$_{max.}$	R/L$_{max}$
Labile (L)	$Y_1 = 0.27e^{5.44x}$	0.92	13.36	1.51
Recalcitrant (R)	$Y_2 = 0.39e^{4.97x}$	0.89	20.10	

Table 4. *Soil organic carbon based crop choice, input management practices and C management priority class in different LMUs*

LMU	Soil taxonomy	C pool based crop choice	R/L (Profile)	% increase to reach C saturation	C priority class	Suggested input management practices
LMU1	*Typic Humudepts*	Forest	1.27	18.5	4	Erosion control, soil pulverization, and afforestration
LMU2	*Humic Dystrudepts*	Deep rooted, intensive & exhaustive crops	1.31	15.1	4	Intercrop, deep tillage, less external C input, INM, CT and CA
LMU3	*Typic Udifluvents*	Shallow & Medium rooted, less intensive crops	1.05	44.0	1	Intercrop, zero tillage, more external C input in subsoil, AF
LMU4	*Humic Endoaquepts*	Deep rooted, intensive & exhaustive crops	1.27	19.00	4	Intercrop, deep tillage, less external C input, INM, CT and CA
LMU5	*Typic Fluvaquents*	Shallow & medium rooted, less intensive	1.12	35.2	2	Intercrop, zero tillage, more external C input in subsoil/ deep rooted crops/AF
LMU6	*Typic Dystrudepts*	Deep rooted, intensive & exhaustive crops	1.23	23.3	3	Intercrop, zero tillage, medium external C input in subsoil/ deep rooted crops, CA/AF
LMU7	*Typic Endoaquepts*	Deep rooted, intensive & exhaustive crop	1.22	23.4	3	Intercrop, zero tillage, medium external C input in subsoil/deep rooted crops, CA/ AF

0-10 (5); 10-20 (4), 20-30 (3); 30-40 (2); 40-50 (1)

identify C management priority class for cropping intensity and input management practices such as tillage and external C input requirement. The developed methodology will be more long-term sustainable owing to C restorative process which may improve ecosystem services of soil *via* mitigating climate change and may effectively be utilised as better indicator for land use planning.

References

Benbi, D.K., Brar, K., Toor, A.S. and Sharma, S. 2015. Sensitivity of labile soil organic carbon pools to long-term fertilizer, straw and manure management in rice-wheat system. *Pedosphere,* **25**: 534-545.

Bhattacharyya, T., Pal, D. K., Chandran, P., Ray, S. K., Mandal, C. and Telpande, B. 2008. Soil carbon storage capacity as a tool to prioritize areas for carbon sequestration. *Curr. Sci.* **95:** 482-494.

Bhattacharyya, R., Tuti, M.D., Kundu, S., Bisht, J.K. and Bhatt, J.C. 2012. Conservation tillage impacts on soil aggregation and carbon pools in a sandy clay loam soil of the Indian Himalayas. *Soil Sci. Soc. Am. J.* **76:** 617-627.

Biswas, S. 2012. Assessment of biological health of soil for rice-rice cropping systems. *Ph.D.*

Thesis, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, pp. 207.

Chang, C.W., Laird, D.A, Mausbach, M. J. and Jr Hurburgh, C. R. 2001. Near-infrared reflectance spectroscopy – Principal components regression analyses of soil properties. *Soil Sci. Soc. Am. J.* **65**: 480-490.

Chapman, H.D. 1965. Cation-exchange capacity. In: C.A. Black (ed.). Methods of soil analysis - Chemical and microbiological properties. *Agronomy* **9**: 891-901.

Ghosh, B.N. Das, K., Bandhyopadhyay, S., Mukhopadhyay, S., Nayak, D.C and Singh, S.K. 2017. Impact assessment of GIS based land resource inventory towards optimizing agricultural land use plan in Dandakaranya & Eastern Ghats physiographic confluence of India. *J. Ind. Soc. Rem. Sen.* **46**: 641-654

Ghosh, B.N., V. Prakash; Kundu, S., Singh, R.D. and Gupta, H.S.2001. Relationship between oxidizable and total organic C content in an Inceptisol after 27 years of soybean – wheat cropping cycles. *J. Ind. Soc. Soil Sci.* **49:** 744-745.

Mandal, B. 2011. The 29th Professor JN Mukherjee-ISSS Foundation lecture-soil carbon research in India—a way forward. *J. Ind. Soc. Soil Sci.* **59:** S9-S22.

Piper, C.S. (1966). Soil and Plant Analysis. Hans Publisher, Bombay.

Smith, G.D. 1986. The Guy Smith Interview: Rationale for concepts in Soil Taxonomy. SMSS Technical Monograph No. 11, SMSS, SCS, USDA.

Six, J., Conant, R.T., Paul, E.A. and Paustian, K. 2002. Stabilization mechanisms of soil organic matter: Implications for C saturation of soils. *Plant Soil,* **241:** 155-176.

Tong, X., Xu, M., Wang, X., Bhattacharyya, R., Zhang, W. and Cong, R. 2014. Long-term fertilization effects on organic carbon fractions in a red soil of China. Catena, **113:** 251-259.

Walkley, A. and Black, I.A. 1934. An examination of degtjareff method for determining soils organic matter and a proposed modification of the chromic acid titration method. Soil Sci. **34**: 29-38.

(Received February, 2019; Accepted June, 2019)

Clay Research, Vol. 37, No. 2, pp. 74-83 (2018)

Pedogenesis of Some Hydromorphic Soils of Terai Region of West Bengal, India

B.N. GHOSH[1, *], SILADITYA BANDYOPADHYAY[1], SUBRATA MUKHOPADHYAY[1], KRISHNENDU DAS[1], D.C. NAYAK[1], AND S.K. SINGH[2]

[1] *ICAR-National Bureau of Soil Survey and Land Use Planning, Regional Centre, Kolkata-700091.*
[2] *ICAR-National Bureau of Soil Survey and Land Use Planning, Nagpur- 440033*

Abstract–*Hydromorphic soils can be identified by the determination of hydromorphic index (HI), particle distribution ratios and CEC/ clay using details soil survey database followed by their appropriate classification in USDA Soil Taxonomy. Results of the study indicate that soils were dark gray in matrix colour with occurrence of nodules of iron (ferrous and manganese manganous) in reduction phases at a depth below 18 to 22 cm along with redoximorphic depletions at a depth below 42 to 59 cm in lower piedmonts and older alluvial plains. Hydromorphic index (HI) varied from 20.6 in soils of older alluvial plains to 4.5 in soils of active alluvial plains following the order as Older alluvial plains (20.6) > Lower piedmont (17.6) > Older meander plains (5.8) > Younger alluvial plains (5.5) > Active alluvial plains (0.45). These index exhibited significant relationship with soil physical and chemical properties. In these soils, the rate of accumulation of organic matter tends to exceed the rate of its decomposition. The criteria considered for confirmation and establishment as hydrmorphic soils could be a useful information for management of these soils for better productivity and land uses.*

Key words: Hydromorphic soils, Hydromorphic index, Landforms, Particle size ratio, Terai region.

Hydromorphic soils are characterized by the reduction or localized segregation of iron, owing to the temporary or permanent water logging of the soil pores which causes a lack of oxygen over a long period. Changes in the degree of water saturation affect the supply of oxygen to the soil which in turn affects the "Ferrolysis", a hydromorphic soil forming process (Breemen and Buurman, 1998). To understand the process, different criteria's were followed and investigations in these lines of concept were rare in the eastern states of India. Generally, the occurrence of these soils worldwide as reported (Bouma *et al.*, 1990) were in *Histosols, Inceptisols, Entisols* and rarely in *Alfisols* order but Indian hydromorphic soils are mostly in Inceptisols order under *Aquic* moisture regimes (*Aquepts*) (Gangopadhyay *et al.*, 2015 and Bhattacharyya *et al., 2013a*) and were found in the states of Assam, India. Reports were mostly on north-eastern states and no systematic studies were conducted in eastern states though having similar physographic region specifically in the *Terai* region of West Bengal. The *Terai* region of West Bengal constitutes 3.1% of total geographic area (TGA) of the country in which a significant proportion is under Teesta alluvium. As per Soil Resource Mapping prepared by ICAR-NBSS&LUP in smaller scale (1:250K), the soils are of recent formations with many pockets under prolonged waterlogged situations affecting crop growth and may differ in pedogenic processes because of parent materials composition, microclimate variation. Arnaud (1988) emphasized mostly the pedogenic attributes to quantify the changes occurred in soils during their

---

***Corresponding Author Email :** bnghosh62@rediffmail.com

development. The informations, however, were very limited and scattered due to limitation of scale of mapping and attributes considerations. Proper identification and characterization of these soils would be beneficial for better management, productivity and crop planning. To address these issues, the objective of the study was to characterize these soils to qualify as hydromorphic in the Terai region of West Bengal and to understand their pedogenesis processes involved in details in a larger scale.

Materials and Methods

Study area

The study was conducted in Maynaguri Block of Jalpaiguri district of West Bengal in between the geographic extent from 26⁰30´N to 26⁰57´N latitude and 88⁰31´E to 88⁰49´E longitude) having a total geographic area of 55,000 hectare (Fig. 1). The major physiographic division is *Terai i.e.,* foothills of lesser and sub duded Himalayas Region. The geology of the study area is constituted of *Quaternary* deposits, mainly of fluvial origin from Teesta and Jaldhaka river basins forming *alluvial fans.* The representative landforms in the study area have altitudinal range from 100 m from MSL in active alluvial plains to 300 m above MSL in lower piedmont. The climate is humid sub tropical with mean annual rainfall of 3000 mm. The mean annual soil temperature is 24.5 ºC, mean summer soil temperature is 26.3 ºC and mean winter soil temperature is 19.1 ºC. The soil temperature regime is *Hyperthermic* and soil moisture regimes are *Aquic* and *Udic* (Soil Survey Staff, 2003). The agro-ecological sub region is Teesta-Brahmaputra Basin, which is hot, moist humid sub region with length of growing period of 270 to 300 days (Velayutham *et al.,* 1999).

Methodology of soil survey

Soil-landform analysis was made in the study area by visual interpretation, ground truth verification and intensive soil survey using Resourcesat2 IRS LISS-IV along with open

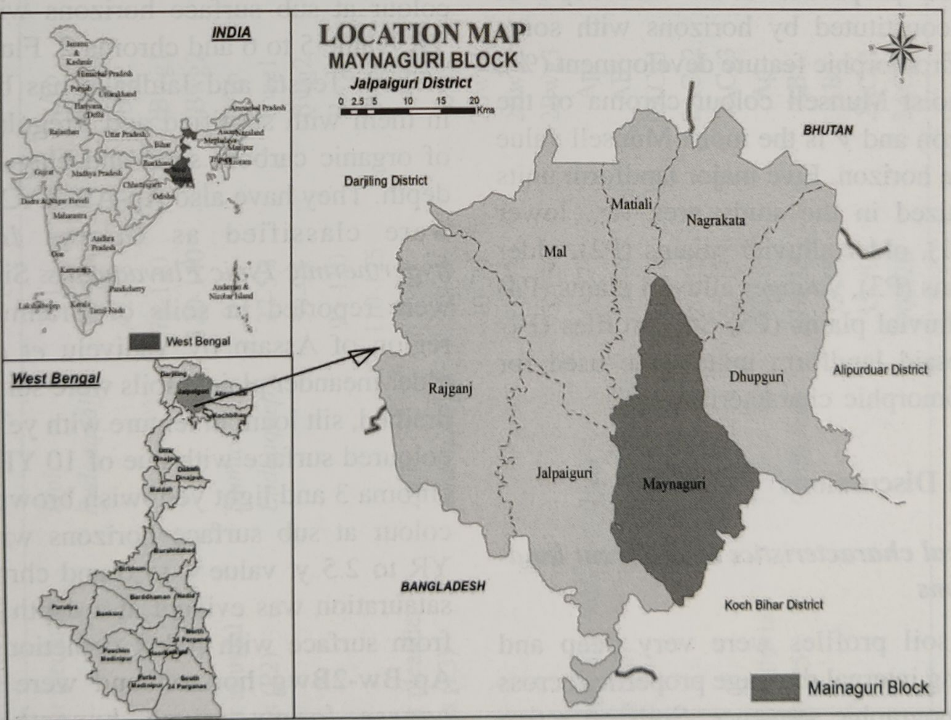

Fig. 1. *Location map of the study area*

source digital elevation data like Shuttle Radar Topographic Mission (SRTM) (30 m resolution). Morphological (Soil Survey Staff, 2003), physical (Hillel, 1982) and chemical characteristics (Jackson, 1973) were determined in representative landform of the study area. The soil-landform relationships were established following standard methods.

Pedogenic considerations

The pedogenic attributes were applied to understand the pedogenesis of hydromorphic soils of the study area. The indices include particle size ratios *viz.,* sand/silt, silt/clay, very fine plus fine sand/ total sand [(VFS+FS)/ TS)] following the method of Schatzael and Thompson (2015) and CEC/Clay as outlined by Smith (1986).

Details of Hydromorphic and landform considerations

Hydromorphic index was calculated following the method outlined by Chaplot *et al.* (2000) using the equation $HI = P/ (Ch \times V)$, where P is the proportion of the total depth of soil profile constituted by horizons with some degree of hydromorphic feature development (%), Ch is the moist Munsell colour chroma of the surface horizon and V is the moist Munsell value of the surface horizon. Five major landform units were recognized in the study area *viz.,* lower piedmont (P1), older alluvial plains (P2), older meander plains (P3), younger alluvial plains (P4) and active alluvial plains (P5) Soil profiles (P1-P5) of aforesaid landform units were used for details hydromorphic characterization.

Results and Discussions

Morphological characteristics in different landform situations

All the soil profiles were very deep and having varying internal drainage properties across the micro-topographic sequence. Soils on active alluvial plains (P5) were moderately well drained, sandy loam textured in surface and sandy loam to loamy sand in sub surface horizons with a regular decrease in clay fraction and subsequent increase in sand fraction with depth. The structure is fine weak sub angular blocky at surface and fine weak sub angular blocky to single at sub surface horizons. They have matrix colour of yellowish gray at surface with hue of 10 YR, value 6 and chroma 2 and gray to light gray with hue of 2.5 Y, value 5 to 6 and chroma 2 (Table 1). The soils have *fluvents* sub order due to stratified deposition of fine and coarse sand fractions, which is further confirmed by irregular distribution of organic carbon with depth (Soil Survey Staff, 2014). This may be attributed to frequent flood hazards of Jaldhaka river. The soils have Ap-AB-2ACg horizons. They were classified as *Coarse loamy mixed hyperthermic Typic Udifluvents* (P5). Soils on younger alluvial plains were somewhat poorly drained, silt loam in texture throughout with yellowish brown coloured surface with hue of 10 YR, value 4 and chroma 3 and light yellowish brown to yellowish gray colour at sub surface horizons with hue of 10 YR, value 5 to 6 and chroma 2. Fluvial influence of both Teesta and Jaldhaka has been observed in them with stratified and irregular distribution of organic carbon, sand and clay fractions with depth. They have also Ap-AB-2ACg horizon and were classified as *Coarse loamy mixed hyperthermic Typic Fluvaquents.* Similar findings were reported in soils of Brahmaputra valley region of Assam by Vadivelu *et al.* (2004). In older meander plains, soils were somewhat poorly drained, silt loam in texture with yellowish brown coloured surface with hue of 10 YR, value 4 and chroma 3 and light yellowish brown to light gray colour at sub surface horizons with hue of 10 YR to 2.5 y, value 4 to 6 and chroma 2. Endo-satauration was evident at a depth below 40 cm from surface with redox depletions. They have Ap-Bw-2Bwg horizon and were classified as *coarse loamy mixed hyperthermic Typic*

Table 1. Diagnostic features of soil profile for soil –landform relationship

Landforms (Pedons)	Taxonomy	Depth	Horizon	Texture	Colour	Structure	Drainage	Diagnostic features
Lower piedmont (P1)	*Typic Endoaqualfs*	0-18	Ap	sil	2.5 Y 5/1	Massive	Poor	
		18-42	Btg1	sil	2.5 Y 5/2	1msbk		Fe-Mn nodules
		42-78	Btg2	sil	2.5 Y 5/2	1msbk		Redox depletions
		78-120	2Bwg1	sil	2.5 Y 6/2	1msbk		Redox depletions
		120-140	2Bwg2	sil	2.5 Y 6/2	1msbk		Redox depletions
Older alluvial plains (P2)	*Humic Endoaquepts*	0-22	Ap	l	2.5 Y 4/1	Massive	Poor	
		22-59	Bwg1	l	2.5 Y 4/2	1msbk		Fe-Mn nodules
		59-95	Bwg2	l	2.5 Y 5/2	1msbk		Redox depletions
		95-110	Bwg3	sl	2.5 Y 6/2	1fsbk		Redox depletions
		110-125	Bwg4	sl	2.5 Y 6/2	1fsbk		Redox depletions
Older meander plains (P3)	*Typic Endoaquepts*	0-20	Ap	sil	10 YR 4/3	1msbk	SW Poor	
		20-41	Bw1	sil	10 YR 4/3	1msbk		Fine few RMF
		40-70	2Bwg1	sil	10 YR 5/2	1msbk		Redox depletions
		70-93	2Bwg2	sil	2.5 Y 5/2	1msbk		Redox depletions
		93-130	2Bwg3	sil	2.5 Y 5/2	1msbk		Redox depletions
Younger alluvial plains (P4)	*Typic Fluvaquents*	0-27	Ap	sil	10 YR 4/3	Massive	SW Poor	
		27-46	AB	sil	10 YR 5/2	1msbk		
		46-78	2ACg1	sil	10 YR 6/2	1msbk		Redox depletions
		78-100	2ACg2	sil	10 YR 6/2	1msbk		Redox depletions
		100-135	2ACg3	sil	10 YR 6/2	1msbk		Redox depletions
Active alluvial plains (P5)	*Typic Udifluvents*	0-16	Ap	sl	10 YR 6/2	1fsbk	Mod. Well	
		16-33	AB1	sl	2.5 Y 5/2	1fsbk		Fine few RMF
		33-55	AB2	sl	2.5 Y 5/2	1fsbk		Fine few RMF
		55-70	2ACg1	ls	2.5 Y 6/2	Single grain		Gleyed LD
		70-120	2ACg2	ls	2.5 Y 6/2	Single grain		Gleyed LD

Abbreviations: sil-silt loam; sl-sandy loam; ls-loamy sand; l-loam

Endoaquepts. In older alluvial plains, soils were poorly drained, loamy at surface and loamy to sandy loam at sub surface horizons, very dark gray coloured surface with hue of 2.5 Y, value 4 and chroma 1 and dark to light gray coloured sub surface with hue of 2.5 Y, value 4 to 6 and chroma 2. Dark coloured surface may represent high organic carbon content of soils. They have Ap-Bwg horizon and classified as *coarse loamy, mixed hyperthermic Humic Endoaquepts.* Soils on lower piedmonts were poorly drained, silt loam textured throughout, dark gray in colour at surface with hue of 2.5 Y, value 5 and chroma 1 and gray to light gray at sub surface horizons with hue of 2.5 Y, value 5 to 6 and chroma 2. Dark colour surface attributed to presence of high organic carbon content which gradually decreases with depth of soils as well as endo-saturation of B horizons. It has been observed that the B horizons at depth of 18 to 42 cm and 42 to 78 cm in P1 showed 23.5% and 20.6% clay enhancement from surface horizon, respectively (Table 2), qualifying the as gleyed argillic horizons (Btg), though there was no evidence of occurrence of any cutans, clay films or stress features (Soil Survey Staff, 2003), which might be attributed to high rainfall and impeded drainage situation in the study area. The soils of P1 might show very early stage of Alfisols formation (at a depth between 18 to 78 cm), which is possibly first time reported in the Terai region of West Bengal. They have Ap-Btg-2Bwg horizon. They were classified as *coarse loamy, mixed hyperthermic Typic Endoaqualfs* (USDA, 2014).

Characteristics of soils and correlation

The physical and chemical properties reported in table 2 showed that bulk density increases with depth and varies from 1.32 to 1.35 Mg m^{-3} in surface soils of different land forms. The correlation studies among different soil properties (Table 3) showed that only silt fraction had positive significant correlation (r = 0.73**) with bulk density whereas, sand fraction has a significant negative relation with the same (r = -0.67**) indicating importance of silt deposition due to frequent fluvial influence of both Teesta and Jaldhaka rivers. Soils have high silt deposits over sands forming alluvial fans, which may be the reason for higher bulk density of soils with higher silt and lower sand fractions, leading to internally imperfect (somewhat poor) drainage situations of soils in-spite of having coarse loamy texture. The effect of clay fraction had no significant effect on bulk density. Sand, silt and clay fractions of soils varied from 9.4% (older meander plains) to 87.8% (active alluvial plains), 6.5% (active alluvial plains) to 79.9% (younger alluvial plains) and 4.0% (younger alluvial plains) to 16.8% (lower piedmont), respectively. The study further indicated that the occurrence of silt fractions was geogenic effect of river fluvial actions but the presence of sand and clay was *in situ* soil forming processes of parent materials due to weathering. Higher sand fractions in active alluvial plains represented slower rate of pedogenic development, whereas, higher clay fractions in lower piedmonts represented relatively rapid pedogenic developments.

The soils were moderately acidic (pH 4.9) in lower piedmont to neutral (pH 7.1) in reaction in active alluvial plains. Soil organic carbon at surface horizon ranges from low (0.40%) in active alluvial plains to high (1.92%) in lower piedmonts. High organic carbon in surface soils of lower piedmont may attribute to sufficient amount of pH dependent surface charge, which may cater the strong soil acidity. Similar findings were reported in soils of Nagaland (Bandyopadhyay *et al.*, 2018). Cation exchange capacity of soils ranges from low [1.4 cmol (p^+) kg^{-1}] in active alluvial plains to medium (8.0) in lower piedmonts, whereas, base saturation ranges from 57 to 79% in active alluvial plains. Soil pH had significant positive correlation with base saturation (r = 0.83**) and negative with SOC (r = -0.86**) and CEC (r = -0.80**) of soils

Table 2. *Physical and chemical characteristics of soils*

Pedons	Depth (cm)	BD	Sand	Silt	Clay	Sand/ Silt	Silt/ Clay	VFS+ FS/TS	pH	SOC	CEC	SCA	BSP	CEC/ Clay
P1	0-18	1.35	19.0	67.4	13.6	0.28	4.96	0.76	4.9	1.92	8	4.6	58	0.59
	18-42	1.36	21.4	61.8	16.8	0.35	3.68	0.79	5.4	1.18	7.5	4.6	61	0.45
	42-78	1.38	22.5	61.1	16.4	0.37	3.73	0.90	5.5	0.55	6.9	4.4	64	0.42
	78-120	1.40	35.1	58.1	6.8	0.60	8.54	0.89	5.7	0.32	5	3.3	66	0.74
	120-140	1.42	13.1	79.5	7.7	0.16	10.32	0.84	5.8	0.22	5.3	3.7	70	0.69
P2	0-22	1.34	43.1	42.8	14.1	1.01	3.04	0.43	5.1	1.25	6.8	4.2	62	0.48
	22-59	1.35	45.8	39.2	15.0	1.17	2.61	0.63	5.4	0.98	6.5	4.2	65	0.43
	59-95	1.34	46.9	43.1	10.0	1.09	4.31	0.59	5.9	0.75	5.9	4.1	69	0.59
	95-110	1.35	56.3	35.2	8.5	1.60	4.14	0.57	5.8	0.52	4	2.7	68	0.47
	110-125	1.36	54.3	39.3	6.4	1.38	6.14	0.51	5.9	0.32	3.8	2.6	68	0.59
P3	0-20	1.34	9.4	79.8	10.8	0.12	7.39	1.84	5.9	0.80	6.5	3.1	64	0.60
	20-41	1.36	13.1	77.7	9.2	0.17	8.45	1.07	6.1	0.40	5.7	2.7	69	0.62
	40-70	1.38	32.2	58.5	9.3	0.64	13.60	0.60	6.4	0.21	5.3	1.7	71	0.57
	70-93	1.40	11.1	79.5	9.4	0.14	8.46	3.77	6.4	0.30	4.3	3.8	72	0.46
	93-130	1.42	22.6	68.5	8.9	0.33	7.70	1.81	6.5	0.24	2.0	3.2	73	0.22
P4	0-27	1.38	24.1	66.1	9.8	0.36	6.74	0.90	5.2	0.91	4.4	2.8	64	0.45
	27-46	1.40	35.6	59.4	5.0	0.60	11.88	0.83	6.2	0.19	3.2	2.3	72	0.64
	46-78	1.43	47.4	48.4	4.0	0.98	12.10	0.69	6.6	0.10	2.4	1.8	75	0.60
	78-100	1.45	17.5	78.2	4.3	0.22	18.19	0.72	6.5	0.12	3.5	2.6	74	0.81
	100-135	1.45	13.5	79.9	6.6	0.17	12.11	0.71	6.7	0.13	3.8	3	79	0.58
P5	0-16	1.32	55.8	35.7	8.1	1.56	4.41	0.41	6.2	0.40	2.3	1.3	57	0.28
	16-33	1.30	56.1	36.0	7.9	1.56	4.56	0.60	6.6	0.13	2.0	1.5	75	0.25
	33-55	1.30	52.3	39.7	8.0	1.32	4.96	0.62	6.3	0.13	2.2	1.7	77	0.28
	55-70	1.29	87.8	6.5	5.7	13.51	1.14	0.72	6.5	0.04	1.6	1.2	75	0.28
	70-120	1.30	85.3	0.1	4.6	8.45	2.20	0.72	7.1	0.12	1.4	1.1	79	0.30

indicating the acidic behaviour of soils of lower piedmont due to more pH dependent charges at surface caused by high organic carbon content. Similar findings were reported in soils of Nagaland by Bandyopadhyay *et al.* (2018). On the other hand, active alluvial plains comprise soils with higher pH due to higher base saturation percentage caused by more silt fractions (Birkland, 1984) deposited by rivers. The low clay content (4.6-8.1%) in soils contributed to low CEC and low sum of cations in these soils (Gerrad, 1992).

Hydromorphic consideration

Hydromorphic characterization and index (HI) of soils were presented in Table 3 and Fig. 2. It varied from 20.6 in soils of older alluvial plains to 4.5 in soils of active alluvial plains with an order as Older alluvial plains (20.6) > Lower piedmont (17.6) > Older meander plains (5.8) > Younger alluvial plains (5.5) > Active alluvial plains (0.45). Higher HI values in lower piedmont and older alluvial plains may be attributed to higher degree of hydromorphosis occurring at major proportions of soil depth (P1 with 82.4 and P2 with 87.1) as postulated by Chaplot *et al.* (2000). The phenomenon is better indicated by dark gray colour of the surface horizons as well as occurrence of nodules of iron (Fe^{2+}) and manganese (Mn^{2+}) in reduction phases at a depth below 18 to 22 cm along with redoximorphic depletions at a depth below 42 to 59 cm in soils of lower piedmonts and older alluvial plains. Sub surface matrix colour of 2.5 Y hue with chroma of 2 is indicative of reduction phases of iron and manganese with depletions, which supports the formation of soils of *Aqualfs* and *Aquepts* sub orders in these two aforesaid landforms. On the other hands, soils of younger alluvial plains and active alluvial plains were much less hydromorphic compared to that in lower piedmonts and older alluvial plains. The close association of river banks of Teesta and Jaldhaka may be attributed to stratification of sand and silt deposition, which may cause imperfect to moderately well drained situation of soils. Few and faint redoximorphic features were occurred at a range of depth below 33 to

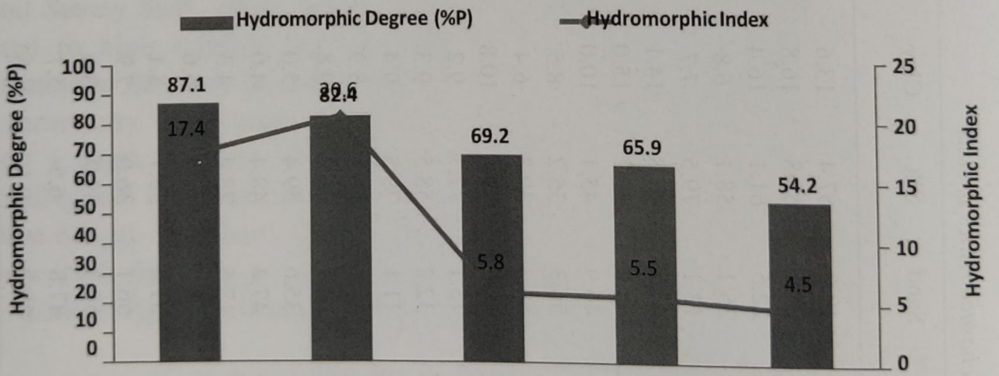

Fig. 2. *Hydromorphic Index in a landform sequence*

Table 3. *Hydromorphic Characteristics of soils*

Landforms	Taxonomy	HI	P (%)
Lower piedmont	*Typic Endoaqualfs*	17.4	87.1
Older alluvial plains	*Humic Endoaquepts*	20.6	82.4
Older meander plains	*Typic Endoaquepts*	5.8	69.2
Younger alluvial plains	*Typic Fluvaquents*	5.5	65.9
Active alluvial plains	*Typic Udifluvents*	4.5	54.2

46 cm, although depletions of iron and manganese are scarce. Frequent flooding hazards may have a causative effect on hydromorphosis in these soils. These soils were, therefore, have almost no profile development and were placed under *Fluvents* and *Aquents* sub orders as reported by Gangopadhyay *et al.* (2015) in soils of Assam.

Pedological considerations

The correlation study (Table 4) indicated that the assessed pedogenic indices *viz.,* sand/ silt showed negative relationship with pedogenesis, whereas, CEC/ clay, silt/ clay and (VFS+FS)/ TS showed positive effect on the same (Schatzael and Anderson, 2015). It has also been observed from table 3 that the average sand/ silt ratio follows the order as P3 (0.28) < 0.35 (P1) < P4 (0.47) < P2 (1.25) < P5 (5.28), whereas, average silt/ clay ratio had a sequence of P5 (3.45)<P2(4.05)<5.25(P1)<9.12(P3) <12.20.(P4) to support the process. To supplement the fact, it was noted that he ratios of (VFS+FS)/TS showed the sequence of P2 (0.55) < P5 (0.61) < P4 (0.77) < P1 (0.84) < 1.82 (P3) where as CEC/ clay sequence as P5 (0.28) < P3 (0.49) > P2 (0.51)> P1 (.0.58) > P4 (0.62). These fact established that soils on lower piedmonts, older alluvial plains and older meander plains have higher value of CEC/ clay, (VFS+FS)/ TS and silt/ clay as compared to that on younger and active alluvial plains establishing pedogenic processes were more rapid in these landforms. On the contrary, higher sand/ silt ratio in active alluvial plains leads to formation of lithologically discontinue gleyed layers below 55 cm from surface indicating slow rate of pedogenesis in soils on active alluvial plains (Bandyopadhyay *et al.*, 2017). The Clay, CEC and SOC were found to have synergistic relationship with HI (Fig.3.) *vis-à-vis* pedonesis. Thus, the process of hydromorphosis and humification were simultaneous in P1 and P2, which was

Table 4. *Correlation coefficient between soil properties and hydromorphic characters*

Parameters	BD	Sand	Silt	Clay	Sand/ Silt	Silt/ Clay	VFS+ FS/TS	pH	SOC	CEC	SCA	BSP	CEC/ Clay
BD	1.00												
Sand	-0.67**	1.00											
Silt	0.73**	-0.99**	1.00										
Clay	-0.18	-0.34*	0.18	1.00									
Sand/ Silt	-0.54**	0.78**	-0.75**	-0.32	1.00								
Silt/ Clay	0.80**	-0.54**	0.64**	-0.47*	-0.45*	1.00							
VFS+FS/ TS	0.25	-0.45**	0.46**	0.05	-0.17	0.13	1.00						
pH	0.06	0.32*	-0.20	-0.75**	0.37*	0.33*	0.14	1.00					
SOC	-0.18	-0.27	0.15	0.77**	-0.28	-0.39*	-0.07	-0.86**	1.00				
CEC	0.11	-0.57**	0.45*	0.80**	-0.48*	-0.10	0.03	-0.80**	0.79**	1.00			
SCA	0.30*	-0.60**	0.50**	0.75**	-0.51**	-0.12	0.23	-0.74**	0.70**	0.85**	1.00		
BSP	0.15	0.26	-0.15	-0.68**	0.34*	0.33*	0.09	0.83**	-0.78**	-0.68**	-0.54**	1.00	
CEC/ Clay	0.62**	-0.52**	0.57**	-0.16	-0.44*	0.67**	-0.04	-0.22	0.08	0.44*	0.32*	-0.09	1.00
Mean	1.37	36.85	54.06	9.08	1.53	7.01	0.92	6.02	0.49	4.41	2.89	69.08	0.50
SD	0.05	21.93	21.02	3.65	2.98	4.15	0.69	0.56	0.46	1.98	1.12	6.18	0.16

Fig. 3a. Relationship between CEC & HI

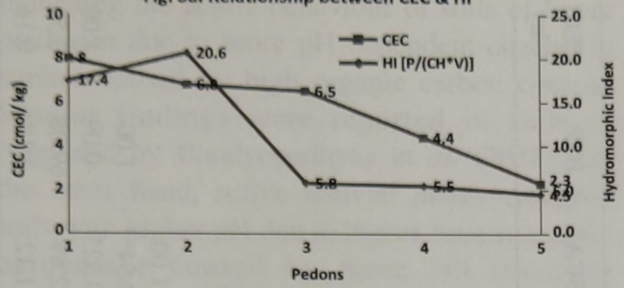

Fig. 3b. Relationship between Clay & HI

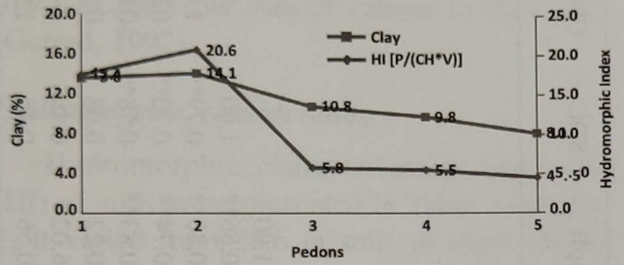

Fig. 3C. Relationship between SOC & HI

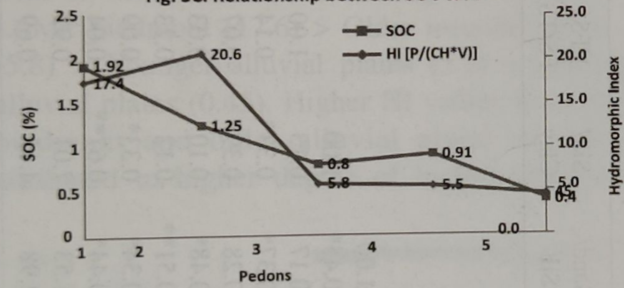

Fig. 3. *Relationship between soil properties and hydromorphic index*

responsible for the formations of Typic Humaquepts and Humic Endoaquepts in lower piedmonts and older alluvial plains, respectively. Occurrence of humic hydromorphic soils is an indicative of relative elderliness of landforms. On the contrary, non humic hydromorphic soils in active alluvial plains and younger alluvial plains exhibits their juvenile nature. The older meander plain represents an intermediate stage of weathering which stands in between older alluvial and younger alluvial plains. Their formation may be attributed to shifting of river courses in the geological past in the *Terai* region.

Conclusions

The soil characteristics (soil horizons and properties) served as evidence of past processes and an indicator of present processes. These areas had synergistic (between gleyization and Humification) relationship favoured by warm to hot and humid climate. The hydromorphic index developed, confirm the pedogenic processes as these soils exhibit signs of chemical reduction rather than oxidation, including mottling (spots of reduced iron compounds, grayish rather than red). Spatial information on soils of hydromorphic soil properties established can be used to understand and assess soil water retention, flooding potential, erosion hazard, and depth to seasonal high water table. These properties influence soil use and management interpretations for construction, waste disposal, plant production, and water management.

References

Arnaud, R.J. St. 1988. Application of the 'Pedogenic Index' to soil fertility studies, Saskatchewan. *Geoderma* **43:** 21-32.

Bandyopadhyay, S., Ray, P., Ramachandran, S., Jena, R.K., Singh, S.K. and Ray, S.K. 2017. Pedogenesis of Some Hydromorphic Soils of Upper Brahmaputra Valley Region, Assam, India. *Clay Res.* **36:** 77-89.

Bandyopadhyay, S., Ray, R., Padua, S., Ramachandran, S., Jena, R.K., Deb Roy, P., Dutta, D.P., Baruah, U., Sah, K.D., Singh, S.K., Nayak, D.C., and Ray, S.K. 2018. Forms of acidity in soils developed on different landforms along an altitudinal sequence in Nagaland, India. *J. Indian Soc. Soil Sci.* **66:** 125-135.

Bhattacharyya, T., Pal, D. K., Mandal, C., Chandran, P., Ray, S.K., Sarkar, D., Velmourougane, K., Srivastava, A., Sidhu, G. S., Singh, R. S., Sahoo, A.K., Dutta, D., Nair, K.M., Srivastava, R., Tiwary, P., Nagar, A.P. and Nimkhedkar, S.S. 2013. Soils of India: Historical perspective, classification and recent advances. *Current Sci.,* **104(10):** 1308-1323.

Birkland, P.W. 1984. Topography-soil relationship in Soils and Geomorphology. Oxford University Press, pp. 234-259.

Bouma, J, Fox, C.A. and Miedema, R. 1990. Micromorphology of Hydromorphic Soils: Applications for Soil Genesis and Land Evaluation. *Dev. Soil Sci.* **19**: 257- 278.

Chaplot, V., Walter, C. and Curmi, C. 2000. Improving soil hydromorphy production according to DEM resolution and available pedological data. *Geoder.* **97**: 405–422.

Gangopadhyay, S.K., Bhattacharyya, T. and Sarkar, D. 2015. Hydromorphic soils of Tripura: Their pedogenesis and characteristics. *Current Sci.* **108(5):** 984-993.

Geological Survey of India. 1990. *Geological and Mineral Map of West Bengal (on 1: 2M scale).* 1990. GSI, Govt. of India.

Gerrard J. 1992. *Soil Geomorphology. An integration of pedology and geomorphology.* Chapman and Hill, 269 pp.

Hillel, D. 1982. *Introduction to Soil Physics*. Academic, New York.

Jackson, M.L. 1973. *Soil Chemical Analysis*. Prentice Hall, New Delhi, 498 pp.

Schaetzl, R.J. and Thompson, M.L. 2015. *Soils - Genesis and Geomorphology*. 2nd Edition. Cambridge.

Smith, G.D. 1986. *The Guy Smith Interview:* Rationale for concepts in Soil Taxonomy. *SMSS Technical Monograph No.* **11**, SMSS, SCS, USDA.

Soil Survey Staff. 2003. *Soil Taxonomy. Agricultural Handbook*, **436**,3rd Edition, USDA, Washington, DC.

Soil Survey Staff. 2014. *Keys to soil Taxonomy*, 12th Edition. NRCS, USDA, Washington DC.

Vadivelu, S., Baruah, U., Bhaskar, B.P., Mandal, C., Sarkar, D., Walia, C.S. and Gajbhiye, K.S. 2004. *Soil Resource Atlas, Jorhat District (Assam),* NBSS Publ. **107**, NBSS & LUP (ICAR), Nagpur, India.

Velayutham, M., Mandal, D.K., Mandal, C. and Sehgal, J.L. 1999. *Agro-ecological Sub Regions of India for Planning and Development. NBSS Publ.* **35**, NBSS & LUP (ICAR), Nagpur, India.

(Received: 30 March, 2019; Accepted: 27 June, 2019)

ACKNOWLEDGEMENT

I grate fully acknowledge the help received from the followings scientists /Professors who reviewed the manuscripts for 2018 issue.

1. Dr Padikkal Chandran
2. Dr Sanjay Ray
3. Dr Goutam Goswami
4. Dr Siddhartha Mukhopadhyay
5. Dr K.M Manjaiah

INSTRUCTIONS FOR CONTRIBUTORS

CLAY RESEARCH is the official publication ofTHE CLAY MINERALS SOCIETY OF INDIA and is published twice a year, in June and December. The Journal undertakes to publish articles of interest to the international community of clay scientists, and will cover the subject areas of mineralogy, geology and geochemistry, crystallography, physical and colloid chemistry, physics, ceramics, civil and petroleum engineering and soil science.

The Journal is reviewed in *Chemical Abstracts, MineralogicalAbstracts, and Soils and Fertilizers.*

Paper (in English) should be submitted to the Editor, Clay Research **"The Clay Minerals Society of India"** Division of Soil Science and Agricultural Chemistry, I.A.R.I., New Delhi-I to 012. samar1953@yahoo.com. At least one of the authors should be member of THE CLAY MINERALS SOCIETY OF INDIA. Submission is an undertaking that the manuscript has not been published or submitted for publication elsewhere.

Manuscripts should not exceed sixteen typed (double spaced) pages including tables and illustrations. **The original and two copies of text and illustrations should be submitted.**

Form Manusciprts should be typewritten, double spaced on white paper, with wide margins. Intending contributors should consult a recent issue of CLAY RESEARCH for the standard format and style. The manuscript should have the sections ABSTRACT, introductory portion (untitled), MATERIALS AND METHODS, RESULTS and DISCUSSION and REFERENCES.

Title page should contain manuscript title, full name(s) of author(s), address (es) of the institution(s) of the author(s), a short running title not exceeding 60 characters including spaces, footnotes if any to the title, and complete mailing address of the person to whom communications should be sent.

Abstract should be a condensation of the ideas and results of the paper. It should not exceed 25'0 words. Do not make reference to the literature in the abstract.

Tables should have the simplest possible column headings. Type each table on a separate page; indicate location in the text by marking in the margin of text page.

Figures should be self-illustrative, drawn with black India ink on tracing paper or white Board. The lattering should be large enough to permit size reduction to one Journal page column width (about 7.0 cm) without sacrificing legibility. **The original tracing should be submitted**. The size of the drawing should not exceed 24 × 17 cm. Give the numbered legend on a separate sheet, not on the figure itself. Data available in the tables should not be duplicated in the form of illustrations. Indicate the location of the figure in the text by marking in the margin of the page.

Photographs should be in the form of glossy prints with strong contrast. In photomicrographs, the scale in micron or other suitable unit should be drawn on the print. Give the numbered legend on a separate sheet. Indicate the location of the photograph in the text by making in the margin of the text page.

References should be cited in the text by the name(s) of author(s) if two or less, and year of publication. If there are more than two authors, give the name ofthe first author followed by *'et al'* and year. Full references giving author(s) and initial(s), year, title of paper, (journal, volume, number if paged separately), first and last pages should be listed alphabetically at the end of the paper. Journal title should be abbreviated in accordance with the World List of Scientific Periodicals and its sequences. Examples are

Grim, R.E., Bray, R.H. and Bradley, W.R. 1937. The mica in argillaceous sediments. *Am. Miner.* **22**:813-829.

Brindley, G.W. 1961. Chlorite minerals. In *(G.* Brown, Ed.) *The X-ray Identification and Crystal Structures of Clay Minerals,* Mineralogical Society, London, pp.242-296.

Theng, B.K.G. 1974. *The Chemistry of Clay Organic Reactions,* Adam. Hilger, London, 343 pp.

Review Every manuscript submitted to CLAY RESEARCH is independently reviewed by one or more referees. Acceptance or rejection of a manuscript is the responsibility of the Editor.

Reprints No free reprints are supplied to authors. Order for priced reprints should be sent when required by the Editor.

Clay Research

Vol. 37 **December 2018** **No. 2**

CONTENTS

Printed at : Cambridge Printing Works, New Delhi-1100028. (Mobile : 9811860113)