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The 32nd Prof. J.N. Mukherjee ISSS - Foundation Lecture*

Pedology: The Grammar of Soil Science

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I deeply appreciate the honour the Indian Society of Soil Science has done me for delivering the 32nd Prof. J.N. Mukherjee ISSS Foundation Lecture. I came to know about Prof. Mukherjee during later part of my under-graduate courses in Agricultural Sciences in Kalyani, West Bengal, when my teacher mentioned about Prof. Mukherjee's contribution while discussing the diffuse double layer theory. Later during my post-graduate studies at the Indian Agricultural Research Institute, New Delhi, I could know more about him. During the passage of 36 years, Prof. Mukherjee's contribution influenced me through deliberations made by my senior colleagues from this platform. Prof. Mukherjee was a scientist of international reputation with a great vision. His scholarly contribution enriched the subject of soil science to a great extent. As a student of soil science with my little experience in pedology, I have decided to share some of our research findings which could be a humble tribute to this great scientist.

Pedology is the study of soils in their natural environment. It is one of the two main branches of soil science, the other being edaphology. Pedology deals with pedogenesis, soil morphology and soil classification whereas edaphology studies the way soils influence plant, microbes and other living things. Pedology, in its broad sense includes soil survey, mapping, geomorphology, soil micromorphology, and soil and clay mineralogy with special reference to soil formation. Since soils are formed from different types of rocks or sediments, pedology has a close relation with geology and geological sciences. With the advent of modern technologies like remote sensing and geographical information system, pedometrics, pedotransfer and taxotransfer rules, soil database storage and retrieval, the subject of pedology has become much incisive. Since all the gamutes of agriculture depend directly on soils which is controlled by the pedological processes, it is appropriate to revisit pedology and its grammar to understand all about soils and how they influence other aspects of soil science. It is for this reason, I have decided to flag some examples of pedological significance in soil science for arriving at a common understanding that *pedology is the grammar of soil science*.

I. Pedology: the building block to develop soil information system

Spatial Hierarchy and Level of Mapping: It has long been felt that our natural environment should be mapped and monitored with the active participation of agencies responsible for managing natural resources, industry groups and community organizations. This organized information forms a basis for storing soil and land database for implementation and monitoring various efforts on land resource management. Thus, pedological information on soil and land resources is fundamental and therefore soil information system (SIS) plays a pivotal role in capturing pedological information in the form of soil and terrain digital database (SOTER) (1:1 M) as the data storage and retrieval for improved mapping, modelling and monitoring of changes of world soil and terrain resources (Batjes *et al.* 2007; Bhattacharyya *et al*. 2014a; Chandran *et al*. 2014). Pedological information has been generated and collated through different sources and at various scales to develop user-friendly datasets at different scales depending on purpose of survey and its use (Table 1) (Staff NBSS&LUP 2002; Bhattacharyya *et al*. 2014a).

Soil information system to develop soil loss and conservation for crop productivity model: Since soil erosion is the major reason for soil loss and consequent decline in soil and crop productivity, it becomes imperative for the land use managers and planners to adopt appropriate soil conservation measures (Fig. 1). Loss of crop yield due to loss of topsoil is compensated by the use of manures and fertilizers. At the same time, loss of topsoil by soil erosion is also com-

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Table 1. Available soil and land information system – spatial hierarchy*

Level	Land unit	Soil unit	Descriptive legends	Description of map unit	Map Scale
				Level 1	
1.	Country	Order	Soil Orders	Inceptisol, Entisols	1:25 million
2.	State	Suborder	Soil Suborder	Red and yellow soils, red loamy soils, mixed red and black soils	1:7 million
3.	State	Old soil classification	Traditinal soil names	Bengal plains, hot subhumid to humid LGP 210-300 days (AER 15)	1:4 million
4.	State (Region)	-	Agro-ecological region (AER)	Bengal plains, hot subhumid to humid LGP 210-300 days (AER 15)	1:4.4 million
5.	State (sub-region)	~	Agro-ecological subregion (AESR)	Bengal basin and north Bihar plains, hot moist subhumid with medium to high AWC and LGP (210-300 days) (AER 15.1)	1:4.4 million
6.	Country (sub country)	Soil family	Soil family association	Total 1649 units in the country (Indo-Gangetic Plains:IGP had 74 no. of units)	1:1 million
				Level 2	
7.	State (Physiography)	Soil family	Soil family association	Total 74 soil map units in the IGPshowing association of dominant (60% average in polygon) and subdominant (40% in a polygon soils); and 50%, 30% and 20% where 3 soil families exist.	1:250,000
8.	District (Hooghly, West Bengal)	Soil series	Soil series association	Total 28 soil units showing association of dominant and subdominant soil series with inclusions	1:50,000
9.	Watershed (Chuchura, West Bengal)	Soil series	Soil series association	Two soil series and five map units in Chuchura farm	1:2400

**Source:* Bhattacharyya *et al*. (2014a)

pensated by the formation of fresh soil layers through pedogenesis. To calculate loss of topsoil it is necessary to take into account the amount of soil regenerated, keeping in view the difference in the rate of soil formation under different types of climatic conditions using pedological and geological information of the study area. Pedological data-aided improvised FAO model helped estimating the annual loss of soil as 15 mt yr^{-1} and also to assess its tolerable limit (Bhattacharyya *et al*. 2010).

Soil information system – clay minerals vis-a-vis land use options in humid tropics: Pedology as a part of basic science finds its application when clay mineralogy, physiography, soil chemistry and land use options are linked (Bhattacharyya *et al*. 2010, 2013a). During humid tropical weathering huge quantity of Al^{3+} ions (149 kg ha^{-1} soils) are liberated to cause higher acidity (H^+). To form hydroxy-interlayered vermiculites/smectites (HIV/HIS), vermiculites/smectites adsorb these Al^{3+} ions. The vermiculite/smectite minerals thus act as a natural sink to sequester Al^{3+} ions. This fact may possibly help in removing the myth about the Al–toxicity in acid soils *vis-à-vis* the concept of acid-loving crops.

Georeferencing pedological information: Web technology has made it easier to bring out web-based publications which has been used for disseminating georeferenced soil information system (web GeoSIS) in an electronic format (Fig. 2). This enables the users to access information/ datasets for various purposes including land resource inventory and management. Query-based information on soil, and land use along with their spatial distribution can also be accessed for a specific purpose. Web GeoSIS can enable collaboration between different agencies, facilitating better communication and can save duplication of research. This exercise can open a new vista for participatory research programmes using common people and other organisations, and can, therefore, provide scope for revising the database for monitoring soil health and changing land use pattern (Bhattacharyya *et al*. 2014 b,c).

Soil correlation and pedology: Computer-aided soil correlation software (SOILCOR) was developed for correlating soil series and to enrich the existing soil and land resource databse. Pedological significance finds its edaphological application to assess soil quality in terms of both organic and inorganic form of soil carbon and their influence on soil properties through an indigenous soil and land quality (SOLAQ) software for assessing soil and land quality (Figs. 3-4).

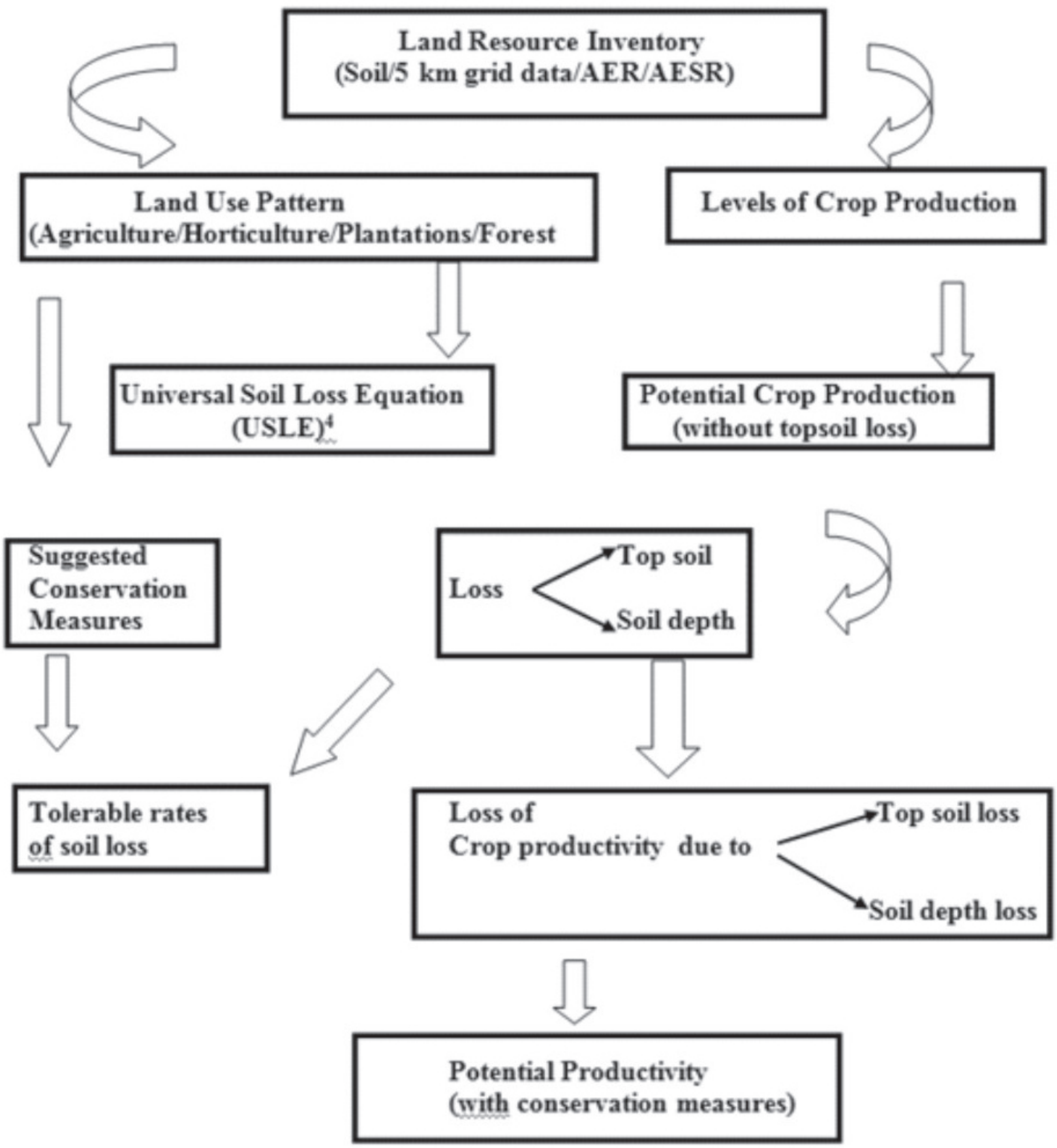

Fig. 1. Soil erosion-crop productivity model (Source: Bhattacharyya *et al*. 2010)

II. Pedology (soil taxonomy) and map scales: multidisciplinary approach

Pedology in terms of soil genesis, mineral transformation and soil taxonomy is always linked with mapping. Mapping refers to developing different polygons in the form of features of natural or artificial objects as are observed on the surface. Various available products such as topomaps, aerial photo, remotely-sensed data and other collateral information spread *below the surface* which cannot be seen with the above mentioned tools.

The basic reason why soil survey is important because resource inventory with special reference to soil rests on the principles of pedology including geomorphology, soil formation and the techniuqe to group soils following the US soil taxonomy. This suggests the exercise of resource inventories as a basic and fundamental research carried out by a group of dedicated soil scientists more precisely known as pedologists. The basic concept of converting a map into soil map is to incorporate and link soil information with the map and at the same time revising the boundaries

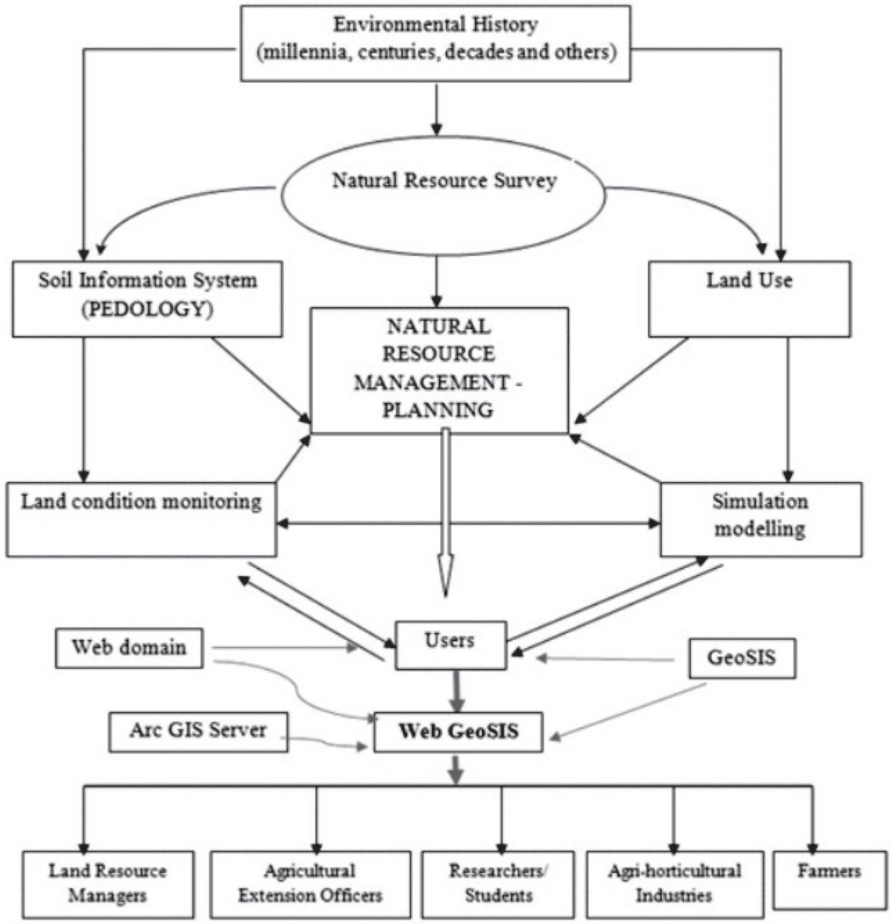

Fig. 2. Mapping, monitoring and modelling are complementary activities to use and update Georeferenced Soil Information System with pedological input for web based GeoSIS (Source: Bhattacharyya *et al*., 2014 b, c)

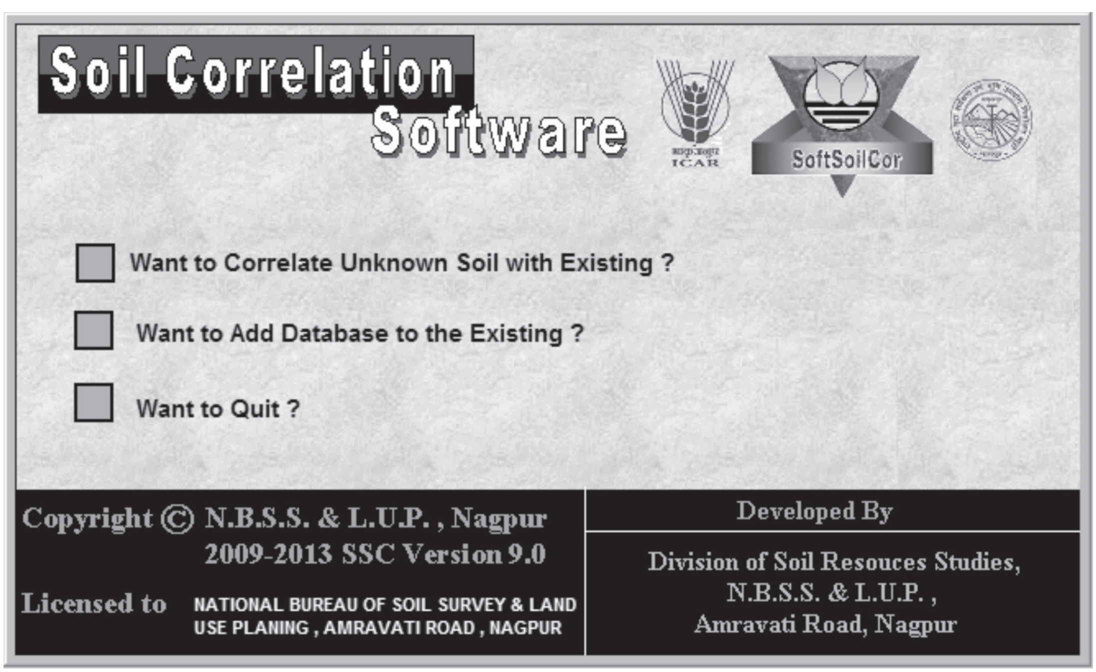

Fig. 3. Soil correlation software to correlate soil series with the exixsting database

Fig. 4. Soil and land quality (SOLAQ) software for assessing and monitoring soil health

of the base map (prepared by a mapper with the knowledge of remote sensing and cartography or both). The type of soil information is embedded in the basic concept of the US taxonomy as evidenced by clear definition of order, sub-order, great group, sub-group, family, series and phase. Each of these categories is mutually inclusive down the line as we reach the base of the pyramid to a large scale soil map showing soil phase information. This statement requires retrospection in terms of detailing soil information system and incorporating it in the large scale soil map. In other words, a large scale soil map (say 1:10000 or 1:5000 scale) requiring phase level soil information should not end up with a mere mention of only one soil information showing surface and subsurface phase; the entire pedigree of soil information with that phase must be detailed in the large scale soil map.

III. Pedology, geomorphology and soil genesis through landscape reduction process

Landscape reduction process and influence of zeolite in soil formation: Formation of soil and its persistence in the humid tropical climate (HTC) in the Western Ghats prevailing since the early Tertiary is comprehended by pedological information. The deep black soils in the valleys are formed due to the progressive landscape reduction process and persist in HTC due to the presence of base-rich zeolites of amygdoloidal basalt. The knowledge gained on the role of zeolites in soils provides a check on the reasoning of models on the formation of soils in HTC. Zeolites also prevent the soils from losing their productivity even in an intense leaching environment (Bhattacharyya *et al*. 1993).

Gibbsite formation model and anti-gibbsite effect: Presence of gibbsite in soils does not indicate their advanced stage of weathering. The formation of typically rod-shaped and well-crystallized gibbsite in the presence of large amounts of 2:1 minerals indicates that the anti-gibbsite hypothesis may not be tenable in the tropical acid soils (Bhattacharyya *et al*. 2000). Pedological information on the presence of gibbsite in rubber-browing soils (Chandran *et al*. 2005) suggests researchable issues to link rubber production in gibbsitic and non–gibbsitic rubber soils in Kerala and Tamil Nadu.

IV. Pedology and soil carbon sequestration: an inverse pyramid relation

The qualitative nature of the soil substrate and their quantitative proportion of surface reactivity, referred as surface charge density (SCD) control the rate of SOC sequestration. The presence of smectites and SOC increases SCD, which offer greater scope of carbon sequestration in black soils. Black soils reach more than 2% quasi-equilibrium value of SOC (Bhattacharyya *et al*. 2014a). A minimum 78% of the total organic matter in soil is controlled by inorganic substrate (precisely phyllosilicates minerals with higher surface area in the finer fractions) (Bhattacharyya and Pal 2003) which finds support in the formation and persistence of Mollisols in the humid tropical climate (Bhattacharyya *et al*. 2014a) and Vertisols in Australia. Importance of SCD, rainfall and their combined influence shows an inverse pyramid relation of SOC with soil taxonomy (Fig. 5).

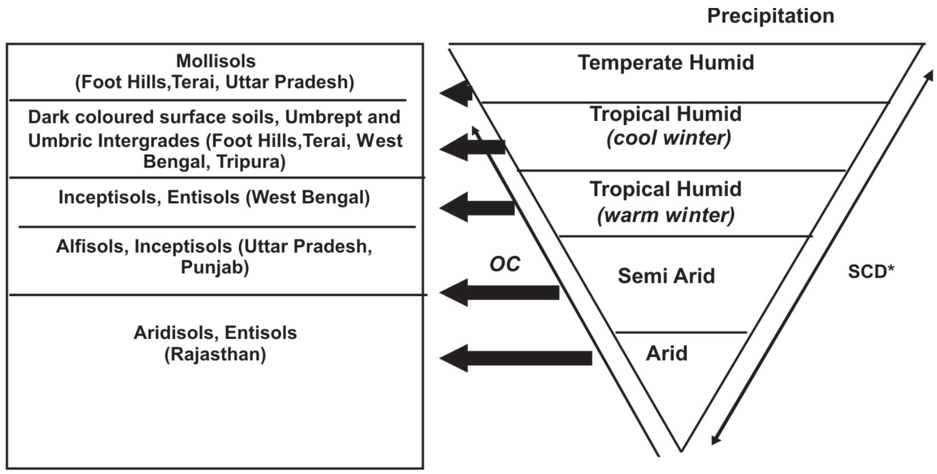

Fig. 5. Inverse pyramid relation with accumulation of organic carbon (OC) in soils influenced by precipitation, temperature and substrate quality (* SCD: Surface charge density) (*Source:* Bhattacharyya *et al*. 2014a).

Pedology and carbon transfer model: Detailed studies on Indian Vertisols and other alluvial and ferruginous soils and elsewhere in the world (Lal and Kimble 2000a, b; Breecker *et al*. 2009; Hua, 2011) indicate that the drier climate is the prime factor responsible for the depletion of Ca^{2+} ions from the soil solution due to $CaCO_3$ formation (Pal *et al*. 2000; Bhattacharyya *et al*. 2014a). The $CaCO_3$ (as pedogenic carbonate, PC) enhances the pH and also increases the relative abundance of Na^+ ions in both soil exchange sites and solution. Thus, the formation of $CaCO_3$ accentuating inorganic C sequestration has a deleterious effect on soil quality since it affects soil pH, exchangeable sodium percentage (ESP) and hydraulic properties. Roth*C* model arrived at a threshold limit of MAR of 850 mm while determining SOC turnover rate. Pedological (soil survey) data also attaineded similar threshold limit for MAR to describe inorganic carbon sequestration and its consequences to soil sodicity (Fig. 6) (Bhattacharyya et al., 2011).

Pedology, paleopedology, paleosols and climate change: Jenny's soil formation model indicates *climate* as an important state factor. Therefore, it is no wonder that climate change due to global warming will have its effect on soil. With the change in the soil environment clay mineral assemblage over time gets modified (Jenkins 1985). But the pedogenic clay minerals of the intermediate weathering stages, when preserved in a paleosol, can also be helpful not only for paleoclimatic interpretation but also to identify the polygenesis of soils (Pal *et al*. 1989). It appears that polygenesis in soils is a rule than an exception. Time is the essence in the emerging environmental observatories across scientific disciplines, such as

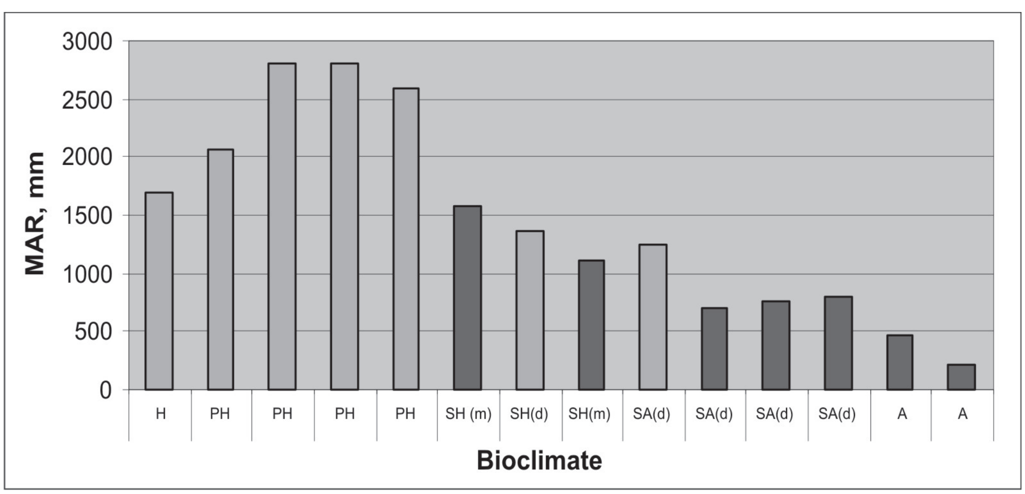

Fig. 6. Different bioclimate showing accumulation of $CaCO_3$ (red areas) (MAR : Mean annual rainfall; H : Humid; PH : Per humid; SH(m) : Sub humid moist; SH(d) : Sub humid dry; SA(d) : Semi-arid dry; A : Arid; blue areas are non-calcareous) (*Source:* Bhattacharyya *et al*. 2014a).

critical zone observatories (Lin 2011). Long-term recording of soil-health through monitoring its *blood pressure* (*soil water potential*), and other important soil parameters suggest importance of climate change and global warming for monitoring soil health. This demands periodic monitoring of soil parameters (Lin, 2011; Bhattacharyya *et al*., 2014a). Soils have a unique capacity of memorising landscape development over time, which stores information about environmental conditions (read *pedological processes*) through their complex interactions with the environment. Identifying these signatures in soil requires the experience, wisdom and eyes of an expert pedologist who has a fairly good idea about geology, pedology, climate, biology, environment and many other allied subjects. Decoding these signatures helps pedologists to understand influence of paleo-climate to predict future changes in soils in terms of their quality and health for agricultural sustenance. Capacity of soil to memorize events and to retrieve them to the expert pedologists has also been mentioned by Lin *et al*. (2011) and Bhattacharyya *et al*. (2013a).

Clay minerals as indicator of climate change: The products of the self-terminating, irreversible reactions such as calcareous or siliceous incrustions in soils are the identifiable indicators of paleo-environmental conditions. In spite of difficulty in arriving at a particular or a group of minerals as carrirrers of climate change signatures, several Indian reserachers have linked smectite, smectite/kaolin, and pedogenic $CaCO_3$. with climate change (Bhattacharyy *et al*. 1993, 1999, 2014a; Chandran *et al*. 2000; Pal *et al*. 1989, 2012).

Pedology in soil carbon and crop modelling: Terrestrial Ecosystem model found out equilibrium response of soil carbon to climate change for estimating global loss of SOC as 26.3 Pg assuming 1^{o}C warming (Mcguire *et al.* 1995). Soil moisture is an important parameter in the empirical models to arrive at better SOC responses. Considering soil as a uniform layer in century, the model makes it less suitable than those (such as DNDC model) which treat soil as multiple layers as pedologists do. Realization of the usefulness of multi-layered soil carbon model faces a challenge for the modellers since most of the experimental studies rarely contain reliable time-series data of SOC in the long-term fertilizer experimental trials (Bhattacharyya *et al*. 2013b). The role of pedological information with primary datasets on various soil parameters has been extremely beneficial. To project actual effects of global warming in accelerating decomposition of soil C and the resultant release of CO_2 from soil organic matter, soils must be treated as different layers. Effect of warming on SOC loss is buffered by increased soil depth which is further reduced by the application of organics. Soil conservation should be a recommended practice with special reference to humid tropical climate to conserve soil organic carbon to mitigate global warming (Bhattacharyya *et al*., 2011; 2013b; 2014 a, b, c).

Benefits of soil carbon and pedology: Soils provide important ecosystem services of landscape at local and global level. They provide the basis for crop production and help mitigate climate change by storing carbon. A rapid decline of soil carbon due to human clearing of natural vegetation for agricultural land use and management practices followed by a crisis phase of diminished soil fertility and finally by recovery due to good agricultural mangement. The carbon transition curve conveys the impact of major land use changes on soils with examples from arable, grazing and forest land in different parts of the world (Bhattacharyya *et al*. 2015; Van Noordwijk *et al*. 2015).

V. Pedology and soil and land quality

Assessment of the quality of cultivated land (Liu *et al*. 2010) and development of crop-specific land quality index (LQI) using soil quality index (SQI) from the pedological dataset were detailed by Mandal *et al*. (2001). Principal Component Analysis (PCA) technique was used to identify the minimum soil parameters which can give the interpretable information to explain soil parameters ably supported by the expert opinion (EO). Here comes the role of pedologist as an expert who interprets the surface soils of the IGP as overstressed. Comparison of total available K stock for the IGP and the black soil regions (BSR) bring similar scenario (Bhattacharyya *et al*. 2007). Primary pedological datasets were useful to assesss LQI to suggest crop planning (Ray *et al*. 2014) (Fig. 7).

Pedology and soil microbiology : In recent years, indicative components like soil microbial biomass carbon (MBC), community structures, functions, and enzyme activities have been used to describe soil qualities under different agricultural practices (Vallejo *et al*. 2010). The MBC generally comprises 1–4% of soil organic matter (Anderson and Domsch 1989) and is the most active component of soil organic carbon that regulates biogeochemical processes in terrestrial ecosystems (Paul and Clark 1996). The MBC is one of the most promising indicators of soil quality because it responds promptly to environmental changes,

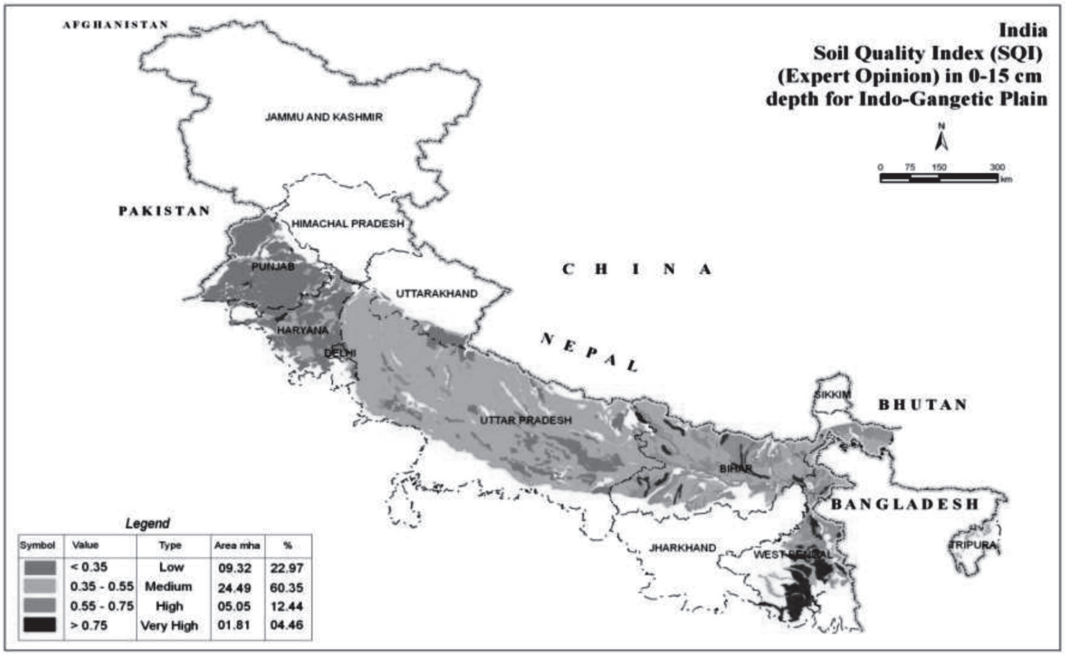

Fig. 7. Variation of soil quality index in the Indo-Gangetic Plains (0-15 cm depth) (*Source:* Ray *et al*. 2014)

often much earlier than bulk soil organic matter. The pooled comparisons of MBC in different soils indicated significant differences between the soil types (Fig. 8). Pedological investigations suggest (Velmourougane *et al*. 2014) smectite clay to enhance protection of mineralizable SOC within macroaggregates in Vertisols.

Pedology and soil potassium: The BSR stores 326 to 891 kg ha^{-1} more K than the IGP soils in first 30 and 150 cm soil depth, respectively. Exhaustive mining of K through extensive agricultural landuse during the green revolution era and also thereafter caused low reserve in the IGP. In BSR, this is not observed as these soils are under rainfed conditions supporting mostly single crop in a year. It has been experimentally found that the apparently high available K of BSR soils is not sustainable when genetically modified deep-rooted crops like hybrid cotton was introduced because these soils contain very low amount of K-releasing minerals like biotite. Such crops started responding to K application after 3 years of cropping. In contrast, the crop response to K fertilizer application in soils of IGP is seldom observed even after cropping for the last 30 years. This is due to the high K reserve in soils rich in biotite mica (Pal *et al*. 2003; Bhattacharyya *et al*. 2007).

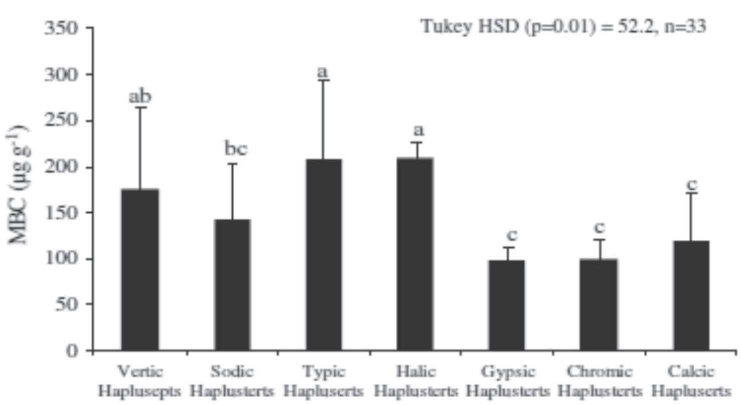

Fig. 8. Impact Variation of soil sub-groups on microbial biomass carbon (MBC) in different types of soils (*Source:* Velmourougane *et al*. 2014)

Table 2. Soil carbon stocks in different bioclimatic systems in India

Bioclimatic systems*	Area		SOC		SIC		TC		Pg/m ha	
	Coverage (m ha)	TGA (%)	Stock	% of total SOC	Stock	% of total SIC	Stock	% of total TC	SOC	SIC
Arid Cold	15.2	4.6	0.6	6	0.7	17	2.7	20	0.0192	0.0327
Arid Hot	36.8	11.2	0.4	4	1.0	25				
Semi arid	116.4	35.4	2.9	30	1.9	47	4.8	35	0.0249	0.0163
Sub Humid	105	31.9	2.5	26	0.3	8	2.8	20	0.0238	0.0029
Humid to per Humid	34.9	10.6	2.1	21	0.04	1	2.14	15	0.0602	0.0011
Coastal	20.4	6.2	1.3	13	0.07	2	1.37	10	0.0637	0.0034

*Ranges in rainfall: Arid = <550 mm, Semi arid = 550-1000 mm, Sub Humid = 1000-1500 mm, Humid to per humid = 1200 - 3200 mm, Coastal = 900-3000 mm. (Source: Bhattacahryya *et al*. 2014a)

VI. Pedometrics and Conservation Agriculture (CA)

Prioritization of areas for CA in rainfed (dry) area: The criterion such as SOC stock per unit area as well as point data for individual soil indicate that the vast areas in the arid, semi-arid and drier part of sub-humid bioclimatic systems (155.8 Mha) are low in SOC and high in SIC stock (0-1.5 m soil depth) and thus should get priority for organic carbon management (Table 2, Fig. 9). Altough soil carbonates play an important role in the global carbon cycle yet their contribution as a probable source of calcium nutrition in soils was reported rarely (Bhattacharyya *et al*. 2014a). This suggests management intervention and its effects through CA to maintain soil quality in drier tracts through C transfer model and to recommend *"not to keep any parcel of land fallow"* (Fig. 10).

Pedometric approach in (humid) rainfed areas: The quantitative methods for the spatial distribution patterns of soil are collectively categorized in the emerging field of soil science as pedometrics (McBratney *et al.* 2000). Geostatistics are one of the most popular tools of pedometrics as well as of digital soil mapping. Pedometrics address the issues related to the application of mathematical and statistical methods for the study of the distribution and genesis of soils. Probability distributions of soil type can be obtained from soil maps using pedometric methods such as indicator Krigging (Goovaerts and Journel 1995; Oberthur *et al.* 1999). Soil survey reports accompanying traditional soil maps often provide areal estimates of soil type occurring within the map units. Such information may be used to define a frequency distribution for each map unit which can again serve as a probability distribution of any map unit.

Soil erosion, degradation and conservation agriculture are inter-woven. Soil erosion is the most widespread form of soil degradation and signiûcant amounts of carbon are either relocated in soils at lower elevations, water bodies and sediments or degraded to CO_2 during soil erosion (Alewell *et al.* 2009). The range of SOC lost by erosion in the top 25 cm of moderately and severely eroded soils can be as much as 19–51% for Mollisols and 15–65% for Alûsols (Kimble *et al.*, 2001). The estimation of the spatial

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AESRs	SOC (Pg)	SIC (Pg)	TC (Pg)	AESRs	SOC (Pg)	SIC (Pg)	TC (Pg)	AESRs	SOC (Pg)	SIC (Pg)	TC (Pg)
1.1	0.032	0.039	0.071	7.3	0.113	0.159	0.272	14.5	0.029	0	0.029
1.2	0.554	0.660	1.214	8.1	0.092	0.100	0.192	15.1	0.098	0.041	0.139
2.1	0.057	0.390	0.447	8.2	0.153	0.058	0.211	15.2	0.109	0	0.109
2.2	0.018	0.021	0.039	8.3	0.106	0.140	0.249	15.3	0.099	0	0.099
2.3	0.102	0.120	0.222	9.1	0.049	0.004	0.053	15.4	0.097	0	0.097
2.4	0.089	0.360	0.449	9.2	0.101	0.002	0.103	16.1	0.019	0	0.019
3	0.121	0.050	0.171	10.1	0.250	0	0.250	16.2	0.148	0	0.148
4.1	0.117	0.149	0.266	10.2	0.088	0.019	0.107	16.3	0.620	0	0.620
4.2	0.191	0.070	0.261	10.3	0.170	0.034	0.204	17.1	0.450	0	0.450
4.3	0.229	0	0.229	10.4	0.108	0	0.108	17.2	0.321	0	0.321
4.4	0.129	0	0.129	11.0	0.141	0	0.141	18.1	0.023	0	0.023
5.1	0.078	0.130	0.208	12.1	0.630	0	0.630	18.2	0.051	0	0.051
5.2	0.470	0.161	0.631	12.2	0.056	0	0.056	18.3	0.070	0	0.070
5.3	0.061	0.057	0.118	12.3	0.079	0	0.079	18.4	0.063	0	0.063
6.1	0.130	0.111	0.241	13.1	0.081	0.153	0.234	18.5	0.031	0	0.031
6.2	0.230	0.470	0.700	13.2	0.091	0	0.091	19.1	0.082	0.063	0.145
6.3	0.149	0.030	0.179	14.1	0.319	0	0.319	19.2	0.390	0	0.390
6.4	0.139	0.216	0.355	14.2	0.369	0.109	0.478	19.3	0.371	0	0.371
7.1	0.131	0.059	0.190	14.3	0.010	0	0.010	20.1	0.059	0	0.059
7.2	0.310	0.148	0.458	14.4	0.020	0	0.020	20.2	0.062	0.014	0.076

Fig. 9. Soil carbon stock (in Pg) map in different agro-ecological subregions showing prioritized areas (shaded areas) for carbon sequestration (0–0.3 m soil depth) (*Source:* Bhattacharyya *et al*. 2014a)

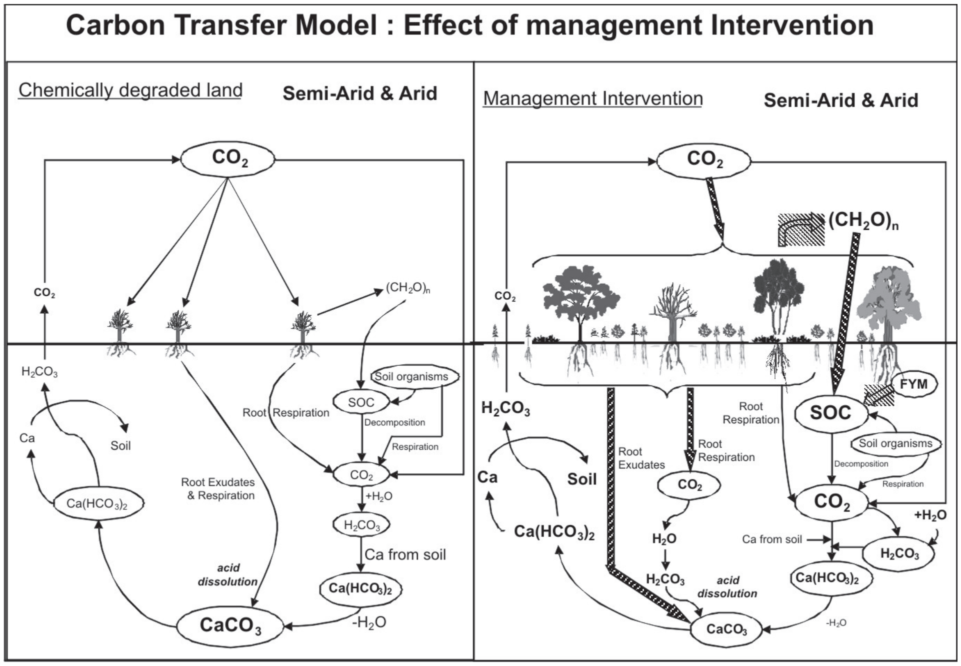

Fig. 10. Carbon transfer in semi-arid and arid bioclimatic systems of (a) chemically degraded land, and (b) areas showing management intervention (the size of circle and letters indicate relative proportion of individual component) (*Source:* Bhattacharyya *et al*. 2014a)

distribution of the loss of SOC is also essential in view of its impact upon soil quality. The production of digital soil maps, as opposed to digitized (existing) soil maps, is moving inexorably from research phase to production of maps at the sub-country and country level. Since 1960s there has been an emphasis on what might be called geographic or purely spatial approaches, to enable prediction of soil attributes from spatial position largely by interpolating soil and observation locations. In view of maintaining the natural ecosystem, it will be prudent to bridge two sets of information on soil loss and SOC status to assess SOC loss in a case study state of Tripura.

VII. Pedology and soil modifiers

Formation of pedogenic calcium carbonate (PC) at the expense of non-pedogenic calcium carbonate (NPC) is the prime chemical reaction for the natural chemical degradation realized in terms of impairment of hydraulic properties of soils mediated through the development of subsoil sodicity. Presence of gypsum and Ca-zeolites, on the other hand, prevented the rise of pH, decrease in Ca/Mg ratio of exchange sites and improved the hydraulic properties even if exchangeable sodium percentage (ESP) >15. The improvement in saturated hydraulic conductivity (sHC) (>10 mm h^{-1}) of zeolitic sodic soils does commensurate fairly well with the performance of rainy season crops. Thus, characterization of sodic soils in terms of sHC <10 mm h^{-1} instead of any ESP or sodium adsorption ratio (SAR) is considered as a robust criterion for better use and management of naturally-degraded soils (Pal *et al*. 2000; 2006; Bhattacharyya *et al*. 2014a) (Fig. 11).

Chemical degradation in tropical ferruginous soils: Presence of pedogenic carbonate as spongy nodules and cluster of lubinite needles below 40 cm depth indicates their formation in the prevailing semi-arid climate in the southern Peninsula (Pal *et al*. 2000). Supersaturation of the soil solution with $CaCO_3$ facilitating the formation of lubinite crystals in the lower horizons was favoured by the presence of smectite clay. The formation of pedogenic $CaCO_3$ caused the development of subsoil sodicity in the lower horizons due to the formation of $CaCO_3$ (@ 0.20 g $100g^{-1}$ of soil yr^{-1} in the first 100 cm) (Pal *et al*. 2000). Although it is not alarming now; however, with time these soils are prone to become more calcareous and sodic and might demand management intervention.

VIII. Pedology: agro-ecozone based agricultural land use planning

Improved agro-technology can reclaim physical conditions of soils (Bhattacharyya *et al*. 20014a; Sidhu *et al*. 2014) using the knowledge of pedology (Bhattacharyya *et al.* 2014 b, c). Agro-ecological sub-

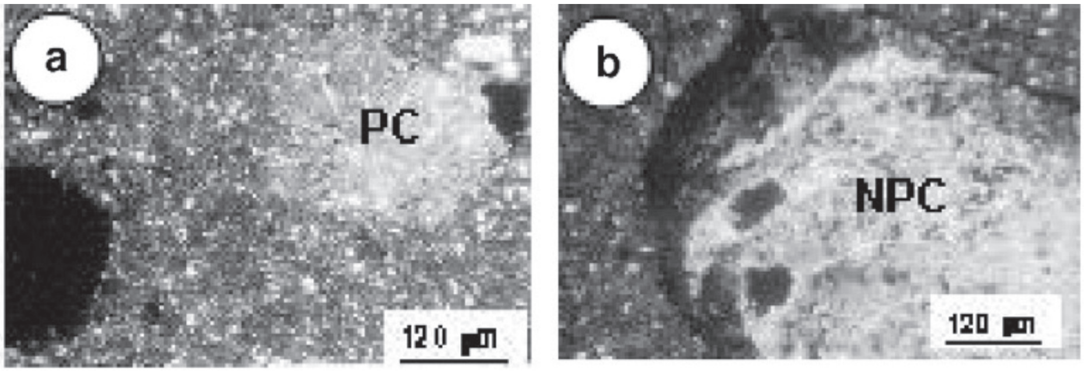

Fig. 11. Calcium carbonate in cross polarized light. (a) pedogenic carbonate (PC) and (b) non-pedogenic carbonate (NPC) (*Source:* Pal *et al*. 2000)

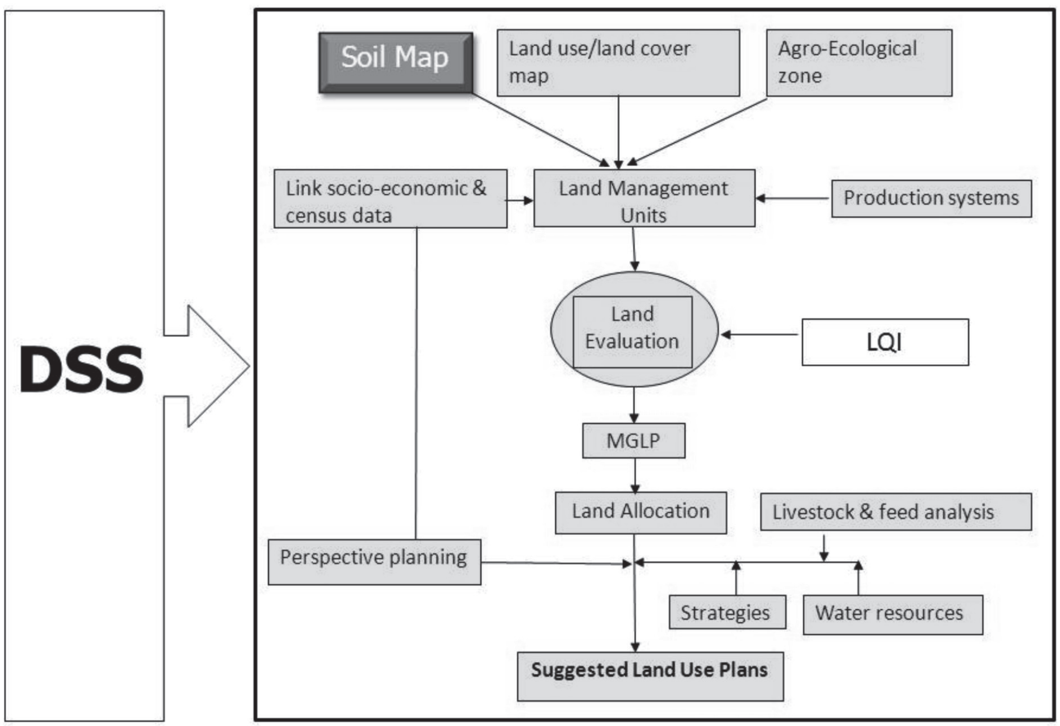

Fig. 12. Decision support system (DSS) for developing land use plans at district level-A framework (*Source:* Bhattacharyya *et al*. 2014 b, c)

region (AESR) map can act as an agro-technology transfer wheel (Mandal *et al*. 2014a,b) using appropriate land evaluation methods (Chatterji *et al*. 2014). Soil, landuse/land cover and AESR maps in conjunction with information on socio-economic and production systems are used in various steps of land evaluation that help in land allocation for suggesting agricultural land use plans (Fig. 12). The framework for district level can be downscaled to block level using large scale soil map at 1:10,000 with appropriate method of soil survey and mapping by using expert pedological knowledge to arrive at a decision support system to develop AESR-based crop planning.

Concluding Remarks

In the terrestrial system many events keep on happening everyday: but only a few occurring aboveground are visible. Most of these natural events occur in the soils without any notice of the beholder. Pedological processes which govern the changes within the pedo-environment belong to such events. To understand these processes and their signatures preserved quietly and affectionately by the mother earth within the soil are identified only by the pedologists. Identifying and capturing the signatures of nature form a multidisciplinary approach. This is more so, since different kinds of soils indicate that the soil diversity is quite large because of variability of several factors of soil formation. The inherent capacity of tropical soils demands that the most productive agriculture of the world may begin with indepth research. It will depend again on how rapidly institutions for eduction, research and other public and private sectors including the professional societies will revisit importance of this important natural resource. It is never too late to introspect about the basic and fundamental research on soils to address soil-related problems in agriculture and other allied fields. We have to keep pace with research and development of other countries in Asia, Europe and the United States shown in the past by our predecessors led by Professor J.N. Mukherjee. Let us remind ourselves, our students and the gennext that science is Truth, science is God and science is Worship. If we do not understand the importance of the basics and the grammar of pedology as the fundamentals of soil science, we may not be able to appropriately manage tropical and subtropical soils for their restoration and preservation.

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References

Alewell, C., Schaub, M. and Conen, F. (2009) A method to detect soil carbon degradation during soil erosion. *Biogeosciences*, **6**, 2541–2547.

Anderson, T.H., Domsch, K.H. (1989) Ratios of microbial biomass carbon to total organic carbon in arable soils. *Soil Biology Biochemistry* **21**, 471–479.

Batjes, N.H., Al-Adamat, R., Bhattacharyya, T., Bernoux, M., Cerri, C.E.P., Gicheru, P., Kamoni, P., Milne, E., Pal, D.K. and Rawajfih, Z. (2007) Preparation of consistent soil datasets for modelling purposes: Secondary SOTER data for four case study areas. *Agriculture Ecosystems & Environment* **122**, 26-34.

Bhattacharyya, T., Pal, D. K. and Deshpande, S. B. (1993) Genesis and transformation of minerals in the formation of red (Alfisols) and black (Inceptisols and Vertisols) soils on Deccan basalt in the Western Ghats, India. *Journal of Soil Science* **44,** 159–171.

Bhattacharyya, T., Pal, D.K. and Srivastava, P. **(**1999) Role of zeolites in persistance of high altitude ferriginous Alfisols of the Western Ghats, India. *Geoderma*, **90**, 263-276.

Bhattacharyya, T., Pal, D.K. and Srivastava, P. (2000) Formation of gibbsite in presence of 2:1 minerals: an example from Ultisols of North-East India. *Clay Minerals* **35,** 827-840

Bhattacharyya, T., and Pal, D.K. (2003) Carbon sequestration in soils of the Indo-Gangetic Plains. In: RWC-CIMMYT. Addressing Resource Conservation Issues in Rice-Wheat System of South Asia. A Resource Book. Rice Wheat Consortium for Indo-Gangetic Plains. International Maize and Wheat Improvement Centre, New Delhi, India pp. 68-71.

Bhattacharyya, T., Pal, D.K. Chandran, P , Ray, S.K., Durge, S.L., Mandal, C. Telpande, B. (2007) Available K reserve of two major crop growing regions (alluvial and shrink-swell soils) in India, *Indian Journal of Fertilizers* **3,** 41-52.

Bhattacharyya, T., Sarkar, Dipak, Pal, D.K., Mandal, C., Baruah, U., Telpande, B. and Vaidaya, P.H. (2010) Soil Information System for resource management-Tripura as a case study, *Current Science* **99,** 1208-1217.

Bhattacharyya, T., Pal, D.K., Deshmukh, A.S., Deshmukh, R.R., Ray, S.K., Chandran, P., Mandal, C., Telpande, B., Nimje, A.M. and Tiwary, P. (2011) Evaluation of RothC Model Using Four Long Term Fertilizer Experiments in Black Soils, India, *Agriculture Ecosystems & Environment* **144**, 222-234.

Bhattacharyya, T., Pal, D.K., Mandal, C., Chandran, P., Ray, S.K., Sarkar, Dipak, 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.(2013a) Soils of India: Their Historical Perspective, Classification and Recent Advances in Knowledge: A Review. *Current Science* **104**, 1308-1323.

Bhattacharyya, T., Pal, D.K., Ray, S.K., Chandran, P., Mandal C., Telpande, B., Deshumkh, A.S. and Tiwary, P. (2013b) Simulating change in soil organic carbon in two long term fertilizer experiments in India : with the RothC model. *Climate Change and Environmental Sustainability* **1**, 104-117.

Bhattacharyya , T., Chandran, P., Ray, S.K., Mandal, C., Tiwary, P., Pal , D.K., Wani, S.P. and Sahrawat, K.L. (2014a) Processes Determining the Sequestration and Maintenance of Carbon in Soils: A Synthesis of Research from Tropical India, *Soil Horizon*, July 9, doi: 10.2136/sh14-01-0001

Bhattacharyya, T., Sarkar, D., Ray, S.K., Chandran, P., Pal, D.K., Mandal, D.K.et al (2014b) Georeferenced Soil Information System: assessment of database, *Current Science* **107**, (forthcoming issue)

Bhattacharyya, T., Sarkar, D., Ray, S.K., Chandran, P., Pal, D.K., Mandal, D.K. et al (2014c) Soil information system: use and potentials in humid and Semi-Arid Tropics *Current Science* **107,** (forthcoming issue).

Bhattacharyya, T. (2015) Assessment of organic carbon status in Indian soils, Chapter 28 In Soil Carbon: Science, Management and Policy for Multiple Benefits (Eds S.A. Banwart, E. Noellemeyer and E. Milne) SCOPE Volume 71, CAB International 2015 pp 402-417 (in press).

Breecker, D.O., Sharp, Z. D., McFadden, L. A. (2009) Seasonal bias in the formation and stable isotopic composition of pedogenic carbonate in modern soils from central New Mexico, USA. *Geological Society of America* **121**, 630-640.

Chandran, P., Ray, S.K., Bhattacharyya, T. Krishnan, P. and Pal, D.K. (2000). Clay minerals in two ferruginous soils of Southern India. *Clay Research,* **19,** 77-84.

Chandran, P. Ray, S., Bhattacharyya, T., Srivastava, P., Krishnan, P. And Pal, D. K. (2005) Lateritic soils (Ultisols) of Kerala, India: their genesis and taxonomy *Australian Journal of Soil Research* **43** 839-852.

Chandran, P., Tiwary, P., Bhattacharyya, T., Mandal, C., Prasad, J., Ray, S.K., Sarkar, D. , Pal, D.K., Mandal, D.K. (2014) Development of SOTER database for major foodgrowing regions of India for resource planning, *Current Science* **107,** (forthcoming issue).

Chatterji, S., Tiwary, P., Sen, T.K., Prasad, J., Bhattacharyya, T., et al.(2014) Land Evaluation for major crops in the Indo-Gangetic Plains and Black Soil Region using fuzzy model.*Current Science* **107**, (forthcoming issue).

Goovaerts, P. and Journel, A.G. (1995) Integrating soil map information in modeling the spatial variation of continuous soil properties. *Europian Journal of Soil Science* **46**, 397-414.

Hua, L. Z. (2011). Is pedogenic carbonate an important atmospheric CO_2 sink? *Chinese Science Bulletin* 56: 1-3. Doi: 10.1007/s 11434-010-4288-8.

Jenkins, D.A. (1985) Chemical and mineralogical compositon in the identification of paleosols. In J. Boardman (Ed.). *Soils and Quaternary Landscape Evolution*, Wiley, New York, pp.23-43.

Kimble, J.M., Lal, R. and Mausbach, M. (2001) Erosion effects on soil organic carbon pool in soils of Iowa. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds), Proceedings of the 10th International Soil Conservation Organization meeting on Sustaining the Global Farm, May 24–29, 1999. Purdue University, Indiana, pp. 472–475.

Lal, R., and Kimble, J. M. (2000a) Pedogenic carbonate and the global carbon cycle. In.: Lal, R., Kimble, J.M., Eswaran, H. and Stewart, B.A., editors, Global climate change and pedogenic carbonates. CRC Press. USA, pp.1 -14.

Lal, R., and Kimble, J. M. (2000b) Inorganic carbon and the global carbon cycle: research and development priorities.. In.: Lal, R, J.M. Kimble. H. Eswaran and B.A. Stewart, editors, Global climate change and pedogenic carbonates. CRC Press. USA, pp. 291-302

Lin Henry (2011) Three principles of soil change and pedogenesis in time and space. *Soil Science Society of American Journal* **75**, 2049-2070.

Lin, H.S., Hoffmans, J., Richter, S. (2011) Inter-disciplinary sciences in a global network of critical zone observatories. *Vadosa Zone Journal*, 10:781-785.

Liu, Y., Zhang, Y. and Liying, G. (2010) Towards realistic assessment of cultivated land quality in an ecologically fragile environment: a satellite imagery-based approach. *Applied Geography* **30**, 271–281.

Mandal, C., Bhattacharyya, T., Venugopaln, M.V., Tiwary, P., and Pal. D.K. Mandal, D.K. , Bhattacharyya, T. , Sarkar, D. , Pal, D.K., et al. (2014b) Revisiting agro-ecological subregions of India – A case study of two major food production zones. *Current Science* **107**, (forthcoming issue).

Mandal, C., Bhattacharyya, T., Sarkar, D., Pal, D.K., et al. (2014a) Agro-ecological subregion: a wheel of technology transfer for crop planning. *Indian farming* **64,** 97-101.

Mandal D. K., Mandal, C. and Velautham, M. (2001). Development of a land quality index for sorghum in Indian semi-arid tropics (SAT). *Agricultural Systems* **70,** 335-350.

McBratney, A.B., Odeh, I.O.A, Bishop, T.F.A., Dunbar, M.S. & Shatar, T.M. 2000. An overview of pedometrics techniques for use in soil survey. *Geoderma* **97**, 293-327.

Mcguire AD, Melillo JM, Kicklighter DW and Joyce LA (1995) Equilibrium responses of soil carbon to climate change: empirial and process based estimates. *Journal of Biogeography* **22,** 785-796.

Oberthur, T., Goovaerts, P. & Dobermann, A. (1999) Mapping soil texture classes using field texturing, particle size distribution and local knowledge by both conventional and geostatistical methods. *Europian Journal of Soil Science* **50**, 457-479.

Pal, D.K., Deshpande, S.B., Venugopal, K.R.and Kalbande, A.R. (1989) Formation of di- and trioctahedral smectite as evidence of Paleoclimatic changes in southern and central Peninsular India. *Geoderma* **45**, 175-184.

Pal, D. K., G. S. Dasog, S. Vadivelu, R. L. Ahuja, and T. Bhattacharyya (2000) Secondary calcium carbonate in soils of arid and semiarid regions of India. In *Global Climate Change and Pedogenic Carbonates* (edsLal, R. *et al.*), Lewis Publishers, FL, USA, pp. 149–185.

Pal, D.K., Srivastava, P., Durge, S.L. and Bhattacharyya, T. (2003) Role of microtopography in the formation of sodic soils in the semi-arid part of the Indo-Gangetic Plains, India, *Catena* **51**, 3-31.

Pal, D.K., Bhattacharyya, T., Ray, S.K., Chandran, P., Srivastava, P., Durge, S.L., and Bhuse, S.R. (2006) Significance of soil modifiers (Ca-zeolites and gypsum) in naturally degraded Vertisols of the Peninsular India in redefining the sodic soils. *Geoderma* **136**, 210-228.

Pal, D.K., Bhattacharyya, T., Chandran, P., Ray, S.K. (2012) Linking minerakls to selected soil bulk properties and climate change: a review, *Clay Research* **31,** 38-69.

Paul, E.A., and Clark, F.E, (1996) Soil microbiology and biochemistry. Academic Press, New York.

Ray, S.K., Bhattacharyya, T., Sarkar, D., Chandran, P., Pal, D.K., Mandal, D.K. (2014) Soil and land quality of the Indo-Gangetic Plains of India *Current Science* **107**, (forthcoming issue).

Sidhu, G.S., Bhattacharyya, T., Sarkar, D., Ray, S.K., Chandran, P., Pal, D.K., Mandal, D.K. (2014) Impact of soil management levels and land use changes on soil properties in rice-wheat cropping system of the Indo-Gangetic Plains (IGP), *Current Science* **107**, (forthcoming issue).

Staff, NBSS&LUP (2002) Soils of India, NBSS Publ. No 94, National Bureau of Soil Survey & Land Use Planning, Nagpur, pp.

Vallejo, V., E, Roldan, F., Dick, R.P. (2010) Soil enzymatic activities and microbial biomass in an integrated agroforestry chronosequence compared to monoculture and a native forest of Colombia. *Biol Fertil Soils* **46**, 577–588

van Noordwijk, M, Goverse, T, Ballabio, C, Banwart, S, Bhattacharyya, T, Goldhaber, M, Nikolaidis, N, Noellemeyer, E, Zhao, Y. (2015) Soil carbon transition curves: reversal of land degradation through management of soil organic matter for multiple benefits, Chapter A In Soil Carbon: Science, Management and Policy for Multiple Benefits (Eds S.A. Banwart, E. Noellemeyer and E. Milne) SCOPE Volume 71, CAB International 2015 SCOPE Volume 71, pp 1-28 (in press).

Velmourougane, K., Venugopalan, M.V., Bhattacharyya, T., Sarkar, D., Ray, S.K., et al. (2014) Impacts of bioclimates, cropping systems, landuse and management on the cultural microbial population at different soil depths in black soil regions of India. *Current Science* **107**, (forthcoming issue).

About the Lecture

This Lecture is being organized by the Indian Society of Soil Science to commemorate its foundation in 1934 and its founder - Professor J.N. Mukherjee, a doyen of Colloid and Soil Sciences, known internationally. The lecture was first instituted in 1983 as a part of felicitations to Professor J.N. Mukherjee on the eve of his 90th birthday celebration (on April 23, 1983). Unfortunately, after a few days, on May 10, 1983, the members of the Society had to mourn his demise. A short life sketch of this reputed scientist and his achievements can be seen in an earlier issue of this Journal (*Journal of the Indian Society of Soil Science* Vol. **31**, pp. 350-358, year 1983), while a brief account of the birth, growth and achievements of the Society is available in another publication of the Society (*Souvenir*, pp. 26-35), which was released during the Diamond Jubilee Celebration of the Society on 28th November, 1994.

Most appropriately, the privilege and honour of delivering the First Lecture in this series went to another internationally known Soil Scientist, Dr. S.P. Raychaudhuri - one of the brilliant students of Professor Mukherjee (*Journal of the Indian Society of Soil Science* Vol. **31**, pp. 359-363, year 1983). The subsequent lectures in this series were delivered by Prof. L.N. Mandal (1984), Dr. G.S. Sekhon (1985), Dr. K.V. Raman (1986), Dr. N. Panda (1987), Dr. S. Patnaik (1988), Dr. N.T. Singh (1989), Dr. I.P. Abrol (1990), Dr. S.B. Varade (1991), Dr. Raj Pal (1992), Dr. S.S. Khanna (1993), Dr. U.S. Sreeramulu (1994) Dr. N.N. Goswami (1995), Dr. P.N. Takkar (1996), Dr. S.K. Ghosh (1997), Dr. S.R. Poonia (1998), Dr. D.K. Das (1999), Dr N.K. Tomar (2000), Dr. S.K. Sanyal (2001), Dr. N.S. Pasricha (2002), Dr. D.K. Pal (2003), Dr. Sridhar Komarneni (2004), Dr. A.K. Sarkar (2005), Dr. Bijay Singh (2006), Dr. Kunal Ghosh (2007), Dr. K.N. Tiwari (2008), Dr. Kanwar L. Sahrawat (2009), Dr. A. Subba Rao (2010), Dr. Biswapati Mandal (2011), Dipak Sakar (2012) and Dr. S.C. Datta (2014). The 32nd lecture in 2014 was delivered by Dr. Tapas Bhattacharyya in Hyderabad and his biography in brief appears in the next section. This is for the information of the Readers that all the

Prof. J.N. Mukherjee-ISSS Foundation lectures delivered up to year 2002 have been published as the ISSS Bulletin No. 21.

About the Speaker

Dr. Tapas Bhattacharyya was born in November, 1956. He is an agricultural graduate and a Ph.D. from the Indian Agricultural Research Institute, New Delhi. As a Soil Scientist he is working in the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) under Indian Council of Agricultural Research (ICAR), New Delhi for the last 28 years. He is carrying out basic and fundamental pedological research in terms of soil genesis, classification, survey and mapping. He has also been working for various national and international projects with special reference to soil carbon sequestration and soil carbon modelling to address global warming and climate change. He has nearly 100 referred journal papers and review articles in books. Dr. Bhattacharyya is now working as Head, Soil Resource Studies Division at NBSS&LUP, Nagpur.