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Soils: Past, Present and Future — SAT as Example*

T. BHATTACHARYYA
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth
Dapoli - 415 712, Ratnagiri, Maharashtra

I am extremely grateful to the organizers for the invitation to participate in this seminar. As a student of soil science I am still trying to understand how best I can utilize the soil datasets for the benefit of scientists and students engaged in different spheres of scientific activities. Amidst global warming due to climate change it's a great concern for us to maintain soil quality for food and other requirements. To do that we need to monitor soils closely. We have done it for a group of benchmark soils in the Indo-Gangetic Plains (IGP) and black soil region (BSR). Here I'll take the help of these datasets to talk about past, present and future of soils with some riders.

Soil sustainability is threatened by management practices including over-cultivation, decreased or increased water abstraction, under or over-fertilisation, non-judicious use of biocides, failure to maintain soil organic matter levels and clearing natural vegetation. When soil management is not appropriate, soil sustainability is often threatened by a combination of physical, chemical and biological factors. Climate change may further increase the threat to soil sustainability in poor countries because the cereal crop yields are predicted to decline in most tropical and sub-tropical regions under the future climatic scenarios, and in countries which have a low capacity to adapt.

The impact of climate change in soils of tropical parts of the Indian subcontinent, in particular and globally, in general, has attracted the attention of soil researchers in recent years as indicated by degradation in soil physical, chemical and biological properties. Amidst neo-tectonics and the global warming phenomenon, rising temperature and shrinking annual rainfall with erratic distribution pose perpetual threats for soils not only for the Indian subcontinent but also for soils of similar climatic conditions elsewhere. In India, a change of climate has been recorded from humid to semi-arid in rainfed areas only during the Holocene period.

The lack of soil water impairs the possibility of growing both rainy and winter crops in a year, especially in vast areas especially in black soils of semi arid tropics (SAT) with mean annual rainfall (MAR) <1000 mm and thus the black soils cease to be sustainable for growing agricultural crops under SAT environments. Keeping this in view, we have tried to show the associated red and black soils of the ICRISAT farm in Patancheru focussing on the changes in soil quality through management interventions (anthropogenic activities) over time. An attempt is also made to predict on their quality in the future using available datasets.

Study area

Geomorphic history showed that the farm area forms a part of a peneplained surface of the ancient and stable Deccan peninsula which had undergone several cycles of erosion, deposition and uplift. The general elevation ranges from 500-620 m above mean sea level (msl). In the basaltic terrain, the highest point is 620 m and the lowest is 580 m above msl, the corresponding figures in the granitic area are 610 m and 500 m above msl, respectively. Sporadic monolithic domes as *tors* are also present.

Mean annual rainfall, no. of rainy days and mean annual air temperature is different now during 2016 considering 1975 as taken as the base.Mean annual rainfall and rainy days have decreased over the last 41 years as evidenced by the climate shift. These data helped us to explain the soil parameters and their changes with time. The pattern of rainfall is bimodal with weak rains during the winter. The variation of Patancheru climate reduced the length of growing period (LGP) to 60 from 90 days during 1980 (Bhattacharyya *et al.*, 2016 a & b).

E-mail : tapas11156@yahoo.com

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Detailed soil survey of the ICRISAT Farm was carried out using the base map generated by interpretation of the aerial photographs during 1970's and was published later (Murthy and Swindale, 1993). An aerial photomosaic of the ICRISAT farm (1:15000 scale) was developed to delineate the interpretative units. Actual mapping was done at 1:4000 scale (cadastral map) with cartographic details showing fourteen soil series**.** Among these 14 soils, Kasireddipalli and Patancheru soils occupy the dominant proportions which are nearly 40 and 18% of the farm area, respectively. These two soils were selected for bringing out the changes over time using the soil data sets for four different time series.

Land Use During 1975

Nearly 94% area was intensively cultivated (Murthy and Swindale, 1993) mostly under dry land farming with traditional management (TM).

Land Use during 1980, 2001, 2010

Black soils (Kasireddipalli) were cultivated for chickpea, pigeon pea, sorghum and safflower; and red (Patancheru) soils were cultivated for rainfed sorghum, maize, and pulses.

***Land Use* during 2014**

Black soils (Kasireddipalli) were cultivated for soybean with pigeon pea as intercropping under rainfed condition (*Kharif* season). The site chosen for Patancheru soil during this period was inside the ICRISAT farm which was under permanent fallow (grass land). This was chosen to assess the datasets of the pristine Patancheru soils.

Soil Properties

Black soils

Black soils (Kasireddipalli) were very deep, alkaline, calcareous, non-sodic, non-saline Vertisols showing intersecting slickenside's. As compared to the black soils formed in the states of Maharashtra, Gujarat, and Madhya Pradesh, Kasireddipalli soils contain more sand (15-22%). Data on exchangeable sodium percent (ESP) showed that during 1975 these soils were non-sodic. Patancheru red soils were reported to be non-calcareous, nearly neutral, non-saline showing the illuvial Bt horizons and are grouped as Alfisols. During 1980, organic carbon in surface layer of the black soils *(Kasireddipalli)* decreased. Amount of $CaCO_3$ increased alongside an increase in subsoil sodicity as evidenced by relatively high ESP (13 within the control section but >15 beyond this depth). Other than sodium, relative proportion of extractable magnesium also increased in the subsurface layers.

Red soils

Red soils (Patancheru) were reported to be non-calcareous, during 1980s. After 5 years since 1975 these soils developed acidity as evidenced by relatively low pH. During 1975, the benchmark spot of the Patancheru soils were reported from outside ICRISAT farm area. Although changes of exchangeable sodium percent (at ESP ~5) were not well pronounced, but an increase in extractable magnesium was noticed.

During 2001, organic carbon in the black soils *(Kasireddipalli)* remained stable nearly at around 1%, indicating a near-equilibrium value (Naitam and Bhattacharyya, 2003). The level of $CaCO_3$ marginally increased down the depth. Interestingly, the ESP decreased, although the range remained well above the limit of concern to group these soils as sodic soils (Sodic Haplusterts) (Soil Survey Staff, 2014). Patancheru red soils were sampled from the pristine ICRISAT farm maintained as virgin forest land (Bhattacharyya *et al*., 2006, 2007a & 2008). These soils developed calcareousness with 0.4 to 0.9% $CaCO_3$. Such calcareousness induces subsoil sodicity in SAT environment (Pal *et al*., 2000). The SOC content was high due to the maintenance of grass cover under protection in these red soils.

During 2010, $CaCO_3$ decreased due to its dissolution and the released Ca ions helped in bringing down the ESP in the black soils *(Kasireddipalli)*. It seems that the cropping and crop management practices in both these soils reduced the rate of formation of pedogenic $CaCO_3$ and the subsoil sodicity (Bhattacharyya *et al*., 2004). Resilience of these soils suggest the importance ofvegetative cover on soil and land to mitigate the adversity of the SAT climate. The major problem in the SAT is the formation of pedogenic $CaCO_3$ (Pal *et al*., 2000, Bhattacharyya *et al*., 2007a) which triggers other associated soil problems (Bhattacharyya *et al*., 2014) that affect crop performance. Over time $CaCO_3$ formation increased considerably and now seems stabilised within 0-30 cm depth of black soils. Similar rise in $CaCO_3$ in red soils could have been observed if they were analysed for $CaCO_3$ in similar SAT soils of southern peninsula. These carbonates coated by Fe-Mn mottlesmay not effervesce in field with dilute HCl, but in laboratory with 100 mesh soil samples the presence of carbonates has been ascertained. In earlier report on red soils (Patancheru)

$CaCO_3$ was not reported, but pristine red soils (as collected for the present study) do show the presence of climatically induced pedogenic $CaCO_3$ in SAT environment. Extractable bases (Ca, Mg, Na, and K) in both black and red soils showed variations after 20 to 30 years in surface and subsurface. Extractable Mg increased in the lower depth of red and black soils. This is also reflected in reduced Ca/Mg ratio in soils. Concentration of extractable Mg down the depth of soil along with extractable Na, especially in red soils indicates the initiation of subsurface sodicity which might affect the entire soil if management intervention is not adopted in SAT areas. Potassic fertilizers are not added in black soils at ICRISAT farm. This is due to the presence of biotite mica as the inherent supplier of native K in these soils. However, our datasets showed native K to decrease over a period of 25-35 years at ICRISAT. This is in accordance with the earlier observations on agronomic experiments on the Vertisols of central India where crop responded to K fertilisers after two years of cropping with hybrid cotton. Therefore, the present available K status may not be sustainable over a long time because the contents of sand and silt biotites are low. This information helps dispel the myth that the Vertisols are rich in available K and that they may not warrant the application of K fertilisers. An analysis on the K stock of soils in the black soil region (BSR) held the same view (Bhattacharyya *et al*., 2007b) and thus warrants application for K fertilizer in ICRISAT soils. In contrast to black soils, the K available status of Patancheru soils still remains very high (exchangeable K is around 4% of the CEC even in subsoils) as compared to that in black soils (~ 1%) . Thus crops do not respond to K fertilizer application in these soils of ICRISAT. Because of the almost unweathered sand and silt biotites, K release increased with the increase in silt- sized mica. Thus, quite favourable K release rate from both silt and clay micas explains as to why crop response to fertilizer K is seldom obtained in many rainfed red soils (Alfisols) under SAT environments. It is observed that dynamic chemical properties of soils *viz.* soil organic carbon and calcium carbonate influence physical properties of soils which influence crop performance and thus these properties along with climate (rainfall and temperature) are closely related to establish a cause-effect relationship. When the soil pH reaches > 8.5, fine clays are dispersed blocking the micro pores of soils. Under this condition and in extreme limit of high pH (> 9.0), saturated hydraulic conductivity (SHC) (soil drainage) reaches to its minimum which does not allow free passage of water movement resulting in an extremely hostile pedo environment for soil microflora and fauna. Under these situations the soils become very hard showing high bulk density. This is the reason why the pedo transfer functions (PTFs) developed for the black soils (Tiwary, 2014) do not work for assessing saturated hydraulic conductivity in these soils with high pH, SOC and SIC or $CaCO_3$ have an inverse relation with rainfall and other chemical and physical parameters (Bhattacharyya *et al*., 2016a, b).

Climate and soil properties with special reference to SIC is closely related. It influences soil quality and health. Soil survey data shows that as one traverses from the humid to the semi arid areas reaching a mean annual rainfall (MAR) of 850, calcium carbonate formation begins indicating the initiation of chemical soil degradation. It's a warning for land resource managers. Earlier from Roth*C*model we found that almost at ~ 800 mm of MAR, SOC decomposition retards; this indirectly validates the threshold MAR of 800 mm at which point formation of SIC initiates as shown from the soil survey data. For land resource manager this threshold limit in the form of mean annual rainfall might help for decision making in management intervention.

It is difficult to assess soil properties for monitoring their changes over time (Bhattacharyya *et al*., 2016a). This is due to many reasons such as reaching the exact spot of sampling due to changes in land use pattern, economics, and expertise. It was for this reason that we need to develop an information system on soils, landscape, climate and related earth parameters which directly and/or indirectly influence these parameters. Developing such robust system requires a host of datasets which are lacking on many occasions. Use of pedo transfer functions help in this regard as has already been demonstrated while developing soil information system for the Indo-Gangetic Plains and the Black soil regions of India. Such exercise not only helps monitoring soil parameters, but also permits the trend of changes in the dynamic properties of soils through appropriate data interpretation, soil carbon and crop modelling.

An effort is made here to understand the nature of the SAT soils in future. Judging by the rate of changes in chemical and physical soil parameters (Bhattacharyya *et al*., 2016a) and also on the basis of available trend of data in the semi-arid tropics. An attempt is made to project changes in soil properties in case the present land use and management interventions are continued (business as usual, BAU) and also, if appropriate, management interventions are adopted. It is quite likely that soil organic C level in black soils will further decrease until management interventions are not adopted to add mineral fertilizers and organic matter following the recommended dose of fertilizers (RDFs). Results from the modelling exercise and long term fertilizer experiments (LTFE) predict that soil organic carbon can be increased if RDFs along with farm yard manure (FYM) (10 t ha^{-1}) are applied (Telpande *et al*., 2013). For Patancheru soils, business as usual (BAU) indicates an increase of SOC since the site is pristine. This area is under perennial grass, which cites an effective land use practice to sequester OC in SAT soils. To capture the changes in the level of $CaCO_3$ soil survey and soil age data (assuming ~ 1 mg/100 g soil/year $CaCO_3$) formation were used. In spite of the projected increase in $CaCO_3$, ESP showed a decreasing trend. Although SOC, SIC, BD, and other properties are inter-related, this shows that the management interactions especially addition of FYM has a positive influence in offsetting the ill effect of the increased sodium in soil exchange complex.ESP can be controlled by adopting the appropriate intervention.

As mentioned earlier, exchangeable K is getting depleted and requires attention in both black and red soils of Patancheru. Increase in bulk density is a cause of concern in both these types of soils. Interestingly, the trends in hydraulic conductivity appeared positive. It might be due to the addition of farm yard manure and also due to enhanced soluble and exchange Ca^{2+} ions available through the dissolution of $CaCO_3$ by the acidic crop root exudates. The projections under business as usual (BAU) was derived on the basis of available trend during the past 26-36 years. A progressive development of subsoil sodicity due to increase in pedogenic carbonates (PCs) under SAT environment with time happens when anthropogenic activities in terms of sustainable management interventions to raise agricultural crops are not made. If appropriate management techniques are not adopted, the soils will lose their productivity as demonstrated through the carbon transfer model (Bhattacharyya *et al*., 2004). It may be mentioned here that the black soils in sub humid ecosystems contain less $CaCO_3$ and maintain higher Ca/Mg (exchangeable) ratio (> 2) than those in dry areas like Kasireddipalli. If appropriate management techniques are adopted, the Ca/Mg ratio could be 2 or higher (Bhattacharyya *et al*., 2007b, Bhattacharyya, 2015). Higher Ca/Mg ratio helps black soils in the wetter climate to maintain good physical conditions and in better productivity than the SAT black soils. The threshold ratio of Ca/Mg ($\geqslant$ 2) could thus be a useful soil health parameter for the SAT soils. Other than PC, non-pedogenic carbonates (NPCs) get dissolved in wetter climate to release Ca^{2+}ions to modify soil properties and enhance available soil water content during the cropping seasons.

Concluding remarks

Soil inorganic carbon (PCs) is a curse for the famers while soil organic carbon (SOC) is boon. To control formations of PCs, therefore, no parcel of land should be kept fallow in SAT regions. Predicting behaviour of natural resources like soils has always been a difficult proposition. This is more so amidst the changing situations in resource management (anthropogenic activities), and natural calamities including climate change. Such effort require data on soils for the past, and present, fortunately the soil information system developed over years for the semi-arid tropics permit us to comment on soil qualities (Bhattacharyya, 2014a & b). Sustainable management interventions for red and black soils of the ICRISAT, India for the last few decades have made possible both the soil types resilient. Resilience of these soils was possible because of increased soluble Ca ions both in soil solution and on the exchange sites through the continuous dissolution of $CaCO_3$ during the crop stand under the improved management systems. Even after decades of management interventions that created favourable environment in terms of Ca ions, red soils (Alfisols) remain as Alfisols and less sodic black soils (Sodic Haplusterts) have become non-sodic soils (Typic Haplusterts), indicating a the positive effect of appropriate recommendations and the management protocols on soil quality. Moreover, such example of soil resilience strongly demonstrates that initially degraded soils of the SAT could be made the vibrant crop production areas.

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