Degradation of Red Ferruginous Soils of Humid and Semi-Arid Tropical Climate - A Critique

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Abstract

To make degraded soils resilient, the establishment of cause-effect relationship needs to be developed on identification of basic pedogenic processes that are linked to regressive and progressive pedogenesis in semi-arid (SAT) and humid tropical (HT) climates, respectively. Proper understanding of the operative pedogenic processes and the determination of the exact mineralogy class are mandatory requirements for suggesting/deciding the extent of degradation of HT and SAT soils. New knowledge gain will obviously guide the land resource managers in a right way to develop the innovative management protocols for making degraded soils resilient. This critique provides a deductive check on the inductive reasoning on the physical and chemical degradation of RF soils of both HT and SAT climates, which may help land resource managers to take appropriate decisions for cost-intensive rehabilitation programmes.

Key Words : Red ferruginous soils, humid and semi-arid tropical climate.

Introduction

Soil is a dynamic and living entity, which supports to produce goods and services of value to humans but not necessarily with perpetual ability to cushion the degradative processes. Soil formation is a slow process, and a substantial amount of soil can form only over a geologic timescale. Therefore, soil misuse and extreme climatic conditions can damage self-regulating capacity and give way to regressive pedogenesis (Pal *et al.* 2013) and, as a result, the soil will regress from higher to lower usefulness and or drastically diminished productivity. Such an un-favourable endowment of soils is termed 'soil degradation (Lal *et al.* 1989). However, soils do have an inherent ability to restore their life support processes if the disturbances created by anthropogenic activities are not too drastic, and enough time is allowed for life-support processes to restore themselves (Lal 1994). This intrinsic ability of soils to regenerate their productivity is called resilience (Szabolcs 1994). In the present critique, discussion shall remain restricted to the physical (soil loss due to water erosion) and natural chemical degradation caused by two extreme climatic conditions i.e. SAT and HT climates.

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Physical degradation in Indian HT soils

Soils under HT climate of NEH (north-eastern hills) and southern peninsular areas are most affected by water erosion, and the highest area under this category of degradation is in Nagaland (87%), followed by Meghalaya (78%), Arunachal Pradesh (73%), Assam (66%), Manipur (53%), Tripura (38%), Sikkim (37%) and Kerala (15%). These estimates were based on an assumption that soil erosion < 10 t $ha^{-1}yr^{-1}$ (using the empirical Universal Soil Loss Equation, USLE to estimate spatial variations of soil loss factors like R, K, L, S, C and P factors) generally does not significantly affect soil productivity. On the basis of this assumption, the HT soils with soil loss of < 10 t $ha^{-1}yr^{-1}$ were not considered degraded (ICAR-NAAS, 2010). The rate of soil formation varies from < 0.25 mm yr^{-1} in dry and cold environments to > 1.5 mm yr^{-1} in humid and warm environments (Kassam *et al*., 1992). If the rate of soil formation is taken as minimum of 2.0 mm yr^{-1} for soils of HT climate, the amount of top soil formation would be close to 29 t $ha^{-1}yr^{-1}$ (Bhattacharyya *et al*., 2007a). This soil gain is in contrary to the assumed value of soil loss and thus strongly suggests that the rate of soil loss by water erosion from Ultisols, Alfisols, Mollisols and Inceptisols is not at all significant (Bhattacharyya *et* *al*., 2007a). The impact of the progressive pedogenetic processes in HT soils were not given due consideration although they ensure the positive balance of soil formation, while following the USLE for estimation of soil erosion. Due to positive balance of soil formation, the occurrence of mature soils (like Ultisols, Alfisols, Mollisols and clay-enriched Inceptisols) on a stable landscape under HT climate is a reality. The major pedogenetic processes in HT soils are evident through the addition of C by litter falls and its accumulation as soil organic matter under adequate vegetation and climate, translocation of clay particles (to form clay-enriched B horizons) and transformation of 1.4 nm minerals to 1.4-0.7 nm mixed layer minerals which are not pure kaolinite but are kaolins with a basal spacing of around 0.7 nm (Pal *et al*., 2014). In contrast, in acidic Entisols on higher slopes (ridges, scarps and terraces) under low vegetation with only shrubs and bushes, soil development is greatly hampered by the severe soil loss due to water erosion. Soil loss is also evident in other soils that have less vegetative cover. Besides proper mechanical conservation measures, areas under such soils may be suitable for forestry, horticultural and plantation crops to build resilience in them (Bhattacharyya *et al*., 1998, 2007a).

Chemical degradation (soil acidity) in Indian HT soils

Development of acidity in soils is indeed a sign of natural chemical degradation due to profuse chemical weathering under HT climate. Acid soils of the HT climate are generally considered to have less soil fertility. In the report of ICAR-NAAS (2010) such soils with strong (pH < 4.5) and moderate acidity (pH 4.5–5.5) only was considered. They occupy about 6.98 m ha area, which is about 9.4% of the total geographical area of the country (ICAR-NAAS, 2010). Soils of HT climate in the states of Kerala, Goa, Karnataka, Tamil Nadu and NEH areas are strongly to moderately acidic Alfisols, Ultisols and Mollisols and their further weathering in HT climate would finally close at kaolin dominated Ultisols with considerable amount of layer silicate minerals (Pal *et al*., 2014).Thus siliceous nature of the HT soils (especially the Ultisols of Kerala) is reflected in the SiO_2:R_2O_3 (1.4–5.0) and SiO_2:Al_2O_3 (1.8–6.0) ratios (Chandran *et al*., 2005; Varghese and Byju, 1993), suggesting an incomplete desilication process. The amount of SiO_2 and its molar ratios are comparable with some of the Oxisols reported from Puerto Rico (Jones *et al*., 1982), Brazil (Buurman *et al*., 1996; Muggler, 1998), and other regions of the World (Mohr *et al*., 1972). However, in the acidic Alfisols, Ultisols and Mollisols, the process of desilication no longer operates in present day conditions because the pH of the soils is well below the threshold of 9 (Millot, 1970). The OC rich Ultisols have less Al-saturation in surface horizons due to the downward movement of Al as organo-metal complexes or chelates, but have higher base saturation than the sub-surface horizons due to addition of alkaline and alkaline metal cations through litter fall (Nayak *et al*., 1996), and there is no desilication and transformation of kaolin to gibbsite. In view of contemporary pedogenesis, it is difficult to reconcile that Ultisols would ever be weathered to reach an unproductive stage like in Oxisols with time (Pal *et al*.,2014) as envisaged by Smeck *et al*. (1983) and Lin (2011). Such OC-rich acid soils are not kaolinitic as they are dominated by kaolin mineral (a mixed mineral) as their clay CEC is > 24 cmol (p^+) kg^{-1} determined by $BaCl_2$-TEA for total acidity plus bases by NH_4OAc, pH 7 method, (Smith, 1986) and do respond to management interventions and support luxuriant forest vegetation, horticultural, cereal crops, tea, coffee and spices (Sehgal, 1998). In view of their successful use for food production for centuries would it be prudent to consider such acid soils as degraded? This warrants for a revision in the present methodology giving due recognition of their pedogenetic processes that do not drive to an unproductive stage of soils.

Physical degradation in Indian semi-arid (SAT) soils

Under the SAT environments, the red ferruginous (RF) soils of Indian states suffer soil loss due to erosion, and the loss is maximum in Karnataka (49%) followed by Andhra Pradesh (40%) and Tamil Nadu (20%) (ICAR-NAAS, 2010), considering soil loss > 10 t $ha^{-1}yr^{-1}$ as the threshold for soil degradation. The RF soils of SAT dominantly belong to Alfisols, and the other soil orders are Inceptisols, Entisols and Mollisols (Pal *et* *al*., 2014). Considering the rate of soil formation in dry environments at < 0.25 mm yr^{-1} (Kassam *et al*., 1992), SAT Alfisols would gain soil at least 3.67 t $ha^{-1}yr^{-1}$. However, short-term hydrological studies on small agricultural watershed on Alfisols at the ICRISAT Center, Patancheru, India indicate an average soil loss from SAT Alfisols under traditional system is around 3.84 t $ha^{-1}yr^{-1}$ (Pathak *et al.* 1987). On the other hand, the results from long-term study reported an annual soil loss of 4.62 t ha^{-1} yr^{-1} (Pathak *et al.* 2013). To reduce unwarranted soil loss of the SAT Alfisols, improved system of management developed by the ICRISAT (Pathak *et al.* 1987) made Alfisols resilient as reflected by the minimized soil loss to nearly 1 t $ha^{-1}yr^{-1}$ and simultaneously increased crop productivity compared to traditional system on a sustained manner. Thus it is safe to understand that SAT RF soils under successful agricultural production system do not suffer from any major soil loss. The higher soil loss on the SAT Alfisols under traditional management is due to clay enriched B horizons with substantial amount of smectite clay in the subsoils (Pal *et al.* 1989), which is reflected in COLE > 0.06 (Bhattacharyya *et al.* 2007), and reduced sHC (Pathak *et al.* 2013) due to formation of PC and concomitant development of subsoil sodicity (ESP) (Pal *et al.* 2013). Such physical and mineralogical environments in the subsoil restrict vertical movement of water in the soil profile, resulting in greater soil loss from the SAT Alfisols through overland lateral flow of water. This suggests that a threshold value of soil loss by water erosion as a sign of degradation, need be based on pedogenesis and experimental results rather than assuming an arbitrary value of >10 t $ha^{-1}yr^{-1}$ to avoid unwarranted national expenditure for the current and future conservation measures (Pal *et al.*2014).

Chemical degradation in Indian SAT soils

Factors that cause soil degradation are of both natural and human-induced degradation in nature. Such degradation leads to changes in properties of soils and the attributes for their life support (Lal *et al.* 1989). Although selected pedogenic processes such as laterization, hard setting, fragipan formation and clay-pan formation are hitherto considered as natural soil degradation processes (Hall *et al.* 1982; Lal *et al.* 1989), the majority of the information on soil degradation at national (Sehgal and Abrol 1992,1994), regional (FAO 1994) or international level (Oldeman 1988; UNEP 1992) has focussed only on degradation caused by anthropogenic activities.

FAO (1994) recorded land degradation in south Asia but the potential effects of global climatic change to cause degradation in soils was not considered. It was, however, envisaged that if adverse changes occur in some areas, then these processes will certainly constitute a most serious form of human-induced degradation of natural resources. As a matter of fact, climate change from the humid to semi-arid climate did occur during the late Holocene period in major parts of the Indian subcontinent (Pal *et al.* 2012, 2013; Srivastava *et al.* 2015), which created adverse physical and chemical environment, leading to reduced productivity of soils in many parts of the world including India. A few recent reports on major soil types (Indo-Gangetic Plains or IGP, Red Ferruginous and Deep Black Soils) at the Indian Council of Agricultural Research-National Bureau of Soil Survey and Land Use Planning (ICAR-NBSS & LUP), Nagpur, India showed that the regressive pedogenesis (Pal *et al.* 2013) in terms of the formation of the pedogenic $CaCO_3$ (PC) and concomitant development of sodicity and accumulation of relatively higher amounts of exchangeable Mg (EMP) than that of exchangeable Ca (ECP) in soils, is also a natural chemical process of soil degradation in SAT climatic conditions (Balpande *et al.* 1996; Pal *et al*., 2000, 2001, 2003, 2006, 2012; Vaidya and Pal, 2002; Chandran *et al*., 2013). Such a precise account of regressive pedogenesis in terms of factors of natural chemical degradation in major soil types of India forms a robust database for reference (Pal *et al*., 2009, 2012, 2014; Srivastava *et al*., 2015) to expand the present knowledge on natural chemical soil degradation and to protect the livelihood of humankind. Such database could be important for adapting sustainable soil management and long-range resource management strategies for many developing nations in the arid and semi-arid regions of the world, especially in the Indian subcontinent, where arid and semi-arid environments cover more than 50% of the total geographical area (Pal *et al*., 2000).

Concluding remarks

- At present, the extent of degradation of HT RF soils (especially Ultisols, and acidic Alfisols, Mollisols and Inceptisols with clay-enriched B horizons) is not at all in an alarming stage.
- Proper understanding of the operative pedogenic processes and the determination of the exact mineralogy class are of mandatory requirements for suggesting/deciding the extent of degradation of HT and SAT soils.
- Finally, this critique provides a deductive check on the inductive reasoning on the physical and chemical degradation of RF soils of both HT and SAT climates.
- It is hoped it may help land resource managers to take appropraite decisions for cost-intensive rehabilitation programmes.

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