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Impact of Climate Change in Soils of Semi-Arid Tropics (SAT)

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ABSTRACT

The review of research results on Indian major soil types under semi-arid tropics (SAT) indicates that climate change from humid to arid occurred in the Peninsular regions of India during the Holocene period. This change is being realized in the rise in mean annual temperature (MAT) and decrease in mean annual rainfall (MAR). The prevailing arid climatic adversities favoured the sequestration of inorganic carbon as $CaCO_3$ with concomitant development of soil sodicity in major soil types of India, representing regressive pedogenesis. As a result, crop productivity in these soils often has reduced to less than 50%. Thus the regressive pedogenetic processes under SAT environments pose a threat to agriculture being an unfavourable natural endowment that will ever demand for extra resources for raising crops (especially the winter crops) by the resource poor farmers in the naturally degraded soils.

Keywords: Climate change, Impacts, Regressive pedogenesis, Natural soil degradation, Loss of soil sustainability, Decline in crop productivity.

1. INTRODUCTION

In response to the global climatic event during the Quaternary, the soils of many places of the world witnessed climatic fluctuations, especially in the last post-glacial period. Climatic changes have also been frequent during

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the Quaternary (Ritter, 1996). In India we have experienced change of climate from humid to semi-arid in rain-fed areas only during the Holocene period (Pal *et al.,* 2001, 2003a, 2009a, b). Tectonic slopes/faults determine the courses of large rivers (Singh *et al.*, 2006) and play a significant role in the evolution of geomorphology and soils (Srivastava *et al.,* 1994; Kumar *et al.,* 1996; Pal *et al.*, 2003a; Singh *et al.,* 1998, 2006). Crustal movements also caused the change in climate from humid to semi-arid as experienced with the formation of the Western Ghats (Brunner, 1970). Maintenance of the agricultural productivity in arid and semi-arid lands of the world would ever remain a great challenge including the Indian sub-continent where arid and semi-arid environments cover more than 50% of the total geographical area (Pal *et al.*, 2000). It is quite likely that due to the current aridic environment that is prevailing in many parts of the world including India may create adverse changes in physical and chemical properties of soils that may reduce both soil and crop productivity. Such areas are prone to be chemically degraded in terms of subsoil sodicity. Rain-fed ecosystems cover many such areas. Thus a new research initiative can help us in improving our knowledge to follow the changes in soil properties by identifying climatically–controlled pedogenetic processes. To adapt sustainable soil management such information will be helpful.

2. SEMI-ARID CLIMATE: PEDOGENETIC PROCESSES

The soils of the semi-arid tropics (SAT), in general, are calcareous and sodic, either at the subsoil regions or throughout the soil depth (Pal *et al.,* 2000, 2006). The presence of pedogenic $CaCO_3$ (PC), which can only be distinguished from pedorelict $CaCO_3$ (NPC) by the soil thin section studies (Pal *et al.,* 2000), is very common in major soil types of India (alluvial soils of the Indo-Gangetic plains, ferruginous soils and shrink–swell soils) (Fig. 1a–c) (Pal *et al.,* 2000). In the SAT environment the water loss through evapo-transpiration is considered as the primary mechanism in the precipitation of PC (Arkley, 1963; Scholz, 1971; Rabenhorst, *et al.,* 1984) while temperature controls the water flow in the soil (Arkley, 1963; Ahmad, 1978). In fact this is manifested in soils of the dry (sub-humid to arid) regions of India as evidenced by the progressive increase of PC in Vertisols from the humid to arid regions (Fig. 2). The formation of PC results in concomitant sodicity in clay-rich soils (Wilding *et al.*, 1963; Balpande *et al.,* 1996; Pal *et al.,* 2000). However, the development of sodicity is not realized yet in desert soils due to their sandy texture, ensuring better leaching of bicarbonates and thus PC is generally observed at greater depth unlike loamy and clayey soils (Pal *et al.*, 2000). These pedogenetic processes are active in ferruginous soils (Alfisols) of southern India, which have ~30% clay and are dominated by 2:1 expanding clay minerals and developed in humid tropical climate of pre-Pliocene. PCs are found in these Alfisols due to the present day semi-arid climate. These PCs are identified as lubinites (Fig. 1c) that are formed when the soil solution is supersaturated with $CaCO_3$ in the semi-arid environment (Wright, 1988). The texture can play an important role in the accumulation of carbonates in soils besides climate (Wieder and Yaalon, 1974).

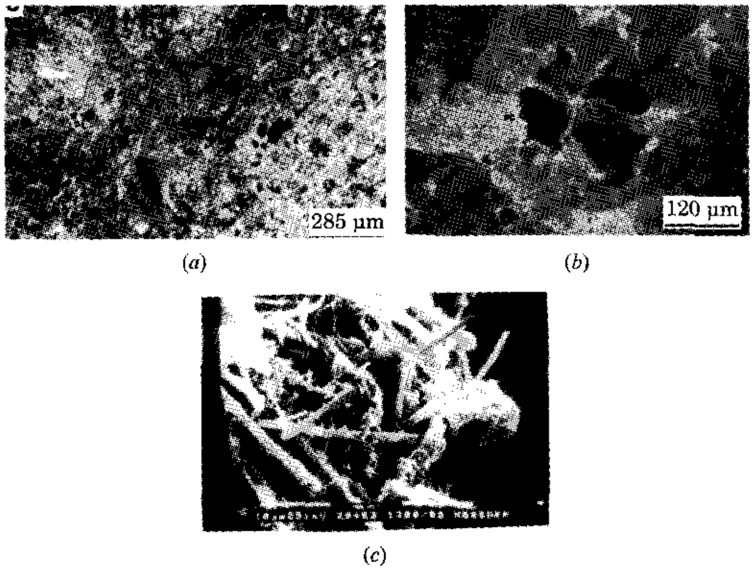

Fig. 1. Representative photomicrographs of pedogenic $CaCO_3$ (PC) in the (*a*) soils of the IGP (Natrustalfs), (*b*) Vertisols of central India and (*c*) ferruginous soils of southern India (Alfisols).

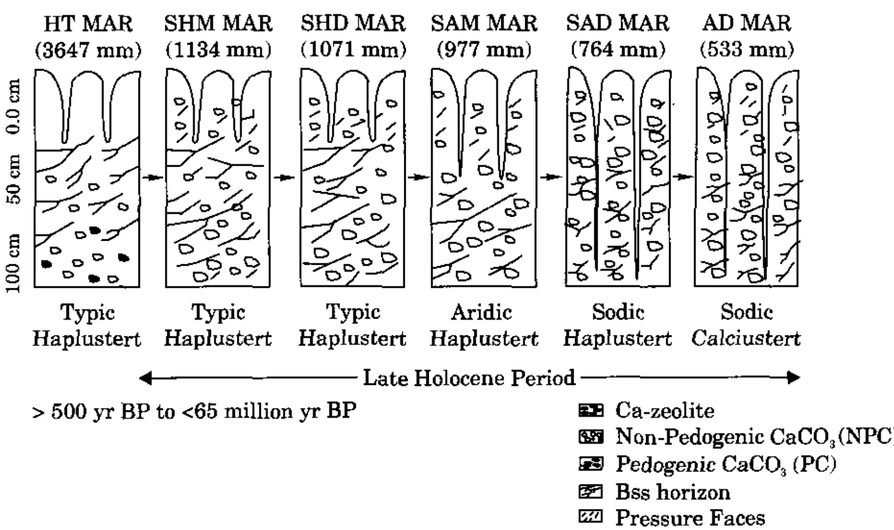

Fig. 2. Schematic diagram of the progressive increase of PC in Vertisols from humid to arid bioclimatic systems (HT: humid tropics; MAR: mean annual rainfall; SHM: sub-humid moist; SHD: sub-humid dry; SAM: semi-arid moist; SAD: semi-arid dry; AD: arid).

The accumulation of soil inorganic carbon (SIC) in terms of formation of PC in soils hitherto is considered to be a bane as it causes the impairment of soil productivity (Pal *et al.*, 2000; Srivastava *et al.*, 2002; Bhattacharyya *et al.*, 2000, 2004, 2008). The formation of PC in arid climate enhances the pH and also the relative abundance of Na^+ ions in both soil exchange sites and solution, and the Na^+ ions in turn cause dispersion of the fine clay particles. The dispersed fine clays translocate in major soil types of India (Pal *et al.*, 2003b, 2009a; Pal, 2005). The formation of PC creates a chemical environment to deflocculate clay particles to move downward. Therefore, the formation of PC and the clay illuviation are two concurrent and contemporary pedogenetic events, resulting in the increase in the relative proportion of sodium causing higher sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) and soil pH down the depth (Fig. 3). The formation of PC is thus a natural degradation process (Pal *et al.*, 2000), which exhibits the regressive pedogenesis (Johnson and Watson-Stegner, 1987) to immobilize inorganic C.

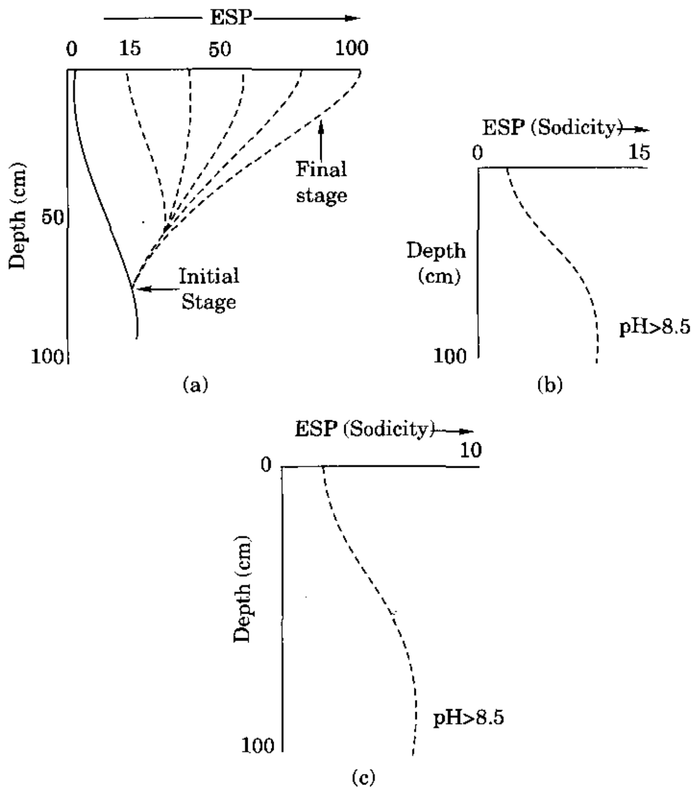

Fig. 3. Illuviation of Na-clay triggered by formation of PC, causing higher ESP and pH in the subsoils of the (*a*) IGP (Natrustalfs), (*b*) Vertisols of Central India, (*c*) Ferruginous soils (Alfisols) of southern India.

The PC is considered to be of no significance as the displacement of exchangeable Na by Ca^{2+} ions from $CaCO_3$ is not feasible in soils with pH > 8.0 (Pal *et al.*, 2000). At this pH its ionic strength is so low that correction for the difference of molality and activity is hardly worthwhile (Garrels and Chirst, 1965). Therefore, the formation of PC with concomitant development of ESP in subsoils results in (i) poor hydraulic conductivity (Pal *et al.*, 2003a, 2009a, b) and (ii) modified microstructure of soils (Pal *et al.*, 2003a, 2006, 2009a) (Fig. 4). The formation of PC for the soils of Indian IGP, black soil region and red soil areas in the Indian Peninsula representing SAT was estimated as 129, 37.5 and 30 kg $CaCO_3$ ha^{-1} yr^{-1}, respectively (Pal *et al.*, 2000).

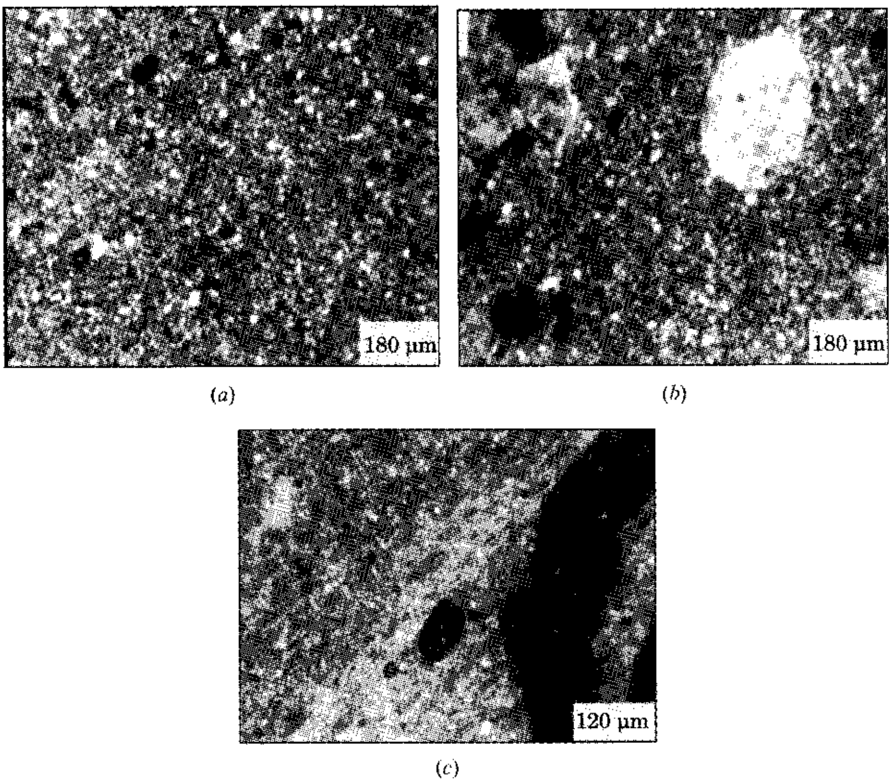

Fig. 4. Representative microphotographs of Vertisols of India showing (*a*, *b*) poor plasma separation due to subsoil sodicity (ESP < 15) in contrast to strongly separated plasma (*c*) in non-sodic Vertisols (ESP < 5).

3. REGRESSIVE PEDOGENESIS IN SAT AND ITS IMPLICATIONS IN RAIN-FED AGRICULTURE

It was stated earlier that consequent upon the regressive pedogenesis, the major soil types of India under SAT are calcareous and sodic with modified physical and chemical properties. These changes in soils hamper crop growth (Pal *et al.*, 2009b, 2011). Figure 5 indicates how the rate of formation of PC and ESP increases in Vertisols under a climosequence with the lowering of mean annual rainfall (MAR) from sub-humid to arid bioclimatic zones. The impact of climate change from humid to arid in these Vertisols during the Holocene (Pal *et al.,* 2009a) has also been realized in the development of PC, ESP and impairment of hydraulic properties that cause the decline of cotton yield from high to low MAR in Vidarbha region of central India (Table 1).

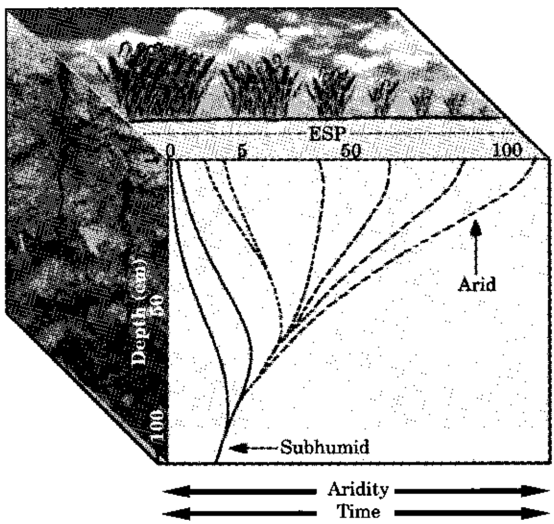

Fig. 5. A projected view of progressive development of sodicity *vis a vis* decline in crop productivity with time and aridity: a threat to agriculture in SAT areas.

The magnitude of degradation (regressive pedogenesis) may not be very high in ferruginous soils at present but it may prove fatal in shrink-swell soils (Vertisols and vertic intergrades) because of huge amount of smectite clays (Pal *et al.*, 2000). Perception of the natural degradation process often remains deceptive in shrink-swell and ferruginous soils as they lack evidence of salt-efflorescence on their surface. However, the degradation process is proceeding at a much faster rate in soils of the IGP as compared to other two soil types. Therefore, attempts to increase and stabilize yields in these soils by extension of canal-irrigation may prove to be highly disastrous (Pal *et al.,* 2009b, 2011). Thus the pedogenic threshold (regressive pedogenetic processes) provides a scenario of how SAT environments pose a threat to agriculture by being an unfavourable natural endowment that will ever demand for extra resources for raising crops (especially the winter crops) by the resource-poor farmers in the naturally degraded soils (Fig. 5).

Table 1: Range in values of PC, ESP, sHC and yield of cotton in shrink–swell soils of Vidarbha, Central India.

Location	*Soil classification*[1]	*PC (%)*[2]	*ESP*[3]	*sHC*[4] *(mm hr⁻¹) weighted mean in the profile (1 m)*	*Cotton yield (t ha⁻¹) (seed + lint)*
Nagpur (MAR–1011 mm)	Typic Haplusterts and Typic Calciusterts	3–6	0.5–11	4–18	0.95–1.80
Amravati (MAR–975 mm)	Aridic Haplusterts	3–7	0.8–4	2–19	0.60–1.66
	Sodic Haplusterts	3–13	16–24	0.6–9.0	0.25–0.79
Akola (MAR–877 mm)	Aridic Haplusterts	3–4	7–14	3–4	0.60–1.00
	Sodic Haplusterts	3–4	19–20	1–2	0.64

[1] USDA Soil Taxonomy (Soil Survey Staff, 2003). MAR = mean annual rainfall; [2] PC = pedogenic $CaCO_3$, [3] ESP = exchangeable sodium percentage (sodicity), [4] sHC = saturated hydraulic conductivity. Adapted from Kadu *et al.* (2003).

CONCLUSIONS

This review of research on major soil types of India under SAT indicates how in dry climate both soil and crop productivity is being impaired. This expands the basic knowledge in pedology that may have relevance in soils of other SAT areas of the world.

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