Chapter 1
Indian Tropical Soils: An Overview

Abstract The Indian subcontinent, which collided with the Asian mainland during the Eocene period, is a very old mass and has not been under water since the Carboniferous period. A girdle of high mountains, snow fields, glaciers and thick forests in the north, seas washing lengthy coasts in the Peninsula, a variety of geological formations, diversified climate, topography and relief have given rise to varied physiographic features. Temperature varies from arctic cold to equatorial hot. Such varied natural environments have resulted in a great variety of soils in India compared to any other country of similar size in the world. Many however think of tropical soils as the deep red and highly weathered soils, and are often thought are either agriculturally poor or virtually useless. The major soils of India are Vertisols, Mollisols, Alfisols, Ultisols, Aridisols, Inceptisols and Entisols. Although soils of India occur in 5 bio-climatic systems, but only a few soil orders are spread in more than one bio climate. Vertisols belong to arid hot, semi-arid, sub-humid and humid to per-humid climatic environments. Mollisols belong to sub-humid and also humid to per-humid climates. Alfisols belong to semi-arid, sub-humid and also in humid to per-humid climates, whereas Ultisols belong to only humid to per-humid climates. Both Entisols and Inceptisols belong to all the 5 categories of bio-climatic zones of India, and Aridisols belong mainly to arid climatic environments. This baseline information indicates that except for the Ultisols and Aridisols, the rest 5 soil orders exist in more than one bio-climatic zones of India. The absence of Oxisols and a small area under Ultisols, suggest that soil diversity in the geographic tropics in India, is as large as in the temperate zone. These soils are not confined to a single production system and generally maintain a positive organic carbon balance. Thus they contribute substantially to India's growing self-sufficiency in food production and food stocks. Therefore, any generalizations about tropical soils are unlikely to have wider applicability in the Indian subcontinent. The genesis of Ultisols alongside acidic Alfisols and Mollisols for the millions of years in both zeolitic and non zeolitic parent materials in Indian humid tropical (HT) climatic environments indicates how the parent material composition influences the formation of Alfisols, Mollisols and Ultisols in weathering environments of HT climate; and also how the relict Alfisols of semi-arid tropical (SAT) environments are polygenetic. The critical evaluation of the nature and distribution of naturally occurring clay minerals,

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calcium carbonates, gypsum, gibbsite and zeolites can yield valuable and important information to comprehend the complex factors involved in the pedogenesis of soils formed in the present and past climates. Thus, the conventional management protocols to improve and sustain their productivity need to be revised in the light of new knowledge gained in recent years. Global distribution of tropical soils and the recent advances in knowledge by researching on them (Entisols, Inceptisols, Mollisols, Alfisols, Vertisols and Ultisols) in the Indian sub-continent indicates that some of the agricultural management practices developed in this part of the tropical world for enhancing crop productivity and maintaining soil health, might also be adoptable to similar soils elsewhere. In the following chapters from 2 to 9, arguments are presented in terms readily understood by all stake holders of tropical soils and with both scientific and economic rigor so that they are not easily refuted.

Keywords Indian tropical soils · Advances in pedology · Climate change · Edaphology · Soil modifiers

Tropical soils are those soils that occur in geographic tropics (that part of the world located between 23.5° north and south of the Equator), meaning simply, the region of the earth between the Tropic of Cancer and the Tropic of Capricorn. This region is also known as Torrid Zone. The Indian subcontinent, which collided with the Asian mainland during the Eocene period, is a very old mass and has not been under water since the Carboniferous period. A girdle of high mountains, snow fields, glaciers and thick forests in the north, seas washing lengthy coasts in the Peninsula, a variety of geological formations, diversified climate, topography and relief have given rise to varied physiographic features. Temperature varies from arctic cold to equatorial hot; rainfall from barely a few centimetres in the arid parts, to per-humid with world's maximum rainfall of several hundred centimetres per annum in some other parts. These conditions provide for a landscape of high plateaus, stumpy relic hills, and shallow open valleys, rolling uplands, fertile plains, swampy low lands and dreary barren deserts. Such varied natural environments have resulted in a great variety of soils in India compared to any other country of similar size in the world (Bhattacharyya et al. 2013).

Major part of the land area in India is however, in the region lying between the Tropic of Cancer and Tropic of Capricorn, and the soils therein are termed "tropical soils". Many however think of tropical soils as the soils of the hot and humid tropics only, exemplified by deep red and highly weathered soils and are often thought improperly they are either agriculturally poor or virtually useless (Sanchez 1976; Eswaran et al. 1992). India has 5 distinct bioclimatic systems (Bhattacharjee et al. 1982) with varying MAR; and they are arid cold and hot (MAR $<$ 550 mm), semi-arid (MAR 550–1000 mm), sub-humid (MAR 1000–1500 mm), humid to per-humid (MAR 1200–3200 mm) and coastal (MAR 900–3000 mm). The major soils of India are Vertisols, Mollisols, Alfisols, Ultisols, Aridisols, Inceptisols and Entisols covering 8.1, 0.5, 12.8, 2.6, 4.1, 39.4 and 23.9%, respectively of the total geographical area (TGA) of the country (Bhattacharyya et al. 2009). However, the

Andisols in the humid tropical (HT) Nilgiri Hills, southern India, are non-allophanic Andisols derived from a special kind of non-volcanic material consisting of low-activity clay (LAC) residuum, rich in Al and Fe oxides, and deserve a special mention. LAC soils and the most common volcanic Andisols are often considered to be representative of advanced and juvenile stages of soil formation, respectively. The occurrence of these soils was unexpected. Secondary oxides, inherited from a previous cycle of soil genesis, appear to play the same role as volcanic glasses do in most Andisols (Caner et al. 2000). Andisols are not however, considered as one of the major soils of India because they are not mappable in 1:250,000.

Although soils of India occur in 5 bio-climatic systems, but only a few soil orders are spread in more than one bio climate. Vertisols belong to arid hot, semi-arid, sub-humid and humid to per-humid climatic environments (Bhattacharyya et al. 2005; Pal et al. 2009a). Mollisols belong to sub-humid and also humid to per-humid climates (Bhattacharyya et al. 2006). Alfisols belong to semi-arid, sub-humid and also in humid to per-humid climates (Pal et al. 1989, 1994, 2003; Bhattacharyya et al. 1993, 1999), whereas Ultisols belong to only humid to per-humid climates (Bhattacharyya et al. 2000; Chandran et al. 2005). Both Entisols and Inceptisols belong to all the 5 categories of bio-climatic zones of India, and Aridisols belong mainly to arid climatic environments (Bhattacharyya et al. 2008). This baseline information indicates that except for the Ultisols and Aridisols, the rest 5 soil orders exist in more than one bio-climatic zones of India. The absence of Oxisols and the Ultisols, occupying only 2.56% of total geographical area of the country, suggest that soil diversity in the geographic tropics in general and in India in particular, is at least as large as in the temperate zone (Eswaran et al. 1992; Sanchez and Logan 1992). These soils are not confined to a single production system and generally maintain a positive organic carbon (OC) balance without adding significantly to greenhouse gas emissions (Pal et al. 2015). Thus they contribute substantially to India's growing self-sufficiency in food production and food stocks (Pal et al. 2015; Bhattacharyya et al. 2014). Therefore, India can be called a land of paradoxes because of the large variety of soils and any generalizations about tropical soils are unlikely to have wider applicability in the Indian subcontinent (Pal et al. 2012a, 2014, 2015).

Mohr et al. (1972) stated that the parent rock seems to influence soil formation in such a way that similar soils are formed under quite different climatic conditions. However, an extensive pedogenetic study of Vertisols in an Indian climosequence (from arid hot to humid bio climates) expands the basic understanding of Vertisol evolution from Typic Haplusterts to Udic/Aridic/Sodic Haplusterts and Sodic Calciusterts (Pal et al. 2009a, 2012a). The genesis of Vertisols and soils with vertic character in the extra-peninsular region like in the micaceous alluvium of the IGP area needs to be reconciled through the role of Cratonic flux (Tandon et al. 2008; Pal et al. 2012b). While the formation of Vertisols in humid tropical (HT) climate is possible in the alluvium of zeolitic Deccan basalt, the formation of sodic shrink-swell soils (Sodic Haplusterts and Sodic Calciusterts, Pal et al. 2009a), sodic IGP soils (Typic Natrustalfs/Natraqualfs, Pal et al. 2003), and sodic red ferruginous (RF) soils (Typic Natrustalfs, Chandran et al. 2013) in semi-arid tropical

(SAT) environments is caused by the tectonic-climate linked natural soil degradation process (Pal et al. 2009b). These Vertisols, RF and IGP soils may remain in equilibrium with their climatic environments until the climate changes further, after which another pedogenic threshold is reached.

It is also believed that differences in rock composition lead to the formation of different soils even if the climate is similar over the whole area of study. But, Chesworth (1973) opined that the effect of the composition of parent rock on the composition of resulting soil in HT climate is an inverse function of time, and given enough time the chemical effect of parent rock would be nullified. In contrast, the genesis of Ultisols alongside acidic Alfisols and Mollisols for the millions of years in both zeolitic and non zeolitic parent materials in Indian HT climatic environments indicates how the parent material composition influences the formation of Alfisols, Mollisols and Ultisols in weathering environments of HT climate; and also how the relict Alfisols of SAT environments are polygenetic (Pal et al. 2014). These are some important but diverse issues on understanding the soils, tropical soils in particular.

It is generally understood that coarse-grained rocks tend to weather faster than fine-grained ones, and basic rocks faster than acid ones. Soils formed from basic rocks, as compared to those from acid rocks, are usually more fertile. The distribution of different geological rock formations (Fig. 1.1a) vis-a-vis different soils of India (Fig. 1.1b) reflects the relation between rocks and soils thereby suggesting the effect of parent rock on soil formation. For example, the fine textured Deccan basalt has been responsible for the formation of black (shrink-swell) soils whereas coarse-grained metamorphic rocks have given rise to red ferruginous soils (Pal et al. 2000a). However, the occurrence of spatially associated red ferruginous soils (Alfisols) in areas dominated by black soils (Vertisols) and vice versa almost under same topographical situation reflects two contrasting chemical environments that were conducive for the formation of these two groups of soils on the same parent material presumably under similar climatic conditions. This enigmatic but interesting fact has been a topic of researches the world over (Mohr et al. 1972). Research attempts made in India (Pal 1988, 2008; Bhattacharyya et al. 1993) and elsewhere (Beckmann et al. 1974) suggest their formation through a progressive landscape reduction process.

It has been recently demonstrated that the critical evaluation of the nature and distribution of naturally occurring clay minerals, calcium carbonates, gypsum, gibbsite and zeolites resulting either from inheritance or from the weathering of parent material whether mineral or rock, can yield valuable and important information to comprehend the complex factors involved in the pedogenesis of soils formed in the present and past climates (Birkland 1977; Rengasamy et al. 1978; Murali et al. 1978; Singer 1980; Pal et al. 1989, 2000a, b, 2001, 2009a, b, 2012a, b, 2014; Bhattacharyya et al. 1993, 1999, 2000; Chandran et al. 2005; Jenkins 1985; Wilson 1985). These situations emphasize the fact that since soils are the product of chemical, biochemical and physical processes acting upon earth materials under various topographic and climatic conditions, they bear the signatures as much as do landforms, the climatic and geomorphic history of the region in which they are

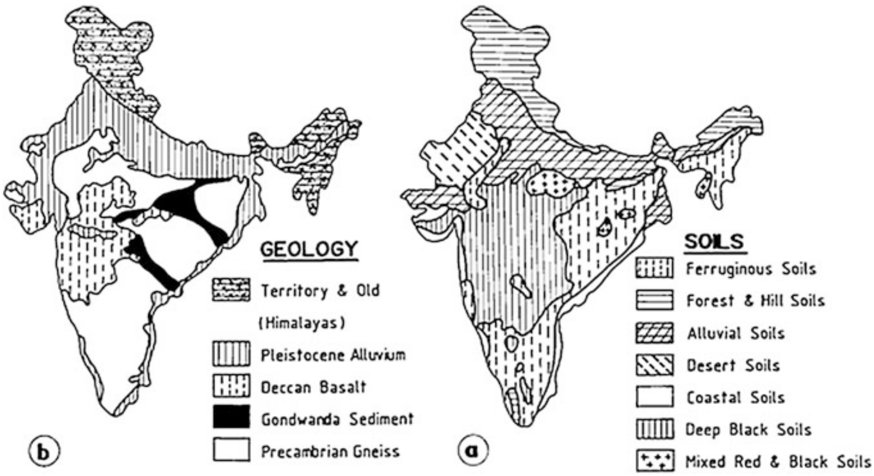

Fig. 1.1 Distribution of different kinds of soil (**a**) and the spread of geological formations (**b**) (Adapted from Pal et al. 2000a)

evolved (Thornbury 1969). Thus, the edaphological issues of soils of tropical environments in terms of following the conventional management protocols to improve and sustain their productivity need to be revised in the light of new knowledge gained in recent years (Pal et al. 2012a, c, 2014; Srivastava et al. 2015).

As the tropics comprise approximately 40% of the land surface of the earth, more than one-third of the soils of the world are tropical soils (Eswaran et al. 1992). Global distribution of these soils and the recent advances in knowledge by researching on them (Entisols, Inceptisols, Mollisols, Alfisols, Vertisols and Ultisols) in the Indian sub-continent indicates that some of the agricultural management practices developed in this part of the tropical world for enhancing crop productivity and maintaining soil health, for example, through carbon sequestration and other management interventions might also be adoptable to similar soils elsewhere. Arguments are presented in terms readily understood by all stake holders of tropical soils and with both scientific and economic rigor so that they are not easily refuted (Greenland 1991).

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