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Review

Vertisols of tropical Indian environments: Pedology and edaphology

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ABSTRACT

Vertisols in the tropics occur in a range of climates and are used in a range of production systems. This review is a synthesis of the recent developments in pedology of vertisols achieved via high-resolution micro-morphology, mineralogy, and age-control data along with their geomorphologic and climatic history. This knowledge has contributed to our understanding of how the climate change-related pedogenic processes during the Holocene altered soil properties in the presence or absence of soil modifiers (Ca-zeolites and gypsum), calcium carbonate and palygorskite minerals. These state-of-the-art methods have established an organic link between pedogenic processes and bulk soil properties; the review also considers the need to modify the classification of vertisols at the subgroup level. We hope this review will fulfil the need for a handbook on vertisols to facilitate their better management for optimising their productivity in the 21st century.

Contents

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1. Introduction

Vertisols have attracted global attention in research, yielding a large body of data on their properties and management (Coulombe et al., 1996; Mermut et al., 1996). Although substantial information is available on vertisols, it remains challenging to optimise their use and management (Coulombe et al., 1996; Myers and Pathak, 2001; Syers et al., 2001).

The global area under vertisols is estimated to be approximately 308 M ha, covering nearly 2.23% of the global ice-free land area (USDA-SCS, 1994); however, the reliability of this estimate remains uncertain because several countries have not yet been included in the inventory (Coulombe et al., 1996). In addition, the area under vertisols in a soil survey area may often be too small to resolve at the scale of map compilation (Table 1). Vertisols and vertic intergrades occur in 80 countries, but more than 75% of the global vertisol area is contained in only 6 countries: India (25%), Australia (22%), Sudan (16%), the USA (6%), Chad (5%), and China (4%; Dudal and Eswaran, 1988; Wilding and Coulombe, 1996).

Vertisols occur in wide climatic zones, from the humid tropics to arid areas (Ahmad, 1996), but they are most abundant in the tropics and sub-arid regions. In the tropics, they occupy 60% of the total area; in the subtropics, they cover 30%, while they cover only 10% in cooler regions (Dudal and Eswaran, 1988; Wilding and Coulombe, 1996). In humid and sub-humid regions, vertisols occupy 13% of the total land area; in sub-arid regions, 65%; in arid regions, 18%; and in the Mediterranean climate, 4% (Coulombe et al., 1996).

Vertisols are an important natural agricultural resource in many countries including Australia, India, China, the Caribbean Islands and the USA (Coulombe et al., 1996). Because of their shrink–swell properties and stickiness, vertisols are known by a number of local regional and vernacular names (Dudal and Eswaran, 1988). They are known in India by at least 13 different names (Murthy et al., 1982). These names are related to the characteristic dark colour and/or to aspects of their workability. These soils are often difficult to cultivate, particularly for small farmers using handheld or animal-drawn implements. The roots of annual crops do not penetrate deeply because of poor subsoil porosity and aeration; therefore, farmers (especially in India) allow these soils to remain fallow during the rainy season and cultivate them only in the post-rainy season.

Current agricultural land uses (edaphological) demonstrate that although vertisols are a relatively homogeneous soil group, they occur in a wide range of climatic environments globally and also show considerable variability in their uses and crop productivity (Pal et al., 2011a). Vertisol use is not confined to a single production system. In general, management of vertisols is site-specific and requires an understanding of degradation and regeneration processes to optimise management strategies (Coulombe et al., 1996; Syers et al., 2001). Basic pedological research is needed to understand some of the unresolved edaphological aspects of vertisols (Puentes et al., 1988) to develop optimal management practices. Thus, a critical review is in order to establish the connection between the pedology and edaphology of vertisols.

Most of the vertisols in India lie in the Torrid Zone between the Tropic of Cancer and the Tropic of Capricorn, where the soils are classed as "tropical". As in several parts of the world, vertisols also occur in wider climatic zones in India (Table 1), in humid tropical (HT), sub-humid moist (SHM), sub-humid dry (SHD), semi-arid moist (SAM), semi-arid dry (SAD) and arid dry (AD) climatic environments. In total, they occupy 8.1% of the total geographical area of the Indian sub-continent (Table 1). Additionally, outside the Deccan basalt region of the peninsula, in the states of Punjab, Bihar and West Bengal, vertisols and their vertic intergrades occur in SHM, SHD and SAM climates (Pal et al., 2010), but they are not mappable at the 1:250,000 scale. Over the past two decades; however, the focus of research has shifted from general pedology to mineralogical and micro-morphological research. By 2009, a total number of 306 BM (benchmark) vertisols and vertic intergrades had been identified by the National Bureau of Soil Survey & Land Use Planning (NBSS&LUP; ICAR), Nagpur, India, which included 112 BM vertisols (Pal et al., 2009c). They have been indicated (along with their global distribution) on a 1:1 million-scale map (NBSS&LUP, 2002; Pal et al., 2011a). Although this review is based on the Indian vertisols, data from other tropical parts of the world are included where relevant. This review uses state-of-the-art data on the recent developments in the pedology of vertisols, including variation in their morphological, physical, chemical, biological, mineralogical and micro-morphological properties. The aim of this review is to provide a better understanding of vertisols created by the climate change phenomena of the Holocene, with the goal of optimising their efficient use and management in tropical India and other tropical regions. The main objective of the paper is to join pedology and edaphology for better management of vertisols and to optimise their productivity in the tropical world during the 21st century.

Table 1
Distribution of vertisols in different states of India under a broad bioclimatic system. Adapted from Bhattacharyya et al. (2009).

States	Bio-climate[a]	Area (mha)(%)[b]
Uttar Pradesh	SAM, SHD	0.41 (0.12)
Punjab	SAM[c]	
Rajasthan	AD	0.98 (0.30)
Gujarat	AD, SAD, SAM	1.88 (0.57)
Madhya Pradesh	SAM, SHD, SHM[d]	10.75 (3.27)
Maharashtra	SAD, SAM, SHD, SHM[d]	5.60 (1.70)
Andhra Pradesh	SAD, SAM, SHD	2.24 (0.68)
Karnataka	AD, SHD, SHM, H	2.80 (0.85)
Tamil Nadu	SAD, SAM, SHD, SHM, H	0.91 (0.28)
Puducherry and Karaikal	SHM	0.011 (0.003)
Jharkhand	SHM, SHD	0.11 (0.034)
Orissa	SHM, SHD, H	0.90 (0.28)
West Bengal	SHD, SHM[c]	
Bihar	SHM[c]	
India		26.62 (8.10)

[a] AD: arid dry: 100–500 mm MAR(mean annual rainfall); SAD: semi arid dry: 500–700 mm MAR; SAM: semi arid moist: 700–1000 mm MAR; SHD : subhumid dry: 1000–1200 mm MAR; SHM: subhumid moist: 1200–1600 mm MAR; H: Humid: 1600–2500 mm MAR.

[b] Parentheses indicate percent of the total geographical area of the country.

[c] In the states of Punjab, Bihar, and West Bengal vertisols and vertic intergrades also occur in SHM, SHD, and SAM climates (Pal et al., 2010) but they are not mappable in 1:250,000.

[d] In addition vertisols occur in HT climate (>2500 mm MAR) in Madhya Pradesh and Maharashtra but they are not mappable in 1:250,000 scale (Bhattacharyya et al., 1993, 2005, 2009; Pal et al., 2011a).

2. Factors in the formation of vertisol

The soil-forming factors are the most relevant and appropriate factors explaining vertisol formation. They are interdependent and highly variable and therefore influence the properties of vertisols in