Indian Journal of Fertilisers **15** (10) : 1156-1166, October 2019

Acid Soils in Agro-Ecological Sub-regions of India : A Revisit

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Received : 20/06/2019 Accepted : 16/09/2019

Abstract

Soil is acidic if pH is less than 7 and alkaline if it is above 7.0. Plants suffer from suboptimal availability of nutrients at pH below 5.5 and above 8.5 resulting in lower yield of arable crops. The acid soils mainly occur in the hilly areas of north-east (NE) and north-west (NW) Himalayan region, eastern plateau and the western coastal plains of India with more than 1200 mm mean annual rainfall (MAR). To understand the potential and constraints of the acid soils it is necessary to locate these areas in a map and characterize them scientifically. Efforts made earlier to estimate area and extent of acid soils were mainly based on the surface soil acidity to address the issues of soil degradation. However, in the humid tropical (HT) climate, excessive leaching of soluble salts causes acidity in surface soils; sub-soil acidity, on the contrary, is due to exchangeable Al and Fe hydroxide in the interlayer of silicate clays. Therefore, it is imperative to map the soil-scape of acid soils and their spatial distribution in different agro-ecological regions (AER) and sub-regions (AESRs) to assess the severity of degradation as it will help prioritize/catalyze the amelioration of acid soils. The Soil Resource Mapping (SRM) data bases of all the 29 states on 1:250,000 scale have been pooled up, categorically generalized through cartography, and re-digitized in Geographic Information System (GIS) to produce the acid soil map of India. The resultant acid soil map when superimposed on AER/ AESR maps in GIS overlaying technique indicated that acid soils in India occupy ~ 93 Mha (28% of the total geographical area of India) covering 48 AESRs of the country. To tap the potential of these soils, agro-interventions like liming and adopting acid-tolerant crop varieties and tree species are necessary.

Key words : Acid soil, AESR, mapping, agro-interventions

Introduction

By definition, acidic soils are the soils having pH less than 7.0. Soils having pH less than 5.5 are problematic due to severe deficiencies of phosphorus (P), calcium (Ca), magnesium (Mg) and molybdenum (Mo) and toxicities of aluminium (Al) and iron (Fe) (Panda and Chamuah, 2002). Acid soils occupy 3950 million hectares (Mha) of ice free land of the world. They belong to Spodosols, Alfisols, Inceptisols, Histosols, Ultisols and Oxisols soil orders with udic or ustic moisture regimes (von Uexkull and Mutert, 1995). Approximately 179 Mha (4.5%) of these lands are cultivated for arable crops and about 33 Mha are used for perennial tropical crops. As per estimates by Lal (2002), annual production from the acid soils is approximately valued at Rs. 150 billion.

In India, acid soils are found from extreme south just above 8º N latitude to 36º N latitude in north; these have developed under different climate, vegetation, topography and parent materials over a long period of time. Strong and very strongly acid soils (pH 4.5-5.5) have been reported in the north-eastern, eastern, and peninsular regions including Bihar plateau, sub-plateau regions of Bengal and major parts of Odisha, Andhra Pradesh, Telangana, Tamil Nadu, Kerala, Maharashtra, and Bay Islands. Moderately acid soils (pH 5.6-6.5) are found in the states namely, Gujarat, Karnataka, Madhya Pradesh (parts), Chhattisgarh (hills), Uttar Pradesh and Uttarakhand (Panda et al., 1996).

The acid soils are classified as i) soils with overlying organic matter, ii) soils without overlying organic matter, iii) acid sulphate soils or cat clays, and iv) degraded alkali soils. Acid organic soils are divided into peaty and muck soils. Mandal (1997) reported that acid soils are cultivated in 100 Mha. Sharma and Sarkar (2005) reported that out of 90 Mha area under acid soils, 31 Mha soils show pH less than 5.5 and the remaining 59 Mha soils have pH 5.5 to 6.5. Maji et al. (2012) reported the state-wise acid soils area of India. As per their report, acid soils occupied ~31.0 Mha area of which moderately acidic soils (pH <5.5) and strongly acid soils together constituted 6.98 Mha area. Interestingly, plant roots of arable crops penetrate deep beyond surface soils for nutrients and water and face the adversity of acidity. Many acid soils in India have pH less than 5.0 throughout the soil depth and under such circumstances application of lime to ameliorate soil acidity needs a rethinking (Bhattacharyya et al,1993,1999, 2006; Pal et al., 2006, 2014). The other strong reason may be that in some moderately acidic Alfisols of Western Ghats the crop

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response to liming is not observed (Kadrekar, 1979) because of the presence of Ca-zeolites in the soil (Bhattacharyya et al, 1993, 1999; Pal et al. 2012). However, Ultisols and Inceptisosls (Dystropepts) of Kerala, Goa, Tamil Nadu, Karnataka and North-East are strongly to moderately acidic which respond well to liming despite high extractable total acidity. This indicates that Al^{3+} ions released during humid tropical weathering are trapped by vermiculites and smectities to form interstratified hydroxy interlayered vermiculites and smectitite minerals (Bhattacharyya et al. 2008). Some gibbsite containing Ultisols (Kerala, Meghalaya) and Alfisols (Goa) have low KCl extractable acidity where lime requirement (LR) needs a revisit. All the above facts need introspection in view of their pedo-environment as the assessment of soil acidity based on only surface soils may be in error.

So far no systematic appraisal of the area under acid soils in different AESRs has been done by attaching importance to the classification based on pedogenic observations. The present paper is a maiden attempt to map the areal extent of these soils in different AESRs of India taking into consideration the geo-referenced soil data available from Soil Resource Mapping (SRM) data on 1: 250,000 scale for different states and also arraying the data in map of agro-ecological regions (AER)/sub-regions (AESR) (Sehgal et al., 1996). The revisit thus involves the revision in areal assessment based on soil survey and actual soil survey data. Spatial distribution under different categories of acid soils in AESRs of India is the need of the hour because of the great emphasis being given for AESR-based agricultural land use planning (Abrol and Chopra, 2008; Mandal et al. 2014; Bhattacharyya et al., 2015).

Formation and Occurrence of Acid soils

Acid soils are formed mainly due to acidic parent materials and leaching of bases caused by heavy precipitation which is conditioned by soil-forming factors like parent materials, temperature, vegetation and hydrological cycles on landscape. Acid soils occurring in different AESRs indicate their diverse geological origin from granite-gneiss, laterite, ferruginous sandstone, calcareous sandstone, limestone, micaceous sandstone and calcic-gneiss. Soil acidity also develops on soil colloids by isomorphous substitution of H^+ or Al^{3+} ions in silicate minerals which form the exchange sites. The permanent acidity (exchangeable) is due to the formation of polymers of Fe^{3+} and Al^{3+} ions with soil organic matter. The processes of laterite (Alfisols, Ultisols) and podzol (Spodosols) formation are the soil forming processes which control the degree of acidity. Humic, hymetamalonic and fulvic acids of humus contribute to the soil acidity in various ways. Murthy et al. (1976) prepared the acid soil map of India and established the relation between pH and different soil taxonomic categories.

Soil acidity of the Himalayan region was studied by Dhir (1967). He identified three types of rocks associated with soil acidity namely, metamorphic rocks at higher Himalayas, sedimentary and metamorphic rocks in middle and lower Himalayas, and Shiwalik sediments of the Tertiary period in sub-Himalayan zone. Acid soils of the Peninsular India with mean annual rainfall (MAR) more than 1500 mm and geological strata of Archean granite and gneiss and sedimentary of Vindhyan and mixed Dharwarians are associated with natural vegetation consisting of tropical moist deciduous and moist semi evergreen forests (Raychaudhuri and Govindarajan, 1971). The acidity of Assam valley and north eastern India is due to aggradation and degradation work of Brahmaputra and its tributaries compounded by the varying valley elevation ranging from 100-300 m (Nayak et al., 1996; Gangopadhyay et al., 2001). Bhattacharyya et al. (1994) identified the presence of kandic horizon in highly weathered low base saturated acid soils of Manipur and Meghalaya. High MAR (>2000 mm) associated with dense, mixed, semi-evergreen and wet, deciduous, forest influenced the formation of soil acidity. On the contrary, the formation of acidic Mollisols in association with the acidic Alfisols under sparse forest in the basaltic landscape under HT (Humid Tropical) climate has been explained in terms of the presence of Ca-zeolite (Bhattacharyya, 2014).

Coastal soil acidity (Kerala in south-west and deltaic area of Sunderbans in the east) is due to the influence of sandy beach of coastal Sunderbans and flat alluvial tracts along the river deltas, lagoons and estuaries with humid tropical climate and >1500 mm precipitation associated with mangrove forests (Murthy et al., 1976; Verghese et al., 1970). In Kerala, Nambiar et al. (1966) mentioned soils with pH as low as 2.1, and Verghese et al. (1970) referred to *Pokkali* and *Kari* soils with pH of 3.1. All these extremely acid soils of Kerala have high amount of organic matter and sulphate present in them. The acid sulphate soils of coastal Konkan showed a pH range of 3.9 to 4.1.

Methodology

The LANDSAT Imagery (FCC) (1:250,000 scale) was interpreted for landform analysis and later transferred on Survey of India topographical sheets (1:250,000) to make the base maps for ground checking. The mapping unit consists of soil association. Association more than one soil type in a polygon is representative of one dominant and another sub-dominant unit with respect to relative coverage in

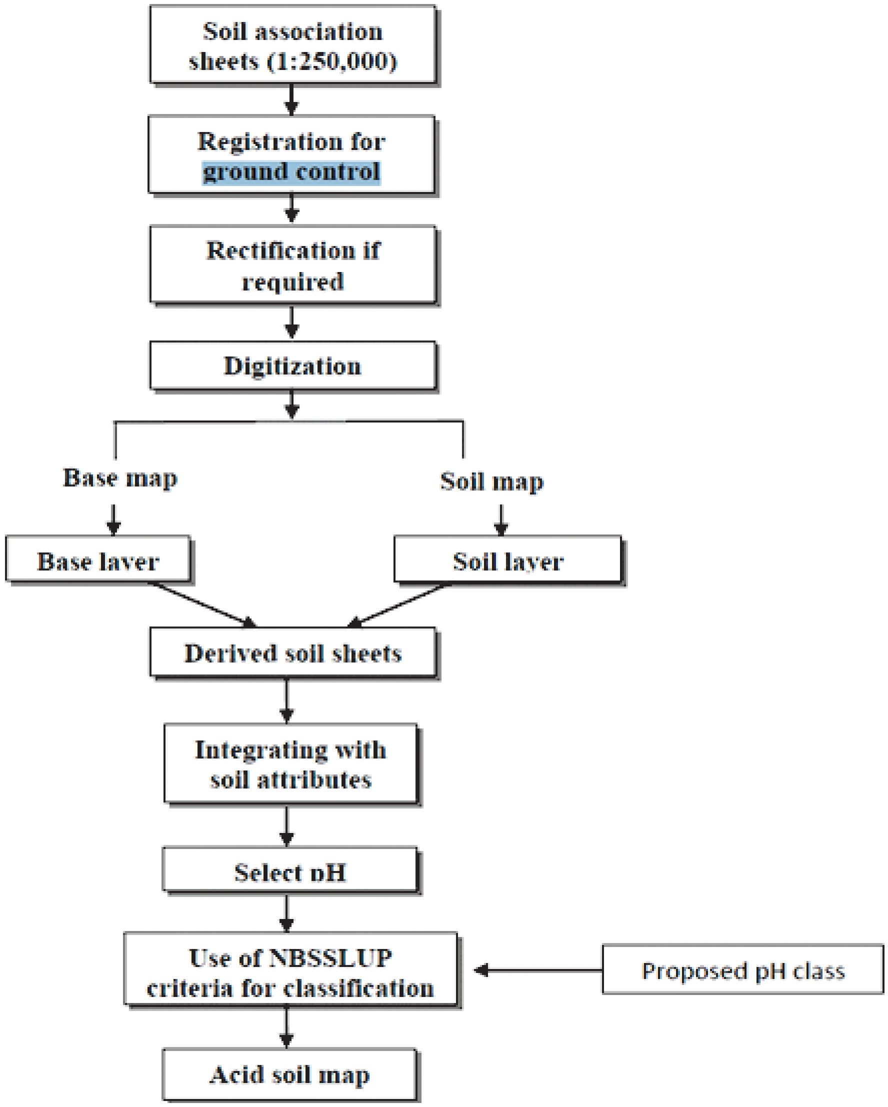

Figure 1. Schematic diagram showing steps in preparation of acid soil map

that polygon. Normally if there are two associations, the dominant and sub-dominant soils occupy 60 and 40% area, respectively. The criteria for soil association and soil mapping unit delineations reflect on the pedological relationship within the landscape (Sehgal, 1993). The data processing for acid soil delineation in GIS was carried out using the sequences represented in diagram (**Figure 1**).

Digitization of soil map in GIS for deriving digital soil resource information included creating and updating the soil resource data base (spatial and non-spatial) and digitization of soil information to the level of family association (of soil properties). The methodology also consisted of geo-referencing, attribution of polygons, and linking of non-spatial data with soil polygons and their area analysis.

Types of Soil Acidity in India

Acid soils have been classified based on pH (1: 2.5:: soil: H_2O) value of soils. Acid soils have been subdivided into different categories by different agencies (**Table 1**). As per the criteria of NBSS&LUP, total area of 93 Mha comes under different categories of acidity (**Table 2**).

Strongly acid soils (6.35% of TGA), occur mainly in the Eastern Himalayan region and to a very small extent in the Western Ghat region of Kerala. The moderately acid soils (26% of TGA) are common in the north-eastern hill region including Sikkim and the eastern plateau region comprising of the Dandakaranya (Bastar region in Chhattisgarh), Chotanagpur plateau (Jharkhand) and some hilly areas of Madhya Pradesh. These are also spread in

Table 1. Proposed soil reaction (water pH) classes of acid soils in India

Class of soil acidity	pH values (USDA)*	pH values (China)**	Proposed pH class***
Extremely acid	<4.5	-	-
Very strongly acid	4.5 -5.0	-	-
Strongly acid	5.1 - 5.5	< 4.5	< 4.5
Moderately acid	5.6 - 6.0	4.5 - 5.5	4.5 -5.5
Slightly acid	6.1 - 6.5	5.5 - 6.5	5.5- 6.5

*USDA (1957); ** Soil maps and databases of China (Zhang et al., 2008); *** based on SRM mapping criteria (Maji et al., 2012)

Table 2. Area under different categories of acid soils in India

Acidity class	Soil pH	Area under different categories	
		Mha	Percent of total
Strong	<4.5	6	6
Moderate	4.5-5.5	24	26
Slight	5.5-6.5	63	68
Total		93	100

the western Ghats from Maharashtra to Kerala and the western Himalayan regions including Himachal Pradesh, Uttarakhand and parts of Jammu and Kashmir. The western coastal areas comprising of Kerala, Maharashtra and very small areas of Gujarat also show soils with moderate acidity. Most of the acid soils in India are classified as slightly acidic (~68 % of TGA) which are mainly spread in the western Himalayan region, Chotanagpur plateau, Bundelkhand region, lower Gangetic plain, Odisha plain and coastal areas, Brahmaputra and Wainganga valley, Vindhyaan range, and the eastern parts of Madhya Pradesh. Soil acidity is also observed in Tamil Nadu uplands, Karnataka plateau and coastal Maharashtra and parts of Malwa plateau (**Tables 3 and 4; Figure 2**).

Table 3. Distribution of acid soils in different agro-ecological sub regions (AESR)

AESR no.	Area		AESR no.	Area	
	Mha	Percent of total		Mha	Percent of total
1.2	0.002	0.00	13.1	1.75	1.88
3.0	0.23	0.25	13.2	0.26	0.28
4.3	0.20	0.21	14.1	0.45	0.48
4.4	1.79	1.93	14.2	4.84	5.21
5.2	1.25	1.34	14.3	0.68	0.73
6.1	0.12	0.13	14.4	0.49	0.53
6.2	0.54	0.58	14.5	0.57	0.61
6.3	0.23	0.25	15.1	2.05	2.21
6.4	0.85	0.92	15.2	1.74	1.87
7.1	0.16	0.17	15.3	0.81	0.87
7.2	1.27	1.37	15.4	1.46	1.57
7.3	0.11	0.12	16.1	0.16	0.17
8.1	1.49	1.60	16.2	0.94	1.01
8.2	0.87	0.94	16.3	6.20	6.68
8.3	3.42	3.68	17.1	4.57	4.92
9.1	0.16	0.17	17.2	4.97	5.35
9.2	0.87	0.94	18.1	0.40	0.43
10.1	2.28	2.45	18.2	0.40	0.43
10.2	0.44	0.47	18.3	1.74	1.87
10.3	2.64	2.84	18.4	1.06	1.14
10.4	3.30	3.55	18.5	0.97	1.04
11.0	10.77	11.60	19.1	0.78	0.84
12.1	9.84	10.60	19.2	5.47	5.89
12.2	1.63	1.75	19.3	1.47	1.58
12.3	4.10	4.41	**Total**	**92.97**	**100**

Table 4. Selected acid soils and their properties

Soils	Region	Horizon	Depth (cm)	Clay (%)	Organic carbon (%)	pH		Cation exchange capacity [cmol $(p^+)kg^{-1}$]	Base saturation percent (BSP)	Soil Taxonomy
						H_2O	KCl			
Mawshun	Perhumid East Khasi Hills	A	0-14	12.7	1.70	4.7	-	6.67	27.0	Humic Dystrudepts
		A2	14-32	12.1	1.10	4.3	-	5.10	29.0	
		Bw1	32-55	13.2	0.85	4.2	-	4.70	19.0	
		Bw2	55-75	11.9	0.50	4.1	-	3.90	19.0	
		Bw3	75-125	10.5	0.25	4.6	-	3.90	19.0	
Aharbal	Cold arid, Anantnag district, Jammu and Kashmir	A11	0-12	7.5	3.92	6.4	-	5.98	70.9	Typic Argiudolls
		A12	12-24	5.3	1.89	6.3	-	2.17	96.3	
		AB	24-46	9.8	1.11	6.1	-	6.25	90.1	
		Bt1	46-67	13.3	1.01	5.7	-	8.97	79.3	
		Bt2	67-100	19.5	0.99	5.4	-	12.24	80.4	
Pusaro	Dry/Moist sub-humid, Santhal Parganas, Jharkhand	A	0-9	19.9	0.26	5.1	4.3	8.50	55.0	Typic Paleustalfs
		AB	9-30	26.6	0.23	5.5	5.0	8.80	70.0	
		BA	30-48	31.8	0.13	6.3	5.7	9.10	76.0	
		Bt1	48-73	32.5	0.10	6.3	5.9	9.60	90.0	
		Bt2	73-91	33.7	0.10	6.5	5.6	10.40	86.0	
		Bt3	91-114	33.9	0.08	6.5	5.7	11.40	82.0	
		Bt4	114-141	37.6	0.07	6.5	5.6	13.30	80.0	
		BC	141-186	40.6	0.05	6.3	5.5	14.30	82.0	
Tyama gondalu	Sub-humid, Nelamangala, Bangalore	Ap	0-13	12.8	0.50	6.8	5.5	2.90	93.0	Kandic Paleustalfs
		Bt1	13-34	40.1	0.46	5.9	4.7	8.00	75.0	
		Bt2	34-80	43.3	0.50	6.1	5.0	8.70	79.0	
		Bt3	80-110	48.0	0.49	6.5	5.2	9.10	83.0	
		Bt4	110-160	49.7	0.36	6.5	5.4	9.40	86.0	
Kanjirapally	Moist Sub-humid, Kottayam, Kerala	Ap	0-13	33.0	2.24	4.4	4.3	17.00		Ustic Kandihumults
		Bt1	13-32	39.5	1.63	4.4	4.3	0.14	8.0	
		Bt2	32-56	38.0	1.17	4.5	4.3	0.14	7.0	
		Bt3	56-83	40.5	0.95	4.5	4.4	0.14	6.0	
		Bt4	83-112	36.0	0.83	4.4	4.4	0.14	8.0	
		Bt5	112-150	34.5	0.06	4.4	4.4	0.14	13.0	
Sanjhari	Sub-humid, Raipur	A	0-12	30.4	1.48	5.0	-	7.50	85.0	Typic Ustropepts
		Bw1	12-35	30.6	1.21	5.2	-	8.50	88.0	
		Bw2	35-63	30.6	1.01	5.2	-	8.50	88.0	

Distribution of acid soils is highest in sub-humid agro-eco region (dry and moist); area in this region is 53.41% of the total acid soils (92.97). Soils with pH less than 4.5 are represented by deep yellowish brown soils (Humic Dystrudepts) supporting forests in the East Khasi district of Meghalaya. These are low activity clay soils and occur on an escarp slope in humid condition. Another group of strongly acid soils **Kanjirapally** series (Ustic Kandihumults) occur on mound and hills in Kottayam representing rainfed ecosystem of Kerala. These deep, dark reddish brown soils are formed in humid pedo-edaphic environment and represent 19.1AESR. Soils with pH group (4.5-5.5) are represented by **Sanjhani** series (Typic Ustropepts) of Dhamtari district of Chhattisgarh. These are moderately deep soils of sedimentary origin occurring on undulating plateau and support forests and grasses. The **Pusaro** series (Typic Palestalfs) represents pH group (5.5-6.5) occurring on gently sloping peniplained plateau in Santhal Parganas district of Jharkhand. These are deep, yellowish red soils with clay content ranging from 19.9 to 40.6% in different horizon and are prone to crusting.

Spatial distribution of the acid soils (**Table 4; Figure 2**) indicates that the largest area of these soils (about 10.77 Mha) occurs in AESR 11.0. The moderately acid soils (pH 4.5-5.5) in this AESR occupy 2.99 Mha (27.8%) and the rest are slightly acidic (pH 5.5-6.5). Moderately acid soils are represented by **Urhje** soil series (Typic Haplustalfs) which belongs to the eastern Dandakarnya plateau and is developed on granite-gneiss at an elevation of 360 m above mean sea level (amsl). It falls under dry to moist sub-humid

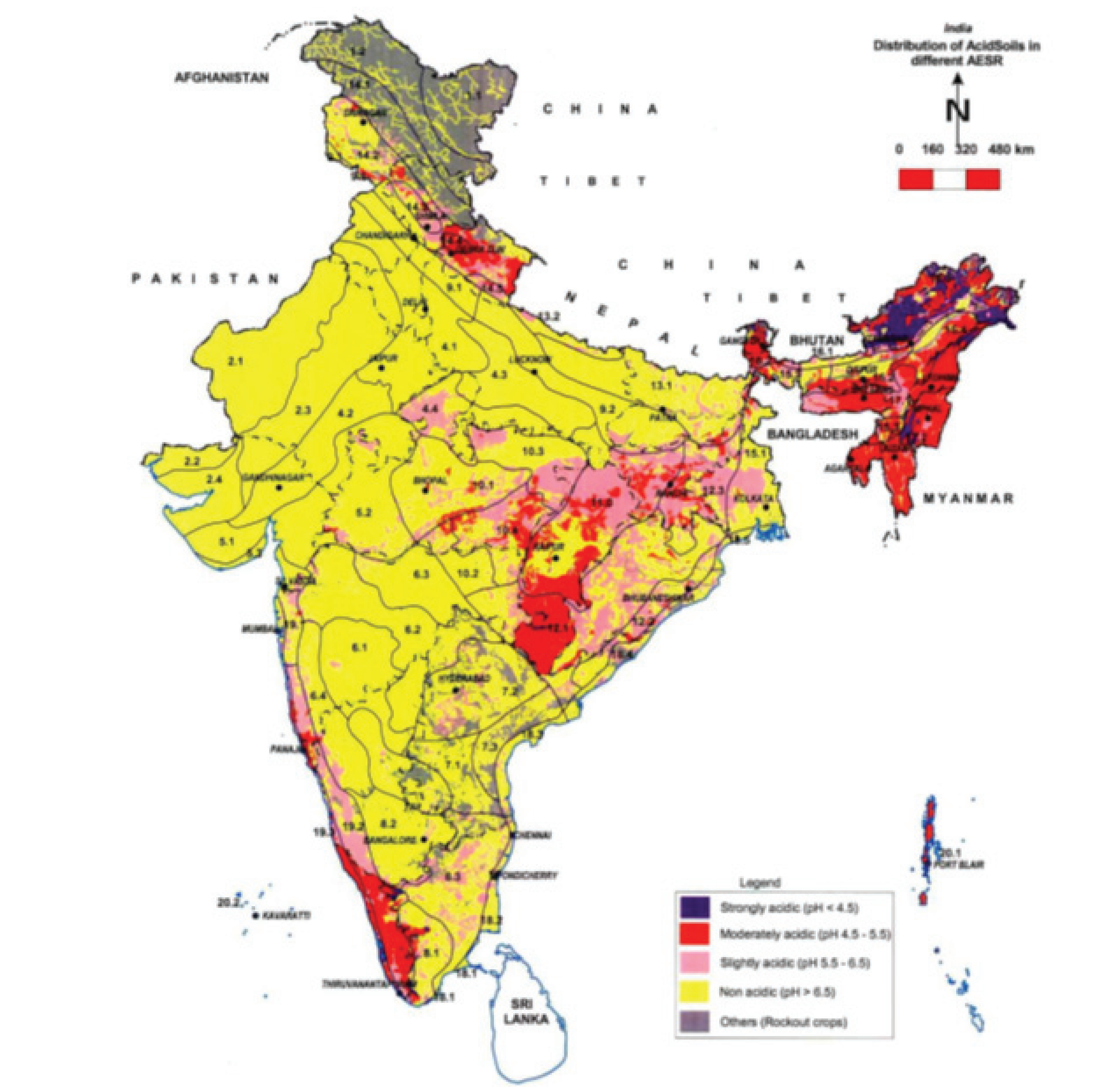

Figure 2. AESR-wise spatial distribution of acid soils in India

(Transitional) climatic regime with rainfall of 1400 mm with mean annual temperature of 25.7 ºC. Soils are well drained with moderate permeability supporting natural vegetation consisting of *Tectona grandis*, *Lagerstroemia passiflora* and *Diospyros melanoxylon*. These soils are cultivated for paddy, wheat and gram. The **Mayapur** series (Typic Haplustalfs) represents slightly acidic soils of 11.0 AESR. This series occurs in the Ambikapur district of Chhattisgarh of eastern Chotanagpur plateau (undulating) and has developed over granitic gneiss and occurs at an elevation of 560 m amsl. These soils are well drained (pH 6.3 to 6.6) and are mainly under forest vegetation comprising of species like *mahua* (*Madhuca indica*), bamboo (*Bambusa vulgaris*), *sal* (*Shorea robusta*) and *ber* (*Ziziphus jujuba*). AESR 12.1 comprising the Garjat hills, Dandakaranya and Eastern Ghats with moist sub-humid climate has deep loamy red and lateritic soils in the states of Chhattisgarh, Orissa and Maharashtra. The AESR has about 9.84 Mha of acid soils which covers 55.9% of total area of this AESR (17.6 Mha) and about 10.6% the acid soils of India. Area under slightly acidic soils is 6.82 Mha. Moderately and strongly acid soils cover 2.89 and 0.13 Mha, respectively mostly in AESR 12.1 and are represented by benchmark soils of **Chaugel** series (Plinthustalfs) having pH ranging from 5.7 to 6.2. The soils are with pale brown to dark clay loam A horizon and light yellowish brown to brownish yellow gravelly sandy clay loam to gravelly sandy clay B horizon. The soils are developed on weathered feldspathic quarzite, schist and granite gneiss on level plain at an elevation of 500 to 600 m amsl. Climate is sub-humid tropical with total rainfall 1400 mm and annual temperature of 25.7 ºC. The soils are well drained with moderate permeability and are under forest with vegetation consisting of mostly teak (*Tectona grandis*), *Cassia* spp. and *sal* and occasionally mustard and minor millets are cultivated on these soils. The soils of other series **Durgkondal** are slightly acidic (pH 5.6-5.5). **Sunugarh** series (Aquic Haplustepts) with pH ranging between 6.2-6.7 have formed on alluvium on nearly level alluvial plains at an elevation of about 18 m amsl with rainfall of 1520 mm and mean annual temperature of 27.0 ºC. These soils are imperfectly to poorly drained with slow permeability and are cultivated to paddy. Natural vegetation consists of *Phoenix sylvestris* (date palm) and *Bombax mala Baricum* (semul). In the *rabi* season with conserved moisture adaptable crops like *rabi* paddy, black gram, sesame, finger millets and maize can be grown. The other soil series of the AESR are **Bararakhaman** (moderately acid), **Kusumi** (strongly acid), **Laxmiprasad** (moderately acid), and **Parichhal** (moderately to very strongly acid). The AESR 16.3 has acid soils with an area of 6.20 Mha (6.68%) and occur in eastern Himalayas having per-humid climate in state of Arunachal Pradesh. The soils are mostly strongly acidic in nature (pH <4.5). Distribution of acid soils shows that 4.0 Mha area is strongly acidic, 1.4 Mha moderately acidic and 0.8 Mha is slightly acidic. Strongly acid soils (4.4 to 4.8) are represented by **Ngasajut** series (Typic Palehumults). These occur on foothills having developed on shale. These soils are very deep, well drained, fine textured with gravels in sub-soil and are mostly under forest. The AESR 19.2 of central and south Sahyadri represents moist sub-humid to humid transitional climatic type covering the states of Kerala, Karnataka, Goa and Maharashtra (parts). Total area under acid soils in the AESR is 5.47 Mha (5.89%) of which 3.46 Mha is slightly acidic; strongly and moderately acid soils are spread over 0.22 and 1.79 Mha area, respectively. The AESR is represented by **Trivandrum** series (Ustoxic Dsytropepts) which is strongly acidic (pH 4.5) characterized by reddish yellow to yellowish red colour. The soils are formed on gneissic rocks and occur on laterite mounds at an elevation of 600 m amsl. The mean annual temperature and rainfall are 27.1 ºC and 1840 mm, respectively. These soils are well drained and are cultivated to tapioca, ginger, coconut, pepper and cashew. Natural vegetation is *Rupatorium* spp. (ayapana) and grasses. These soils are gravelly. Due to low pH and high content of sesquioxides, phosphate fixation may pose problems. The other soil series namely, **Mannam** (Ustic Kannaplohumults) has pH 4.3 while Kanjrapally (Ustic Kandihumults) has pH 4.4. The representative soil series of Karnataka state includes **Channasandra** (Kandic Paleustalfs). It is dark red in colour and slightly acidic (pH 6.0-6.7). These gravelly well drained soils have developed over granite-gneiss on undulating pediment surfaces at an elevation of 850-900 m amsl with mean annual temperature 23.6 ºC and rainfall 750-850 mm. These soils are mainly cultivated to rainfed finger millet and pulses. Natural vegetation consists of *Pongamia* spp. (*Karanja*) and *Ficus* spp. (*banyan*). The other benchmark series include **Guttapalli** (slightly acidic), **Hugaluru** and **Vijapura** (strongly acidic) and **Rayalpadu** (moderately acidic). Goa state is represented by **Arukot** series (Kandic Paleustalfs) developed on schist on 3 to 8% slope in inter-hill basins of western Ghats. A variety of crops like coconut intercropped with banana, pineapple and vegetables can be grown. Bench terracing is necessary to control the soil erosion. The other soil series are **Gavane** (moderately to slight acidic); **Karven** and **Saligao** (moderately acidic), and **Metavada** (slightly acidic). Acid soils of Maharashtra are mostly located in the coastal areas (Sindhudurg and Ratnagiri districts). These are slightly acidic (pH 5.7 6.1) and **Nandgaon** series (Typic Haplustepts) developed over basalt represents the zone. These severely eroded soils occur on undulating lands at an elevation of 100 m amsl with rainfall more than 3000 mm. The soils are well drained and are under pasture land.

AESR 17.1 is represented by **Mawlyndair** soil series (Humic Dsystrudepts) with pH 4.5-5.1. These soils are located in East Khasi hill district of Meghalaya developed on sandstone and occur on steep to very steep slopes of Meghalaya at an elevation of 1000 to 1400 m amsl. The mean annual temperature is 17.5 ºC with annual rainfall of 11418.7 mm. These are well drained soils and support dense forest with occasional *jhum*. Lower slopes are cultivated to oranges and pineapple. AESR 17.2 is represented by **Tuilet** series of Mizoram (Ultic Hapludalfs) with pH 4.4-4.5. These soils occur on steep slopes of the hills and are well drained. Mean annual air temperature is 20.1 ºC and annual rainfall is 2170 mm.

AESR 14.2 represents western Himalayas with transition from moist to dry sub-humid climate and covers states of Jammu and Kashmir and Himachal Pradesh. Area under acid soils is about 5.21% (4.84 Mha). Of the total acid soils in the subzone, 1.19 Mha is moderately acidic and 3.65 Mha is slightly acidic. Soils of the region are represented by **Rapura** series (Typic Paleudalfs) in Himachal Pradesh which is slightly acidic in nature. These are deep soils developed on very gently to moderately sloping piedmont plain of lesser Himalayas at an elevation of

1200 m amsl. The climate is sub-humid with mean annual temperature of 19 °C and annual rainfall of 1744 mm. These well drained soils are cultivated to maize and wheat. Natural vegetation consists of *Acacia catechu* (*khair*), *Acacia* spp. (*babul*) and *Pinus* spp. (pine). These soils are capable of producing high yield with proper soil conservation measures. The other AESR having acidic soils is AESR 12.3 (4.41%) of Chotanagpur plateau with moderately acid soils (3.58 Mha) and slightly acid soils (0.52 Mha). AESR 8.3 comprising of Tamil Nadu uplands constitutes about 3.68% of acid soils, while area under acid soils in AESR 10.4, AESR 15.1 and AESR 10.1 is 3.55, 2.21 and 2.45% of the total area, respectively.

Management of Acid Soils

Management of acid soils should be directed to enhance crop productivity either through addition of amendments to correct the soil acidity or by manipulating the agronomic practices depending upon climatic and edaphic conditions. Acid soils under rice monocropping require no lime application but for rice-pulse, rice-oilseed rotations application of lime is a must to get higher production. Among the naturally occurring lime sources, calcitic and dolomitic lime stones are important. Out of the total recoverable cement grade, 32.5% are low grade of dolomite limestone and may be used for reclamation.

Several industrial wastes such as steel mill slag, blast furnace slag, ferrochrome slag, lime sludge from paper mills, press-mud from sugar mills using carbonation process, cement kiln wastes, precipitated $CaCO_3$ from fertilizer factories have been successfully and economically used as amendments for acid soils which are eco-friendly (Panda and Das, 1971; Vithal Rao et. al., 1976). It is estimated that for every tonne of hot metal about 500 kg of blast furnace slag is produced. Waste from the steel mills located in different places of country can be fruitfully utilized. Basic slag with less than 1% of free iron content and ground to 80 mesh can be promoted as cheap amendment material whose requirement is almost 1.0 to 1.5 times of lime (Panda and Das 1971).

Crops (mostly legumes) respond well to lime if they are raised after maize, sorghum and wheat. High response group (pigeon pea, soybean, cotton, etc.), medium response group (gram, lentil, peas, maize, sorghum and field peas etc.) and low or no response group (paddy, small millets, mustard etc.) of the crops have been recognized (Mandal, 1976). In fact, short duration upland rice can tolerate acidity. Minor millet (*Panicum miliare)* and finger millet (*Eleusine coracana)* are quite tolerant to acidity. Pigeon pea, soybean and cotton are sensitive to soil acidity and respond well to liming. Crop varieties tolerant to acidity are listed in **Table 5**. It is reported that lime applied in furrows @ 10% (varying from 5 to 20%) of lime requirement (LR) to each crop, is economical.

Experiment conducted on acid (pH 5.2) Alfisols of Kharagpur with application of 3 t lime along with 120 kg N, 60 kg P_2O and 40 kg K_2O ha^{-1} to the rainfed upland rice (variety MW-10) revealed that band placement of 'N' fertilizer in four splits increased the rice yield from 3.0 to 3.7 t ha^{-1}. But the effect of the lime in raising the yields of rice and wheat grown in a sequence was almost insignificant even after successive three rotations.

In humid tropical climates, liming is generally recommended for strong to moderately acid soils.

Table 5. Crop varieties relatively tolerant to soil acidity (pH < 5.5) in different states

Acid soil region state	Crop	Varieties
Assam	Rapeseed Summer green gram	Varuna, Sonmukhi K851, Sonmugu
Himachal Pradesh	Soybean *Gobhi sarson*	Bragg, Pb1, Harasoya ONK1, HPN3
Jharkhand	Black gram	KU 301
Kerala	Vegetable cowpea Cowpea (bush type)	Bhagyalakshmi V 16
Meghalaya	French bean	HUR 15
Odisha	Groundnut, Pigeon pea	Smruti, Upas-120
West Bengal	Mustard Wheat	Sanjukta, Pusa Bold K 9107, PBW 343

Contribution of Al^{3+} ions to soil acidity is significant in the soils of humid climate. Researchers have reported that in some moderately acidic Alfisols of the Western Ghats, crop response to applied lime is not observed because of the presence of Ca-zeolites in these soils (Pal et al., 2014). Aluminium toxicity to plants is a constraint in acidic Oxisols, Ultisols and Dystropepts of Kerala, Goa, Tamil Nadu, Karnataka and North-Eastern Hills. Liming is often recommended to correct soil acidity and improve nutrient availability or to bring exchangeable aluminium level in the soil to <1 mg kg^{-1} (Sanchez, 1976) for maintaining sustained productivity as a result of general improved nutrient availability (Nayak et al., 1996). The KCl extractable aluminium is used for liming tropical acid soils. It is intriguing that despite being equally strongly acidic, Ultisols and Dystropepts of North Eastern Hills (NEH), Ultisols of Kerala, and Alfisols of Goa have varying KCl-extractable exchange acidity.

The lime requirement (LR) of these acidic soils varies widely. Pal et al. (2014) indicated that the lime requirement is around 1 t lime ha^{-1} for Ultisols of Meghalaya, and for Dystrochrepts and Ultisols of other states of NEH, it ranges from 4 to 12 t ha^{-1}. Such a low LR (<1 t ha^{-1}) may be expected for zeolitic soils as soil solution would remain adequately high in soluble Ca-ions due to dissolution of Ca-zeolite. The role of zeolites and in some cases of gibbsite in modifying the lime requirement of acid soils needs to be understood to recommend lime on the basis of KCl exchangeable acidity. Highly acidic pH Ultisols of Kerala, Karnataka, Tamil Nadu and NEH and moderately acidic Alfisols of Goa, Karnataka and Tamil Nadu have very high $BaCl_2$-TEA extractable acidity; in contrast to that they are low to very low in 1*N* KCl exchangeable acidity. This suggests that Al^{3+} ions released during the humid tropical weathering are trapped as $Al(OH)_2^+$ ion in the interlayers of 2:1 minerals. Both smectites and vermiculites act as sinks for aluminium and thus protect the biota from Al toxicity.

Agro-forestry is an emerging option in acid soils of North-Eastern Hills region and Western Ghats. Sericulture–based agroforestry and aquaculture based agro–forestry, horticultural crops, spices, timber farming, regenerative forestry, silvi-pastoral system, dairying and goat farming can enhance the income of people of acid red and lateritic soils regions.

These soils develop in humid and per-humid areas due to excessive leaching of cations with high rainfall, resulting in lowering of pH and loss of soil fertility, and can be reclaimed by addition of chemical amendments like lime. For assessing area under acid soils, soil maps of different states on 1: 250,000 scale were digitized in the GIS format. The non-spatial (attribute) data on pH values were linked to master soil layer to generate soil reaction (pH) map of India, which was reclassified to produce a soil acidity map of India. The acidity map of India, thus produced, facilitates understanding of spatial distribution and pH status of soils in different parts of India. Based on the range of pH values, the map has been reclassified as strongly acidic (pH < 4.5); moderately acidic (pH 4.5–5.5); slightly acidic (pH 5.5–6.5) and non-acidic (pH > 6.5).

Conclusions

In India, nearly 92.97 Mha of land suffers from various degree of soils acidity and impaired soil fertility. Indeed, development of acidity in soils is a sign of chemical degradation. While estimating the area degraded by acidity, soils with strong (pH< 4.5) and moderate acidity (pH 4.5–5.5) only were considered. With this assumption, it was estimated that about 6.98 Mha area is affected by soil acidity (ICAR-NAAS, 2010). Present treatise updates the information on acid soils in different AESRs, which can help in prioritizing reclamation programme of soil acidity. Soils of hot tropical climate in the states of Kerala, Goa, Karnataka, Tamil Nadu and NEH areas are strong to moderately acidic Alfisols, Ultisols and Mollisols; and their further weathering under hot tropical climate would finally end up in Ultisols with considerable amount of layer silicate minerals (Pal et al., 2012). These acid soils are rich in organic carbon and respond to management interventions and support luxuriant forest vegetation, horticultural, cereal crops, tea, coffee and spices (Sehgal, 1998), which suggests that standard scale of qualitative terms of pH ranges still remain as useful verbal description only. Therefore, it would not be prudent to class them as chemically degraded soils (Pal et al., 2014).

At present, the extent of degradation in terms of soil acidity in Ultisols, Alfisols, Mollisols and Inceptisols is not at an alarming stage. But they require improved management (IM) practices developed through sustained researches to upgrade and maintain their nutrient status and make efficient use of soil water to sustain crop productivity at an enhanced level. The improved management system package includes improved seeds, NPK fertilizers, micronutrients, FYM and use of legumes in the cropping sequence, lime, improved water management, land development and the implementation of the soil conservation practices for acidic Alfisols, Ultisols and Inceptisols (Datta, 2013). There are many trees and shrubs suitable for acid soils. Some of the best known acid tolerant tree species are – *Albizia* sp., *Alnus nepalensis*, *Erythrina* sp., *Gmelina arborea, Sesbania* sp. etc. Many of these tree species in association with mycorrhizae and rhizobia have a great potential for growth and production on such soils. These tree species have capacity to ameliorate aluminum toxicity and increase crop yields on acid soils.

Presently there is no subsidy given to the land treatment except reclamation of alkali Soils (RAS). Treatment of acidic lands through subsidized dolomite scheme in the following AESR namely 4.4, 8.3, 10.1, 10.4, 11.0, 12.1, 12.3, 13.1, 15.1, 15.2. 16.3, 17.1, 17.2, 18.3, 19.2 will enhance the crop productivity. Basic slag with <1% of free iron content and ground to 80 mesh can be promoted as cheap amendment material whose requirement is almost 1.0 to 1.5 times of lime requirement. National Rainfed Area Authority (NRAA), National Land Use and Conservation Board (NLCB), National Wastelands Development Board (NWDB), National Afforestation and Ecodevelopment Board (NAEB), Krishi Vigyan Kendras (KVKs), Non Governmental Organizations (NGOs) and various extension agencies can help in implementing the Integrated Management programmes in conjunction with map of acid soils arrayed in different AESRs. This can act as a great facilitator in terms of meeting the food needs of burgeoning Indian population.

Acknowledgements

Authors are grateful to Dr. D. K. Pal for his constructive criticism and suggestions.

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