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Forms of Acidity in Soils Developed on Different Landforms along an Altitudinal Sequence in Nagaland, India

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The present investigation characterizes different forms of soil acidity in surface soils along an altitudinal sequence of Nagaland state of India and their relationship with soil properties. One hundred surface soil samples were collected from four distinct landforms *viz*., highly dissected high hills (>2000 m above mean sea level, MSL) with very steep slopes (>33%) (HDHH), medium and lower hill ranges (1000-2000 m above MSL) with steep slopes (15-33%) (MLH), moderately dissected piedmonts (500-1000 m above MSL) with moderately steep slopes (10-15%) (MDP) and inter-hill valleys (<500 m above MSL) with gentle slopes (3-5%) (IHV). The soils had dominance of pH dependent acidity followed by exchangeable acidity in all the landforms. Significant correlation was observed between organic carbon (OC) and pH dependent acidity (r = 0.83**) and exchangeable aluminium percentage and exchangeable acidity (r = 0.91**). High OC content in hills and piedmonts due to abundant forest vegetation is likely to generate more variable charges and responsible for high pH dependent acidity, whereas, high aluminium saturation in soil due to rapid weathering of aluminium rich parent material is responsible for exchangeable acidity. The exchangeable aluminium percentage appeared to be a reliable indicator of soil acidity.

Key words: Catenary sequences, inherent soil properties, landforms, soil acidity, variable charges

Formation of acid soils is a natural process, being induced by acid parent materials, high and intense rainfall and vegetative covers (Ritcher 1986). Acidification results in release of aluminium (Al) by ion exchange mechanism increasing its toxic concentration in soil solution which inhibits plant growth. The soils of North Eastern Regions (NER) of India are well known for their strongly acidic reaction with special reference to the state of Nagaland (Sharma *et al.* 2006). It is noted that 11.2 million hectare (Mha) areas of NER of India are occupied by chemically degraded acid soils (pH < 5.5), being most intensified in Nagaland (97% of area) (Sharma *et al.* 2006). Systematic information on soil acidity *vis-à-vis* exchange properties is sporadic only in a few states of NER (Sen *et al.* 1997). It is evident from the soil-landform studies that landform variability has immense impact on inherent soil properties *vis-à-vis* soil acidity (Birkland 1984). Study of soil acidity in elevational sequence has proved to be highly useful to comprehend their nature and formations (Mládková *et al.* 2004). Though soil acidity is a burning issue of Nagaland, there is very limited and scanty information on its genesis and distribution (Patton *et al.* 2007; Amenla *et al.* 2010). The study of different forms of soil acidity and their relationship with other soil properties of Nagaland in altitudinal sequence may enlighten on their genesis and formation under different landform situations.

Thus, in the present investigation, an attempt has been made to study the forms of soil acidity and their relationship with soil properties along an altitudinal sequence of Nagaland.

Materials and Methods

Nagaland is a hilly state of India, sharing its borders with the state of Assam to the north and west, Manipur to the south, Arunachal Pradesh and the international boundary with Myanmar to the east (Fig. 1). The state is situated in the geographic setting

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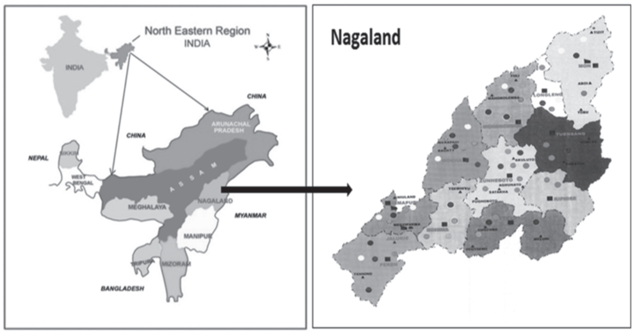

Fig. 1. Location map of Nagaland, India

between 25°06′ to 27°04′ N latitudes and: 93°21′ to 95°15′ E longitudes, covering a total geographical area (TGA) of 1.6579 Mha (Statistical Handbook 2015). The state of Nagaland represents hilly terrains with three major physiographic divisions *viz.,* (i) high hills and mountainous region, (ii) the lower ranges and the mid slopes, and (iii) the foothills. The hills are highly dissected with moderate to very steep slopes with occasional formations of narrow strips of inter-hill valleys (Maji *et al.* 2000). The state belongs to warm to hot, humid to per-humid subtropical climate under the agro-ecological sub region of 17.1 (Velayutham *et al.* 1999). The soil moisture regime is udic. The temperature varies from 0 °C in winter to about 35 °C in summer depending upon elevation. The mean annual soil temperature (MAST) at higher elevations (more than 1000 m above MSL) ranges from 15 to 22 °C and more than 22 °C at lower elevations (less than 1000 m above MSL). Agriculture is the main occupation of the people, mostly practiced by traditional and primitive methods. In the state, the forest cover occupies 80.5% of TGA, whereas, net area sown covers only 21.8% of TGA and gross irrigated lands encompass only 4.7% of TGA. The single cropping system is prevalent in the state resulting in low cropping intensity of 110% (Statistical Handbook 2015). In the state, Ultisols (Hapludults and Paleudults) and Alfisols (Paleudalfs and Hapludalfs) are predominant in high and medium hills, whereas, in lower hills and piedmonts Inceptisols (Dystrudepts) are predominant. In inter-hill valleys Inceptisols (Dystrudepts) and Entisols (Udorthents and Udifluvents) are the dominant soil orders (Maji *et al.* 2000). The distribution of soil orders along catena indicates that landforms at high altitude may favour the formations of more matured soils due to high degree of weathering accelerated by rainfall and abundant vegetation, whereas, in inter-hill valleys younger soils are formed as a result of colluvial deposition.

In the present investigation, Survey of India Topographical sheets (on 1: 50,000 scale) (83-G/ 6,7,9,10,11,13,14,15; 83-K/1,2,5,6,9,10,13,14; 83-J/ 3,4,6,7,8,10,11,12,13,14,15,16; 83-N/ 1,2,3,4 and 83-O/ 1,2) were used as base maps to recognize four representative landform units along altitudinal sequence in the state *viz.,* (i) highly dissected high hills (>2000 m above MSL) with very steep slopes (>33%) (HDHH), (ii) medium and lower hill ranges (1000-2000 m above MSL) with steep slopes (15-33%) (MLH), (iii) moderately dissected piedmonts (500-1000 m above MSL) with moderately steep slopes (10-15%) (MDP), and (iv) inter-hill valleys (< 500 m above MSL) with gentle slopes (3-5%) (IHV). One hundred surface soil samples (0-25 cm) were collected from the aforesaid landform units in the altitudinal sequence (25 from each altitude) on random sampling basis covering whole state. The soils were analyzed for important physicochemical parameters *viz*., particle size distribution by International Pipette method; pH (1: 2.5 water and 1*N* KCl); ΔpH as pH in KCl minus pH in water, cation exchange capacity (CEC), sum of exchangeable bases (Sparks 1996), organic carbon (OC) (Walkley and Black 1934), exchangeable aluminium percentage (EAP) as exchangeable Al extracted by 1 *N* KCl divided by effective cation exchange capacity (sum of bases plus exchangeable Al) and multiplied by 100 (Nye *et al.* 1961), different forms of soil acidity *viz.,* exchangeable acidity by 1 *M* KCl (van Reeuwijk 1993), total potential acidity by $BaCl_2$-TEA at pH 8.0±0.2 (Hesse 1971) and pH dependent acidity by subtracting exchangeable acidity from total potential acidity (Coleman and Thomas 1967). The soil data base was fed into SPSS software (version 15.0) for Pearson's bi-variate analysis.

Results and Discussion

The soil characteristics and forms of soil acidity in the altitudinal sequence are depicted in table 1 and table 2.

Mechanical composition of soil

The mechanical composition of soils revealed that soils on HDHH were clay loam to silty clay in texture, whereas, the same on MLH and MDP were clay loam to silty clay loam and on IHV were clay loam in texture (Table 1). The sand content varied from 10.0% in HDHH to 30.6% in IHV, whereas, the silt fraction ranged from 34.8% in IHV to 52.1% in HDHH and clay fraction from 33.8% in IHV to 40.5% in HDHH. The increase in sand fraction and decrease

Table 1. Physicochemical properties of soils along altitudinal sequence of Nagaland

Sample No.	Sand (%)	Silt (%)	Clay (%)	Textural class	pH	Δ pH	SOC (g kg^-1^)	CEC [cmol(p+)kg^-1^]	Ca^{2+}	Mg^{2+}	K^+	Na^+	Sum of cations	ECEC	CEC/ clay
Highly dissected high hills (HDHH) (>2000 m above MSL)															
1	20.5	42.6	36.9	Cl	4.8	-1.2	30.1	5.2	1.1	0.8	0.3	0.1	2.3	6.3	0.14
2	22.6	44.5	32.9	Cl	4.9	-1.3	35.7	5.7	1.2	0.7	0.3	0.1	2.3	7.4	0.17
3	10.0	52.1	37.8	Sicl	4.3	-0.7	22.1	4.5	1.2	0.9	0.3	0.1	2.5	5.8	0.12
4	24.3	43.5	32.3	Cl	4.9	-1.3	39.4	6.9	1.1	0.9	0.3	0.1	2.4	7.9	0.21
5	20.8	43.0	36.2	Cl	4.9	-1.2	31.1	5.2	1.3	0.6	0.2	0.1	2.2	6.3	0.14
6	11.1	51.5	37.4	Sicl	4.3	-0.7	24.9	4.5	1.3	0.9	0.2	0.2	2.6	6.0	0.12
7	21.1	42.3	36.6	Cl	4.8	-1.2	30.4	5.2	1.0	0.8	0.3	0.2	2.3	6.4	0.14
8	11.9	50.6	37.5	Sicl	4.3	-0.7	25.9	4.5	1.5	0.7	0.3	0.1	2.6	6.0	0.12
9	23.6	42.9	33.5	Cl	4.9	-1.3	34.3	5.5	1.2	0.6	0.3	0.2	2.3	6.8	0.16
11	13.6	49.6	36.8	Sicl	4.4	-0.7	26.3	4.8	1.7	0.7	0.2	0.1	2.7	6.4	0.13
12	21.0	43.9	35.1	Cl	4.9	-1.2	32.2	5.2	1.0	0.8	0.3	0.1	2.2	6.4	0.15
13	23.6	42.9	33.5	Cl	4.9	-1.3	33.9	5.4	1.3	0.7	0.2	0.1	2.3	6.7	0.16
14	22.8	42.9	34.3	Cl	4.9	-1.3	32.9	5.2	1.1	0.8	0.3	0.1	2.3	6.6	0.15
15	22.6	44.6	32.9	Cl	4.9	-1.3	36.0	6.7	1.2	0.6	0.3	0.2	2.3	7.4	0.20
16	22.8	43.4	33.7	Cl	4.9	-1.3	33.6	5.2	1.3	0.7	0.2	0.1	2.3	6.7	0.16
17	22.8	43.7	33.5	Cl	4.9	-1.3	36.7	6.7	1.1	0.8	0.3	0.1	2.3	7.6	0.20
18	23.1	42.7	34.2	Cl	4.9	-1.3	33.2	5.2	1.3	0.7	0.2	0.1	2.3	6.7	0.15
19	22.7	44.0	33.2	Cl	4.9	-1.3	38.1	6.9	1.1	0.9	0.3	0.1	2.4	7.9	0.21
19	23.5	43.9	32.6	Cl	4.9	-1.3	35.0	5.5	1.2	0.8	0.3	0.1	2.4	7.0	0.17
20	22.6	44.7	32.7	Cl	4.9	-1.3	35.3	5.6	1.2	0.6	0.3	0.2	2.3	7.1	0.17
21	20.6	43.2	36.2	Cl	4.9	-1.2	31.5	5.2	1.0	0.8	0.3	0.1	2.2	6.4	0.14
22	12.8	46.7	40.5	Sic	4.4	-0.7	27.7	4.8	1.1	0.7	0.3	0.1	2.2	5.8	0.12
23	18.8	43.0	38.2	Cl	4.8	-1.2	29.7	5.2	1.0	0.8	0.2	0.2	2.2	6.2	0.14
24	23.7	42.9	33.4	Cl	4.9	-1.3	34.6	5.5	1.2	0.8	0.3	0.1	2.4	7.0	0.16
25	13.3	46.3	40.4	Sic	4.8	-1.2	29.0	4.9	1.1	0.7	0.2	0.2	2.2	6.2	0.12
Range	10-24.3	42.3-52.1	32.3-40.5	Cl-Sic	4.3-4.9	-0.7 to -1.3	22.1-39.4	4.5-6.9	1.0-1.7	0.6-0.9	0.2-0.3	0.1-0.2	2.2-2.7	5.8-7.9	0.12-0.21
Mean	19.9	44.9	35.3		4.8	-1.1	32.0	5.4	1.2	0.8	0.3	0.13	2.34	6.7	0.15
SD	4.6	2.9	2.4		0.2	0.2	4.3	0.7	0.2	0.1	0.05	0.046	0.14	0.6	0.028
CV (%)	23.3	6.5	6.9		4.7	20.9	13.4	12.9	13.5	12.8	17.8	35.8	5.8	9.0	18.3
Medium and low hill ranges (MLH) (1000-2000 m above MSL)															
1	15.5	49.2	35.3	Sicl	4.3	-0.6	14.5	4.3	1.6	1.1	0.4	0.1	3.3	6.9	0.09
2	26.7	39.1	34.2	Cl	4.5	-0.8	30.4	6.0	1.4	0.8	0.3	0.1	2.6	7.7	0.15
3	26.6	39.2	34.2	Cl	4.4	-0.8	29.0	5.8	1.2	0.9	0.3	0.1	2.5	7.3	0.15
4	26.1	39.7	34.1	Cl	4.5	-0.9	33.2	6.5	1.1	0.9	0.3	0.1	2.5	8.0	0.16
5	26.0	39.7	34.3	Cl	4.4	-0.8	27.7	5.7	1.5	0.7	0.2	0.1	2.5	7.1	0.14
6	17.0	46.8	36.2	Sicl	4.3	-0.6	14.5	4.5	1.7	1.2	0.3	0.3	3.5	7.4	0.10

7	26.2	39.4	34.3	Cl	4.4	-0.8	26.3	5.5	1.1	0.9	0.3	0.2	2.5	7.1	0.14
8	26.0	39.8	34.1	Cl	4.5	-0.9	34.6	7.1	1.5	0.7	0.3	0.1	2.5	8.2	0.18
9	26.1	39.6	34.3	Cl	4.5	-0.9	35.3	7.2	1.3	0.6	0.3	0.2	2.5	8.3	0.18
11	26.0	39.6	34.4	Cl	4.4	-0.8	25.9	5.4	1.5	0.6	0.2	0.1	2.4	6.9	0.14
12	26.1	39.7	34.2	Cl	4.6	-0.9	36.0	7.3	1.2	0.9	0.3	0.1	2.6	8.5	0.18
13	26.6	39.2	34.2	Cl	4.5	-0.8	29.7	6.0	1.5	0.8	0.2	0.1	2.6	7.7	0.15
14	24.0	40.9	35.2	Cl	4.3	-0.7	17.1	5.2	1.3	0.9	0.4	0.1	2.7	7.0	0.13
15	24.1	40.9	35.0	Cl	4.4	-0.7	22.1	5.3	1.4	0.7	0.3	0.2	2.6	7.0	0.13
16	26.7	39.3	34.0	Cl	4.5	-0.8	31.1	6.1	1.5	0.8	0.2	0.1	2.6	7.9	0.16
17	24.4	40.5	35.1	Cl	4.3	-0.7	17.9	5.2	1.3	1.0	0.4	0.1	2.8	7.2	0.13
18	24.3	40.7	35.0	Cl	4.4	-0.7	19.0	5.2	1.5	0.8	0.2	0.1	2.7	7.1	0.13
19	26.1	39.8	34.2	Cl	4.5	-0.9	33.9	6.6	1.1	0.9	0.3	0.1	2.5	8.0	0.16
19	27.3	38.8	33.9	Cl	4.6	-1.0	36.7	7.3	1.2	0.8	0.3	0.1	2.5	8.8	0.19
20	17.8	45.5	36.7	Sicl	4.3	-0.6	15.5	4.7	1.5	0.8	0.4	0.3	2.9	7.0	0.10
21	18.2	45.2	36.6	Sicl	4.3	-0.7	16.1	4.8	1.3	1.1	0.4	0.1	3.0	7.0	0.11
22	22.5	41.9	35.6	Cl	4.3	-0.7	16.8	5.1	1.4	0.9	0.4	0.1	2.8	7.0	0.12
23	24.6	40.6	34.8	Cl	4.4	-0.8	24.9	5.4	1.1	0.9	0.2	0.2	2.5	6.9	0.13
24	19.0	45.2	35.8	Sicl	4.3	-0.6	14.8	4.7	1.7	1.1	0.4	0.1	3.4	7.5	0.10
25	17.7	46.2	36.1	Sicl	4.3	-0.6	14.7	4.5	1.7	1.1	0.3	0.3	3.4	7.4	0.10
Range	15.5-27.3	38.8-49.2	33.9-36.7	Cl-Sicl	4.3-4.6	-1.0 to -0.6	14.5-36.7	4.3-7.3	1.1-1.7	0.6-1.2	0.2-0.4	0.1-0.3	2.4-3.5	6.9-8.8	0.09-0.19
Mean	23.7	41.5	34.9		4.4	-0.8	24.7	5.7	1.4	0.9	0.3	0.2	2.7	7.5	0.14
SD	3.7	3.0	0.9		0.1	0.1	8.0	0.9	0.2	0.2	0.1	0.1	0.3	0.6	0.03
CV (%)	15.7	7.2	2.4		2.3	13.2	32.4	16.2	13.8	18.3	21.4	41.9	12.2	7.4	21.1
Moderately dissected piedmonts (MDP) (500-1000 m above MSL)															
1	25.1	40.1	34.7	Cl	4.8	-1.1	34.9	7.3	1.1	0.8	0.3	0.1	2.3	6.7	0.21
2	25.0	40.3	34.7	Cl	4.8	-1.1	35.5	7.5	1.1	0.7	0.3	0.1	2.2	6.6	0.22
3	14.4	47.3	38.3	Sicl	4.4	-0.7	12.5	5.1	1.0	0.7	0.2	0.1	2.0	4.1	0.13
4	25.3	39.7	35.0	Cl	4.5	-0.9	24.8	5.4	1.0	0.8	0.3	0.1	2.2	6.3	0.16
5	15.5	46.9	37.6	Sicl	4.4	-0.8	13.0	5.1	1.7	0.8	0.3	0.1	2.9	6.0	0.14
6	23.9	40.6	35.5	Cl	4.5	-0.9	23.8	5.4	1.1	0.8	0.2	0.2	2.3	6.4	0.15
7	24.9	40.6	34.5	Cl	4.7	-1.1	32.9	6.8	1.0	0.8	0.3	0.2	2.2	6.6	0.20
8	24.9	40.5	34.6	Cl	4.7	-1.1	33.4	6.9	1.3	0.6	0.3	0.1	2.3	6.6	0.20
9	26.2	39.6	34.2	Cl	4.8	-1.2	36.1	7.5	1.1	0.6	0.3	0.2	2.2	6.7	0.22
11	24.9	40.6	34.6	Cl	4.8	-1.1	34.3	7.2	1.4	0.6	0.2	0.1	2.3	6.7	0.21
12	25.5	39.6	34.9	Cl	4.6	-0.9	26.2	5.6	1.0	0.8	0.3	0.1	2.3	6.5	0.16
13	17.3	44.2	38.5	Sicl	4.4	-0.8	14.7	5.2	1.5	0.8	0.2	0.1	2.6	6.0	0.13
14	17.7	43.9	38.4	Sicl	4.4	-0.8	14.7	5.2	1.3	0.9	0.4	0.1	2.7	6.1	0.13
15	25.8	39.6	34.7	Cl	4.6	-1.0	29.0	5.9	1.1	0.6	0.3	0.2	2.2	6.5	0.17
16	25.2	40.0	34.8	Cl	4.6	-1.0	27.6	5.8	1.3	0.7	0.2	0.1	2.3	6.5	0.17
17	22.5	40.8	36.8	Cl	4.5	-0.8	15.5	5.2	1.2	0.9	0.3	0.1	2.5	6.2	0.14
18	23.7	40.2	36.1	Cl	4.5	-0.8	16.1	5.2	1.4	0.7	0.2	0.1	2.5	6.1	0.14
19	25.8	39.6	34.7	Cl	4.7	-1.0	30.4	6.1	1.0	0.8	0.3	0.1	2.2	6.5	0.18
19	16.1	46.2	37.7	Sicl	4.4	-0.8	13.2	5.1	1.4	0.9	0.4	0.1	2.8	6.0	0.14
20	17.6	45.2	37.1	Sicl	4.4	-0.8	13.2	5.2	1.5	0.7	0.4	0.2	2.9	6.1	0.14

21	23.9	40.3	35.8	Cl	4.5	-0.9	21.0	5.2	1.1	0.9	0.3	0.1	2.4	6.4	0.15
22	23.7	40.4	35.9	Cl	4.5	-0.9	22.7	5.3	1.2	0.8	0.3	0.1	2.5	6.5	0.15
23	24.2	39.9	36.0	Cl	4.5	-0.8	17.1	5.2	1.2	1.0	0.2	0.2	2.6	6.6	0.15
24	25.8	39.6	34.6	Cl	4.7	-1.1	30.7	6.2	1.1	0.7	0.3	0.1	2.2	6.5	0.18
25	25.6	40.1	34.4	Cl	4.7	-1.1	30.9	6.4	1.1	0.7	0.2	0.2	2.2	6.5	0.18
Range	14.4-26.2	39.6-47.3	34.2-38.5	Cl-Sicl	4.4-4.8	-1.2 to -0.7	12.5-36.1	5.1-7.5	1.0-1.7	0.6-1.0	0.2-0.4	0.1-0.2	2.0-2.9	4.1-6.7	0.13-.22
Mean	22.8	41.4	35.8		4.6	-0.9	24.2	5.9	1.2	0.8	0.3	0.1	2.4	6.3	0.17
SD	3.8	2.5	1.4		0.1	0.1	8.4	0.8	0.2	0.1	0.1	0.1	0.2	0.5	0.03
CV (%)	16.6	6.1	4.0		3.0	16.1	34.8	14.3	15.4	14.4	20.5	38.7	10.1	8.1	17.4
						Inter-hill valleys (IHV) (<500 m above MSL)									
1	29.7	35.1	35.2	Cl	5.4	-1.8	23.1	7.4	1.4	1.0	0.4	0.1	2.9	7.0	0.21
2	29.6	35.3	35.1	Cl	5.4	-1.8	21.7	7.3	1.6	0.9	0.4	0.1	3.0	7.1	0.21
3	24.3	36.6	39.2	Cl	5.1	-1.5	7.5	6.2	1.8	1.4	0.5	0.2	3.8	6.5	0.16
4	25.9	36.4	37.7	Cl	5.2	-1.6	8.8	6.3	1.4	1.2	0.4	0.1	3.1	5.8	0.17
5	29.7	35.4	35.0	Cl	5.5	-1.9	23.4	7.5	1.7	0.8	0.3	0.1	2.8	7.1	0.22
6	25.4	35.7	38.9	Cl	5.2	-1.6	8.9	6.3	1.6	1.1	0.2	0.2	3.2	6.0	0.16
7	30.6	35.7	33.8	Cl	5.5	-1.9	23.9	7.5	1.2	1.0	0.4	0.2	2.9	7.1	0.22
8	29.9	35.0	35.1	Cl	5.4	-1.8	14.7	6.7	1.7	0.8	0.3	0.1	3.0	6.7	0.19
9	28.8	35.0	36.1	Cl	5.3	-1.7	10.4	6.5	1.6	0.8	0.4	0.3	3.1	6.5	0.18
11	29.6	35.1	35.2	Cl	5.3	-1.7	13.2	6.5	1.9	0.8	0.2	0.1	3.1	6.7	0.19
12	28.8	34.8	36.4	Cl	5.2	-1.6	9.6	6.4	1.4	1.1	0.4	0.1	3.0	6.3	0.18
13	29.0	34.8	36.1	Cl	5.3	-1.7	9.7	6.4	1.7	0.9	0.3	0.1	3.1	6.4	0.18
14	29.9	35.0	35.1	Cl	5.3	-1.7	14.7	6.6	1.4	1.0	0.4	0.1	3.0	6.6	0.19
15	28.9	35.2	35.9	Cl	5.3	-1.7	12.5	6.5	1.7	0.8	0.4	0.3	3.2	6.7	0.18
16	28.9	35.0	36.1	Cl	5.3	-1.7	9.9	6.4	1.7	0.9	0.3	0.1	3.1	6.4	0.18
17	29.5	35.3	35.2	Cl	5.4	-1.8	17.8	7.0	1.4	1.0	0.4	0.1	3.0	7.1	0.20
18	25.2	36.5	38.3	Cl	5.2	-1.6	7.8	6.2	1.8	1.0	0.3	0.1	3.1	5.8	0.16
19	24.8	36.7	38.5	Cl	5.1	-1.5	7.8	6.2	1.8	1.4	0.5	0.2	3.8	6.5	0.16
19	30.0	35.0	35.0	Cl	5.4	-1.8	15.5	6.7	1.3	0.9	0.3	0.1	2.7	6.4	0.19
20	29.5	35.4	35.1	Cl	5.4	-1.8	17.5	6.9	1.4	0.7	0.4	0.2	2.7	6.4	0.20
21	29.6	35.0	35.3	Cl	5.3	-1.7	13.0	6.5	1.4	1.2	0.4	0.1	3.2	6.8	0.18
22	29.9	35.3	34.9	Cl	5.4	-1.8	16.1	6.9	1.3	0.9	0.4	0.1	2.7	6.4	0.20
23	28.1	35.0	37.0	Cl	5.2	-1.6	9.3	6.3	1.4	1.1	0.3	0.3	3.0	6.0	0.17
24	29.7	35.0	35.3	Cl	5.3	-1.7	13.2	6.5	1.6	1.1	0.4	0.1	3.2	6.8	0.18
25	25.7	35.6	38.7	Cl	5.2	-1.6	9.2	6.3	1.4	0.9	0.3	0.3	2.8	5.6	0.16
Range	24.3-30.6	34.8-36.7	33.8-39.2	Cl	5.1-5.5	-1.9 to -1.5	7.5-23.9	6.2-7.5	1.2-1.9	0.7-1.4	0.2-0.5	0.1-0.3	2.7-3.8	5.6-7.1	0.16-0.22
Mean	28.4	35.4	36.2		5.3	-1.7	13.6	6.6	1.6	1.0	0.4	0.2	3.1	6.5	0.18
SD	1.93	0.56	1.51		0.11	0.12	5.19	0.43	0.19	0.18	0.07	0.06	0.29	0.43	0.02
CV (%)	6.79	1.58	4.18		2.07	6.79	38.29	6.43	12.16	18.16	20.77	35.64	9.36	6.61	9.86

Abbreviations: Cl-clay loam; Sicl-silty clay loam; Sic-silty clay

Table 2. Acidity components of soils along altitudinal sequence of Nagaland

Sample No.	Exch. H^+	Exch. Al^{3+}	Exch. acidity	pH dependent acidity	Total potential acidity	EAP (%)
	←	[cmol(p^+)kg^{-1}]			→	
Highly dissected high hills (HDHH) (>2000 m above MSL)						
1	1.2	4.0	5.2	13.8	19.0	64
2	1.3	5.1	6.4	14.4	20.8	69
3	1.0	3.2	4.3	12.2	16.5	56
4	1.4	5.5	6.9	14.4	21.3	70
5	1.2	4.1	5.3	14.1	19.4	65
6	1.1	3.3	4.4	12.9	17.3	56
7	1.2	4.1	5.3	13.9	19.2	64
8	1.1	3.4	4.5	13.8	18.3	57
9	1.2	4.5	5.7	14.3	20.0	66
11	1.1	3.6	4.8	13.5	18.3	57
12	1.2	4.3	5.5	13.9	19.4	66
13	1.2	4.4	5.7	14.3	20.0	66
14	1.2	4.4	5.6	14.0	19.6	66
15	1.3	5.1	6.4	14.6	21.0	69
16	1.2	4.4	5.7	14.1	19.8	66
17	1.4	5.3	6.7	14.3	21.0	70
18	1.2	4.4	5.7	14.1	19.8	66
19	1.4	5.5	6.9	14.4	21.3	70
19	1.3	4.6	5.9	14.3	20.2	66
20	1.3	4.8	6.1	14.5	20.6	68
21	1.2	4.2	5.4	14.0	19.4	66
22	1.1	3.7	4.8	13.7	18.5	63
23	1.2	4.0	5.2	13.8	19.0	64
24	1.3	4.6	5.9	14.3	20.2	66
25	1.2	3.9	5.1	13.7	18.8	64
Range	1.0-1.4	3.2-5.5	4.3-6.9	12.2-14.6	16.5-21.3	56-70
Mean	1.2	4.34	5.6	14.0	19.6	65
SD	0.1	0.64	0.7	0.5	1.2	4.0
CV (%)	8.6	14.7	13.4	3.8	6.1	6.5
Medium and low hill ranges (MLH) (1000-2000 m above MSL)						
1	1.1	3.7	4.8	13.5	18.3	53
2	1.3	5.1	6.4	14.4	20.8	66
3	1.3	4.8	6.1	14.1	20.2	66
4	1.4	5.5	6.9	14.1	21.0	69
5	1.3	4.6	5.9	14.3	20.2	65
6	1.2	3.9	5.1	13.4	18.5	53
7	1.3	4.6	5.9	14.1	20.0	65
8	1.4	5.7	7.1	14.2	21.3	69
9	1.5	5.8	7.3	14.1	21.4	70
11	1.2	4.5	5.7	14.3	20.0	65
12	1.5	6.0	7.5	14.2	21.7	70
13	1.3	5.1	6.4	14.2	20.6	66
14	1.2	4.3	5.5	13.9	19.4	61
15	1.2	4.4	5.7	14.1	19.8	63
16	1.4	5.3	6.7	14.3	21.0	67
17	1.2	4.4	5.6	13.8	19.4	61
18	1.2	4.4	5.7	13.9	19.6	62
19	1.4	5.5	6.9	14.4	21.3	69
19	1.5	6.3	7.9	14.4	22.3	72
20	1.2	4.1	5.3	13.7	19.0	58
21	1.2	4.1	5.3	13.9	19.2	58
22	1.2	4.2	5.4	14.0	19.4	60
23	1.2	4.4	5.7	14.1	19.8	64
24	1.2	4.0	5.2	13.8	19.0	54
25	1.2	4.0	5.2	13.6	18.8	54
Range	1.1-1.5	3.7-6.3	4.8-7.9	13.4-14.4	18.3-22.3	53-72
Mean	1.3	4.7	6.0	14.1	20.1	63
SD	0.12	0.7	0.8	0.3	1.1	6.0
CV (%)	9.3	15.2	13.9	2.0	5.3	9.0
Moderately dissected piedmonts (MDP) (500-1000 m above MSL)						
1	1.2	4.4	5.7	14.1	19.8	66
2	1.2	4.4	5.7	14.1	19.8	67
3	0.9	2.2	3.0	11.2	14.2	52
4	1.2	4.1	5.3	13.9	19.2	65
5	1.0	3.1	4.1	11.3	15.4	52
6	1.2	4.1	5.3	13.7	19.0	64
7	1.2	4.3	5.6	14.1	19.7	66
8	1.2	4.4	5.6	14.2	19.8	66
9	1.2	4.5	5.7	14.3	20.0	67
11	1.2	4.4	5.7	14.1	19.8	66
12	1.2	4.2	5.4	14.0	19.4	65
13	1.1	3.3	4.4	12.1	16.5	56
14	1.1	3.4	4.5	12.8	17.3	56
15	1.2	4.3	5.5	14.1	19.6	66
16	1.2	4.3	5.5	14.0	19.5	65
17	1.1	3.6	4.8	13.5	18.3	59
18	1.1	3.7	4.8	13.5	18.3	60
19	1.2	4.3	5.5	14.1	19.6	66
19	1.0	3.2	4.2	11.6	15.8	53
20	1.0	3.2	4.3	12.0	16.3	53
21	1.2	4.0	5.2	13.6	18.8	62
22	1.2	4.0	5.2	13.8	19.0	62
23	1.2	3.9	5.1	13.4	18.5	60
24	1.2	4.3	5.5	14.2	19.7	66
25	1.2	4.3	5.5	14.2	19.7	66
Range	0.9-1.2	2.2-4.5	3.0-5.7	11.2-14.3	14.2-20.0	52-67
Mean	1.2	3.9	5.1	13.4	18.5	62
SD	0.1	0.6	0.7	1.0	1.6	5.0
CV (%)	8.2	14.5	13.1	7.4	8.8	8.5
Inter-hill valleys (IHV) (<500 m above MSL)						
1	1.0	3.1	4.1	7.2	11.3	59
2	1.0	3.1	4.1	7.2	11.3	58
3	0.8	1.9	2.7	6.6	9.3	41
4	0.8	1.9	2.7	7.2	9.9	46
5	1.0	3.2	4.2	7.2	11.4	60
6	0.8	1.9	2.7	7.3	10.0	46
7	1.0	3.2	4.3	7.3	11.6	60
8	1.0	2.7	3.7	7.1	10.8	55
9	0.9	2.5	3.4	7.0	10.4	52
11	0.9	2.7	3.6	7.1	10.7	54
12	0.9	2.4	3.3	6.9	10.2	52
13	0.9	2.4	3.3	7.0	10.3	52
14	0.9	2.7	3.6	7.1	10.7	55
15	0.9	2.6	3.5	7.0	10.5	52
16	0.9	2.4	3.3	7.1	10.4	52
17	1.0	3.1	4.1	7.1	11.2	58
18	0.8	1.9	2.7	7.2	9.9	46
19	0.8	1.9	2.7	6.9	9.6	41

19	1.0	2.7	3.7	7.2	10.9	58
20	1.0	2.8	3.7	7.4	11.1	58
21	0.9	2.6	3.6	7.0	10.6	53
22	1.0	2.8	3.7	7.3	11.0	58
23	0.9	2.1	3.0	7.2	10.2	50
24	0.9	2.7	3.6	7.0	10.6	53
25	0.8	2.0	2.8	7.3	10.1	50
Range	0.8-1.0	1.9-3.2	2.7-4.3	6.6-7.4	9.3-11.6	41-60
Mean	0.9	2.5	3.4	7.1	10.5	53
SD	0.07	0.45	0.53	0.17	0.60	5.0
CV (%)	8.13	17.90	15.29	2.43	5.63	10.41

in silt plus clay fractions in soils followed the sequence: IHV > MDP > MLH > HDHH. Occurrence of fine textured soils in higher altitudes indicates rapid pedogenesis influenced by high rainfall and vegetation, whereas, occurrence of medium and coarse textured soils in inter-hill valleys signifies their formation by colluvial deposition by gravitational force (Birkland 1984).

Soil reaction (pH)

The soils were extremely to very strongly acidic (pH 4.3 to 4.9) in HDHH, MLH and MDP with average pH values of 4.8, 4.4 and 4.6, respectively. Soils in IHV were strongly to moderately acidic (pH 5.1-5.5) with average pH value of 5.3. Steepness of the slope in HDHH (> 33%), MLH (15-33%) and MDP (10-15%) may be responsible for loss of bases resulting in the low soil pH. Gentle slope (3-5%) of the terrain with impeded sub-surface drainage may favour higher pH in soils of inter-hill valleys (Rebertus and Boul 1985).

Presence of high organic matter in soils of higher elevations may be one of the reasons of soil acidity by generating pH dependent charges. Secondly, aluminium release may be strongly influenced by high organic matter in soils of the state, in the development of acid soils of varying nature (Ritchie 1994).

The ΔpH was low in soils of MDP and HDDH ranging from -0.6 to -1.3, whereas, the same was high in soils of inter-hill valleys, ranging from -1.5 to-1.9. Negative ΔpH indicates occurrence of net negative charge in soil colloids which is common in this environment (Gangopadhyay *et al.* 1986). Higher negative value of ΔpH in inter-hill valleys indicated net negative charge of the soil colloid due to high exchangeable Al in soils. However, low negative ΔpH values in higher altitudes (1000 m and above) may be due to formation of variable charges from soil organic matter. Several indigenous agro-forestry (alder based cropping and plantation), agri-horti and agri-silviculture systems are practiced in MDP, MDH and HDDH, for long period (Sharma *et al.* 2006), which may have an impact in building high organic carbon *vis-a-vis* variable charges in surface soils.

Soil organic carbon

Wide variability of OC was noticed across the various landform units ranging from 7.5 g kg^{-1} on IHV to 39.4 g kg^{-1} on HDHH. Average OC has a decreasing trend along the altitudes with following sequence: HDHH (32.0 g kg^{-1}) > MLH (24.7 g kg^{-1}) > MDP (24.2 g kg^{-1}) > IHV (13.6 g kg^{-1}). The abundance of forest vegetation at higher elevation, deforestation and shifting cultivation at lower and mid-hills and piedmonts and terraced rice cultivation (TRC) on inter-hill valleys are responsible for the above trend.

Cation exchange capacity and sum of exchangeable bases

The soils of Nagaland were low in CEC ranging from 4.3 to 7.5 cmol(p+)kg^{-1}. Soils occurring on HDHH [5.4 cmol(p^+)kg^{-1}], MLH [5.7 cmol(p^+)kg^{-1}] and MDP [5.9 cmol(p^+)kg^{-1}] have lower average CEC compared to that on IHV [6.6 cmol(p^+)kg^{-1}]. The CEC/clay ratio of soils ranged from 0.09 to 0.22. The mean CEC/clay ratio followed the sequence: MLH (0.14) < HDDH (0.15) < MDP (0.17) < IHV (0.18) (Table 1). Low CEC/ clay ratio on MLH and HDDH signifies the formation of low activity clays (kaolinitic) (Smith 1986) accelerated by rainfall and vegetations, whereas, soils on MDP and IHV have relatively higher CEC/clay values due to occurrence of mixed mineralogy with kaolin-interstratified minerals in clay fraction due to slower rate of pedogenesis (Curtin and Smillie 1981).

The sum of exchangeable bases is low in all the landforms ranging from 2.2 to 3.8 cmol(p^+)kg^{-1} with dominance of calcium over magnesium followed by potassium and sodium due to heavy leaching and well to excessively well drained nature of soils in MDP, MLH and HDHH. In the soils of IHV, sum of bases is relatively higher than other landforms because of impeded drainage in sub-surface soils as influenced by terraced rice cultivation for long period.

Effective cation exchange (ECEC)

The ECEC of soils ranged from 5.6 cmol(p^+)kg^{-1} in MDP to 8.8 cmol(p+)kg^{-1} in MLH. The mean value of ECEC followed the altitudinal sequence as MLH (7.5) > HDHH (6.7) > IHV (6.5) > MDP (6.3). The ECEC has an irregular increasing trend with altitudes indicating increasing degree of Al saturation in soils at higher elevation.

Soil acidity components

The soil acidity can be described in its three different forms *viz.,* exchangeable acidity, pH dependent acidity and total potential acidity. Exchangeable acidity is well known due to occurrence of exchangeable Al (pH < 5.5) in soil, whereas, pH dependent acidity in soils is developed due to proton generation mainly from phenolic and carboxylic groups of humic substances and also low activity clays and oxides of Fe and Al (Hoyt 1977). Total potential acidity includes the both. All forms of soil acidity were found to increase with altitude in the following sequence: MLH > HDHH > MDP > IHV (Table 2). The exchangeable acidity was low in inter-hill valleys ranging from 2.7 to 4.3 cmol(p^+)kg^{-1} with an average of 3.4 cmol(p^+)kg^{-1} and highest in MLH ranging from 4.8 to 7.9 cmol(p^+)kg^{-1} with an average of 6.0 cmol(p^+)kg^{-1}. As soil pH increased, exchangeable Al decreased and became lowest [1.8 cmol(p^+)kg^{-1}] at pH 5.5 in inter-hill valleys. The results emphasize the normal exchange reaction of Al in soils. The pH dependent acidity ranged from 6.6 cmol(p^+)kg^{-1} in soils on inter-hill valleys to 14.6 cmol(p^+)kg^{-1} in soils on MLH. High OC was prevailing in MLH under forest vegetation compared to that in inter-hill valleys under mono-cropping (terraced rice). This may cater the formation of high pH dependent acidity. Total potential acidity also followed the same sequence ranging from 9.3 cmol(p^+)kg^{-1} in inter-hill valleys to 22.3 cmol(p^+)kg^{-1} in MLH. Further, contribution of pH dependent acidity towards total potential acidity was much higher (67.6-72.4%) than exchangeable acidity (27.6-32.4%) regardless of any landform. The higher contribution of pH dependent acidity to the total potential acidity along the altitudes was observed due to higher organic matter content in soils. Contribution of pH dependent acidity towards total potential acidity followed the decreasing trend as: MDP (72.4%) < HDHH (71.4.%) < MDP (70.1%) < IHV (67.6%) (Fig. 2). Contribution of exchangeable acidity followed the decreasing sequence of IHV (32.4%) < MLH (29.9%) < HDHH (28.6%) < MDP (27.6%). Higher contribution of pH dependent acidity is attributed to variable charge due to high OC content under forest vegetation at higher elevations and presence of low activity clays (Hoyt 1977). It was earlier reported that the pH dependent acidity contributed 88% of total potential acidity in Mokokchung district (Amenla *et al.* 2010) and 75% of the same in the entire state of Nagaland (Patton *et al.* 2007). Hence, the present study substantiates the earlier findings in the state.

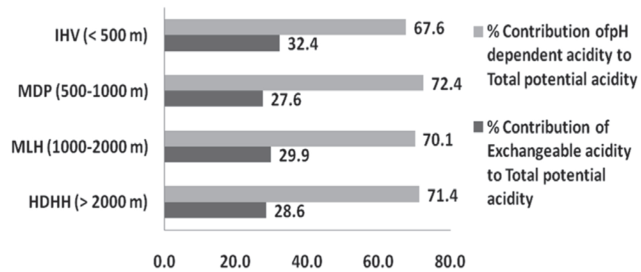

Fig. 2. Relative contribution of forms of soil acidity along altitudinal sequence in Nagaland

Exchangeable aluminium percentage (EAP)

The EAP varied from 41% on IHV to 72% on MLH ranges and average values of the same followed the sequence of HDHH (65%) > MLH (63%) > MDP (62%) > IHV (53%). Gradual increase of EAP with altitude indicates release of Al by rapid weathering of primary minerals (Graham and Boul 1990) and formations of low activity (kaolinitic) clays in soils. Simultaneously, high OC content may also cater the release of Al from parent material at higher altitudes. Relatively lower Al saturation on IHV indicates formation of kaolin interstratified layer silicates (hydroxyl inter-layered vermiculites) in clay fractions of soils (Gangopadhyay *et al.* 1986; Sen *et al.* 1997). Secondly, its release may be relatively less fast than soils on higher altitude because of comparatively lower OC content in IHV under mono-cropping in terraced rice system. From fertility point of view, an EAP of less than 60 have been regarded as an indicator of soil acidity constraint that can be modified by liming (Sanchez *et al.* 2003) and the same exceeding 60% has been considered toxic for plant (Nye *et al.* 1961). Except IHV (EAP 41-60%), soils occurring in all other landforms exceed the threshold limit (EAP 62-72%). High OC appears to cater the release of Al from non-exchangeable sites (Ritchie 1994). At higher elevations, steepness of the slope may facilitate heavy leaching of bases and consequent increase of exchangeable Al in soils and also abundance of forest vegetation further caters its release in the soils. Soils on IHV experienced limited leaching due to impeded drainage in sub-surface horizons and comprise relatively lower exchangeable Al due to relatively lower OC content.

Interrelationship between soil properties and soil acidity

The study indicates differential pedogenic processes under topographic variability at an altitudinal sequence of the state as influenced by local variability of micro-climate and vegetations (Graham and Boul 1990). At higher altitudes (MDP, MLH and HDHH), the soil formation process is much faster. The parent material was rapidly weathered to release Al. The intensity of weathering decreased while the extent of water stagnation increased at lower altitude (Arteaga *et al*. 2008). In IHV, soils formed on colluvial deposits due to fluvial impact of drainage streams. As a result, these soils contained relatively less exchangeable Al. Results reveal significant inter-relationships among the soil properties (Table 3). Soil pH had significant positive correlation with sand (r = 0.65**) and negative correlation with silt fractions (r = -0.46**) indicating that particle size distribution has a strong influence on soil pH. The silt content was higher in HDHH, MLH and MDP compared to IHV, which is responsible for low pH of soils. Soil OC had significant negative correlation with pH (r = -0.69**) indicating its role in lowering soil pH by formation of variable charges in surface soils. The CEC had significant negative correlation with clay (r = -0.39*) indicating that with increase in clay content along the altitude, the CEC value decreased. Formation of low activity clays by rapid weathering at high altitude may result in low CEC of soils (Smith 1986). The CEC/clay ratio was significantly correlated with ΔpH (r = -0.71**). It indicates that with increase in clay content with altitude, the CEC of soils declines which in turn depresses pH both in water and in KCl and suppresses low ion exchange capacity of soils. It was found that soil OC had significant negative correlation with sum of bases (r = -0.78**) and positive correlation with EAP (r = 0.93**). It indicates that high OC in soils appears to cater faster release of Al from non-exchangeable sites and also helps to leach down of bases by solubilization (Ritchie 1994). The origin of high exchangeable Al in soils was also indicated by significant correlation of EAP with clay (r = 0.69**). The influence of OC was found to be more conspicuous in the formation of soil acidity as evident from highly significant positive correlations with exchangeable acidity (r = 0.85**), pH dependent acidity (r = 0.83**) and total potential acidity (r = 0.78**) due to formation of variable charges from phenolic and carboxylic groups (Ritchie 1994) that might arise from decomposition of soil organic matter (Hoyt 1977). Clay and organic matter bridging may be responsible for facilitating acidity due to pH dependent charges, which may originate from mineralization of organic matter in surfaces under humid and subtropical climatic situations. The soils were characterized by high negative ΔpH attributing high net negative charge of soil colloids. As pH of variable charge soils decreases, CEC also decreases as observed in the present investigation. Decrease in CEC with increase in negative ΔpH with altitude indicates that low activity clays (kaolinitic type) predominates in the mineral assemblage of soils (Smith 1986) due to rapid weathering of parent materials. On the other hands, significant correlation of EAP with exchangeable acidity (r = 0.91**) indicates high degree of weathering of alumino-silicate rich parent materials and subsequent accumulation of Al in clay fraction of soils, pertaining to high exchangeable acidity. The pH dependent acidity was significantly and positively correlated with

Table 3. Correlation coefficient (r) among soil properties and forms of soil acidity

	Sand	Silt	Clay	pH	ΔpH	OC	CEC	Sum of bases	ECEC	CEC/ clay	EXA	PDA	TPA
Silt	-0.93**												
Clay	-0.49**	0.15											
pH	0.65**	-0.46**	-0.08										
Ä pH	-0.64**	0.70**	0.07	-0.51**									
OC	-0.03	0.30*	-0.63**	-0.69**	0.19								
CEC	0.76**	-0.70**	-0.39*	0.45**	-0.64**	0.18							
Sum of bases	0.15	-0.32*	0.35*	0.52**	-0.27*	-0.78**	0.01						
ECEC	0.33*	-0.10	-0.67**	-0.27*	0.10	0.48**	0.35*	0.03					
CEC/clay	0.71**	-0.61**	-0.47**	0.36*	-0.71**	0.29*	0.94*	-0.14	0.22				
EXA	-0.06	0.34*	-0.65**	-0.67**	0.50**	0.85**	0.01	-0.60**	0.72**	0.01			
PDA	-0.24	0.50**	-0.54**	-0.76**	0.64**	0.83**	-0.16	-0.65**	0.55**	-0.14	0.90**		
TPA	-0.36*	0.58**	-0.45**	-0.77**	0.72**	0.78**	-0.29*	-0.68**	0.44**	-0.25*	0.92**	0.98**	
EAP	0.05	0.21	-0.69**	-0.60**	0.28*	0.93**	0.15	-0.82**	0.53**	0.23	0.91**	0.86**	0.83**

EXA-Exchangeable acidity; PDA-pH dependent acidity; TPA-Total potential acidity
**Significant at 1% level; *Significant at 5% level

total potential acidity (r = 0.98**) indicating that major pool of total potential acidity of studied soils originated from pH dependent acidity. Organic carbon had significant correlation with EAP (r = 0.93**) as well as exchangeable acidity (r = 0.85**). High organic carbon in soils may facilitate the release of Al from non-exchangeable site to exchangeable form and may enhance exchangeable acidity of soils by formations of organo-aluminium complexes (Ritchie 1994). Thus, high OC in hills and piedmont regions may be instrumental in accelerating the acidity due to release of Al in soil solution (Borùvka *et al.* 2009). High OC and low CEC/clay ratio together hasten the release of exchangeable Al in soils. Soils of hill slopes (above 1000 m) and piedmonts (500-1000 m) have considerably low CEC/clay ratios, high EAP and hence comprise high total potential acidity compared to the soils of IHV. This may result from heavy leaching of bases due to steepness of the slopes and abundant forest vegetations.

The pH dependent acidity appears to take dominant role for contributing acidity in soils. The EAP was less than 60% below 500 m elevation (IHV), whereas, the same exceeded its toxic concentrations (>60%) at an elevation above 500 m. The EAP was highly and significantly correlated with exchangeable acidity (r = 0.91**), pH dependent acidity (r = 0.86**) and total potential acidity (r = 0.83**). Linear regression equations between forms of acidity (independent variables) and EAP (dependent variable) were derived for predicting severity of soil acidity constraints in Nagaland. Three forms of soil acidity *viz.,* exchangeable acidity (EXA), pH dependent acidity (PDA) and total potential acidity (TPA) were chosen as independent variables and EAP as dependent variable having highly significant correlation with all forms of acidity.

(i) EAP = 5.275 EXA + 34.11 ($R^2 = 0.83$) (Threshold value of EXA = 4.91 cmol(p^+)kg^{-1}).

(ii) EAP = 1.952 PDA + 37.25 (($R^2 = 0.74$) (Threshold value of PDA = 11.65 cmol(p^+)kg^{-1}).

(iii) EAP = 1.419 TPA + 36.28 ($R^2 = 0.69$) (Threshold value of TPA = 16.72 cmol(p^+)kg^{-1}).

Considering EAP as the key indicator of soil acidity, it was noted that at threshold limit of EAP (60%), the estimated values of exchangeable, pH dependent and total potential acidity were 4.91, 11.65and 16.72 cmol(p^+)kg^{-1}, respectively. Therefore, it may be inferred that the values exceeding the above for respective acidity components would become highly detrimental for plant growth, especially for terraced rice cultivation in IHV. The respective acidity values may be regarded as the threshold limits of all the three forms of soil acidity for the state of Nagaland towards crop planning and management.

Conclusions

From the aforesaid investigation, it is evident that pH dependent acidity is the major form of acidity in soils of Nagaland. It gradually increases in an altitudinal sequence from lower to higher elevation. Higher elevation appears to favour leaching loss of bases due to steepness of the slope. Abundant vegetation may enhance pedogenic development under humid sub-tropical climate at higher elevations. This may result enough variable charges in surface as well as release sufficient exchangeable aluminium in soil solution, ultimately, generating high total potential acidity. On the other hand, at lower elevations, soil forming processes are relatively slow because of long-term terraced cultivation. Development of soil acidity is slow in younger soils at lower elevations. The threshold limit of all forms of soil acidity as measured based on exchangeable aluminium percentage (EAP) is proved to be an important indicator of soil acidity in the state of Nagaland.

Thus, blanket application of liming materials should be avoided. It may be determined based on threshold value of different forms of soil acidity considering EAP as a reliable indicator.

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