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Rising levels of soil acidity in Meghalaya: Evidences and Imperatives

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ABSTRACT

In order to examine the current status of soil acidity in Meghalaya, representative soil samples (n= 497) were collected (during 2015-2016) from across the state and analyzed for soil acidity and associated parameters. Averaged across the samples, pH of the soils was found to be very strongly acidic (4.94). Nearly 20 % of the soils had pH below 4.50, 59% below pH 5.0 and 80% below pH 5.50. Only 3.4% of the samples recorded pH more than 6.0. East Khasi Hills District had the maximum percentage (95.1%) of strongly acidic soils (pH ≤ 5.50) while Garo Hills had the least (50.2%). All other districts recorded more than 85% of the strongly acidic soils. Average exchangeable acidity, exchangeable Al and effective CEC were found to be 1.60, 1.27 and 3.86 meq/100g soil, respectively. Mean base saturation was recorded below 60%. Aluminium saturation (percentage of effective CEC being occupied by exch. Al) ranged from 1.5 to 79.7% with its mean value being as high as 33%. Principal component analysis provided three PCs with Eigen values >1 and together they explained 83.2 % of the variance in total dataset. The soil acidity in Meghalaya is on rise, with 80.2% of its soils being strongly acidic (pH ≤ 5.50) in contrast to the previous reports of 53% soils being strongly acidic. This calls for widespread adoption of soil acidity ameliorative measures in agriculture of Meghalaya, Northeast India.

Keywords: Exchangeable Al, base saturation, lime requirement, Al toxicity, P deficiency

INTRODUCTION

Acid soils occupy more than 30% of the world's ice-free land and nearly 50% of the potentially arable land. In India, nearly 25 million hectares (m ha) of land is having pH below 5.5 and another 23 m ha in the pH range of 5.6-6.5, which accounts approximately one-third of cultivated land in the country. Majority of them (54%) are concentrated in North Eastern Region (NER) of India where more than 95% area is affected by acidity, with around 65% of the area being under extreme forms of soil acidity (pH below 5.5) (Sharma and Singh, 2002). Crop productivity on such soils is mostly constrained by aluminium (Al), iron (Fe) and manganese (Mn) toxicity, and phosphorus (P), calcium (Ca) and magnesium (Mg) deficiency. This type of soil has mostly low base saturation, cation exchange capacity (CEC), impaired biological activity and other acidity-induced soil fertility and plant nutritional problems (Kumar, 2011 & 2015; Kumar *et al.*, 2016). Owing largely to these acidity-induced constraints, despite having ~6% of the total geographical area and ~13% of the total rainfall of the country, the NER contributes only 1.5% to the national food grain production (Singh and Satapathy, 2007). Management of soil acidity therefore warrants top priority for enhancing crop productivity and ensuring food security in the region.

For effective management of soil acidity, knowledge of its extent and distribution in an area is important. Meghalaya is a hilly state in north-eastern India where, as per existing report by National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), as cited by Sharma and Sarkar (2005) and Sharma *et al.* (2006), 53% of the geographical area is below pH 5.5 and another 47% between pH 5.5 to 6.5, making soil acidity an omnipresent feature in the state. Thus, although entire soils of Meghalaya are acidic, the debilitating effect of soil acidity on crop growth is more pronounced below pH 5.5 (*i.e.* on 53% of soils in Meghalaya) where severity of Al toxicity and P deficiency is considered to be very high. Soil pH is a dynamic property which may change with time depending on rainfall and soil/nutrient management practices, among other factors. High rainfall increases soil acidity consequent to leaching of basic cations from soil profile. Application of acid-producing fertilisers (ammonium-based fertilisers) for long-term may also contribute to soil acidity. Considering the traditionally low use of fertilisers in Meghalaya, the excessive rainfall (2400 mm average annual

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rainfall) is perceived to be the prime factor responsible for high levels of soil acidity in the state. In view of the excessively high rainfall in Meghalaya (which is credited to have some of the wettest places on earth ─ Mawsynram and Cherrapunji), the levels of soil acidity could be expected to be rising with time, necessitating thereby the periodic appraisal of soil acidity in the state.

Although important, measurement of soil pH alone is not a true representation of soil acidity. The acidity-induced impact on soil fertility and plant growth is mediated largely through its effect on nutrient availability/toxicity in crop rhizosphere, which in turn is governed by various acidity components (total, exchangeable and non-exchangeable acidity, exchangeable Al and H) and associated soil parameters (such as exchangeable Ca and Mg, cation exchange capacity, base saturation, acid and Al saturation levels in soil etc.). Understanding of these acidity components and associated soil attributes are therefore crucial to better appreciate the effect of soil acidity on plant growth and to formulate strategies for effective soil acidity management. For example, soil pH alone is of little use while estimating lime requirement of acidic soils; exchangeable Al rather gives a better indication of the same. Also, while P adsorption in acidic soils is usually considered to be higher in soil with low pH and vice-versa, many a times the opposite could be observed based on the interplay of the effects of exchangeable Al vis-à-vis Ca and Mg levels (as observed frequently in recently limed soils). These instances further necessitate the wholesome understanding of the acidity components instead of soil pH alone. In this backdrop, based on the analysis of soil samples collected from across the state, we are reporting here the current extent and distribution (district-wise) of soil acidity and acidity components in soils of Meghalaya, hoping that the information will be useful for efficient management of soil acidity for crop production in the region.

MATERIAL AND METHODS

In order to examine the levels of soil acidity and acidity components in Meghalaya, a total of 497 soil samples (0-20 cm depth) were collected (during 2015-16) from across the districts of Meghalaya, namely East Khasi Hills (81), Garo Hills (East, West and South Garo Hills) (126), Jaintia Hills (97), Ri-Bhoi (115) and West Khasi Hills (78). Soil samples were air-dried and passed through 2.0 mm sieve for analysis of acidity and acidity parameters. Soil pH was measured in 1: 2.5 soil: water ratio. Total acidity ($H^+ + Al^{3+}$) was measured directly by the extraction with molar ammonium acetate solution at pH 7, followed by titration. Exchangeable Al and acidity was determined by potassium chloride method (McLean, 1965; Page *et al.*, 1982) and exchangeable Ca and Mg were determined through versene titration (Baruah and Barthakur, 1999). Effective CEC (ECEC) was calculated as the sum total of exchangeable cations (K, Ca, Mg, Al and H). The difference between exchangeable acidity and exchangeable aluminum gave the estimation of exchangeable hydrogen (H^+) content. Non exchangeable acidity was found as the difference between total acidity and exchangeable acidity. Percentage of the basic cations in CEC_e was taken as base saturation (BS) while that of exchange acidity was deemed as acid saturation (AS). Percentage of CEC_e occupied by exchangeable Al was taken as Aluminum saturation (AlS). Data were subjected to the analyses of descriptive statistics where mean, median, standard deviation, range, minimum and maximum values were estimated using standard statistical procedures. Pearson's correlation coefficients were used to determine the strength of relationships among soil attributes. Principal component analysis was also undertaken to know the principal components (PC) with their Eigen values and proportion of variance (%) explained, along with rotated factor loadings and communalities of soil acidity-related attributes.

RESULTS AND DISCUSSION

Analysis of the soil samples revealed wide variations in acidity and associated components across the soils of Meghalaya. Soil pH ranged from as low as 3.73 in West Khasi Hills to near neutral (6.97) in Garo Hills, with a difference of over 3.2 pH unit between maximum and minimum values (Table 1).

Table 1: Descriptive statistics of the soil pH in Meghalaya

District	No. of samples	Minimum	Maximum	Mean	Standard Deviation
East Khasi Hills	81	3.94	5.59	4.75	0.37
Garo Hills*	126	4.50	6.97	5.40	0.62
Jaintia Hills	97	4.45	5.57	5.09	0.32
Ri-Bhoi	115	3.75	5.82	4.74	0.47
West Khasi Hills	78	3.73	5.76	4.74	0.44
Total (Meghalaya)	497	3.73	6.97	4.94	0.54

**includes samples from all the three districts of Garo Hills i.e. East, West and South Garo Hills*

Mean pH of the soils in Meghalaya was found to be strongly acidic (4.94). Nearly 20 % of the soils had pH below 4.50, 59% below pH 5.0 and 80% below pH 5.50. Only 20% of the samples recorded pH more than 5.50 with merely 3.4% of the soils having pH more than 6.0 (Table 2). East Khasi Hills District had the maximum percentage (95.1%) of strongly acidic soils (pH ≤ 5.50) while Garo Hills had the least percentage (50.2%) of such soils. All other districts recorded more than 85% of the strongly acidic soils (Fig.1).

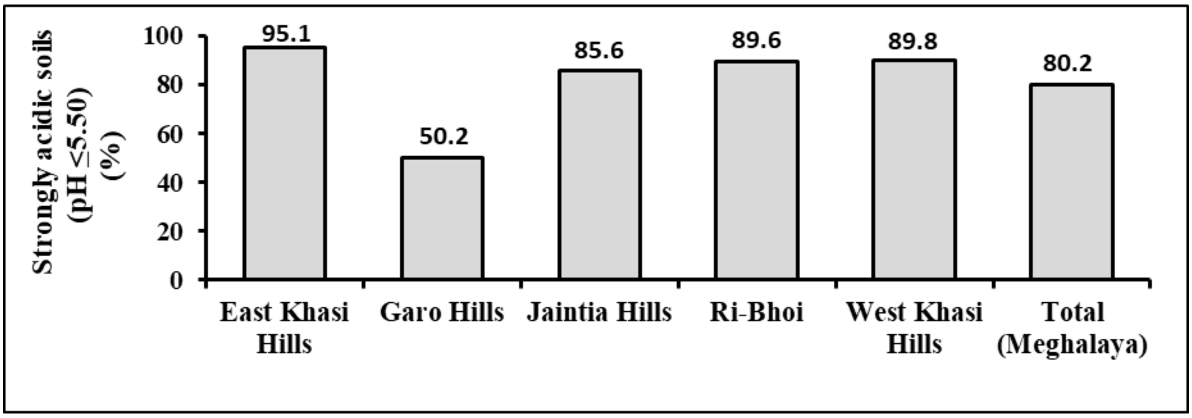

Figure 1: Extent (%) and distribution of strongly acidic soils (pH ≤ 5.50) in Meghalaya (Garo Hills represent all the three districts of Garo Hills: East, West and South Garo Hills)

Table 2: Extent and distribution of soil acidity in Meghalaya

District	Percentage of samples in different acidity classes				
	pH ≤ 4.50	pH 4.51-5.00	pH 5.01-5.50	pH 5.51-6.00	pH pH > 6.00
East Khasi Hills	34.6	48.1	12.3	4.9	-
Garo Hills*	4.8	22.7	22.7	32.6	12.8
Jaintia Hills	6.2	33.0	46.4	14.4	-
Ri-Bhoi	29.6	47.8	12.2	10.4	-
West Khasi Hills	29.5	50.0	10.3	10.3	-
Total (Meghalaya)	19.7	39.0	21.5	16.3	3.4

**includes samples from all the three districts of Garo Hills i.e. East, West and South Garo Hills*

District-wise details of the acidity and related parameters and overall summary for the state are shown in Table 3. Mean total acidity, exchangeable acidity and exchangeable Al in the soils of Meghalaya were found to be 3.41, 1.60 and 1.27 meq/100g soil, respectively. While effective CEC ranged from 1.84 to 17.2 meq/100g soil with a mean value of just 3.86. Mean base saturation was recorded below 60% while acid saturation was found above 40%. Percentage of effective CEC being occupied by exch. Al (Aluminium saturation) ranged from 1.5 to 79.7% with a mean value being as high as 33%.

Table 3: Soil acidity and related attributes (district-wise) in soils of Meghalaya

	pH	Total acidity	Exch. acidity	Exch. Al	Exch. H	Non-Exch. acidity	Exch. Ca	Exch. Mg	Exch. K	CEC_e	BS (%)	AS (%)	AlS (%)
	(meq/100g soil)												
Eeast Khasi Hills (n= 81)													
Minimum	3.94	1.85	0.63	0.25	0.13	1.13	0.40	0.10	0.09	1.84	16.9	24.2	10.8
Maximum	5.46	6.45	3.75	3.38	0.63	3.63	2.60	1.10	0.40	4.78	75.8	83.1	74.8
Mean	4.70	4.11	1.89	1.59	0.30	2.22	0.90	0.45	0.19	3.43	44.9	55.1	46.4
Std. Dev.	0.38	1.45	0.81	0.83	0.17	0.78	0.57	0.29	0.10	0.99	18.0	18.0	19.2
West Khasi Hills (n= 78)													
Minimum	4.45	1.98	0.63	0.25	0.02	0.93	0.30	0.10	0.01	2.38	17.8	16.9	9.5
Maximum	5.76	4.08	2.13	2.00	0.75	2.45	1.70	2.50	0.44	5.19	83.2	82.2	71.9
Mean	4.78	3.18	1.49	1.19	0.30	1.70	0.66	0.59	0.12	2.86	47.9	52.1	41.6
Std. Dev.	0.41	0.58	0.47	0.54	0.20	0.49	0.35	0.62	0.12	0.70	19.5	19.5	20.8
Ri-Bhoi (n= 115)													
Minimum	3.73	2.25	0.62	0.50	0.02	0.00	0.30	0.00	0.07	2.10	19.4	15.4	12.4
Maximum	5.30	4.70	2.40	2.38	0.25	3.08	2.00	1.10	0.32	4.00	84.6	80.6	79.7
Mean	4.52	3.82	1.78	1.63	0.15	2.04	0.55	0.37	0.15	2.85	37.6	62.4	57.2
Std. Dev.	0.38	0.71	0.48	0.50	0.10	0.71	0.42	0.31	0.07	0.44	17.5	17.5	17.6
Jaintia Hills (n= 97)													
Minimum	4.48	1.65	1.12	0.50	0.12	0.48	0.40	0.00	0.09	2.10	16.3	37.1	14.8
Maximum	5.52	5.45	2.88	2.25	1.75	3.23	1.10	1.00	0.52	5.10	62.9	83.7	75.3
Mean	5.10	3.72	1.94	1.23	0.71	1.78	0.73	0.27	0.20	3.13	38.0	62.0	39.3
Std. Dev.	0.28	1.21	0.55	0.54	0.49	1.00	0.18	0.28	0.12	0.74	11.5	11.5	16.6
Garo Hills (n= 126)													
Minimum	4.50	0.95	0.38	0.25	0.00	0.08	0.60	0.00	0.03	2.50	34.7	2.2	1.5
Maximum	6.97	4.73	1.88	1.75	0.63	3.23	14.90	3.70	1.20	17.20	97.8	65.3	61.0
Mean	5.40	2.49	1.06	0.86	0.20	1.44	3.72	1.13	0.34	6.24	83.0	17.0	13.8
Std. Dev.	0.64	0.94	0.43	0.45	0.17	0.90	3.97	1.00	0.31	4.49	21.4	21.4	19.7
Meghalaya (n= 497)													
Minimum	3.73	0.95	0.38	0.25	0.00	0.00	0.30	0.00	0.01	1.84	16.3	2.2	1.5
Maximum	6.97	6.45	3.75	3.38	1.75	3.63	14.90	3.70	1.20	17.20	97.8	83.7	79.7
Mean	4.94	3.41	1.60	1.27	0.33	1.82	1.46	0.59	0.21	3.86	58.5	41.5	32.9
Std. Dev.	0.54	1.19	0.66	0.65	0.33	0.85	2.38	0.68	0.19	2.70	22.3	22.3	21.9

BS: base saturation; AS: acid saturation; AlS: aluminium saturation; CEC_e*: effective CEC; Std. Dev.: standard deviation*

Soil pH was most strongly correlated with the quantity of exch. Al and percentage of the effective CEC being occupied by exch. Al *i.e.* Al saturation, while effective CEC was most strongly correlated with exch. Ca followed by exch. Mg (Table 4). In the entire correlation matrix, association of effective CEC with exch. Ca was the strongest one (r = 0.97). PCA was performed on measured soil attributes which provided three PC with Eigen values >1 and together they explained 83.2 % of the variance in total dataset (Table 5). A total of 57.3% of the variance was explained by PC-1 itself which has effective CEC as the highest weighted variable (0.915).

Table 4: Correlation matrix for soil acidity and related attributes in the soils of Meghalaya

	pH	Total acidity	Exch. acidity	Exch. Al	Exch. H	Non-Ex. acidity	Exch. Ca	Exch. Mg	Exch. K	CEC_e	BS	AS	AlS
pH	1												
Total acidity	-0.70**	1											
Exch. acidity	-0.67**	0.72**	1										
Exch. Al	-0.78**	0.77**	0.88**	1									
Exch. H	0.21**	ns	0.27**	-0.23**	1								
Non-Ex. acidity	-0.46**	0.84**	0.24**	0.41**	-0.34**	1							
Exch. Ca	0.65**	-0.34**	-0.52**	-0.46**	-0.13*	ns	1						
Exch. Mg	0.53**	-0.27**	-0.53**	-0.48**	ns	ns	0.72**	1					
Exch. K	0.46**	-0.22**	-0.36**	-0.37**	ns	ns	0.43**	0.38**	1				
CEC_e	0.58**	-0.21**	-0.38**	-0.34**	ns	ns	0.97**	0.79**	0.46**	1			
BS	0.73**	-0.52**	-0.83**	-0.78**	-0.12*	ns	0.70**	0.80**	0.54**	0.66**	1		
AS	-0.73**	0.52**	0.83**	0.78**	0.12*	ns	-0.70**	-0.80**	-0.54**	-0.66**	-1.0**	1	
AlS	-0.80**	0.58**	0.74**	0.89**	-0.28**	0.23**	-0.60**	-0.68**	-0.51**	-0.56**	-0.91**	0.91**	1

*** Significant at 0.01 level; * Significant at 0.05 level; ns – not significant*

Results of the present study had quite a few critical revelations regarding rising levels of soil acidity in Meghalaya which has relevance to the acid soil management for enhancing crop productivity and food security in the region. As per the previous reports, as cited by Sharma and Sarkar (2005), and Sharma *et al.* (2006), 53% of the soils in Meghalaya were strongly acidic (pH ≤ 5.50), while our present study shows that 80.2% of the soils in the state are strongly acidic which suggests that soil acidity in Meghalaya is intensifying with time. This can be attributed to the fact that while acidity causing factors like rainfall and base feeding by growing crops are constantly in operation, acidity ameliorative measures like liming (and other supplements with liming values) are not being practiced on large scale in the state. Acidic nature of the parent materials (granitic parent rock) might also be contributing to the increases in soil acidity in the region. Rise in soil acidity may also be caused by the rising levels of atmospheric CO_2. A decade back, Kumar (2011) had reasoned that soil acidity, the biggest impediment to crop productivity in North-eastern region, may further intensify under the rising atmospheric CO_2 concentrations. This possibility stems from the frequent experimental observation of increased CO_2 production in soil due to enhanced soil respiration under elevated CO_2 conditions (Gill *et al.*, 2002). Elevated CO_2 stimulates photosynthesis leading to higher accumulations of photosynthates in plants. Since up to one third of the photosynthates find entry into soil as rhizo-deposites, there is higher accumulation of carbon-rich rhizo-deposites in soil under elevated CO_2 which serves as food source for soil microbes, leading to improved soil respiration and more CO_2 production in soil. It leads to more carbonic acid formation in soil water, which upon leaching, removes base cations from soil, thereby causing soil acidification (Oh and Richter, 2004). Modelling studies by Oh and Richter (2004) suggested that a doubling of atmospheric CO_2 concentration may increase acid inputs from H_2CO_3 leaching by up to 50%. They also asserted that increases in atmospheric CO_2 since the interglacial era might have caused gradual acidification of soils globally, and will continue to do so in the high-CO_2 atmosphere of the future.

Table 5: Results of principal component analysis showing principal components (PC) with their Eigen values and proportion of variance (%) explained, along with rotated factor loadings and communalities of soil acidity-related attributes

Soil parameters	PC-2	PC-1	PC-3	Communalities
pH	-0.641	0.618	0.179	0.825
Total acidity	0.953	-0.147	-0.018	0.929
Exch. acidity	0.728	-0.470	0.447	0.951
Exch. Al	0.811	-0.474	-0.019	0.883
Exch. H	-0.149	-0.002	0.939	0.903
Non-Exch. acidity	0.772	0.158	-0.371	0.758
Exch. Ca	-0.131	0.869	-0.069	0.777
Exch. Mg	-0.131	0.855	-0.162	0.774
Exch. K	-0.126	0.622	0.095	0.411
CEC_e	0.020	0.915	0.012	0.837
Base Saturation (%)	-0.470	0.811	-0.245	0.940
Acid Saturation (%)	0.470	-0.811	0.245	0.940
Al Saturation (%)	0.569	-0.740	-0.118	0.886
Eigen values	2.18	7.44	1.19	
Variance explained (%)	16.8	57.3	9.1	
Cumulative variance explained (%)	74.1	57.3	83.2	

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

The soils were mostly depleted in basic cations, reflecting in very low effective CEC and base saturation in the soils. Conversely, acid saturation and more importantly Al saturation of the soils (% of the ECEC occupied by exch. Al) were very high, raising concerns for Aluminium toxicity to the plants growing thereon. The strongest correlation of effective CEC with exchangeable Ca underlines the utility of liming and Ca containing amendments to improve the ECEC and thus fertility of these soils (Kumar *et al.*, 2012 a & b). Ratio of exch. Ca to Mg should be ideally near 5.0 for a soil with good fertility. However, this ratio was also very low (2.47) across the soils of Meghalaya; Ca containing amendments are therefore required to improve this ratio. Importance of effective CEC and exch. Al as the determinants of soil fertility in such soils was also highlighted by the results of principal components analysis.

Based on the results of our study, it may be conducted that the soil acidity in Meghalaya is intensifying with time as we found over 80% of the soils to be strongly acidic (pH $\leq$ 5.50) in contrast to the previously known level (53%). Base saturation, an important fertility parameter, was found well below 50% in most of the soils, except for Garo Hills' soils. Conversely, Al saturation was frequently found in excess of 50% in majority of the soils. High levels of soil acidity coupled with low base saturation and high abundance of exchangeable Al pose serious management challenges to the agriculture of the state. Liming, an ameliorative practice usually recommended for acid soils, needs to be taken more seriously and should be promoted on wider scale to make the soils better suited for crop production.

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