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Forms of acidity and lime requirement of some Alfisols

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Abstract

Red soils of Bihar and West Bengal (Alfisols) were studied to relate the lime requirement to nature of soil acidity. Exchangeable acidity, hydrolytic acidity and total potential acidity ranged from 0.07 to 0.43, 0.96 to 3.65 and 1.46 to 6.73 cmol(+)kg^{-1}, respectively. Exchangeable acidity and hydrolytic acidity contributed 1.3 to 17.0 and 50.8 to 83.0 percent of total potential acidity, respectively. Grand mean of lime requirement by different methods as expressed in cmol(+)kg^{-1} was in the order of SMP 5.4> New Woodruff 4.3> Woodruff 4.1. Correlations among different forms of acidity and methods of lime requirement with selected soil properties were examined. The New Woodruff did slightly better than Woodruff and SMP, and hence the New Woodruff procedure may be recommended for routine soil testing.

Additional key words : Exchangeable acidity, hydrolytic acidity, total potential acidity.

Introduction

Alfisols in Bihar and West Bengal are mostly acidic and dominated by Fe and Al oxides and mixed clay minerals. Soil acidity is normally expressed in terms of KCl exchangeable and hydrolytic acidity (Coleman and Thomas 1967). The first type of acidity is ascribed to isomorphous substitution, and the second type to the polymers of iron and aluminium and soil organic matter. The proportion of these forms of acidities in soils determines their nutrient capacities and lime requirement values. Knowledge of forms of acidity, therefore, helps in the management of acid soils. The objective of the study was to examine: (i) the contribution of extractable H^+ and Al^{3+} to different forms of acidity, (ii) interrelationship between various forms of acidity and selected soil properties, and (iii) the soil properties and different forms of acidity to predict lime requirement.

Materials and methods

Three red soil profiles, first belonging to Godda series in Godda district, Bihar, second belonging to Pipradih series and third to Surulia series in Purulia district, West Bengal were selected for the present investigation. The samples were air dried and passed through a 2 mm sieve for subsequent analysis. The physical and chemical properties of the soils are reported in table 1. Exchangeable H^+ and Al^{3+} were determined from 1*M* KCl extract of soil by the method of McLean (1965) as described by Black (1965). Hydrolytic acidity was estimated by extracting with 1.0 *M* sodium acetate buffered at pH 7.8 as described by Das *et al.* (1991). Total potential acidity was determined using $BaCl_2$-triethanolamine extract buffered at pH 8.0 ± 0.02 of Peech's method (Black 1965). Lime requirement of acid soils was determined by buffer methods (Woodruff, New Woodruff and SMP) outlined by Brown and Cisco (1984). Relationships between different forms of acidity and various physical and chemical characteristics of the soils were established following standard statistical methods.

Table 1. Physical and chemical properties of Alfisols

Depth (cm)	pH (1:2.5)		EC (1:5) (dSm^{-1})	O.C. (%)	Mechanical separates (%)			Texture	CEC	Extractable aluminium	Exchangeable iron
	Water	1(N)KCl			Sand	Silt	Clay		cmol(+)kg^{-1}		
Pedon A : Godda series : Typic Rhodustalfs											
0 - 16	6.1	5.0	0.015	1.16	43.6	12.6	43.8	c	21.6	0.09	0.007
16–50+	6.3	4.9	0.014	0.93	34.4	12.7	52.9	c	21.5	0.14	0.008
Pedon B : Pipradih series : Typic Haplustalfs											
0 - 11	5.4	4.1	0.015	0.17	89.7	4.5	5.8	s	3.6	0.29	0.008
11 – 26	5.5	3.9	0.014	0.15	80.6	10.0	9.4	ls	7.8	0.49	0.004
26 – 50	5.8	4.4	0.023	0.12	61.1	4.4	34.5	scl	9.1	0.16	0.003
50 – 85	6.3	4.7	0.014	0.09	61.5	6.2	33.4	scl	9.6	0.17	0.002
85 – 95	6.6	4.8	0.007	0.03	80.5	4.6	14.9	sl	4.4	0.16	0.007
95– 110+	6.1	4.5	0.014	0.07	74.2	3.3	22.5	scl	9.1	0.18	0.008
Pedon C : Surulia series : Typic Kandiustalfs											
0 – 12	5.7	4.3	0.028	0.45	73.6	5.7	20.7	scl	7.5	0.17	0.009
12 – 28	5.9	4.2	0.013	0.15	54.8	11.6	33.6	scl	10.9	0.19	0.007
28 – 60	6.3	4.5	0.011	0.08	56.2	13.7	30.1	scl	8.0	0.16	0.004
60 - 85	6.2	4.6	0.020	0.07	58.6	13.8	27.6	scl	7.4	0.15	0.008
85–150 +	6.5	4.7	0.012	0.07	64.7	7.8	27.5	scl	8.3	0.15	0.004

* s = sandy; c = clayey; ls = loamy sand; sl = sandy loam; scl = sandy clay loam

Results and discussion

Exchange acidity : Results on the sum of H^+ and Al^{3+} in exchange acidity accounted for 1.3 to 17.0% of total potential acidity, which is low in all profiles (Prabhuraj and Murthy 1994). The mean value of exchange acidity and its contribution to total potential acidity is high in Pedon B followed by Pedon C and Pedon A(Table 2).

The contribution of EB-Al^{3+} to exchange acidity is higher than the EB-H^+ in all the soils (Table 2). The higher contribution of EB-Al^{3+} towards exchange acidity is in agreement with the findings of Coleman and Thomas (1967) who reported that exchange acidity in soils is mainly due to monomeric Al^{3+} ions. The liberation of Al^{3+} is due to liberation of H^+ by the interaction of 1*N* KCl solution with the acidic clay minerals which in turn react with hydroxyl ions of aluminium octahedra, liberating Al^{3+} into solution (Singh and Aleoshin 1983).

Hydrolytic acidity : In contrast to exchange acidity, the soils exhibited wide variation in hydrolytic acidity (Table 2). Results showed that in various pedons, this acidity ranged from 0.96 to 3.65 cmol(+)kg^{-1} and accounted for 50.8 to 83.0 percent of total potential acidity. The lowest value was observed in Pipradih series at 85-95 cm depth which had low organic matter and clay content. The highest value 3.65 cmol(+)kg^{-1} in 16-50 cm depth (Godda series) due to high organic matter and clay content.

Table 2. Contribution of H^+ and Al^{3+} to different forms of acidity and lime requirement of Alfisols

Depth	Exchangeable acidity			Hydrolytic acidity			Total potential acidity			Lime requirement method [cmol(+)kg^{-1}]		
(cm)	H^+	Al^{3+}	Total	H^+	Al^{3+}	Total	H^+	Al^{3+}	Total			
Pedon A : Godda series : Typic Rhodustalfs												
0 –16	0.03 (33.3)	0.06 (66.7)	0.09 (1.4)	0.28 (8.5)	3.03 (91.5)	3.31 (50.8)	1.84 (28.2)	4.68 (71.8)	6.52	5.0	6.0	5.6
16–50+	0.03 (33.3)	0.06 (66.7)	0.09 (1.3)	0.42 (11.5)	3.23 (80.5)	3.65 (54.2)	2.17 (32.2)	4.56 (67.8)	6.73	5.5	7.0	6.8
Pedon B : Pipradih series : Typic Haplustalfs												
0 – 11	0.05 (27.8)	0.13 (72.2)	0.18 (8.5)	0.45 (27.3)	1.20 (72.7)	1.65 (77.8)	0.82 (38.7)	1.30 (61.3)	2.12	4.5	4.0	5.8
11 – 26	0.09 (20.9)	0.34 (79.1)	0.43 (17.0)	0.51 (26.7)	1.40 (73.3)	1.91 (83.0)	1.06 (41.7)	1.48 (58.3)	2.54	5.0	5.0	4.9
26 – 50	0.05 (38.5)	0.08 (61.5)	0.13 (5.6)	0.20 (13.5)	1.28 (86.5)	1.48 (64.1)	0.58 (25.1)	1.73 (74.9)	2.31	4.0	4.0	5.5
50 – 85	0.02 (28.6)	0.05 (71.4)	0.07 (3.6)	0.12 (9.8)	1.11 (90.2)	1.23 (63.1)	0.63 (32.3)	1.32 (67.7)	1.95	3.5	3.5	4.8
85 – 95	0.01 (14.3)	0.06 (85.7)	0.07 (4.8)	0.08 (8.3)	0.88 (91.7)	0.96 (65.7)	0.41 (28.1)	1.05 (71.9)	1.46	3.5	2.5	4.7
95– 110 +	0.03 (33.3)	0.06 (66.7)	0.09 (5.0)	0.19 (13.7)	1.20 (86.3)	1.39 (78.1)	0.33 (18.5)	1.45 (81.5)	1.78	4.0	3.5	5.0
Pedon C : Surulia series : Typic Kandiustalfs												
0 – 12	0.11 (42.3)	0.15 (57.7)	0.26 (8.5)	1.09 (52.2)	1.00 (47.8)	2.09 (68.7)	1.66 (54.6)	1.38 (45.4)	3.04	4.0	4.5	5.8
12 – 28	0.04 (30.8)	0.09 (69.2)	0.13 (7.1)	0.10 (6.8)	1.38 (93.2)	1.48 (80.4)	0.31 (16.9)	1.53 (83.1)	1.84	4.5	4.5	5.9
28 – 60	0.02 (22.2)	0.07 (77.8)	0.09 (3.1)	0.13 (7.9)	1.52 (92.1)	1.65 (57.7)	1.11 (38.8)	1.75 (61.2)	2.86	3.0	4.0	4.8
60 - 85	0.03 (30.0)	0.07 (70.0)	0.10 (3.4)	0.17 (10.8)	1.40 (89.2)	1.57 (53.0)	1.04 (35.1)	1.92 (64.9)	2.96	3.5	3.5	5.6
85– 150 +	0.02 (22.2)	0.07 (77.8)	0.09 (2.8)	0.15 (9.0)	1.50 (91.0)	1.65 (51.4)	1.18 (36.8)	2.03 (63.2)	3.21	3.5	3.5	5.4

Value in parentheses of H^+ and Al^{3+} indicate percent of their respective total acidity and value in parentheses for total different forms of acidities indicate their percent contribution to total potential acidity.

The percent contribution of hydrolytic acidity towards total potential acidity indicated that the largest contribution was in Pipradih soils with an average of 70.9, intermediate in Surulia soils with an average 66.8 and the lowest in Godda soils with an average of 52.6. Variation in the contribution of hydrolytic acidity towards total potential acidity within the soil series is due to variation of physical and chemical parameters of the soils.

The role of H^+ ion is evident in increasing hydrolytic acidity. However, a major portion of this acidity is contributed by Al^{3+} ions. The high amount of H^+ and Al^{3+} ions extracted by NaOAc might be due to pH dependent H^+ and Al^{3+} ions. Thus it may be inferred that buffered solution was able to extract some of H^+ and Al^{3+} ions which were otherwise inactive in combination with organic colloid.

The average contribution of extractable H^+ and Al^{3+} ions to the hydrolytic acidity was worked out as 16.2 and 83.8 percent for all soils. The mean contribution of extractable Al^{3+} ions to hydrolytic acidity was highest in Godda soils (90.0) intermediate in Pipradih soils (81.9) and lowest in Surulia soils (80.5) which followed the increasing trend of mean percent contribution of extractable H^+ to the hydrolytic acidity as Godda 10.0 < Pipradih 18.1 < Surulia 19.5. The results are in agreement with Singh *et al.* (1993) who also observed that Al^{3+} ions constituted the main component of hydrolytic acidity than H^+ ions for soils developed on granite gneiss and Mahananda alluvium in Bihar. Singh and Aleoshin (1983) while working on acid soils of different origin of the former USSR also noted that the portion of hydrolytic acidity was higher than the exchange acidity.

Total potential acidity : Total potential acidity of soils ranged between 1.46 to 6.73 cmol(+)kg^{-1}. The total potential acidity was the highest in Godda soils, intermediate in Surulia and the lowest in Pipradih soils. This is probably due to high percent of organic matter in Godda soils. The organic matter contributes through their functional groups like COOH and phenolic OH. The major portion of acidity is contributed by Al^{3+} as in exchange and hydrolytic acidity. The high amount of H^+ and Al^{3+} ions extracted by $BaCl_2$ triethanolamine might be due to extraction of pH dependent H^+ and Al^{3+} ions which were otherwise inactive in combination with organic colloid. Hence, H^+ and Al^{3+} ions combined with organic matter was not participating directly in controlling pH of the soils. Extractable Al^{3+} ions of the Godda soils varied from 4.56 to 4.68, Pipradih 1.05 to 1.73 and Surulia soils from 1.38 to 2.03. The results indicated that values of extractable H^+ followed the sequence : Godda 1.84 to 2.17 (2.00) > Surulia 0.31 to 1.66 (1.06) > Pipradih 0.33 – 1.06 (0.64). In order of mean percent of H^+ contribution to total potential acidity, the soils can be arranged as Surulia 38.1 > Pipradih 31.5 > Godda 30.2.

The hydrolytic and exchange acidity together contributes only 54% to total potential acidity in Godda soils, 78.7% in Pipradih and 71.5% in Surulia soils which indicates that H^+ and Al^{3+} ions are not the only ions that contribute to soil acidity as suggested by Yuan (1963). He suggested that Fe and Mn are perhaps the major hydrolysable ions on the exchange sites of the soil complex that produce acidity following hydrolysis. Because, some of these ions are not taken into account in the determination of exchange and hydrolytic acidity, a part of total acidity remained unaccounted for on the basis of these two forms of acidity.

Lime requirement by diagnostic methods : Lime requirement of various soil profiles as determined by diagnostic methods are presented in table 2. The various methods showed a great disparity in determining the lime requirement of a particular soil. This determination involved equilibration with buffer salt solution which reacts with various forms of acidity giving widely different values. The estimate of lime requirement using different methods was put in terms of cmol(+)kg^{-1} as a common basis of comparison instead of the traditional tonnes of $CaCO_3$ per acre furrow of the soil. One unit of cmol(+)kg^{-1} is equivalent to 0.5 tonnes $CaCO_3$ per acre. Lime requirements by Woodruff method ranged from 3.0 to 5.5 cmol(+)kg^{-1}; 2.5 to 7.0 cmol(+)kg^{-1} by New Woodruff method and 4.7 to 6.8 cmol(+)kg^{-1} by SMP method.

Influencing factors : This aspect was studied by regressing the several soil properties with different kinds of soil acidity and methods of lime requirement through bivariate correlation. The pH (H_2O) or pH (KCl) did not show significant correlation with hydrolytic acidity. The pH (H_2O) did not show any correlation with exchange (r = -0.52) and total potential acidity (r = 0.15). The pH (KCl) had a significant negative correlation with exchange acidity (r = -0.82 significant at 0.1% level), indicating that the exchange acidity is primarily responsible for lowering the soil pH in these soils. Das *et al.* (1991) had observed a similar relation. The pH (KCl) also showed correlation with total potential acidity (r = 0.55, significant at 5% level).

Organic carbon did not show significant correlation with exchange acidity. It showed significant correlation with hydrolytic acidity and total potential acidity (r = 0.95 and 0.94, respectively). Such correlations are expected since soil organic matter possesses number of functional groups containing H^+ ions, which contribute to different forms of acidity depending on their magnitude. Organic carbon is significantly correlated with lime requirement (LR) value of Woodruff (r = 0.72), New Woodruff (r = 0.73) and SMP (r = 0.60). Organic matter is the major contributor to hydrolytic and total potential acidity (Hoyt 1977) and to lime requirement of soils low in exchangeable Al (Keeney and Corey 1963). Although different forms of acidity and methods of lime requirement are highly correlated with organic carbon, higher r values were given by clay content and extractable Al. It is evident, therefore, that organic matter is not the only major source of acidity in these soils.

The CEC of soils is not significantly correlated with exchange acidity. CEC has positive correlation with hydrolytic acidity (r = 0.85) and total potential acidity (r=0.92). The CEC indicates the total negative charge of the colloid and in acid soil may be related to the hydrolytic and total potential acidity. The CEC was significantly correlated with LR values determined using Woodruff (r = 0.67) and New Woodruff (r = 0.72) methods. It bears no significant correlation with SMP.

Clay percent in the soil showed significant relationships with exchange acidity (r = -0.85), hydrolytic acidity (r = 0.59) and total potential acidity (r = 0.72). Clay, being important colloidal constituent in most soils, contributes a significant share to the buffering capacity of H^+ and Al^{3+} ions of acid soils. Clay content showed no effect on any of the diagnostic methods of lime requirement.

Extractable aluminium has strong positive correlation with exchange acidity (r = 0.93). Aluminium in the soil solution which is related to NH_4OAc extractable Al, has been identified as a factor responsible for exchange acidity as well as for poor crop growth in many acid soils (Adams 1974). The small amount of extractable Al in soils occurs as coating on the external and interlamellar surfaces of other soil constituents, have a disproportionately high influence on surface properties such as ion retention and exchange (Schwertmann and Taylor 1981). Extractable Al bears no significant correlation with hydrolytic acidity (r = -0.13), total potential acidity (r = -0.33) and methods of LR.

Exchangeable iron has no significant correlation with exchange, hydrolytic, total potential acidity and any of the methods of LR indicating exchangeable iron has no effect on them.

Exchange acidity had no significant correlation with hydrolytic acidity, total potential acidity and any methods of LR. The exchange acidity, which contributed 4.6% to total potential acidity was too low to contribute significantly to LR.

Hydrolytic acidity has high significant correlation with total potential acidity (r = 0.99). Since hydrolytic acidity and total potential acidity are in dynamic equilibrium, they are related to each other.

Hydrolytic acidity and total potential acidity showed significant relationships with LR values determined through Woodruff (r = 0.77; r = 0.65), New Woodruff (r = 0.78; r = 0.73) and SMP (r = 0.65; r = 0.63) methods respectively. Based on the regression analysis it was observed that the New Woodruff buffer methods is slightly better than Woodruff and SMP in estimating lime requirement for the present group of soils.

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