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Basic Slag as a Liming Material to Ameliorate Soil Acidity in Alfisols of Sub-tropical India

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Abstract: Crop production on acid soils can be improved greatly by adjusting the pH to near neutrality. While soil acidity is commonly corrected by calcite, there is evidence that use of basic slag as an amendment can increase the pH of acid soils. The effect of calcite and basic slag ($CaSiO_3$) with different doses on soil acidity, nutrient availability and grain yield was determined in the experiments. Fourteen field experiments were conducted during the rabi season of 2003-2004 and 2004-2005 in Alfisolsof Midnapur West and Purulia districts of West Bengal, INDIA. Besides liming materials, locally available organic resources e.g. farmyard manure (FYM) and poultry manure (PM) were also used along with basic slag to increase its efficacy. The treatments used were as follows: No lime, $1/5^{th}$ LR (basic slag), $1/5^{th}$ LR (calcite), $1/10^{th}$ LR (basic slag), $1/10^{th}$ LR (calcite), $1/5^{th}$ LR (basic slag + FYM @ 5t/ha) and $1/5^{th}$ LR (basic slag + PM @ 3t/ha). Results showed that both calcite and basic slag increased the grain yield of wheat. They were effective when applied @ $1/5^{th}$ LR dose than $1/10^{th}$ LR. On an average, calcite and basic slag caused an increase in grain yield to the extent of 21.9 and 31.0% over the no lime treatment, respectively. Results also showed that increase in the yield of wheat was more with basic slag $1/5^{th}$ LR than with calcite. Incorporation of organic sources of nutrients particularly FYM and PM caused a further increase in yield, the magnitude being 56.2 and 60.2% respectively over the no lime treatment. Results of straw yield also showed the similar trend of change. Uptake of N and P by wheat plants showed that liming caused significant increases in their uptake. There was no significant increase in concentration of K with lime application. Organic matter addition enhanced the uptake of the nutrient elements viz., N, P and K. Results of the analysis of residual soil showed that total acidity, exchange acidity and hydrolytic acidity recorded a decrease upon liming.

Key words: Basic slag · calcite · liming acid soils · organic manures and wheat crop

INTRODUCTION

Soil acidity is a major factor limiting crop yield in vast areas of the world [1]. Acid soils occupy about 3.95 billion ha and account for 30% of the world's ice-free land area [2]. Soil acidity is particularly prevalent in the humid tropics and subtropics, climatic zones that encompass many of the countries struggling most to achieve self-sufficiency in food production. Out of the 328 million hectares of geographical area of India nearly 145 million hectares is cultivated and a rough estimate indicates that 48 million ha of soil is acidic in nature of which 25 m ha shows pH below 5.5 while about 23 m ha has pH between 5.6 and 6.5 [3].

Soil acidity is the major problem of the Alfisols of West Bengal, leading to severe toxicity of iron, aluminium and manganese accompanied by deficiency of phosphorus and low microbial activity leading to poor yield of crops [4]. In general fertility status of these soils is very poor and under strongly to moderately acidic soils the plant growth and development affect to a great extent. The crops grown on these problematic soils do not give remunerative return rather it lowers down the yield to a great extent. Because of the limited land resource it needs judicious management practice so that the yield of the different crops can be increased. So, one of the most important and particularly feasible management practices is the use of lime and liming materials to ameliorate the soil

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acidity. The addition of lime raises the soil pH, thereby eliminating most major problems of the acid soils. Application of lime eliminates actual and exchange acidities, minimizes hydrolytic acidity, raises the calcium content in the soil [5]. Reduced soil acidity following liming also increases the availability of the several plant nutrients, notably phosphorus. Only about 20% of fertilizer phosphorus is taken up by the crop in the year of application. The remainder is fixed in the soil in various degrees of availability to succeeding crops. Therefore, one of the benefits of liming acid soils is the increased utilization of residual fertilizer phosphorus by crop. Liming creates a suitable environment (pH 6.0 - 6.5) for nitrifying bacteria, increase in aerobic N fixation process and organic matter decomposition process. Liming also enhances the mineralization of organic matter, thereby releasing inorganic plant nutrients such as N, P and S to soil solution.

Various liming materials are used to neutralise the soil acidity, thereby overcoming the problems associated with the acidification. One of the important liming materials is basic slag. Basic slag is a by-product of the basic open-hearth method of making steel and its neutralizing value is 86. The calcium contained is in the form of calcium silicate and reacts with soil acids in a manner similar to ground limestone. It also contains P_2O_5 ranging form 2-6% and some micronutrients and magnesium. Generally calcite ($CaCO_3$) is used as agricultural lime but it is to some extent expensive. As a result farmers often become reluctant to ameliorate soil acidity. With this objective basic slag, a low cost liming material was undertaken to judge its suitability as an ameliorant of acid soil comparing calcite.

MATERIALS AND METHODS

Fourteen field experiments were conducted on farmers' field for wheat crop using K-9107 as a test variety in two districts (Midnapur West and Purulia) of red and lateritic tract (Alfisols) of West Bengal in the rabi season of the years 2003-04 and 2004-05 for this purpose. Lime requirement (LR) values of the experimental soils were also determined following SMP method [6]. The LR values in Table 1 gave the amount of $CaCO_3$ needed to neutralise the soil acidity. Another lime source i.e., basic slag was also used as a low cost locally available liming material. The equivalent amount of basic slag needed was also determined by calculating the relative neutralising power of basic slag vis-a-vis calcite. An average composition of basic slag was: Ca (33.2%), Mg (3.2%), P_2O_5 (2.1%), Si (2.3%), Cu (163 μg g^{-1}) and Zn (174 μg g^{-1}). Three doses viz., no lime, lime @ 1/5th LR (lime requirement value) and lime @ 1/10th LR of both the liming materials were used for the experiment. Besides liming materials, locally available organic sources e.g. farmyard manure (FYM) and poultry manure (PM) were incorporated with basic slag in all the places with the assumption that they might help to increase the solubility of basic slag. Thus the treatments used were as follows: No lime, 1/5th LR (basic slag), 1/10th LR (basic slag), 1/5th LR (calcite), 1/10th LR (calcite), 1/5th LR (basic slag + FYM @ 5t/ha) and 1/5th LR (basic slag + PM @ 3t/ha). Crop was sown with the recommended doses of N, P and K (@ 80:40:40 kg ha^{-1}). Full dose of P and K were applied at the time of sowing but for N half of the recommended dose was applied at the time of sowing and the rest half of N was applied at 21 DAS i.e. at crown root initiation stage. Calculated amount of the liming material corresponding to the three doses was mixed up with the soils in the furrows. After harvest grain and straw yield of the crop were recorded and the plant samples were analysed for N, P and K following standard methods. Economy of the liming materials used was also calculated.

Soil samples both the initial and residual (collected after harvest of the crop) were analysed for soil pH (both pH_w and pH_{ca}) and different forms of soil acidity viz., total acidity, exchange acidity, hydrolytic acidity, electrostatically bound H^+(EBH^+) and Al^{3+}($EBAl^{3+}$). Total acidity (TA) and exchange acidity (EA) were determined by extracting soil with 1.0 M sodium acetate (pH 8.2) [7] and 1.0 M KCl [8] respectively and subsequently titrating with NaOH using phenolphthalein as an indicator. Electrostatically bound Al ($EBAl^{3+}$) was determined in 1.0 M KCl extract by titrating with HCl after adding NaF. The difference between EA and $EBAl^{3+}$ represented the electrostatically bound H^+ (EBH^+). The difference between total acidity (TA) and exchange acidity (EA) was designated as hydrolytic acidity (HA) [9].

RESULTS AND DISCUSSION

All the soils used in the experiment were acidic in nature with mean pH values of 5.1 (pH_w) and 4.4 (pH_{ca}) (Table 1). Lower values of pH_{ca} than pH_w explained that the soils were negatively charged. The total acidity (TA) of the soils as extracted by 1.0 M NaOAc, pH 8.2 varied from 1.31 - 2.57 cmol (p^+) kg^{-1} with mean values of 1.76 cmol (p^+) kg^{-1} (Table 1). The hydrolytic acidity (HA) varied from 1.0 to 1.95 cmol (p^+) kg^{-1} with a mean value of 1.42 cmol (p^+) kg^{-1}. The exchange acidity (EA) includes

Table 1: Forms of acidity and lime requirement values of the experimental soils before lime application

Experimental sites	Total acidity	Exchange acidity	Hydrolytic acidity	$EBAl^{3+}$	EBH^{+}	pH_w	pH_{ca}	LR (t ha^{-1})
	[cmol (p^+) kg^{-1}]							
Pukuria	1.43	0.32	1.11	0.21	0.11	5.3	4.5	4.70
Radhanagar	1.31	0.14	1.18	0.05	0.09	5.2	4.6	6.17
Dhenkipora	2.57	0.97	1.60	0.54	0.42	4.8	4.3	4.70
Dahijuri	2.19	0.86	1.33	0.51	0.34	5.1	4.1	7.66
Andharia	2.37	0.90	1.47	0.55	0.34	5.1	4.2	7.66
Binpur	1.33	0.23	1.10	0.15	0.09	4.9	4.5	4.70
Kapgari	1.39	0.14	1.25	0.12	0.02	5.3	4.7	6.17
Bansra	1.33	0.33	1.00	0.30	0.03	5.2	4.1	6.17
Gopladih	1.75	0.10	1.65	0.04	0.06	5.1	4.7	3.45
Manikdih	1.52	0.19	1.33	0.06	0.13	5.3	4.3	7.66
Sirkabad	1.73	0.10	1.64	0.03	0.07	4.7	4.5	7.66
Santladih	2.24	0.29	1.95	0.22	0.07	5.2	4.2	6.17
Govindpur	1.88	0.08	1.80	0.03	0.06	5.0	4.6	4.70
Chakaltod	1.60	0.07	1.53	0.01	0.06	5.0	4.4	4.70
Range	1.31-2.57	0.07-0.97	1.0- 1.95	0.03-0.55	0.02-0.42	4.7-5.3	4.1-4.7	3.45-7.66
Mean	1.76	0.34	1.42	0.20	0.14	5.1	4.4	5.88
SD	0.42	0.32	0.28	0.20	0.13	0.19	0.20	1.41

LR= Lime requirement of soil in the form of $CaCO_3$

Table 2: Effect of liming on grain yield of wheat (q ha^{-1})

Experimental sites	No lime	BS 1/5th	BS 1/10th	Ca 1/5th	Ca 1/10th	BS 1/5th + PM	BS 1/5th + FYM
Pukuria	13.7	23.5	19.1	21.5	15.8	25.1	24.5
Radhanagar	19.3	26.8	21.5	24.5	20.2	28.5	28.0
Dhenkipora	18.2	25.5	20.5	23.3	19.2	28.1	27.4
Dahijuri	16.0	27.5	18.5	25.8	18.2	28.9	28.1
Andharia	18.5	22.6	20.5	21.5	19.3	26.7	25.5
Binpur	17.3	24.2	19.8	20.8	18.5	27.3	26.1
Kapgari	18.5	23.5	20.6	22.8	19.5	27.5	26.4
Bansra	17.8	22.4	20.7	23.7	19.6	25.8	24.3
Gopladih	14.4	25.3	16.2	23.0	18.1	28.6	27.4
Manikdih	16.5	24.5	20.0	21.9	18.8	26.8	25.3
Sirkabad	18.0	23.8	20.2	23.7	19.5	26.3	25.1
Santladih	16.0	27.3	22.5	25.0	17.0	29.5	28.2
Govindpur	17.4	26.2	20.2	24.5	19.3	28.1	27.5
Chakaltod	17.3	24.7	20.0	22.2	18.8	26.7	25.3
Mean	17.1	24.8	20.0	23.2	18.7	27.4	26.8
$Se_m(\pm)$	0.395						
CD (P= 0.05)	1.116						

the exchangeable H^+ and Al^{3+} held at the permanent charge sites of the soil exchange complex. Unlike TA, the EA of all the soils was much less and its value ranged from 0.07 to 0.97 cmol (p^+) kg^{-1} with a mean value of 0.34 cmol (p^+) kg^{-1}. Soils were limed on the basis of lime requirement (LR) estimated.

Effect of lime on grain and straw yield: Results showed that application of lime caused a significant increase in grain (GY) and straw yield (SY) of wheat (Table 2 & 3). The magnitude of increase in GY and SY due to liming was 26.8 and 18.6 per cent respectively over the no lime treatment, irrespective of the sources and levels of lime.

Table 3: Effect of liming on straw yield of wheat (q ha^{-1})

Experimental sites	No lime	BS 1/5th	BS 1/10th	Ca 1/5th	Ca 1/10th	BS 1/5th + PM	BS 1/5th +FYM
Pukuria	21.8	29.3	25.0	26.7	23.3	32.4	31.5
Radhanagar	25.5	31.2	27.2	30.2	25.6	33.1	32.6
Dhenkipora	23.3	30.9	25.5	28.5	23.8	33.8	33.4
Dahijuri	24.8	33.8	30.5	30.5	28.3	36.3	35.4
Andharia	25.4	31.2	29.1	30.6	27.2	34.2	33.6
Binpur	21.5	26.8	24.6	26.4	23.0	29.1	28.5
Kapgari	22.4	29.4	27.1	27.6	25.3	31.6	30.9
Bansra	25.5	34.2	26.3	31.2	24.2	36.8	36.1
Gopladih	20.5	29.5	22.7	33.2	21.1	32.2	31.5
Manikdih	23.3	31.5	27.5	27.2	25.5	33.5	32.6
Sirkabad	24.3	28.8	31.2	30.2	28.6	31.0	30.2
Santladih	25.6	33.2	30.2	29.5	27.5	34.8	34.1
Govindpur	26.1	31.6	26.5	29.2	24.1	34.2	33.5
Chakaltod	21.6	28.5	25.5	25.6	23.3	31.2	30.2
Mean	23.7	30.7	27.1	29.0	25.1	34.1	33.5
$Se_m(\pm)$	0.579						
CD (P= 0.05)	1.635						

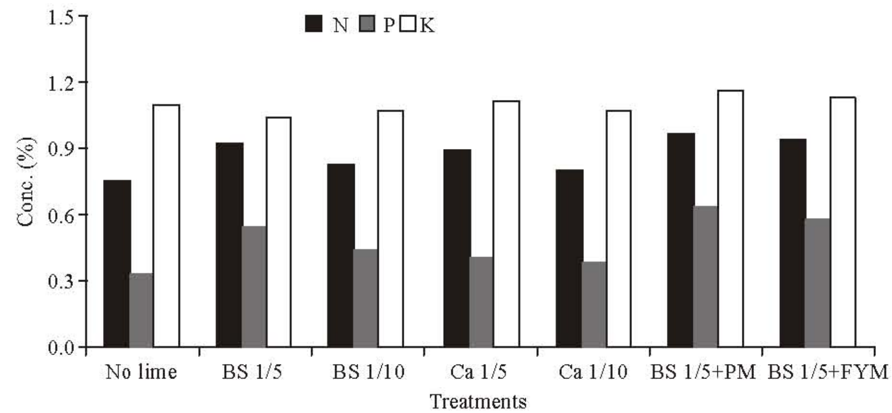

Fig. 1: N, P and K content in wheat plants (mean of 14 experiments)

Such increase in both GY and SY was always higher with basic slag than with calcite, the magnitude of increase in GY and SY being 31.0 and 21.9 per cent with the former but 22.5 and 14.1 per cent with the latter (Table 2 & 3). Results thus indicated a better response of wheat to basic slag than calcite. Response of wheat to liming also varied depending upon their levels of application. There was a higher response with higher doses of lime, the mean magnitude of GY and SY being 17.1, 19.4, 24.0 and 23.7, 26.1, 29.9 q ha^{-1} with no lime, LR1/10th and LR 1/5th levels of added lime respectively (Table 2 & 3). These constituted an increase in GY of about 13.5 and 40.6 per cent over the control with LR1/10th and LR1/5th levels of lime respectively. The corresponding values for SY were 10.0 and 26.1 per cent. The magnitude of increase with basic slag @1/5th LR was further enhanced when it was incorporated either with FYM or PM. Incorporation of FYM and PM caused a yield increase of 56.7 and 60.2% respectively over the no lime and 19.6 and 22.3% over the only basic slag @ 1/5th LR treatment. Straw yield also showed the similar trend of results. Significant increase in grain yield of maize on liming even with 1/4th lime requirement value were recorded [10]. Increase in yield with higher doses of liming material was observed by [11, 12, 13]. The relative order of performance of the treatments was as follow: 1/5th LR (basic slag + PM @ 3t/ha) > 1/5th LR (basic slag + FYM @ 5t/ha) > 1/5th LR (basic slag) > 1/5th LR (calcite) > 1/10th LR (basic slag) > 1/10th LR (calcite) > and no lime. Results thus showed that locally available organic resources like FYM and PM would be effective in increasing the efficacy of basic slag for increasing the productivity of wheat crop in acidic Alfisols of West Bengal.

N, P and K content in wheat plants: Results (Fig. 1) showed that liming caused significant increase in N and P content of crop. Application of lime caused a significant increase in N concentration in wheat plants.

Table 4: Changes in soil acidity parameters [cmol (p^+) kg^{-1}] after harvest of wheat crop

Treatments	pHw	pHca	EB Al^{3+}	EB H^+	Total acidity	Exchange acidity	Hydrolytic acidity
Initial	5.1	4.4	0.20	0.14	1.76	0.34	1.42
No lime	5.2	4.5	0.18	0.12	1.66	0.31	1.35
BS 1/5th LR	6.0	5.6	0.04	0.05	0.84	0.09	0.75
BS 1/10th LR	5.5	5.0	0.09	0.07	1.14	0.16	0.98
Ca 1/5th LR	6.1	5.9	0.03	0.04	0.56	0.07	0.49
Ca 1/10th LR	5.7	5.2	0.07	0.07	1.05	0.14	0.92
BS 1/5th LR + PM	6.3	5.9	0.08	0.07	0.90	0.15	0.81
BS 1/5th LR + FYM	6.2	5.8	0.07	0.06	0.89	0.13	0.76
Mean	5.8	5.3	0.10	0.08	1.10	0.17	0.94
$Se_m(\pm)$	0.039	0.031	0.025	0.019	0.081	0.042	0.075
CD (P= 0.05)	0.110	0.110	0.071	0.054	0.229	0.119	0.212

(Mean of fourteen experiments)

Table 5: Economics of lime application in wheat crop

Treatment	Price of lime (Rs)	Yield (q ha^{-1}) *	Yield increased over check (q)	Percent response	Price of increased yield (Rs)	Profit over check (Rs ha^{-1})	Return in per Re investment (B: C)
No lime	-	17.1	-	-	-	-	-
BS 1/5th LR	1093	24.8	7.7	45.6	6223	5130	4.7
BS 1/10th LR	546	20.0	2.9	17.6	2366	1820	3.3
Ca 1/5th LR	2352	23.2	6.1	35.7	4874	2522	1.1
Ca 1/10th LR	1176	18.7	1.6	9.4	1309	133	0.1
BS 1/5th LR + PM	1093	27.4	10.3	60.2	8240	7147	6.5
BS 1/5th LR + FYM	1093	26.8	9.7	56.7	7760	6667	6.1

•mean of 14 experiments, price of wheat @ Rs 8/- per kg, price of basic slag Rs 80/- per quintal, price of calcite @ Rs 200/- per quintal

The mean increase of N concentration was 17.1 per cent over the no lime. Such increase was higher with basic slag than with calcite; the magnitude being 19.7 per cent and 11.8 per cent over the no lime respectively (Fig 1). Concentration of N in wheat plants also varied depending upon the levels of lime application. The concentration was higher with higher dose LR 1/5th, the magnitude of increase being 22.4 and 9.2 per cent with LR 1/5th and LR 1/10th doses respectively. There was a significant increase in the concentration of N when the organic residues like FYM and PM were incorporated with basic slag. The magnitude of increase was 23.7 and 27.6 per cent with FYM and PM respectively. Highest concentration of N (0.97%) was observed in the treatment LR 1/5th basic slag + PM. This indicates a better nutrition of N nutrition of wheat plants when acid soils are limed. Increase in availability and plant uptake N was also reported by Curtin and Smillie [14], Barade and Chavan [15] and Raychadhury *et al.* [16]. Application of lime also caused significant increase in P concentration (Fig. 1) in wheat plants, the mean increase being 51.5 per cent over the no lime. Such increase in P concentration on liming was higher with basic slag than with calcite, the magnitude being 65.9 and 19.7 per cent respectively. The application of FYM and PM with basic slag caused a significant increase in the concentration of P in plants. The results, therefore, indicated that a better response of wheat crop in respect of P nutrition was observed in limed soils than in the unlimed soils. Increased P availability and uptake by different crop plants upon liming was reported by Patiram Rai and Prasad [17], and Mongia *et al.* 18]. Application of lime did not show any specific trend of increase or decrease in concentration of K (Fig. 1) in wheat plants. The concentration of K was increased to about 0.92 per cent in limed soils. Such increase in concentration was higher when calcite and basic slag were used at lower doses. Significant increase in K content of wheat was observed with the application of organic manures. Results thus indicated that liming showed a mixed responses in K concentration by wheat plants. Decrease in K availability on liming was also observed by Prasad *et al.* [19] and Dwivedi [20].

Analysis of residual soils: Soil samples collected after the harvest of wheat crop were analysed for different soil properties viz., pH_w, pH_{ca}, OC and a few acid parameters such as total acidity, exchange acidity and hydrolytic acidity were also analysed to estimate the changes that occurred upon liming. Results (Table 4) showed that application of amendments caused significant increase in both pH_w and pH_{ca}. The mean magnitude of increase was 0.8 and 1.0 unit for pH_w and pH_{ca} irrespective of doses and sources of lime respectively. The increase was higher (0.9 unit) when calcite 1/5th LR was used as compared to the magnitude of increase (0.7 unit) with basic slag 1/5th LR. There are a number of reports that addition of organic residues to acid soil can reduce Al toxicity (thus lowering the lime requirement) and improve P availability. Significant increase in soil pH with the application of organic sources was observed. During residue decomposition, there is a transitory increase in soil pH and this induces a decrease in exchangeable and soil solution aluminium through their precipitation as hydroxy-Al compounds. It also confers a great negative charge on oxide surfaces and thus tends to decrease P adsorption. Result of acid parameters (Table 4) showed that there was a significant decrease in total acidity, exchange acidity and hydrolytic acidity upon liming. Marked decrease of exchangeable Al upon liming at the rate of 25% of LR was observed by Prasad *et al.* [10]. Increase in pH upon liming was also reported by Datta and Gupta [21], Dhadwal *et al.* [22] and Prasad *et al.* [19]. Results thus indicate that basic slag @1/5th LR caused significant decrease in most of acid parameters in soils.

Economics of lime application: The economics was calculated only for the lime application, because the motive of the research was only to see the effect of liming materials with different doses over the No-lime treatment. Results (Table 5) showed that there was a net benefit out of application of lime. The benefit was more with basic slag than with calcite. With the application of basic slag @ 1/5th LR the B:C ratio was 4.7 as compared to 3.3 with lower dose 1/10th LR. Benefit cost ratio with calcite was 1.1 and 0.1 with @ 1/5th LR and 1/10th LR respectively. There was further increase in grain yield when FYM and PM were applied in combination of basic slag. Value cost and benefit cost ratio was fairly higher when basic slag was applied with PM followed by FYM. Results thus showed that use of basic slag as a liming source was more economical as compared to calcite in Alfisols of West Bengal. It has been mentioned earlier that basic slag contains, in addition to Ca and Mg, good amount of P, Si, Zn and Cu. Since most of the Alfisols of West Bengal are deficient to marginal in respect of P, Zn and Si, such application of P, Zn and Si along with Ca and Mg through basic slag helped to have a better response and economics. This was more so because of low cost of basic slag. Liming in Alfisols through basic slag will thus be a good avenue for increasing productivity of these other-wisely low productive soils.

CONCLUSIONS

From the results it is revealed that use of basic slag as a source of lime will be very much effective to increase as well as to sustain the productivity of acid red and lateritic soils of West Bengal. Results also revealed that B:C ratio of basic slag is higher as compared to calcite. So it will be highly acceptable and affordable to the farmers of the area.

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REFERENCES

1. Shainberg, I., M.E. Sumner, W.P. Miller, M.P.W. Farina, M.A. Pavan and M.V. Fey, 1989. Use of gypsum on soils: a review. Advances in Soil Science. 9: 1-11.
2. Von Uexkull, H.R. and E. Mutert, 1995. Global extent, development and economic impact of acid soils. Plant Soil, 171: 1-15.
3. Sharma, P.D. and A.K. Sarkar, 2005. Managing acid soils for enhancing productivity. NRM Division, ICAR, New Delhi. Technical Bulletin, pp: 23.
4. Bandyopadhyay, P.K. and G.N. Chattopadhyay, 1997. Nature of acidity in some alfisols and inceptisols of Birbhum district of West Bengal. Journal of the Indian Society of Soil Science, 45: 5-8.
5. Somani, L.L., K.L. Totawat and R.A. Sharma, 1996. Liming Technology for Acid Soils. Agrotech. Publishsing Academy, Udaipur, pp: 240.
6. Shoemaker, H.E., E.O. McLean and P.F. Pratt, 1961. Buffer methods for determining lime requirement of soil with appreciable amounts of extractable aluminium. Soil Science Society of America Proceedings, 25: 274-277.
7. Kappen, G., 1934. Pochvennaya, Kislotmost, Selkhogi, Moscow.

8. McLean, E.O., 1965. Aluminum. In C.A. Black (ed.) *Methods of Soil Analysis*, Part II: Chemical and microbiological properties of soils. Am. Soc. of Agron., Inc. Madison, Wis. pp: 978-998.
9. Peech, M., R.L. Cowan and J.H. Baker, 1962. A critical study of the $BaCl_2$-Triethanolamine and ammonium acetate methods for determining the exchangeable hydrogen content of soil. Soil Society of America Proceedings, 26: 37-40.
10. Prasad, R.N., Patiram Rai, R.C. Barooah and Munna Ram, 1983. Direct and residual effect of liming on yield of maize and uptake of nutrients in acid soils of Meghalaya. Journal of the Indian Society of Soil Science, 31: 233-235.
11. Bezdicek, D.F., T. Beaver and D. Granatstein 2003. Subsoil ridge tillage and lime effects on soil microbial activity, soil pH, erosion and wheat and pea yield in the Pacific Northwest, USA. Soil Tillage Research, 74: 55-63.
12. Tang, C., Z. Rengel, E. Diatloff and C. Gazey, 2003. Responses of wheat and barley to liming on a sandy soil with subsoil acidity. Field Crop Research, 80: 235-244.
13. Bhat, J.A., A.K. Chatterjee and B. Mandal, 2004. Performance of different liming materials in increasing yield of mustard and ameliorating acidity in red and laterite soils of West Bengal. In: National Seminar on Developments in Soil Science, 69^{th} Annual Convention Indian Society Soil Science held during Oct 29 - 31, 2004 at ANGRAU, Hyderabad, AP.
14. Curtin, D. and G.W. Smillie, 1995. Effects of incubation and pH on soil solution and exchangeable cation ration. Soil Science Society of America Journal, 59: 1006-1011.
15. Barade, M.D. and K.N. Chavan, 1998. Liming induced changes in characteristics of fluventic ustrochrept of Konkan. Journal of the Indian Society of Soil Science, 46: 5-8.
16. Raychadhury, M., Kailashkumar and S. Raychaudhury, 1998. Response of soybean to lime and phosphorus on Utisols of manipu. Journal of the Indian Society of Soil Science, 46: 628-632.
17. Patiram Rai, R.N. and R.N. Prasad, 1990. Effect of liming on aluminium and yiled of wheat in acidic soil. Journal of the Indian Society of Soil Science, 38: 719-722.
18. Mongia, A.D., N.T. Singh, L.N. Mandal and A. Guha, 1998a. Response of rice to liming and phosphorus application in acid soils of south Andaman. Journal of the Indian Society of Soil Science, 46: 697-700.
19. Prasad, R.N., R.N. Patiram, Rai and Munna, Ram, 1985. Forms of aluminium in soils of East Khasi Hills, Meghalaya. Journal of the Indian Society of Soil Science, 33: 523-527.
20. Dwivedi, G.K., 1996. Tolerance of some crops to soil acidity and response to liming. Journal of the Indian Society of Soil Science, 44: 736-741.
21. Datta, M. and R.K. Gupta, 1983. Response of wheat and maize to lime in acid soils of Nagaland. Journal of the Indian Society of Soil Science, 31: 236-240.
22. Dhadwal, K.S., S. Laskar and R.N. Prasad, 1985. Factros affecting lime requirement of acid soils of Tripura and response of soybean to liming. Journal of the Indian Society of Soil Science, 33: 683-684.