4-1-1976

Lime Applications Seldom Benefit South Dakota Soils

R. C. Ward

P. L. Carson

D. D. Koth

E. Adams

Bulletin 643
April 1976

Lime Applications Seldom Benefit South Dakota Soils

Agricultural Experiment Station
South Dakota State University
Brookings

Soil scientists ordinarily do not recommend application of lime to reduce acidity in South Dakota soils. Several reasons are cited for not following this practice even in potential lime-needing soils in the more humid southeastern part of the state. Seldom are soil pH factors low enough in the root zone to obtain economically justified yield increases through application of lime. Rates of application are usually high for even small increases in yield. This report of research at the South Dakota State University Agricultural Experiment Station shows results of extensive experiments for the past 25 years and includes information useful for producers in making an economic justification for application of lime on South Dakota soils.

By R. C. Ward, former assistant professor; P. L. Carson, professor; D. D. Koth, former graduate assistant; and Earl Adams, Extension soil specialist, Plant Science Department, South Dakota State University.

For your convenience numbered tables in the text have been grouped together beginning on page 9.

850 copies printed at estimated cost of 22 cents each.

Introduction

Acid soils are formed mainly in humid areas because much water percolates through the soil annually removing concentrations of calcium and magnesium. As the basic cations are removed, they are replaced by hydrogen and aluminum ions which form acid soils. In less humid areas, reduced rainfall results in less percolating water. Soil acidity is not as severe in these areas. In arid areas with little or no percolating water, movement of calcium and magnesium is minor. Arid areas already high in calcium and magnesium remain that way.

South Dakota is in the transition zone between a humid climate on the east and an arid climate on the west. South Dakota soils have received enough moisture to result in a slightly acid surface soil (especially eastern South Dakota), but not enough to remove the basic cations from the root zone. When downward water movement stops, the calcium and magnesium ions combine with carbonates forming a layer of carbonate enrichment sometimes called a "lime zone." This zone is identified by small white concretions (stones) intermixed in the soil or as white coatings on pebbles.

The degree of soil acidity is measured by pH, a symbol used for convenience in expressing both acidity and alkalinity on a scale of 0 to 14. A neutral pH has an equal amount of acidity and alkalinity. The pH reading at this neutral point is 7.0. Acid soils have pH readings less than 7.0 and alkaline soils have readings above 7.0. The degree of acidity or alkalinity increases as the pH reading departs further from the neutral point.

A pH reading is a measure of the hydrogen ion concentration in the soil solution and is reported as the negative logarithm of the hydrogen ion activity. Since pH is a logarithmic concept, a decrease of one pH unit means that the actual hydrogen ion concentration is 10 times. A pH reading of 5.5 means the hydrogen ion concentration is 10 times greater than at a pH of 6.5. When pH is less than 6.2 many state soil testing laboratories recommend the use of limestone to reduce the hydrogen ion concentration thus raising soil pH toward neutrality.

Since a lime zone occurs just below the main root zones of South Dakota soils, the South Dakota State University Soil Testing Laboratory has not recommended lime when surface soil pH values were below 6.2. This report summarizes the lime research work conducted by the South Dakota Agricultural Experiment Station for the purpose of evaluating the need for lime in South Dakota.

Field Experimental Plots - 1950's

The first field experiments with lime were on moderately acid surface soils. Table 1 shows the effects of lime, phosphorus (as treble superphosphate designated as TSP), and rock phosphate on yields of oats and alfalfa. The soil pH was 6.0 at the Minnehaha County location and 5.7 at the Lincoln County location.

Treatments were applied in early April for the oats. Alfalfa yields were measured on the residual treatments at the Lincoln County site. Added P_2O_5 (80 lbs. of P_2O_5 as TSP) increased oat yields about

6 bushels per acre at the Minnehaha County site. Added lime at this location did not increase oat yields. At the Lincoln County site, P_2O_5 (either TSP or rock phosphate) did not increase the yield of oats. Oat yield increase for lime was 5-9 bushels per acre at this site.

Lime did not increase alfalfa growth in 1953 or 1954. Statistical evaluation of the yield values for the three cuttings show that all yield increases (up to 1.8 tons of alfalfa) were due to applied phosphate. Rock phosphate was just as effective as treble superphosphate (TSP) when applied at equivalent amounts of available P_2O_5 (rock phosphate was calculated to have 3% available P_2O_5). Lack of lime response with alfalfa indicated that lime deposited in the root zone by soil forming processes adequately supplied the needs of the alfalfa crop. Good establishment of alfalfa on all plots indicated no need for lime.

Table 2 shows yield of oats in Lincoln County (1955) when grown on land treated with phosphorus, lime, and gypsum (another source of calcium). None of the treatments were effective in increasing oat yields.

These early field experiments showed some response to lime. Since alfalfa, a crop that yields best at a neutral pH (pH 6.8-7.2), did not respond to lime it was concluded that lime was not needed in South Dakota. This conclusion was drawn with the knowledge that most soils contain alkaline subsoils.

Greenhouse Experiments

Greenhouse experiments were conducted during the winter of 1960 and 1961 with two soils to further study the need for lime. The purpose was to measure the effects of lime on the plant yield of oats and alfalfa grown on moderately acid surface soils without the presence of alkaline subsoils.

One greenhouse experiment used a soil from the Magee Farm in Lincoln County. The soil had one of the lowest pH measurements (5.5) of any analyzed by the SDSU Soil Testing Lab. The growth of two oat crops are shown in Table 3. The second crop of oats was grown after two cuttings of alfalfa shown in Table 4. Neither lime nor molybdenum increased oat yields. Yield increase from added phosphate was small because of the high phosphorus soil test ($>$ 40 lbs P/acre according to Bray weak acid test).

Alfalfa growth response was similar to that of oats. There was no response to lime, phosphorus, or molybdenum. Molybdenum is required in larger quantities by alfalfa than by many other crops. This element is needed to promote nodule formation on alfalfa roots. Since molybdenum availability decreases as pH becomes more acid, yield comparisons were made with and without molybdenum. The results showed that molybdenum was not deficient.

Soil samples were taken from the Magee greenhouse experiment after the first crop of oats and two cuttings of alfalfa (Table 5). Lime additions increased soil pH from 5.5 to 6.8 which showed that the lime was effective in changing the pH. Although soil pH was increased, it had no effect on increasing the yield of oats or alfalfa.

Another greenhouse experiment used a soil from the Weisner Farm in Deuel County. Initial pH was 5.8. Oats and alfalfa were seeded together and harvested when oat plants were in the heading stage of development. Data from Table 6 show the main response was to added phosphate. The 4-ton lime rate increased growth significantly over the check treatment without an application of P_2O_5. The yield increase to lime was small compared to the yield response to phosphate. One benefit often attributed to liming is increased phosphate availability. The small response at the 4-ton rate of lime could not be attributed to increased phosphorus availability because the phosphorus concentration of the plants (.136% phosphorus, phosphate fertilized) was not significantly different from that of the control treatment (.129% phosphorus).

Field Experiments 1968 - 1971

Further evaluation of lime needs during the 1968-1971 growing seasons included five field experiments. In addition, several soil samples with low pH were collected to study the lime required to raise soil pH to 6.5 or 7.0.

A description of the field experiments is shown in Table 7. The Lake County location was evaluated for 1 year and the others for 4 years.

Initial soil test values are shown in Table 8. The Minnehaha County site was lowest in organic matter, available phosphorus, and exchangeable potassium. Field site locations were chosen by contacting farmers who submitted soil samples to the Soil Testing Lab at SDSU that tested low in pH. The pH values for the plots were similar to much of the farm land in southeastern South Dakota where interest in liming has occurred. The pH of the experimental sites was not as low as the farmer soil samples. Differences between the two samples could be due to sampling of specialized small areas.

Buffer pH (method of determining lime needs) was determined by the University of Minnesota Soil Testing Lab and gives an indication of lime rate needed to bring soil pH to 6.5. A buffer pH of 6.7 shown in Table 8 calls for 2 tons of Ag-lime per acre while a buffer of 6.4 requires 2.5 tons of lime according to University of Minnesota tests for Area II, southwest Minnesota.

The experiment at the Union County site was on a Trent silty clay loam. Trent soils are deep, black, permeable, moderately well-drained silty soils occupying nearly level uplands in a warm, moist climate.

Clay and Lake County sites were on Egan silt loams. Egan soils are deep, black, permeable, moderately well-drained silty soils occupying nearly level uplands in a warm, moist climate.

The Moody and Minnehaha County sites were on Moody silty clay loams. Moody soils are deep, very dark, grayish brown, permeable, well-drained silty soils occupying nearly level uplands in a warm, moist environment.

The four sites studied for 4 years were established to measure the effects of lime over a period of years. The treatments were applied in the spring of 1968. Carryover was measured in succeeding years. Four tons of lime were applied on an acre basis. The lime material had an average neutralizing index of 51.7%, which means the effective (100% $CaCO_3$) lime rate was about 2.1 tons per acre. The phosphorus rate was 60 lbs of P_2O_5 per acre.

Results from the Union County site are in Table 9. No significant differences were noted among treatments. This means that the chances for obtaining real yield increases from lime are small. The moisture content of the ear corn was not affected by treatment.

Corn yields were lower at the Clay County site (Table 10). No significant responses resulted from application of lime or phosphorus. This experiment showed high variation between replications as shown by the coefficient of variation values. The lime did not have an effect on moisture content of ear corn at the Clay County site.

Corn yields were obtained for 1968 and 1971 at the Moody County location (Table 11). Neither phosphorus nor lime increased corn yields or affected the moisture content of the ear corn. Soybean yields were not increased by either treatment (Table 12). This location had an initial pH of 6.3 which is only slightly acid and should not be expected to require Ag-lime.

Effect of lime on alfalfa was studied at the Minnehaha location (Table 13). Lime and phosphate were plowed down and then the field was seeded to alfalfa by the cooperator. No yields were obtained in the seeding year (1968). Yield increases were very small and were not always consistent when comparing different years. Neither lime nor phosphate increased protein enough to be considered important.

A lime rate experiment was conducted at the Lake County site in 1969. The results were variable and nonsignificant (Table 14).

Soil samples were taken from the experimental plots after two and four crop years. Soil pH values are shown in Table 15. A 4-ton lime application (2.1 tons effective calcium carbonate) increased soil pH by 0.4 to 0.5 of a unit. Buffer pH (see Table 8) for Union and Clay County sites was 6.7 which suggested a lime rate of 2 tons per acre to obtain a pH of 6.5 (University of Minnesota, Soil Testing Laboratory). Soil pH with lime was near 6.5 indicating the buffer index is a useful guide for suggesting lime rates. The 1969 sampling after two crop years shows that lime reacted fairly rapidly in the soil.

Laboratory Study

A laboratory study was made to determine the amount of pure lime needed to bring the soil pH to 6.5 or 7.0. Then if a grower wanted to lime a particular soil to a given pH, a lime rate could be suggested.

Many soil samples were collected to find the lowest possible pH values in southeastern South Dakota. The locations chosen are listed in Table 16. The incubation procedure follows:

Seven different levels of reagent grade $CaCO_3$ were added to 200 gram samples of soil in pint jars. The various levels were based on a 2 million pounds per acre furrow slice. The rates were 0, 1, 2, 3, 4, 6, and 8 tons per acre.

The $CaCO_3$ was mixed with the soil by thoroughly shaking the jars. Samples were moistened to field capacity with redistilled water, allowed to air dry, and then remoistened to field capacity. The cycle was continued for a period of 12 months. After every other drying cycle samples were stirred and remixed. Soils were leached with distilled water after the 12-month incubation period. This was done to remove soluble salts, especially nitrates, that accumulated in the soils during the incubation study. Soluble salts lower soil pH and must be removed to obtain an accurate pH reading.

Soil pH was determined on each treatment after leaching. The values are shown in Table 17. In most cases it took between 1 and 3 tons of pure, finely divided $CaCO_3$ to raise soil from the initial pH to 6.5. The initial soil pH's are in the second column (0), Table 17. For most soils 3 to 4 tons of $CaCO_3$ were needed to raise the pH to 7.0. To determine the actual amount of lime needed, soil pH values were plotted against lime rate for each soil. The amount of lime required to reach a pH of 6.5 or 7.0 for each soil was estimated from the individual curves. These "lime equilibration" rates are shown in Table 18.

The lime equilibration study shows that it takes a large amount of lime to increase the pH of these soils to 6.5 or to 7.0. This equilibration study used lime that had a neutralizing index of 100. Most Ag-lime has neutralizing index values of between 60 and 70% so the Ag-lime rate per acre would be greater than shown in Table 18 (1.7 times greater for 60% and 1.4 times greater for 70% neutralizing index values).

Usually Ag-lime rates of less than 2.0 tons per acre are not suggested because of application costs. The buffer index pH appears to be a useful guide for suggesting rates of limestone.

Table 19 indicates exchangeable cations and cation exchange capacity. These results show that most of the soils are highly saturated with basic cations. This is the main reason that very little lime is needed in South Dakota and why yield increases resulting from application of lime are negligible.

Discussion and Summary

Lime has not been recommended in South Dakota when soil pH is below 6.2 because almost all substrata are alkaline. In states where lime is recommended and used by farmers, substrata are usually acid and sometimes more acid than surface soils.

Yield results from research reported here justify the recommendations that no lime should be used.

The laboratory study showed that rather large rates of lime must be applied to increase soil pH to 6.5. In deciding on liming, consideration must be given to the neutralizing index of the limestone so that an adequate rate of limestone can be applied. The neutralizing index is determined by purity (% $CaCO_3$) and fineness of grind. Most lime should pass an 8-mesh sieve and 30% to 50% should pass a 60-mesh sieve. Coarse limestone is of little immediate benefit.

The buffer index is a good method of determining lime rates for soils when pH is below 6.0. The rate of lime should also be based on the alkalinity of the subsoil. A grower would be wise to test the pH of subsoils to know the amount of lime that may be needed. SDSU recommendations are to sample in 1-foot increments to 3 or 4 feet deep for a pH test. Soil Conservation Service district offices may help determine alkalinity of subsoils on individual farms. The pH by soil depth of four of the field experiments are shown in Table 20. The sites did not show lime response and they were alkaline somewhere in the root zone.

The final point concerning liming is the question of economics. The following table shows the economics of applying lime for the given expected yields. The experiments showed that about 2 tons of effective $CaCO_3$ (100% neutralizing index) were needed to obtain the small responses listed below.

Crop*	Yield response	Years to pay for 2 tons lime/acre if lime costs			
		$8/ton	$10/ton	$12/ton	$14/ton
Corn	2 bu/acre/yr.	4	4	5	6
Corn	4 bu/acre/yr.	2	2	3	3
Oats	2 bu/acre/yr.	7	8	10	12
Oats	6 bu/acre/yr.	3	3	4	4
Alfalfa	.2 ton/acre/yr.	2	3	3	4

*Corn at $2.50, oats at $1.25/bu, and alfalfa at $40.00/ton.

The above figures show it takes 4 to 6 years to pay for a lime application of 2 tons per acre when assuming an increase of 2 bushels of corn per acre per year. Other examples are shown with the assumed costs of lime. Since farm prices change rapidly, each grower must use his own cost figures to decide the economics of lime application. Cost of the lime would not be recovered the first year, but eventually in some cases, increased yields may pay for the added lime and provide a profit. Since pH remained at 6.5 after 4 years it can be expected that pH will remain high for several years after an application of lime.

Table 1. Yield of oats and alfalfa as influenced by several materials.

Treatment	Scott Farm Minnehaha Co.	Elsner Farm Lincoln Co.				
	Oats-1953	Oats-1952	Alf.-1953 1st	Alf.-1953 3rd	Alf.-1954 1st	Total
	bu/acre	bu/acre	tons/acre			
Check	29.9	25.3	1.28	0.98	1.40	3.66
40 lbs P_2O_5 (TSP)	32.6	25.3	1.71	1.21	1.23	4.15
80 lbs P_2O_5 (TSP)	36.1	27.0	2.09	1.47	1.53	5.09
Lime-2 tons per acre	31.3	31.7	1.41	0.99	1.26	3.66
80 lbs P_2O_5 (TSP) + Lime	38.5	35.8	2.10	1.48	1.38	4.88
80 lbs P_2O_5 (Total) Rock phosphate	33.0	27.6	1.81	1.22	1.53	4.56
80 lbs P_2O_5 (Available) Rock phosphate	31.2	29.4	2.20	1.42	1.88	5.50
60 lbs K_2O	33.4	25.5	1.36	0.96	1.38	3.70
80 P_2O_5 + 60 K_2O + 2 tons Lime	36.5	37.7	1.99	1.34	1.22	4.55
LSD .05 (tons/A)	ns	ns	0.26	0.33	0.24	
Coefficient	10.7%	27.3%	22.2%	23.1%	17.1%	

Table 2. Effects of phosphorus, lime, and gypsum on yield of oats, Felt Farm, 1955.

Treatment	Yield, bu/acre
0 + 0 + 0	58.2
0 + 40 + 0	52.0
0 + 80 + 0	55.6
Lime - 2 tons/A	53.9
0 + 40 + 0 + Lime	45.6
0 + 80 + 0 + Lime	49.5
Gypsum - 2 tons/A	50.0
0 + 80 + 0 + gypsum	53.2
LSD .05	ns
Coefficient of Variation	13.1%

Table 3. Effects of lime, phosphorus, and molybdenum on oat growth in greenhouse, 1960 (Magee).

Treatment	Crop - 1 Yield, g/pot		Crop - 2 Yiled, g/pot	
	-Mo	+Mo	-Mo	+Mo
Check	16.8	16.6	20.8	21.4
1 ton lime	15.8	15.6	21.8	21.3
2 ton lime	15.4	15.1	21.5	21.2
4 ton lime	15.2	15.1	21.4	21.3
160 lbs P_2O_5	20.0	19.8	22.3	22.1
160 lbs P_2O_5 + 2T Lime	19.8	19.7	21.7	22.1
LSD .05	0.6		0.3	
Coefficient of Variation	12.3%		3.2%	

Table 4. Effects of lime, phosphorus, and molybdenum on alfalfa growth in greenhouse pots, 1960 (Magee).

Treatment	1st cutting Yield, g/pot		2nd cutting Yield, g/pot	
	-Mo	+Mo	-Mo	+Mo
Check	14.7	14.7	14.0	13.7
1 ton lime	14.6	15.1	13.7	14.1
2 ton lime	15.0	14.9	14.2	14.0
4 ton lime	15.0	15.0	14.1	13.7
160 lbs P_2O_5	15.0	14.8	13.6	13.8
160 lbs P_2O_5 + 2T Lime	15.2	15.1	14.0	14.1
LSD .05	ns		0.3	
Coefficient of Variation	1.8%		2.4%	

Table 5. Effects of lime and phosphorus on soil pH and soil phosphorus after one oat and two alfalfa crops, 1960 (Magee).

Treatment	Soil pH	Bray No. 1 P
Check	5.5	42.5
1 ton lime	5.8	41.0
2 ton lime	6.2	42.5
4 ton lime	6.8	43.8
160 lbs P_2O_5	5.4	88.7
160 lbs P_2O_5 + 2T Lime	6.2	108.0

Table 6. Yield, P concentration, and K concentration of an oat and alfalfa crop grown in greenhouse pots, 1961 (Weisner).

Treatment	Yield* g/pot	P Conc.* %P	K Conc.* %K
Check	4.14 c	.129 cd	2.95 a
1 ton lime	5.17 bc	.113 d	3.10 a
2 ton lime	5.27 bc	.117 d	3.11 a
4 ton lime	5.80 b	.136 bc	3.14 a
160 lbs P_2O_5	11.77 a	.161 a	2.00 b
160 lbs P_2O_5 + 2T Lime	11.67 a	.148 ab	2.07 b

* Any values with same letter following are not significantly different (Duncan's multiple range test .05 level).

Table 7. Cooperator and legal description of lime field experiments.

County	Cooperator	Address	Legal Description Sec - Twp - Rng
Union	Lowell Duncan	Alcester	8 - 95 - 49
Clay	S.E. Farm	Beresford	17 - 95 - 51
Moody	Ray Benson	Flandreau	12 - 105 - 48
Minnehaha	Don Zweep	Garretson	9 - 103 - 48
Lake	C. Schladweider	Madison	1 - 106 - 53

Table 8. Initial soil tests for the field experiments, 1968.

Location County	O.M. %	P lbs/A	K lbs/A	pH	Lime Require-ment Tons/A	Salts mmho/cm	Soil Type
Union	4.0	81	682+	6.1	2.0	.49	Trent sicl
Clay	3.1	28	588	6.2	2.0	.52	Egan sil
Moody	4.2	26	294	6.3		.32	Moody sicl
Minnehaha	2.8	16	241	6.1	2.5	.21	Moody sicl
Lake	4.0	96	682+	6.0		.80	Egan sil

Table 9. Effects of lime on yield and moisture content of corn at the Union County site.

Treatment	1968		1969		1970		1971		Average	
	Bu/A	%	Bu/A	%	Bu/A	%	Bu/A	%	Bu/A	%
Check	129	40.7	133	28.0	77	24.8	110	26.3	112	30.0
Lime	132	39.7	135	28.0	83	24.5	111	25.0	115	29.3
Phosphorus	126	40.1	131	28.8	80	26.0	108	26.3	111	30.3
Lime + P	134	39.7	136	28.0	80	25.0	114	25.3	116	29.5
LSD .05	ns	--	ns	ns	ns	ns	ns	ns		
Coefficient of Variation	7.3%	--	4.8%	4.7%	7.2%	6.2%	4.3%	7.5%		

Table 10. Effects of lime on yield and moisture content of corn at the Clay County site.

Treatment	1968		1969		1970		1971		Average	
	Bu/A	%	Bu/A	%	Bu/A	%	Bu/A	%	Bu/A	%
Check	90	30.9	91	37.0	41	18.2	42	26.4	66	28.1
Lime	94	29.3	95	36.3	48	16.9	52	23.8	72	26.6
Phosphorus	99	29.5	90	36.7	41	19.1	40	23.6	68	27.2
Lime + P	95	28.6	86	37.2	45	18.7	52	26.3	70	21.7
LSD .05	ns	--	ns	ns	ns	ns	ns	ns		
Coefficient of Variation	10.7%	--	12.1%		7.1%		9.9%	11.2%	21%	11.6%

Table 11. Effect of lime on yield and moisture content of corn at the Moody County location.

Treatment	1968		1971		Average	
	Bu/A	%	Bu/A	%	Bu/A	%
Check	103	34.0	100	33.3	102	33.7
Lime	105	34.3	99	34.3	101	34.3
Phosphorus	98	34.8	103	33.5	101	34.2
Lime + P	97	34.8	98	35.0	98	34.9
LSD .05	ns	--	ns	ns		
Coefficient of Variation	9.7%	--	13.3%	5.1%		

Table 12. Effect of lime on yield of soybeans at the Moody County site, 1970.

Treatment	Yield, bu/A
Check	44
Lime	46
Phosphorus	45
Lime + P	46
LSD .05	ns
Coefficient of Variation	3.7%

Table 13. Effect of lime on yield and protein content of alfalfa at the Minnehaha location.

Treatment	1969		1970		1971	Average
	tons/A	% Protein	tons/A	% Protein	tons/A	tons/A
Check	4.11	19.1	6.11	20.1	1.46	3.89
Lime	4.08	19.1	6.67	20.0	1.47	4.07
Phosphorus	4.00	20.3	6.24	20.0	1.31	3.85
Lime + P	4.25	20.3	6.37	20.1	1.61	4.08

Table 14. Effect of lime rates on the yield of corn at the Lake County site, 1969.

Lime Rate Tons/acre	Corn Yield Bushel/acre
0	116
2	118
4	114
8	117
LSD .05	ns
Coefficient of Variation	17.4%

Table 15. Effect of treatments on soil pH.

	Union Co.		Clay Co.		Minnehaha Co.		Moody Co.
	1969	1971	1969	1971	1969	1971	1971
Check	6.2	6.3	6.3	6.1	6.1	6.1	6.5
Phosphorus	6.2	6.2	6.3	6.1	6.0	6.2	6.5
Lime	6.5	6.8	6.5	6.4	6.4	6.5	6.6
Lime + P	6.5	6.7	6.5	6.4	6.4	6.6	6.7

Table 16. Location description of soil samples for lime equilibration study.

Sample No.	Identification
11 L	40 yards east of railroad tracks, 70 yards south, southeast of the NW corner of the SE 1/4 11-98-49.
19	80 yards south of Karli house, 40 yards west of fence in the SW 1/4 17-102-47.
40 A	Along half mile fence 250 yards east of the road, 20 yards north, northeast of corner post complex in low area, in the S 1/2 of NW 1/4 12-102-50.
16	30 yards east of trees, 30 yards south of fence along road, 300 yards northwest of gravel pit in the NE 1/4 of the NE 1/4 18-102-47. Across the road from a farm.

Table 16 continued.

Sample No.	Identification
30 A	Top of flat hill, 100 yards west of Wold farmstead tree belt, 50 years north of fence in SW 1/4 14-103-49.
30 B	In swail 20 yards west of Wold farmstead tree belt, 30 yards north of fence in SW 1/4 14-103-49.
23 A	100 yards south of railroad, 150 yards northeast of gravel pit was in corn in 1968. In NW 1/4 33-102-48.
23 B	30 yards south of railroad, 250 yards west of driveway in swail in corn in 1968. In NW 1/4 33-102-48.
8	300 yards east of county highway 136, 30 yards southeast of trees along fence in big flat swail area in NW 1/4 of SW 1/4 11-102-50.
21 B	30 yards northwest of northwest corner of farmstead tree belt, in NE 1/4 27-103-50.
41	150 yards south from NW corner of 27-103-50. 100 yards east of fence at the bottom of the swail that runs down from the road.
42	Just west of the southwest corner of the farmstead tree belt in low area. Field in corn in 1968. In NE 1/4 23-103-50.
43	Go through Ramstod farmyard. Down path east of silo 200 yards to the alfalfa field; 40 yards south of path. In NW 1/4 35-103-50.
19 LB	80 yards east of fence along farmyard, 200 yards west of gate in east fence in SW 1/4 14-98-50.
28 L	SE 1/4 24-98-50. 150 yards west of southeast corner of section, 30 yards north of fence on flat area.
20	30 yards northeast of water pump mailbox, 30 yards north of fence, directly across the road from farm place. In SE 1/4 30-104-48.
9	Just north of lime plot, (Minnehaha County).
16 LA	40 rods north of half mile fence, 300 yards east of fence along road, in wide swail, NW 1/4 18-96-48.
16 LB	200 yards straight east of sample area 16LA. Across hill in flat area about 200 yards west of large trees (was sweet-clover, red clover, pasture in 1968). NW 1/4 18-96-48.
2 LA	Just west of Paulson yard, 50 yards south of gate, 30 yards west of fence. NE 1/4 3-96-49.

Table 17. Soil pH after 18 months incubation at given rates of $CaCO_3$.

Sample No.	(Initial pH) 0	Tons of $CaCO_3$* per 2 million lbs soil 1	2	3	4	6	8
11 L	6.0	6.2	6.4	6.8	7.0	7.7	7.8
19	5.9	6.1	6.7	7.0	7.3	7.7	7.9
40 A	6.1	6.4	6.7	7.1	7.4	7.8	8.0
16	5.8	6.2	6.6	7.0	7.2	7.8	7.9
30 A	6.1	6.3	6.7	6.9	7.3	7.7	7.9
30 B	5.8	6.2	6.7	7.0	7.3	7.8	7.7
23 A	5.7	6.0	6.1	6.6	7.2	7.6	7.8
23 B	5.6	5.8	6.1	6.5	6.7	7.1	7.5
8	5.7	6.0	6.4	6.7	7.1	7.7	7.9
2 LB	5.8	5.9	6.3	6.7	7.0	7.7	7.8
41	5.6	6.0	6.4	6.8	7.0	7.7	7.9
42	6.2	6.4	6.9	7.2	7.4	7.8	7.9
43	5.8	6.1	6.4	6.8	7.1	7.8	7.9
19 LB	5.7	6.1	6.3	6.7	7.0	7.5	7.8
28 L	6.3	6.7	7.1	7.3	7.8	7.9	8.0
20	6.2	6.4	6.9	7.2	7.6	7.9	8.0
9	6.1	6.4	6.8	7.1	7.4	7.8	7.8
16 LA	5.8	6.1	6.6	6.9	7.3	7.8	7.9
16 LB	5.8	6.1	6.6	7.0	7.3	7.8	7.9
2 LA	6.3	6.4	6.6	7.0	7.4	7.8	7.9

* pure $CaCO_3$ - finely ground.

Table 18. Soil pH, Buffer index, and lime requirement by buffer index and $CaCO_3$ incubation.

Sample No.	Lime Equilibration pH 6.5 tons/A	pH 7.0 tons/A	Buffer Index	B.I.* Lime Requirement tons/A
11 L	2.2	4.0	6.3	2.5
19	1.7	3.0	6.3	2.5
40 A	1.3	2.7	6.5	2.0
16	1.8	3.0	6.3	2.5
30 A	1.5	3.2	6.5	2.0
30 B	1.6	3.0	6.3	2.5
23 A	2.8	3.6	6.3	2.5
23 B	3.0	4.7	5.9	3.5
8	2.3	3.8	6.1	3.0
2 LB	2.5	4.0	6.2	3.0
41	2.2	4.0	6.2	3.0
42	1.2	2.3	6.4	2.5
43	2.2	3.6	6.2	3.0
19 LB	2.5	4.0	6.1	3.0
28 L	0.5	1.7	6.5	2.0
20	1.2	2.4	6.4	2.5
9	1.2	2.7	6.4	2.5
16 LA	1.8	3.2	6.3	2.5
16 LB	1.8	3.0	6.2	3.0
2 LA	1.5	3.0	6.6	2.0

* Buffer index

Table 19. CEC and exchangeable cations of the soils used in the lime equilibration study.

Sample No.	CEC*	Exchangeable Cations* Na	Ca	Mg	K
11 L	23.25	0.07	20.39	5.25	0.91
19	27.42	0.08	27.50	5.94	1.88
40 A	27.10	0.08	21.64	5.68	0.56
16	24.72	0.06	14.92	4.89	0.63
30 A	27.05	0.08	19.72	6.93	1.32
30 B	26.80	0.10	20.50	6.00	0.88
23 A	25.77	0.05	15.59	4.41	1.11
23 B	28.09	0.07	23.14	4.74	1.35
8	23.60	0.06	14.21	4.89	0.70
21 B	28.03	0.08	18.64	6.58	1.23
41	23.32	0.13	19.20	5.57	0.46
42	27.62	0.03	24.85	8.63	0.80
43	28.86	0.07	18.41	7.90	1.36
19 LB	21.74	0.06	18.90	6.44	0.79
28 L	23.23	0.07	16.80	5.97	0.58
20	23.66	0.08	18.55	5.15	0.37
9	28.80	0.06	22.06	5.52	0.51
16 LA	29.51	0.06	23.41	5.76	0.76
16 LB	27.34	0.06	18.81	5.70	0.79
2 LA	23.34	0.06	20.33	5.48	1.47

* All results are reported in meq/100 gms.
CEC extraction made using .1 N neutral ammonium acetate.

Table 20. Soil pH of surface and subsurface soils of lime experimental site.

Location	Soil Depth, In.	Soil pH
Lake County	0- 6	6.0
	6-12	6.2
	12-24	7.3
	24-36	7.3
Union County	0- 6	6.2
	6-12	6.5
	12-24	6.7
	24-36	6.8
	36-48	6.9
	48-60	7.7
Clay County	0- 6	6.2
	6-12	6.1
	12-24	6.2
	24-36	6.1
	36-48	6.7
	48-60	8.1
Minnehaha County	0- 6	6.2
	6-12	6.2
	12-24	6.6
	24-36	7.3
	36-38	8.0