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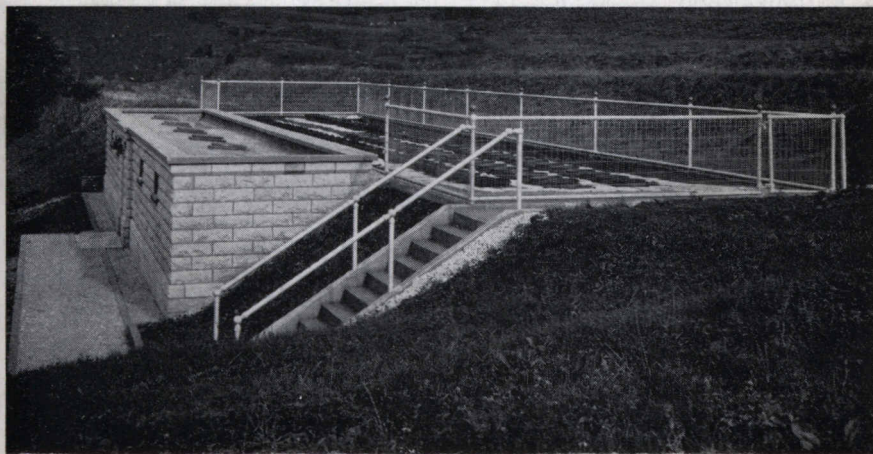
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THE CONSERVATION OF CALCIUM AND MAGNESIUM FROM
INPUTS OF BURNT LIME, LIMESTONE, DOLOMITE,
AND DICALCIUM SILICATE, AS INFLUENCED BY
RATE AND FREQUENCY OF LIMING AND
BY ZONE OF INCORPORATION.

A Twenty-Year Lysimeter Experiment on Two Soil
Types, at the Tennessee and Virginia
Experiment Stations.

By
W. M. SHAW and W. H. MacINTIRE
of the Tennessee Station
and
H. H. HILL
of the Virginia Station



A Lysimeter Installation at the Tennessee Station

KNOXVILLE

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Interior View of the Lysimeter Installation at the Tennessee Station

THE CONSERVATION OF CALCIUM AND MAGNESIUM FROM INPUTS OF BURNT LIME, LIMESTONE, DOLOMITE, AND DICALCIUM SILICATE, AS INFLUENCED BY RATE AND FREQUENCY OF LIMING AND BY ZONE OF INCORPORATION.

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INTRODUCTION

Both natural weathering processes and crop production effect continual depletion of the calcium content of soils in the humid regions of the United States. After its calcium has been depleted to certain levels, the soil becomes acidic, or "sour," and cannot support the growth of ordinary crops. Liming was introduced to correct soil acidity and to supply nutrient calcium, and is deemed an essential factor in a program for greater farm prosperity.

The widespread practice of liming has resulted in problems that have been studied through experimentation in laboratory, lysimeter, and greenhouse, and in the field. Although the beneficial effects of liming have been widely recognized, some injurious effects upon crop growth due to liming have been observed (30).

Among the problems awaiting solution are: (a) The rate at which limestone should be incorporated in relation to pH value and type of soil; (b) the depth to which limestone should be incorporated in the soil; (c) the fineness of ground limestone, or of dolomite, that is most economical; (d) the liming effectiveness of industrial byproduct calcium silicate slags in comparison with ground limestone; and (e) the effect of calcium upon the availabilities of other nutrient elements.

Some of these problems have been dealt with through pot cultures under controlled temperature and moisture conditions in the greenhouse and also through cropping systems under field conditions. Certain problems, however, call for an accounting of the fate of a particular input and of its effects upon cation and anion fixation, and upon release from the soil complex to the solution phase of the soil system. Outdoor lysimeters make the securing of such information possible, since the incorporated materials are exposed to natural weather conditions and react with the soil as they would in the field, but without mechanical loss through erosion and indeterminate drainage, and without variance in crop uptake. The rain-water leachings serve to register outgo of the essential nutrient

elements, and the soil is available for future sampling and examination to establish the extent of transformation and translocation of an incorporated element, or other changes which may be effected in the soil's composition.

The lysimeter experiments, supplemented by chemical studies, have been used extensively at the Tennessee Agricultural Experiment Station for nearly forty years. The earlier investigations dealt with the specific activities of various calcic, magnesian, and dolomitic materials, liming value of calcium silicate versus calcium carbonate, the carbonatation of oxide and hydroxide of calcium, and the effects of calcic and magnesian carbonates and oxides upon "reciprocal repression," upon potassium fixation, and upon sulfonation. More recently the studies have dealt with the outgo of phosphorus and of fluorine, from inputs of various carriers of those elements.

EXPERIMENTAL

The 20-year experiment was inaugurated simultaneously at the Tennessee and Virginia Stations in the summer of 1924, and the findings obtained during the initial 8 years were reported (28). Each lysimeter contained 100 pounds of soil, moisture-free basis. The present contribution embodies the results of the 20-year duration to afford a complete picture of the experimental data for the over-all period.

Objectives.—The objectives of the present experiment were to determine the conservation of the calcium and magnesium and other nutrient elements as affected by the following variables:

(a) Specific behaviors of burnt lime, limestone, dolomite, and dicalcium silicate, when equivalent amounts of the 4 materials were incorporated at economic rates and under the various conditions.

(b) Frequency of liming incorporation: a single input for a 4-year period versus 4 annual quarter inputs.

(c) Mode of incorporation: Input mixed through the full depth of 6-2/3 inches of soil versus a corresponding input in the upper 1/3 zone.

(d) Frequency of liming incorporation, extended. Comparison as in (b), except for repetition during a second 4-year period.

Soils.—The Tennessee soil was a brown Cumberland clay loam and had a relatively low content of bases. It was moderately fertile, well adapted to general farm crops, and also to alfalfa after being limed. It was derived chiefly in situ from dolomite, and partly from an old alluvial deposit. For more than 30 years it had been in blue-grass sod, which was skimmed off before the required bulk of soil was taken.

The Virginia soil has been described as a gray-black Onslow fine sandy loam, slightly heavier than the Norfolk series, not so

TABLE 1—*Chemical analyses of the Cumberland clay loam and Onslow fine sandy loam, at Knoxville, Tenn., and at Blacksburg, Va., respectively.*

Soil	pH in 1:5 Aqueous suspension	Totals			Acid-soluble per 100 grams ¹			Exchangeable cations per 100 grams ²				Exchange capacity	Degree of unsat- uration
		Nitrogen	Sulfur	Carbonate CO ₂	Ca	Mg	K	Ca	Mg	K	H ³		
Tennessee Virginia	6.4	Percent	Percent	Percent	M.e.	M.e.	M.e.	M.e.	M.e.	M.e.	M.e.	M.e.	0.48
	5.2	.144	.049	.020	4.68	12.56	3.94	3.60	1.12	0.48	4.60	9.8	0.74
		.057	.028	.003	1.46	1.52	0.52	1.16	0.14	0.12	3.98	5.4	

¹ By digestion in HCl, 1.115 sp. gr.

² By neutral normal ammonium acetate extraction.

³ By difference between exchange capacity and cation content.

TABLE 2—*Analyses of the liming materials used, and proportions of calcium and magnesium, in terms of CaCO₃.*

Liming material	Content			Relative content		Unit input per 2,000,000 pounds of soil		
	Ca	Mg	Ca+Mg	Ca	Mg	Ca	Mg	Ca+Mg
	Percent	Percent	Percent	Percent	Percent	Pounds	Pounds	Pounds
Burnt lime.....	93.8	2.1	95.9	97.8	2.2	3491	79	3570
Limestone.....	92.5	4.5	97.0	95.4	4.6	3406	164	3570
Dolomite.....	49.9	46.0	95.9	52.0	48.0	1856	1714	3570
Dicalcium silicate.....	77.4	6.2	83.6	92.6	7.4	3306	264	3570

fertile nor so well drained, and responds to heavy applications of complete fertilizers (3). The analyses of the 2 soils are given in table 1.

Liming Materials.—The 4 liming materials were of 100-mesh fineness, and the amounts incorporated were equivalent in neutralization value. The unit rate for a 4-year period was 2,000 pounds of CaO, or 3570 pounds of CaCO₃, per 2,000,000 pounds of soil, and every fractional annual incorporation was made at 1/4 of that rate. The dicalcium silicate, a byproduct obtained from the Electric Smelting and Aluminum Company of Sewarren, New Jersey, was leached in the laboratory to remove soluble salts. Neutralization values and calcium and magnesium contents of the liming materials are expressed as percentages and as pounds of input per 2,000,000 pounds of soil and are given in table 2. All the charges of liming materials prescribed for incorporation during the first 8 years were weighed and bottled in duplicate for the two Stations at the beginning of the experiment.

Lysimeter Installations.—The lysimeters were made of 14 gauge ingot iron, which had received 2 coats of asphalt paint. They were 12 inches deep, 1/20,000 acre in area. Their bottoms were concave, and drainage waters passed to receptacles through 5/8-inch block-tin tubing. A 2-inch layer of No. 7 ground quartz served as filter bed for the overlying soils, and the soil zones were demarcated by means of asphaltum-coated circular disks of galvanized-iron wire cloth.

Method of Incorporation.—The over-all bulk of soil was passed through a 4-mesh wire screen and mixed by turning the pile over 6 times. Moisture content was determined overnight while the soil was kept tightly covered with a heavy canvas. In the full-depth liming, each 100-pound charge of soil, moisture-free basis, was spread evenly in a large galvanized-iron mixing box; the liming material was distributed uniformly over the soil's surface and mixed into the soil locally, and the entire charge was turned six times. Each charge then was put into a lysimeter in 1/5 to 1/4 fractions, successively, and each fraction was spread evenly and tamped. In restricting an incorporation to the upper zone, 2/3 of the charge of soil was placed in the lysimeter, as described for the full charge, and the liming material was mixed into the other third of the soil.

Chemical Analyses.—The rainwater leachings were collected 3 to 5 times annually, as governed by periodicity of rainfall and resultant percolation volumes and analyzed for the outgo of nitrate nitrogen, bicarbonate alkalinity, and pH value. The annual composites of the leaching collections of each lysimeter were analyzed for contents of Ca, Mg, K, and SO₄. The NO₃ was determined by the phenoldisulfonic acid procedure and read on electrophotometer against standard curve. The other determinations were made in accordance with the procedures given by the Association of Official Agricultural Chemists (1).

EXPERIMENTAL OUTLINE

The experimental variables were represented by 7 series, designated from A to G, each of which comprised the constant order of burnt lime, limestone, dolomite, and dicalcium silicate, with treatment as follows:

Series A: The full unit inputs of 3570 pounds of CaCO_3 were incorporated full-depth in August 1924, and left undisturbed until August 1928. The entire charge of soil then was removed, and without reliming, was given the same treatment as that required for the reliming of series B and C. Hence, this series was identical with series B and C for the first 4 years, and, except for no repetition of liming, identical with series B thereafter.

Series B: The full unit inputs of 1924 were repeated in 1928, without subsequent disturbance. This series, therefore, was identical with both series A and series C for the first 4 years, and identical also with series A thereafter, except for the stipulated repetition of the full limings.

Series C: Was parallel with series A and B for the first 4 years, after which it received 4 annual quarter-additions in full depth, and so differed from series A and B in aeration incident to the inmixing of the last 3 incorporations that were made during the second 4-year period.

Series D: Received 4 quarter-unit inputs, one being mixed throughout the soil initially and one at the beginning of each year of the next 3-year period. During the next 4 years, the soil of this series was removed and mixed annually as was prescribed for series E.

Series E: Identical with series D for the first 4 years, but received a quarter-unit input annually during the second 4 years.

Series F: Received single full inputs, which were mixed throughout the upper third of the soil, without further inputs and without aeration during the second 4-year period. The upper and lower zones were removed and mixed separately each year during the first 4-year period to parallel the manipulation given series G and also that of series D and E for that period.

Series G: Received the liming materials only into the upper third of the soil. The totals of the inputs during the initial 4 years were the same as the single initial additions in series F, but the inputs to series G were divided into 4 equal annual additions, without subsequent disturbance, as in the case of series F.

Controls: Controls were afforded to correspond to the manipulations given for single treatments and repetitions. Rainwaters were collected in blank lysimeters identical in dimension with those containing the soils.

PRESENTATION OF RESULTS

The results that have most direct bearing upon the main objectives of this experiment are those that pertain to the outgo of Ca and Mg in the rainwater leachings. The total outgo, however, is due jointly to the incorporated liming material, the rain increments, and the Ca and Mg of the native supplies in the soil.

To ascertain the effects of an incorporated liming material, it is necessary that the determined outgo be corrected through the subtraction of corresponding outgo from the unlimed control. This procedure is predicated upon the assumption that outgo from the control is a constant and that any enhancement in outgo is derived from the incorporated material. In some cases, however, the variously limed soil may release less of calcium or magnesium or potassium than the quantity of the corresponding element released by the unlimed soil. Hence, the proportion of additive calcium and magnesium actually derived from a particular input is indeterminate and could be arrived at exactly in no other way than through the use of radioactive calcium as the additive materials. At present, however, it is important to recognize the fact that the untreated soils undergo gradual changes as a result of long-time exposure to rainwater leachings, and to determine the removal of bases and biochemical end products in the rainwater leachings from the untreated soils over the experimental period. Since the rainwaters carry variable quantities of solutes (15), the outgo from the untreated soil cannot be credited solely to the soil. To determine the "net loss" of certain elements from an unlimed control, therefore, it is necessary to apply corrections for the increments carried into the soil by rainwaters. The data on the outgo of Ca, Mg, K, NO_3 , and SO_4 are presented in relation to the following aspects:

(a) Total 20-year outgo of Ca and Mg as influenced by the experimental variables, type of liming material, input rate, and zone of incorporation.

(b) The net outgo of the components; that is, through correction for corresponding outgo from the control soil, in relation to experimental variables.

(c) The comparative speed of outgo of Ca and Mg and other components during the course of the experiment, as affected by experimental variables.

(d) The relative rates of outgo of Ca and Mg from dolomited soils.

(e) The status of each limed and unlimed soil as to the computed content of the various components after 20 years, in relation to the original status.

(f) The rate of depletion of Ca and Mg in unlimed, limestoned, and dolomited soils, with special reference to influence of input upon degree of saturation of those elements in the soil at different periods.

(g) The proportion of various anions responsible for the total outgo of cations.

(h) Cation interrelationships in the lysimeter results; that is, the reciprocal effects of Ca upon Mg, Mg upon Ca, and their effects singly and jointly upon outgo of K, with special reference to the constancy of the Mg/Ca ratio upon the basis of the supply of those elements in the soil.

(i) Correlation of the lysimeter findings and present-day concepts of cation interchange.

A detailed tabulation of annual analyses in itself would prove too cumbersome for a rational presentation and discussion of trends. Pertinent data are presented, therefore, for quadrennial periods as well as in 20-year totals, so that trends can be observed through the changes with progress of the experiment. Presentation of all the data solely through quadrennial averages, however, would obscure important relationships that could be observed only from an examination of the annual results. For example, during the year following lime incorporation the outgo of Ca+Mg possesses certain characteristics that would be blunted when presented as average, inclusive of losses through leachings during the succeeding years. Fluctuations in annual outgo due to rainfall totals and periodicity and other variables are of additional interest. It was believed to be desirable, therefore, to incorporate all annual data in the form of an appendix, which will serve as a source for any desired computations or graphic presentation of results. To distinguish these data from those used in the text, the tables in the appendix are designated by Roman numerals, whereas the tables that embody the partly summarized and presently used data carry Arabic numerals. To facilitate ready visual observation of trends and significant periodic variations, selected annual data are presented also by means of charts.

Terminology.—"Outgo" connotes the quantity of a given element or its equivalent carried in rainwater leaching, whereas "net outgo" connotes the outgo of a component after this value has been corrected for the corresponding outgo from the untreated soil. "Net gain" or "net loss" of a particular element is used to register final gain or final diminution respectively, after due consideration of the combined effects of rainwater increments and specific inputs and outgo in relation to original content of that particular element in the soil. Losses of Ca and Mg, separately and jointly, are expressed in terms of CaCO_3 per 2,000,000 pounds of soil, unless otherwise stated.

RAINFALL AND PERCOLATION VOLUMES AT KNOXVILLE AND AT BLACKSBURG

Total rainfall and its periodicity are important factors in a consideration of lysimeter outgo. Annual precipitations, as rain or snow, are given in tables I and II, and quadrennial summaries are given in table 3. Annual average for 20-year rainfall at Knoxville

TABLE 3—*Quadrennial summary of rainfall and percolation volumes from the variously limed Cumberland clay loam at Knoxville, and Onslow fine sandy loam at Blacksburg.*

Percolation volumes in kilograms per lysimeter and in percentage of rainfall													
Experimental series	Designated values	From Cumberland soil by periods in years						From Onslow soil by periods in years					
		1-4	5-8	9-12	13-16	17-20	1-20	1-4	5-8	9-12	13-16	17-20	1-20
A	Period average	489.2	509.0	575.8	499.2	424.1	2497	274.3	334.5	387.2	366.1	319.4	1672
	Percent of rainfall	48.3	58.0	57.1	49.6	48.7	52.2	39.6	51.8	49.2	62.6	50.5	50.3
B	Period average	487.0	529.5	588.6	506.2	422.9	2529	271.6	336.9	378.4	371.7	325.0	1684
	Percent of rainfall	48.1	60.4	58.3	50.3	48.6	52.9	39.4	52.2	49.2	63.6	51.3	50.7
C	Period average	482.5	489.8	544.6	458.0	390.1	2365	263.8	335.8	378.9	377.5	331.6	1698
	Percent of rainfall	47.7	55.8	54.0	45.4	44.9	49.4	39.7	52.0	49.3	64.5	52.5	51.1
D	Period average	481.5	539.2	571.9	481.3	403.8	2478	277.5	336.1	380.5	372.0	324.9	1691
	Percent of rainfall	47.6	61.5	56.7	47.8	46.4	51.8	40.2	52.1	49.5	63.6	51.3	51.1
E	Period average	476.9	542.7	596.7	488.0	415.0	2519	268.3	331.0	368.3	357.3	312.8	1638
	Percent of rainfall	47.1	61.8	59.1	48.5	47.7	52.6	38.9	51.3	47.8	61.1	49.5	49.3
F	Period average	483.4	530.2	582.9	510.9	426.6	2534	262.8	328.7	366.1	344.7	291.6	1594
	Percent of rainfall	47.8	51.9	57.8	50.7	49.1	53.0	38.1	51.0	47.6	58.9	46.1	48.0
G	Period average	476.1	519.1	575.7	498.8	419.5	2489	257.2	230.6	362.2	347.3	289.4	1587
	Percent of rainfall	47.0	59.2	57.1	49.5	48.2	52.0	37.3	51.3	47.1	59.4	45.6	47.8
Controls	Period average	479.8	487.1	548.4	430.0	402.3	2348	275.4	325.9	366.5	366.5	316.1	1650
	Percent of rainfall	47.4	55.5	54.3	42.7	46.3	49.1	39.9	50.5	47.6	62.7	49.9	49.7
Rainwater	Period total	1012	881	1009	1007	872	4781	690.9	644.5	771.8	584.7	631.7	3324
Rainfall	Period total (inches)	197.1	171.8	213.3	203.2	179.1	964.5	135.3	125.4	159.0	160.7	147.2	727.6

TABLE 4—Quadrennial summary of outgo of calcium from the variously limed Cumberland clay loam at Knoxville, and Onslow fine sandy loam at Blacksburg.

Experimental series	Liming material	Pounds of CaCO ₃ -equivalence per 2,000,000 pounds of soil											
		From Cumberland soil by periods in years						From Onslow soil by periods in years					
		1-4	5-8	9-12	13-16	17-20	1-20	1-4	5-8	9-12	13-16	17-20	1-20
A	Burnt lime	2441	1326	963	645	750	6125	935	982	837	635	532	3921
	Limestone	2519	1239	950	686	671	6065	986	899	727	570	451	3633
	Dolomite	1865	972	776	595	621	4829	522	627	596	438	394	2582
	Dica-silicate	2294	1214	918	695	628	5749	594	903	722	499	460	3178
B	Burnt lime	2425	2200	1195	915	820	7565	826	1609	1217	846	695	5193
	Limestone	2622	2068	1215	898	839	7644	910	1568	1539	848	697	5562
	Dolomite	1795	1368	883	697	602	5345	617	578	860	461	400	3045
	Dica-silicate	2241	2002	1077	922	681	6923	597	1488	1320	809	626	4840
C	Burnt lime	2531	1844	1436	921	916	7648	854	1095	1748	884	692	5273
	Limestone	2522	1821	1391	930	835	7499	827	1008	1665	905	696	5101
	Dolomite	1823	1323	983	639	645	5413	512	659	1061	462	456	3150
	Dica-silicate	2376	1683	1321	906	770	7056	625	1002	1296	853	621	4397
D	Burnt lime	2345	1371	902	709	708	6035	806	960	803	645	602	3816
	Limestone	2380	1297	937	650	655	5919	763	803	769	651	549	3535
	Dolomite	1919	947	718	523	543	4650	479	520	504	530	514	2547
	Dica-silicate	2269	1262	845	636	632	5644	583	849	654	617	553	3256
E	Burnt lime	2293	1971	1369	996	910	7639	729	1212	1228	967	812	4945
	Limestone	2370	1882	1539	1147	867	7805	844	1085	1137	883	772	4721
	Dolomite	1890	1215	978	616	631	5330	485	725	591	532	551	2884
	Dica-silicate	2238	1738	1318	880	856	7030	548	1070	1084	902	766	4370
F	Burnt lime	2125	973	956	702	725	5481	784	772	663	544	525	3288
	Limestone	2104	1018	921	678	715	5434	724	773	614	510	512	3133
	Dolomite	1837	755	677	525	565	4359	487	431	363	276	318	1875
	Dica-silicate	2030	924	876	590	713	5133	528	716	582	497	507	2830
G	Burnt lime	1857	989	967	759	809	5381	738	793	600	571	517	3219
	Limestone	1860	979	937	734	757	5267	691	774	810	584	523	3382
	Dolomite	1705	772	654	538	569	4238	479	416	436	472	505	2308
	Dica-silicate	1850	1006	814	779	753	5179	529	702	659	627	530	3047
Control	None	1416	931	741	548	580	4216	489	604	493	314	262	2162
	None	1558	842	662	491	590	4145	443	556	374	263	237	1873
Rainwater		417	481	520	499	536	2453	217	341	315	216	303	1392

was 48.23 inches, and at Blacksburg, 36.38 inches. The 3:4 ratio for the Virginia:Tennessee rainfall is maintained throughout the tabulations for the quadrennial periods. The average percolation from the controls was nearly 50 percent of the 20-year rainfall on the Tennessee and Virginia soils. Taken by 4-year periods, the percentage percolation from the untreated Tennessee soil was in range between 43 and 55 percent of the rainwaters, whereas the corresponding range for the untreated Virginia soil was from 40 to 63 percent. The general tendency was for the percentage percolation to be larger with increase in rainfall, although this tendency is affected to a like extent by the periodicity of the rainfall. The effects of fluctuations in annual rainfall upon nutrient outgo will be considered later. The variations of rate and method of incorporation of the liming materials effected only slight increases in the percolation volumes for the 2 soils.

INFLUENCE OF TYPE OF LIMING MATERIAL UPON OUTGO

Consideration of other variables would be simplified if it could be shown that under the conditions of this experiment the differences between the outgo of Ca+Mg from burnt lime, limestone, dolomite, and dicalcium silicate were not substantial. The effectiveness of a limestone in supplying nutrient calcium and in neutralization of soil acidity is governed by the speed of its dissolution, or decomposition (36) and sequential adsorption of the base by the soil complex. The outgo of calcium and magnesium through lysimeter leachings might serve as a measure of the rate of reactivity of liming materials within the soil only where the materials were of large particle size or of low rate of reactivity. Although the reactivity of dolomite is less than that of calcic limestone, that difference is diminished when the 2 carbonate minerals are finer than 100-mesh (19). Where the incorporations were in full depth of the soil it may be assumed that all of the 4 liming materials underwent complete reaction with the Cumberland clay loam and with the Onslow fine sandy loam in the first year. The Ca+Mg outgo from incorporations of the 4 types of liming materials might then be taken as a measure of the leachability of the bases, rather than reflecting the dissolubilities of the incorporated materials. During the first 4 years, series A, B, and C represented triplicates of identical incorporations of the 4 liming materials. The results obtained for that period afford an opportunity to compare both the relative leachabilities of the bases derived from the 4 types of liming materials and to indicate the accuracy of the lysimeter data in general.

The data given in table 6 represent annual outgo of Ca+Mg from a 3570-pound full-depth incorporation of the 4 liming materials, annual averages for the triplicate series A, B, and C, and 4-year and 20-year averages for each material. Although the 4-year averages represent leachings from identical treatments to which deviations from averages may be applied, such deviations cannot be applied to the 20-year results because each series of the A, B,

TABLE 5—Quadrennial summary of outgo of magnesium from the variously limed Cumberland clay loam at Knoxville, and Onslow fine sandy loam at Blacksburg.

		Pounds of CaCO ₃ -equivalence per 2,000,000 pounds of soil											
Experimental series	Liming material	From Cumberland soil by periods in years						From Onslow soil by periods in years					
		1-4	5-8	9-12	13-16	17-20	1-20	1-4	5-8	9-12	13-16	17-20	1-20
A	Burnt lime	710	402	268	165	162	1707	200	213	291	162	147	1013
	Limestone	704	398	261	179	150	1692	173	223	234	168	117	915
	Dolomite	1497	708	468	285	236	3194	533	595	588	324	171	2211
	Dica-silicate	809	445	296	207	167	1924	191	239	332	157	144	1063
B	Burnt lime	704	352	225	172	140	1593	140	178	196	182	137	833
	Limestone	707	349	222	171	145	1610	151	216	232	191	126	916
	Dolomite	1467	1206	726	455	347	4201	518	840	1084	539	327	3308
	Dica-silicate	823	547	313	241	186	2110	159	334	366	222	150	1231
C	Burnt lime	715	394	249	153	128	1639	162	187	248	186	144	927
	Limestone	710	396	241	156	123	1626	176	194	262	216	129	977
	Dolomite	1517	1096	806	484	395	4298	561	573	1222	600	367	3323
	Dica-silicate	842	502	342	228	183	2097	173	220	336	246	155	1130
D	Burnt lime	808	375	243	167	143	1736	187	252	197	200	169	1005
	Limestone	798	383	251	162	138	1732	168	213	223	181	136	921
	Dolomite	1395	765	477	308	250	3195	484	620	554	430	244	2332
	Dica-silicate	886	468	281	212	171	2018	222	215	280	200	154	1071
E	Burnt lime	838	418	238	148	126	1768	190	199	192	214	125	920
	Limestone	786	410	270	186	111	1772	192	291	188	222	100	993
	Dolomite	1351	1073	822	470	400	4116	452	755	852	660	424	3143
	Dica-silicate	863	498	339	219	176	2095	190	230	344	227	161	1152
F	Burnt lime	795	306	227	167	140	1635	192	168	213	150	117	840
	Limestone	808	296	247	168	146	1665	155	199	256	151	123	884
	Dolomite	1204	587	500	335	274	2900	462	546	497	353	282	2140
	Dica-silicate	834	345	274	190	174	1817	202	184	242	155	137	920
G	Burnt lime	784	334	224	153	131	1626	198	189	193	149	114	843
	Limestone	855	349	227	157	137	1725	181	183	187	177	177	843
	Dolomite	1026	823	544	371	288	3052	415	578	491	451	225	2160
	Dica-silicate	838	393	286	185	175	1877	187	255	290	199	135	1066
Control	None	729	442	299	166	152	1788	177	189	231	154	155	906
	None	735	439	268	172	147	1761	150	194	230	134	128	836
Rainwater		342	150	172	144	105	913	125	138	195	139	142	739

TABLE 6—Effect of type of liming material upon outgo of Ca+Mg from triplicate lysimeter experiments, in pounds CaCO_3 -equivalence per 2,000,000 pounds of soil.

Experimental series	Liming material	Successive annual periods								4-year total		20-year outgo	
		1		2		3		4					
		Outgo	Dev. ¹	Outgo	Dev.	Outgo	Dev.	Outgo	Dev.	Outgo	Dev.	Total	Net
CUMBERLAND CLAY LOAM, AT KNOXVILLE													
A	Burnt lime	703	+ 9	1067	—53	660	—22	721	+41	3151	—24	7832	2756
B		676	—18	1143	+23	656	—26	654	—26	3129	—46	9158	
C		702	+ 8	1150	+30	730	+48	664	—16	3246	+71	9187	
Avg.		694	±12	1120	±35	682	±28	680	±28	3175	±47	8711	
A	Limestone	836	+24	1058	—30	643	—34	686	+ 1	3223	—38	7747	2754
B		793	—19	1174	+86	667	—10	695	+10	3329	+68	9254	
C		806	— 6	1031	—57	720	+43	675	—10	3232	—29	9125	
Avg.		812	±16	1088	±58	677	±29	685	± 7	3261	±45	8709	
A	Dolomite	796	+ 1	1149	—13	748	+46	669	+ 7	3362	+41	8023	8120
B		787	— 8	1169	+ 7	640	—62	666	+ 4	3262	—59	9490	
C		802	+ 7	1168	+ 6	719	+17	651	—11	3340	+19	9711	
Avg.		795	± 5	1162	± 9	702	±42	662	± 7	3321	±40	9075	
A	Dica-silicate	772	+81	1007	—74	660	— 3	664	—13	3103	—59	7673	2698
B		721	—20	1051	—30	610	—53	682	+ 5	3064	—98	9033	
C		730	—11	1184	+103	718	+55	686	+ 9	3318	+156	9253	
Avg.		741	±21	1081	±69	663	±37	677	± 9	3162	±104	8653	
Control	None	506	+ 3	763	—32	476	—15	400	—32	2145	—74	6004	
Control		499	— 4	827	+32	506	+15	461	+31	2293	+74	5906	
Avg.		503	± 3	798	±32	491	±15	432	±31	2219	±74	5955	
ONSLow FINE SANDY LOAM, AT BLACKSBURG													
A	Burnt lime	436	+68	171	+29	272	+ 1	256	— 1	1135	+96	4933	2871
B		307	—61	132	—10	260	—11	267	+10	966	—73	6026	
C		362	— 8	123	—19	282	+11	249	— 8	1016	—23	6311	
Avg.		368	±45	142	±19	271	± 8	257	± 6	1039	±64	5757	
A	Limestone	408	+18	201	+53	274	+ 1	276	+14	1159	+85	4546	2815
B		421	+31	121	—27	258	—15	261	— 3	1061	—13	6477	
C		341	—49	121	—27	287	+14	254	—10	1003	—71	6081	
Avg.		390	±33	148	±36	273	±10	264	± 9	1074	±56	5701	
A	Dolomite	350	—16	169	+ 9	327	+ 4	209	+ 7	1055	+ 4	4792	2986
B		381	+15	142	—18	309	—14	193	— 9	1025	—26	6353	
C		367	+ 1	169	+ 9	332	+ 9	205	+ 3	1073	+22	6472	
Avg.		366	±10	160	±12	323	± 9	202	± 6	1051	±17	5872	
A	Dica-silicate	298	+ 3	107	+ 4	185	— 1	195	— 4	785	+ 4	4239	2428
B		276	—19	102	— 1	181	— 5	197	— 2	756	—24	6172	
C		312	+17	99	— 4	193	+ 7	204	+ 5	798	+18	5530	
Avg.		295	±13	103	± 3	186	± 4	149	+ 4	780	±19	5314	
Control	None	232	—10	131	+23	140	+ 5	163	— 2	666	+36	3066	
Control		211	+11	86	—22	130	— 5	166	— 1	593	—37	2706	
Avg.		222	±10	108	±22	135	± 5	165	± 2	630	±36	2886	

¹Deviation from the mean.

and C group was handled differently after the 4th year. Nevertheless, the 20-year averages of series A, B, and C afford comparisons of the 4 liming materials, since each average is derived from like quantities and treatments. In a comparison of the effects induced by the 4 types of liming material, it is convenient to use the limestone as the basis, since that material is the one used most extensively.

Findings for Cumberland Clay Loam.—According to the 4-year results, the outgo of Ca+Mg from the burnt lime was 86 pounds less than that from the limestone, against 60 pounds more from the dolomite, and 99 pounds less from the dicalcium silicate. The deviations that affect the result were of the same order of magnitude, except in case of the dicalcium silicate. It is not concluded that the indicated significant difference of 86 pounds means that availability of the Ca+Mg derived from the burnt lime is less than that of the limestone. The indicated difference can be explained on the basis of better distribution of the 100-mesh limestone, since the burnt lime has a tendency to form small lumps in the soil. Although the greater outgo from the dolomite may not appear very significant, it may be taken as true value because of the fact that the Mg in the soil adsorption complex leaches more readily than the calcium analogue. The 99-pound decrease from the dicalcium silicate, however, is significantly less than the outgo from the limestone. Upon the basis of 20-year results, outgo from the burnt lime was identical with that from the limestone; outgo from the dolomite was 366 pounds more, and outgo from the dicalcium silicate was 56 pounds less. The increase in outgo from the dolomite during the initial 4 years was greatly enhanced in the 20-year results.

Findings for Onslow Fine Sandy Loam.—The leachings of Ca+Mg from the limed Onslow soil were much smaller than those from the Cumberland soil for the first 4 years. This may be due jointly to the lower native Ca and Mg contents of the Onslow soil and the smaller outgo from the additive materials. The 4-year outgo from the limed Onslow soil was 1074 pounds; that from the CaO was 35 pounds less; that from the dolomite was 23 pounds less; whereas, that from the dicalcium silicate was 94 pounds less. The 20-year average outgo from the limed soils of series A, B, and C was 5701 pounds; that from the burnt lime was 56 pounds more; that from the dolomite was 172 pounds more; whereas, that from the dicalcium silicate was 387 pounds less. It is apparent that the leachability of Ca+Mg from the dicalcium silicate in the Onslow soil was considerably less than that of the other materials.

Conclusions as to Type of Liming Material.—In view of the fact that the liming materials were all of a 100-mesh fineness and that the initial analyses registered effects of 1-year contact, the resultant findings as to outgo of Ca+Mg from those 4 types of liming materials are not to be taken as establishing reactive capacities for corresponding materials of lower degree of fineness or of grades

of fineness that are sold as liming materials. The present data on outgo of Ca+Mg may be taken to reflect the relative rates of leachability and of other properties of the specific soil-absorption complexes resultant from the incorporation of the respective types of liming materials.

An over-all consideration of the results from the 2 soils indicates little difference between outgo from burnt lime and that from the 100-mesh limestone; the inputs of dolomite show greater outgo of Ca+Mg due to greater dissolubility of the adsorbed Mg, which distinction becomes greater in the long-range comparison. The dicalcium silicate treatment shows lower leachability, or greater conservation of the contained Ca+Mg. The relationship between outgo of calcium and magnesium from inputs of dolomite will be presented under a separate heading. It may be observed, however, that the difference in outgo from the 2 limestones are not sufficiently great to preclude averages in subsequent consideration of other factors in this experiment. Moreover, since to some extent magnesium is also a constituent of the other materials, outgo of calcium and magnesium will be considered jointly, except in special cases.

DIFFERENCES IN OUTGO DUE TO ZONE OF INCORPORATION

The comparative outgo of Ca+Mg from the incorporations in the upper zone and in full depth will be considered as the prime criterion of zone effect, although consideration will be given also to effects upon outgo of other elements, nitrogen and sulfur in particular.

As representing the effects attributable to modes of incorporation, series A can be compared to series F, and series D to series G. In the first comparison, the single 3570-pound incorporation was made at the beginning of the experiment, whereas in the second comparison 1/4 of that amount was incorporated at the beginning of each year for the first 4 years. The quadrennial leachings of Ca+Mg for these 2 pairs of treatments over the 20 years are given for both soils in table 7, and corresponding leachings of potassium are given in table 8. The quadrennial nitrate leachings for the 2 soils during 20 years are given in table 9; those for the sulfur are given in table 10. The annual leachings of each element are reported for the entire period in tables III to XIV, in the appendix.

Findings for Cumberland Clay Loam.—The 20-year outgo of Ca+Mg from the full-depth incorporation (table 7, series A) was 7819 pounds, whereas that from the upper-zone incorporation (series F) was 7106 pounds. Hence, the upper-zone placement of the liming incorporation resulted in a 713-pound saving. A similar comparison of series D and G shows a 748-pound conservation for upper-zone incorporation. In the 20-year period the net leachings of Ca+Mg from series A and D were 52 and 50 percent of the input, where-

TABLE 7—Quadrennial summary of outgo of Ca+Mg from the variously limed Cumberland clay loam at Knoxville, and Onslow fine sandy loam at Blacksburg.

Pounds of CaCO ₃ -equivalence per 2,000,000 pounds of soil													
Experimental series	Designated values	From Cumberland soil by periods in years						From Onslow soil by periods in years					
		1-4	5-8	9-12	13-16	17-20	1-20	1-4	5-8	9-12	13-16	17-20	1-20
A	Period average.....	3210	1674	1225	864	846	7819	1033	1170	1083	738	604	4628
	Annual average.....	803	419	308	216	212	391	258	293	271	185	151	231
	Corrected ann. average.....	248	87	60	44	28	93	100	101	104	76	52	86
B	Period average.....	3196	2524	1457	1118	940	9234	952	1763	1703	1024	814	6257
	Annual average.....	799	631	364	279	235	461	238	441	426	256	204	313
	Corrected ann. average.....	244	299	118	107	51	163	80	249	259	147	105	168
C	Period average.....	3284	2265	1667	1104	999	9319	973	1234	1988	1089	816	6098
	Annual average.....	821	566	417	276	250	466	243	309	497	272	204	305
	Corrected ann. average.....	266	234	171	104	66	198	85	117	330	163	105	160
D	Period average.....	3200	1742	1164	841	810	7757	923	1108	995	862	730	4618
	Annual average.....	800	436	291	210	203	388	231	277	249	216	182	231
	Corrected ann. average.....	245	104	45	38	19	90	73	85	82	107	83	86
E	Period average.....	3107	2310	1743	1165	1022	9389	908	1392	1404	1152	928	5783
	Annual average.....	777	575	436	291	256	469	227	348	351	288	232	289
	Corrected ann. average.....	222	243	190	119	72	171	69	156	184	179	133	144
F	Period average.....	2934	1301	1170	838	864	7106	884	947	883	659	631	4003
	Annual average.....	733	325	292	209	216	355	221	237	221	165	158	200
	Corrected ann. average.....	178	-7	46	37	32	57	63	45	54	56	59	55
G	Period average.....	2694	1335	1174	901	905	7009	855	972	917	807	666	4217
	Annual average.....	674	334	294	225	226	350	214	243	229	202	167	211
	Corrected ann. average.....	119	2	48	53	42	52	56	51	62	93	68	66
Controls	Period average.....	2219	1327	986	688	734	5955	630	771	667	437	394	2889
	Annual average.....	555	332	246	172	184	298	158	192	167	109	99	1445
Rainwater	Period total.....	759	631	69	643	641	3366	342	479	510	355	445	2131

as the corresponding leachings from series F and G were, respectively, 32 and 30 percent of input. The lasting effects of the incorporations may be gauged by the progressive changes shown in table 7 for net annual outgo of Ca+Mg by 4-year periods during the 20 years.

The net leachings registered by the successive 4-year annual averages for series A were 248, 87, 52, 44, and 30 pounds. Those for series F were 178, minus 7, 46, 37, and 34 pounds of CaCO_3 . Thus it appears that any induced outgo of Ca+Mg from the limed upper zone in excess of that from the control was retained completely by the lower layer of unlimed acidic soil, particularly during the second 4-year period. In an earlier experiment with 100-mesh limestone and dolomite, under identical circumstances (22) a Ca+Mg recovery of 6 percent was obtained in 4 years, against the 20-percent recovery in the present experiment.

The outgo of nitrates serves as a reliable index of the effects the additives exerted upon the biochemical activities of the soil. The 20-year outgo of nitrate nitrogen from series A was 1001 pounds, and from series F, 909 pounds. Although the difference is not great in comparison with the total outgo, upon correction for outgo from the untreated soil, series A shows a net loss of 141 pounds of N against a net loss of 49 pounds for series F. Hence, the net outgo of N from series F was only $1/3$ that from series A. A similar comparison between series D and G indicates that the net loss of G was only $1/2$ that from D. It appears that besides effecting conservation of Ca and of Ca+Mg, the upper-zone incorporation of liming materials also effected considerable conservation of the soil's supply of nitrogen. The effect of the 2 modes of liming incorporations upon the course of N outgo during 20 years may be gained from the following net outgo as pounds of that element by 4-year periods: For series A, the succession was 91, 20, 14, 7, and 0; for series F, the succession was 80, minus 42, 1, 1, and 0.

In series A the influence of the liming materials upon nitrate production extended over the first 8 years, whereas in series F such influence was evident only in the first 4 years. The increase in nitrate outgo from series A was meager during the last 8 years, whereas there was no increase from series F during the same period.

The annual and total leachings of sulfur from the limed Cumberland clay loam are given for the 20-year period in table 10. Over-all increases in sulfur outgo were 41 pounds of S for series A and 24 pounds for series F. In both instances the over-all increases were due to the greater outgo during the first 5 years.

Findings for Onslow Fine Sandy Loam.—The leachings of Ca+Mg as annuals and totals from the Virginia soil are given for series A, F, D, and G in table 7. The 20-year net outgo of Ca+Mg from the single full-depth incorporation of series A was 1739 pounds, whereas that from an equivalent input in the upper zone, series F, was

TABLE 8—Quadrennial summary of outgo of potassium from the variously limed Cumberland clay loam at Knoxville, and Onslow fine sandy loam at Blacksburg.

		Pounds of K per 2,000,000 pounds of soil											
Experimental series	Designated values	From Cumberland soil by periods in years						From Onslow soil by periods in years					
		1-4	5-8	9-12	13-16	17-20	1-20	1-4	5-8	9-12	13-16	17-20	1-20
A	Period average	112.0	64.0	54.0	33.0	26.0	280.0	50.0	46.0	50.8	44.8	39.0	239.4
	Annual average	28.0	16.0	11.3	8.3	6.5	14.0	12.3	11.5	12.7	11.2	9.8	12.0
	Corrected ann. average	-4.0	-3.5	-2.4	-1.2	0.0	-2.4	-4.5	-3.7	-3.7	0.1	0.2	-1.8
B	Period average	98.0	59.5	36.5	32.3	21.5	248.0	58.0	42.8	49.5	40.8	37.3	226.0
	Annual average	24.5	14.9	9.1	8.1	5.4	12.4	14.5	10.7	12.4	10.2	9.3	11.3
	Corrected ann. average	-7.5	-4.6	-4.6	-1.4	-1.4	-4.0	-2.3	-4.6	-4.0	-0.9	-0.3	-2.5
C	Period average	102.0	56.3	34.8	26.8	19.0	239.0	55.3	43.5	45.3	24.0	36.3	222.0
	Annual average	25.5	14.1	8.7	6.7	4.8	12.0	13.8	10.9	11.3	6.0	9.1	11.1
	Corrected ann. average	-6.5	-5.4	-5.0	-2.8	-1.7	-4.4	-3.0	-4.4	-5.1	-5.1	-0.5	-2.7
D	Period average	114.0	66.2	50.0	36.3	26.3	293.0	71.8	48.3	47.0	41.8	42.8	254.0
	Annual average	28.5	16.6	12.5	9.1	6.7	14.7	17.9	12.1	11.8	10.5	11.0	12.7
	Corrected ann. average	-3.5	-2.9	-1.2	-0.4	0.2	-1.7	1.1	-3.2	-4.6	-0.6	1.4	-1.1
E	Period average	112.0	64.3	41.0	26.5	20.0	264.0	60.5	50.3	49.3	37.0	42.8	240.0
	Annual average	28.0	16.2	10.3	6.6	5.0	13.2	15.1	12.6	12.3	9.3	10.7	12.0
	Corrected ann. average	-4.0	-3.3	-3.4	-2.9	-1.5	-3.2	-1.7	-2.7	-4.1	-1.8	-1.1	-1.8
F	Period average	134.0	60.5	36.0	26.3	24.5	281.0	59.8	49.8	50.0	35.3	39.8	229.0
	Annual average	33.5	15.1	9.0	6.7	6.1	14.1	15.0	12.5	12.5	8.8	10.0	11.5
	Corrected ann. average	1.5	-4.4	-4.7	-2.8	-0.4	-2.3	-1.8	-2.8	-3.9	-2.3	0.4	-2.3
G	Period average	158.0	61.8	29.3	24.0	21.8	294.0	62.5	41.3	53.0	37.5	39.5	234.0
	Annual average	39.5	15.5	7.3	6.0	5.5	14.7	15.6	10.3	13.3	9.4	9.9	11.7
	Corrected ann. average	7.5	-4.0	-6.4	-4.5	-1.0	-1.7	-1.2	-5.0	-3.1	-1.7	0.3	-2.1
Controls	Period average	128.0	78.0	54.5	38.0	26.0	328.0	67.0	61.0	65.5	44.5	38.5	276.5
	Annual average	32.0	19.5	13.7	9.5	6.5	16.4	16.8	15.3	16.4	11.1	9.6	13.8
Rainwater	Period total	54	31	30	34	32	181	34	60	44	45	54	237

only 1114 pounds. The net outgo of Ca+Mg from the full-depth incorporation of the 4 quarterly inputs in series D and G were 1729 and 1328, respectively. The net leachings for series A and F, therefore, were respectively 49 percent and 31 percent of the input, whereas the corresponding net losses were 48 percent and 37 percent for series D and G. The progression in the effects of the respective modes of incorporation are shown readily by the corrected outgo of Ca+Mg at the various stages of the 20-year period. When divided into 4-year periods, and the annual averages are taken for each period, the following CaCO_3 values obtain: For series A: 100, 101, 104, 76, and 52 pounds; for series F: 63, 44, 54, 30, and 59 pounds. In contrast to the effect of liming on the Cumberland loam, the liming of the Onslow soil has produced a small yet uniform increase in outgo of Ca+Mg over the entire experimental period. During the first 16 years the outgo of Ca+Mg from series A was distinctly greater than the corresponding outgo from series F. In the last 4 years, however, the outgo from the 2 series was nearly equal, and in both cases in excess of that in series A of the Cumberland soil for the same period.

The annual and total leachings of nitrate nitrogen from the limed Onslow soil are given in table 9. The 20-year outgo from series A was 620 pounds, whereas that from series F was 531 pounds. The net outgo from series A for the 20-year period was 111 pounds, whereas that from series F was only 22 pounds. The corresponding net leachings from series D and F were 148 pounds and 73 pounds. The increases in N outgo above that of the control soil were distributed through the five 4-year periods as follows: Series A: 4, 5, 7, 15, and 5 pounds; series F: 1, 1, 1, 1, and 1 pounds of N, as annual average increases during the successive periods. The consistently slow outgo of nitrates is paralleled by the similar outgo of Ca+Mg, and appears to be characteristic of the Onslow soil. Distributions of the N outgo from series D and G parallel closely those of A and F, except that the outgo from G is somewhat greater than that from F.

The increase in outgo of sulfur from the limed Onslow soil over that from controls for the entire period was only slightly over 20 pounds as shown in table 10, and does not constitute an important factor in the consideration of liming effects.

Generalizations as to Effect of Zone Liming.—Although the 2 soils exhibit distinctly different rates of cation and anion outgo, they are in agreement as to the influence of zone of liming. The surface-zone incorporations effected a conservation of 20 percent of the 3570-pound single input, as compared with outgo from the full-depth incorporation. The conservation was equally as large for the 4 annual fractional incorporations on the Cumberland soil, but somewhat smaller on the Onslow soil. The conservations of Ca+Mg were paralleled consistently by conservations in outgo of nitrates, whereas sulfur outgo was affected little by variation in type and manner of incorporation of the liming materials.

TABLE 9—Quadrennial summary of outgo of nitrate N from the variously limed Cumberland clay loam at Knoxville, and Onslow fine sandy loam at Blacksburg.

Experimental series	Designated values	Pounds of N per 2,000,000 pounds of soil											
		From Cumberland soil by periods in years						From Onslow soil by periods in years					
		1-4	5-8	9-12	13-16	17-20	1-20	1-4	5-8	9-12	13-16	17-20	1-20
A	Period average.....	478	246	145	81	51	1001	84	144	130	152	110	620
	Annual average.....	120	61	36	20	13	50	21	36	33	38	27	31
	Corrected ann. average.....	23	4	3	2	0	7.1	-4	5	7	14	5	5.6
B	Period average.....	461	299	136	93	46	1034	66	144	158	128	95	596
	Annual average.....	115	75	34	23	12	52	16	36	40	32	24	30
	Corrected ann. average.....	18	18	1	5	-1	8.7	-9	5	14	8	2	4.4
C	Period average.....	476	308	150	83	45	1060	72	148	202	162	110	696
	Annual average.....	119	77	38	21	11	53	18	37	50	41	28	35
	Corrected ann. average.....	22	20	5	3	-2	10.0	-7	6	24	17	6	9.4
D	Period average.....	470	244	132	77	45	968	89	145	119	153	124	657
	Annual average.....	118	61	33	19	11	48	22	36	30	38	31	33
	Corrected ann. average.....	21	4	0	1	-2	5.4	-3	5	4	14	9	7.4
E	Period average.....	468	284	156	90	52	1050	138	153	141	179	116	726
	Annual average.....	117	71	39	23	13	53	35	38	35	45	29	36
	Corrected ann. average.....	20	14	6	5	0	9.5	10	7	9	21	7	10.9
F	Period average.....	467	184	132	75	51	909	102	126	108	100	94	531
	Annual average.....	117	46	33	19	13	45	26	32	27	25	23	27
	Corrected ann. average.....	20	-11	0	1	0	2.5	1	1	1	1	1	1.1
G	Period average.....	444	196	133	82	36	911	102	125	130	120	105	582
	Annual average.....	111	49	33	21	9	46	26	31	33	30	26	29
	Corrected ann. average.....	14	-8	0	3	-4	2.6	1	0	7	6	4	3.7
Controls	Period average.....	387	226	131	74	51	860	99	122	104	98	89	509
	Annual average.....	97	57	33	18	13	43	25	31	26	24	22	25
Rainwater	Period total.....	12	30	43	50	49	184	7	22	13	9	37 ¹	88

¹The extraordinarily high value of 25 pounds in the 19th year introduces an error in excess of 20 pounds for this period as well as in the 20-year outgo.

DIFFERENCES ATTRIBUTABLE TO FREQUENCY OF LIMING

The factor "frequency of liming" relates to comparisons of the 3570-pound integral inputs at the beginning of a 4-year period and 4 annual fractional incorporations at the beginning of each year of the same period. Such comparisons are afforded by the alignment of series A versus series D, over a single 4-year period; and of series B versus series E, during 2 successive 4-year periods. These comparisons may disclose points of practical significance: (a) the practicability of small frequent incorporations to avoid "overliming" effects, and (b) whether such inputs would preclude the so-called "mineralization" of added bases, a postulation to explain the apparent progression in the decrease in availability of liming residues (19). As noted earlier, the principal criterion of the relative effectiveness of the several methods of liming will be their relative outgo of Ca+Mg in the rainwater leachings. Consideration will be given also to the outgo of biochemical end products, NO_3 and SO_4 , and to outgo of potassium. The findings for the 2 soils will be discussed separately and are followed by a generalized statement.

Findings for Cumberland Clay Loam.—The outgo of Ca+Mg from series A and D, as well as that from series B and E, are given in table 7. The 20-year leachings from series A and D were 1864 pounds and 1802 pounds, respectively, and this difference is not deemed significant. There was a difference in the order of the Ca+Mg outgo, however, since series D did not receive its full input until the 4th year. When subdivided into 4-year averages, the net outgo of Ca+Mg afford the following parallels in successive values:

Series A:	248, 87, 60, 44, and 28
Series D:	245, 104, 45, 38, and 19

These values do not support the postulate that a succession of fractional inputs would preclude the "mineralization" of the residual calcium. On the contrary, the leachings indicate that after the first 4-years the outgo from series D is consistently lower than the outgo from series A. The most significant differences between the 2 series, however, are to be found in the outgo within the first 4 years. During the 1st and 2nd years the outgo from series A was much greater than that from series D, whereas the outgo from series D exceeded that from A during the 3rd and 4th years.

Series B and E represent a duplication of series A and D for the initial 4 years, and an extension of that through the additional inputs during the succeeding 4 years. In a consideration of effects induced by liming frequency, the comparison will be limited to the relationship between B and E, whereas comparisons between A and B and between D and E are considered under a different heading. The net outgo of Ca+Mg from series B for 20 years is 3264 pounds, whereas that from series E is 3434 pounds, a difference of 170 pounds, or 1.8-percent, which is not deemed signifi-

TABLE 10—Quadrennial summary of outgo of sulfate sulfur from the variously limed Cumberland clay loam at Knoxville, and Onslow fine sandy loam at Blacksburg.

Experimental series	Designated values	Pounds of S per 2,000,000 pounds of soil											
		From Cumberland soil by periods in years						From Onslow soil by periods in years					
		1-4	5-8	9-12	13-16	17-20	1-20	1-4	5-8	9-12	13-16	17-20	1-20
A	Period average	223	146	142	143	206	863	82	76	64	62	82	366
	Annual average	56	37	36	36	51	43.1	21	19	16	15	21	18.3
	Corrected ann. average	9.5	0.3	-1.0	0.5	0.1	2.0	1.9	0.6	1.9	0.0	-0.5	0.8
B	Period average	221	177	141	146	201	886	76	80	70	60	84	370
	Annual average	55	44	35	37	50	443	19	20	18	15	21	18.5
	Corrected ann. average	9.0	7.0	-1.0	1.0	-0.3	3.2	0.4	1.6	3.4	-0.5	0.0	1.0
C	Period average	221	177	155	150	214	917	75	81	78	62	88	384
	Annual average	55	44	39	38	53	459	19	20	20	15	22	19.2
	Corrected ann. average	9.0	7.3	2.3	2.3	3.0	4.8	0.1	1.9	5.4	0.0	1.0	1.7
D	Period average	222	153	144	143	206	869	76	78	68	66	83	372
	Annual average	56	38	36	36	51	435	19	20	17	16	21	18.6
	Corrected ann. average	9.2	1.3	-0.5	0.5	1.0	2.4	0.4	1.1	2.9	1.0	-0.3	1.1
E	Period average	224	172	149	153	210	908	74	79	70	65	94	382
	Annual average	56	43	37	38	53	45.4	19	20	17	16	24	19.1
	Corrected ann. average	9.8	6.0	0.8	3.0	2.0	4.3	-0.1	1.4	3.4	0.8	2.5	1.6
F	Period average	222	138	146	137	200	846	75	73	64	66	93	372
	Annual average	56	35	37	34	50	42.3	19	18	16	18	23	18.6
	Corrected ann. average	9.2	-2.5	0.0	-1.0	-1.5	1.2	0.1	-0.1	1.9	1.0	2.2	1.1
G	Period average	216	145	150	141	206	857	72	72	78	67	90	383
	Annual average	54	36	38	35	52	429	18	18	20	17	23	19.2
	Corrected ann. average	7.8	-0.8	1.0	0.0	1.0	1.8	-0.6	-0.4	5.4	1.7	1.5	1.7
Controls	Period average	185	148	146	141	202	822	74.5	73.5	56.5	62.0	84.0	350
	Annual average	46.2	37.0	36.5	35.3	50.5	41.1	18.6	18.4	14.1	15.5	21.0	17.5
Rainwater	Period total	179	138	126	136	187	766	80	49	47	47	96	324

cant for the quantities and duration involved. The net annual Ca+Mg outgo averages, by 4-year periods, from the 2 series are as follows:

Series B: 244, 299, 118, 107, and 51
Series E: 222, 243, 190, 119, and 72

A significantly greater outgo from series B over that from series E occurred only in the 2nd 4-year period, and that increase was cancelled out by the gains that were registered in series E during the succeeding 12 years. The outgo of nitrates from the 2 series followed closely the pattern of the outgo of Ca+Mg in the 2 series.

Findings for the Onslow Fine Sandy Loam.—The losses of Ca+Mg from the Onslow series are given in table 7. The net 20-year outgo from series A was 1739 pounds, whereas that from series D was 1729 pounds. Taken as annual averages by 4-year periods, the increases in outgo due to liming were as follows:

Series A: 100, 101, 104, 76, and 52
Series D: 73, 85, 82, 107, and 83

The leachings of Ca+Mg from the fractional inputs on the Onslow soil were consistently below those from the integral input during the first 12 years, but the reverse obtained during the last 8 years. The lesser outgo from series D during the third 4-year period is puzzling since the accumulated supplies of Ca+Mg in this series were then greater than those in series A.

The net 20-year Ca+Mg outgo from series B was 3368 pounds, against 2894 pounds from the 8 fractional incorporations of series E. This difference of 474 pounds is deemed highly significant, since it constitutes nearly 8 percent of the total outgo. Taken as annual averages by 4-year periods, the increases in outgo of Ca+Mg due to liming were as follows for the 2 series:

Series B: 80, 249, 259, 147, and 105
Series E: 69, 156, 184, 179, and 133

The delayed outgo of Ca+Mg from the fractional inputs of series E follows a pattern similar to that observed earlier as to the outgo from series D.

The data given for nitrate outgo in table 8 fail to reveal any correlation between outgo of nitrogen and outgo of Ca+Mg in any of the limed series of the Onslow soil.

Generalizations as to the Frequency of Liming.—As combined effects exerted by the liming materials on the Tennessee and Virginia soils, the 4 fractional incorporations resulted in decreased outgo of Ca+Mg from one integral input of 3570 pounds in 4-year leachings during the early stages, whereas the opposite relationship

developed during the last half of the 20-year period. However, the total 20-year outgo of Ca+Mg failed to show any appreciable increase in the outgo from the fractional inputs over that from the integral inputs.

EFFECT OF REPEATED LIMING

During the second 4-year interval, series B and E received additional inputs of the liming materials either through one single input, as in series B, or as 4 fractional incorporations, as in series E. A comparison of A and B on one hand and of D and E on the other should show whether such additional increments affected alike the immediate and the long-range leachings of Ca+Mg.

The 20-year net outgo of Ca+Mg from series A and series D of the Cumberland clay loam, were 1864 and 1802 pounds, respectively, whereas those from series B and series E were 3264 and 3434 pounds, respectively. Hence, increases in outgo due to the second inputs of 3570 pounds each were: 1400 pounds and 1632 pounds, respectively. The additional increases in outgo of nitrogen from series B and series E over those from series A and series D were 33 pounds and 82 pounds, respectively, and these increases could account for only 118 and 293 pounds of CaCO_3 . Since variations in sulfate outgo were of minor extent, the determined increases in outgo of Ca+Mg must be attributed largely to bicarbonate combinations.

At what stage of the experiment did this increased outgo take place? By comparing the losses by 4-year periods, we find that averaged annual increases in losses from series B over those from series A were: 212, 56, 63, and 23 pounds for the 2nd, 3rd, 4th, and 5th 4-year periods, respectively. More than half of the 1400-pound increase in outgo took place during the initial 4 years, and about 3/7 of that increase occurred during the remaining 12 years. Of the 1632-pound increase in outgo from series E over the outgo from series B, 2/3 leached out during the 2nd and 3rd 4-year periods. In consideration of the fact that the repetitive incorporations were in effect only 16 years out of the 20 years of the experiment, the loss of 1500 pounds of Ca+Mg from the 3570 input could easily have reached the 50-percent loss that was shown by the single inputs if the leaching had extended through another 4-year period. Hence, it appears that the loss of Ca+Mg from the Cumberland clay loam was proportionate to the input.

Similar comparisons between series A and series B, and between series D and series E show increases of 1629 and 1165 pounds in the outgo of Ca+Mg from the repeat additions to the Onslow sandy loam for the 20-year period. Although the increases from series B approach those from series D in the Cumberland soil, the increase from series E over that from series D is out of line. An increase of 69 pounds in the outgo of N from series E over that from series D accounts for a 245-pound increase in the outgo of Ca+Mg. The outgo of N from series B, however, was 24 pounds less than

that from series A. The N outgo from the Virginia soil was so irregular that a close correlation of it with the Ca+Mg outgo was not feasible. Again, the increased outgo from the repetitive inputs must be ascribed chiefly to bicarbonate combinations. Two-thirds of the increased outgo was evenly distributed over the 2nd and 3rd 4-year periods in series B, whereas in series E the small increase

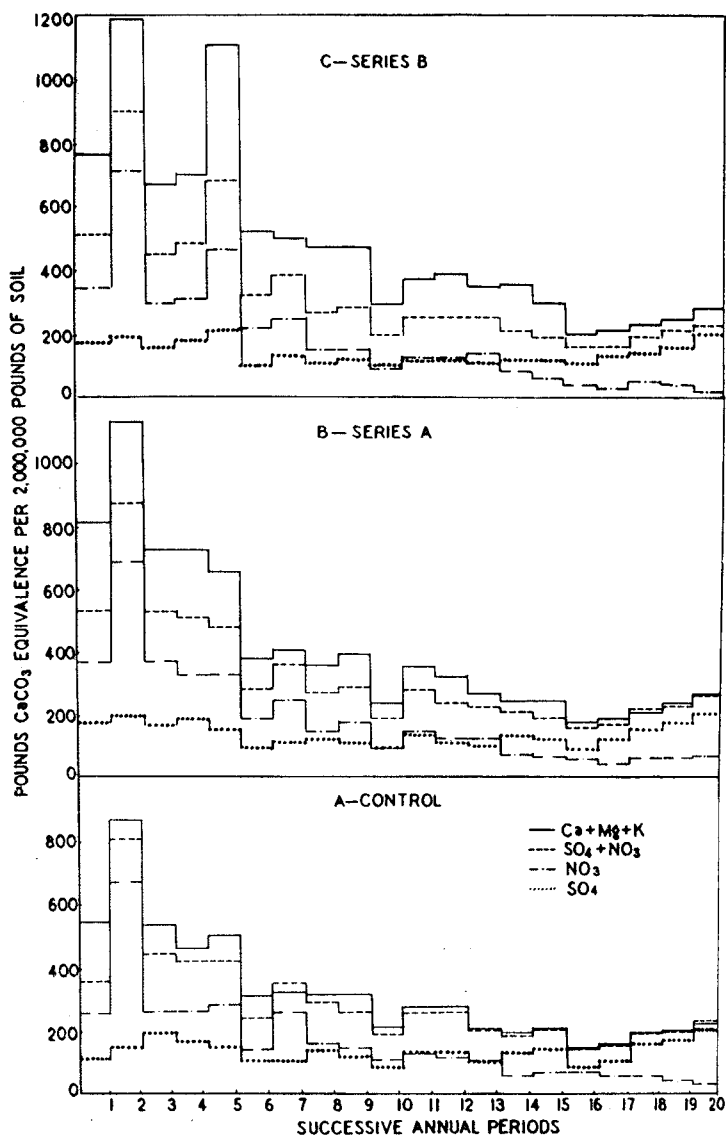


Fig. 1—Comparison of annual cation outgo ($\text{Ca} + \text{Mg} + \text{K}$) with outgo of nitrate and sulfate from a Cumberland clay loam at Knoxville: (A) average of 2 controls; (B) average of 4 liming materials of series A; (C) average of 4 liming materials of series B.

was evenly distributed over the entire experiment. The smaller outgo from E may have been caused by delayed biochemical activities as evidenced by the larger outgo of N from series E rather than that from series B in the last years of the experiment.

As a general conclusion regarding the second 3570-pound input of liming materials in the 2nd 4 years, it appears that the re-

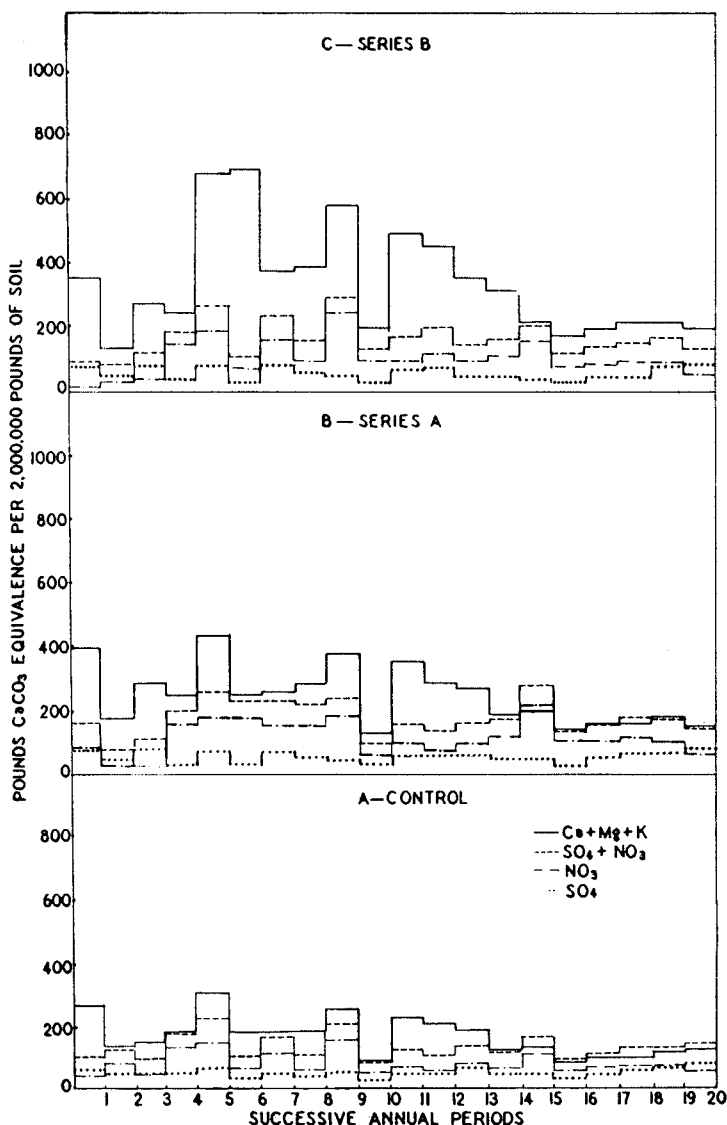


Fig. 2—Comparison of annual cation outgo (Ca + Mg + K) with outgo of nitrate and sulfate from an Onslow fine sandy loam at Blacksburg: (A) average of 2 controls; (B) average of 4 liming materials of series A; (C) average of 4 liming materials of series B.

sultant increases in the outgo of Ca+Mg were proportionate to the extra input, and the increase was attributable chiefly to bicarbonate combination.

RATES OF OUTGO OF Ca AND Mg FROM DOLOMITED SOILS

The use of dolomitic limestone on soils presents problems that are peculiar to that type of material: (a) The comparative speeds of the dissolution of dolomitic and calcic limestone within the soil, particularly when the materials are of only moderate fineness; (b) the chemical behavior of sorbed magnesium, with special regard to leachability by rainwater; (c) the effects upon the dissolution of Ca and K ions in the soil; (d) the replaceability by ion exchange; and (e) the effects of residues of sorbed magnesium upon plants. Previous investigations at the Tennessee Station registered the disintegration of various separates of limestone and of dolomite 4 years after incorporation (20), and related studies (19) demonstrated that when 80-100-mesh dolomite was incorporated full-depth at the rate of 2000-pound CaO-equivalence, complete decomposition of the input occurred within a year or two. Used at the rate of 8 tons of CaO-equivalence, dolomite exerted no deleterious effect upon crop growth (31), although incorporations of hydrated MgCO_3 were found to be toxic to cowpea seedlings (16) a year after its complete decomposition within the soil. The 8-year lysimeter leachings from 100-mesh dolomite at rates of 8-, 32-, and 100-ton CaO-equivalence showed annual averages in Ca+Mg outgo of 825, 1028, and 1107 pounds CaCO_3 -equivalence for outgo of Ca plus Mg (18), and corresponding values of 513, 716, and 795 pounds after correction for the control. Without that correction the Mg/Ca ratios for outgo were 0.84:1, 0.57:1, and 0.48:1 for the respective rates of input. The fact that the soil adsorbs magnesium far beyond the adsorption of calcium was demonstrated by the complete decomposition of 14 tons of hydrated magnesium carbonate, as CaCO_3 -equivalence, in 2,000,000 pounds of soil within 6 weeks (12). Later it was shown that incorporations of hydrated MgCO_3 at the rate of 32 tons CaO-equivalence has caused a Mg adsorption of 40 m.e. per 100 grams of Cumberland clay loam after 4 years of lysimeter exposure (25). The adsorbed magnesium was not extracted completely when the magnesium fortified soils were subjected to prolonged leaching with normal NH_4Cl (27).

Prince and Toth investigated the effects of long-continued usage of dolomitic limestone upon the residues of acid-soluble and replaceable calcium and magnesium in a Sassafras loam (33). They concluded that "... magnesium has been fixed in a form which is not very soluble, whereas the calcium was found to be fairly soluble." In the 8-year report of the early findings in the present lysimeter investigation, however, it was shown that the magnesium adsorbed from incorporations of dolomitic limestone leaches out more rapidly than the concomitantly absorbed calcium.

Outgo of Ca and Mg from the dolomited Cumberland clay loam and from the Onslow fine sandy loam, as actual and net values for

TABLE 11—*Quadrennial summary of total and corrected outgo of Ca and Mg from incorporations of dolomite in Cumberland clay loam and Onslow fine sandy loam.*

Experimental series	Designated values	Ca or Mg	Pounds of CaCO ₃ -equivalence per 2,000,000 pounds of soil											
			From Cumberland soil by periods in years						From Onslow soil by periods in years					
			1-4	5-8	9-12	13-16	17-20	1-20	1-4	5-8	9-12	13-16	17-20	1-20
A	Total	Ca	1865	972	776	595	621	4829	522	627	601	438	394	2582
		Mg	1497	708	468	285	236	3194	533	595	488	324	171	2111
	Corrected	Ca	378	85	74	76	36	648	56	47	167	150	144	564
		Mg	765	267	185	116	86	1419	369	404	257	180	29	1240
	Pct. of input	Ca	20.6	4.6	4.0	4.1	2.0	35.3	3.1	2.6	9.1	8.2	7.8	30.8
		Mg	44.6	15.6	10.8	6.8	5.0	82.8	21.5	23.6	15.0	10.5	1.5	72.3
F	Total	Ca	1837	755	677	525	565	4359	487	431	363	276	318	1875
		Mg	1204	587	500	335	274	2900	462	546	497	353	282	2140
	Corrected	Ca	305	-132	-25	6	-20	178	21	-149	-71	-12	68	-143
		Mg	472	146	217	166	124	1125	298	355	266	209	140	1269
	Pct. of input	Ca	19.0	-7.2	-1.4	0.3	-1.1	9.7	1.1	-8.1	-3.9	-0.6	3.7	-7.8
		Mg	27.5	8.5	12.7	9.7	7.2	65.6	17.5	20.7	15.5	12.2	8.2	74.0
B	Total	Ca	1795	1368	883	697	602	5345	507	817	860	462	400	3046
		Mg	1467	1206	726	455	347	4201	418	840	1084	539	327	3308
	Corrected	Ca	308	481	181	178	17	1164	41	237	426	174	150	1028
		Mg	735	765	443	286	197	2426	354	649	853	395	185	2437
	Pct. of input	Ca	8.4	13.1	4.9	4.8	0.5	31.3	1.1	6.4	11.6	4.7	4.1	23.0
		Mg	21.4	22.4	12.9	8.3	5.7	70.8	10.3	18.9	24.9	11.5	5.4	71.1
E	Total	Ca	1890	1215	978	616	631	5380	485	725	591	532	551	2884
		Mg	1351	1073	822	470	400	4116	452	755	852	660	424	3143
	Corrected	Ca	403	323	276	97	46	1149	19	145	157	244	301	866
		Mg	619	632	539	301	250	2341	288	564	621	516	282	2272
	Pct. of input	Ca	11.0	8.9	7.5	2.6	1.3	31.3	0.5	3.9	4.3	6.6	8.2	23.6
		Mg	18.1	18.4	15.7	8.8	7.3	68.3	8.5	16.4	18.1	15.0	8.2	66.3
Controls	Total	Ca	1487	887	702	519	585	4181	466	580	434	288	250	2018
		Mg	732	441	283	169	150	1775	164	191	231	144	142	817

quadrennial periods are given in table 11, and are graphed in greater detail in figures 3 and 4. The 20-year outgo from series A of the dolomited Cumberland soil show respective totals of 4829 and 3194 pounds for calcium and magnesium. The corresponding values for net outgo were only 648 pounds for calcium and 1419 for magnesium. The values for net outgo of calcium and magnesium comprised 35.3 and 82.8 percent, respectively, of the amounts carried by the incorporated dolomite. The corresponding values for calcium and magnesium from the Virginia soil were: for total outgo, 2582 and 2111 pounds; for net outgo, 564 and 1240 pounds; and values of 30.8 and 72.3 percent, respectively, as proportions of inputs. Hence, in the leachings from the 2 dolomited soils of series A the calcium ions were dominant over the magnesium ions, and the extent of such excess was governed by the native Ca supply in the experimental soil. The uncorrected Mg/Ca ratios were 0.66:1 and 0.82:1. After correction for control outgo, these ratios have assumed the values of 2.17:1 and 2.17:1 for the Cumberland and Onslow soils, respectively. The corrected values indicate for both soils a much higher proportion of Mg to Ca than that given in previous findings (13, 18) for 8-, 32-, and 100-ton CaO-equivalent additions of dolomite where substantial quantities of dolomite remained as such. It was shown that calcite present in a ground dolomite will dissolve preferentially in suspensions of CO₂-charged water (24) and in neutral salt solutions (35), and thus impart to the solutions a higher proportion of Ca than would be expected from the Ca/Mg ratio in the dolomite.

The surface-zone 3570-pound incorporation of dolomite in series F of the Cumberland soil showed an outgo of 4359 pounds of Ca and 2900 pounds of Mg as 20-year totals and corresponding net outgo of 178 pounds and 1125 pounds, which were equivalent to respective percentages of 9.7 and 65.6 of the inputs. The 20-year total losses of Ca and Mg from series F of the Onslow soil were 1875 pounds and 2140 pounds, respectively, which corresponded to net outgoes of minus 143 pounds and 1269 pounds, or minus 7.8 percent and 74.0 percent of respective inputs of Ca and Mg. Thus the additional conservation in series F of the surface incorporation on the Cumberland loam over those in series A were 470 pounds of Ca and 294 pounds of Mg. The corresponding conservations in the Onslow soil were 707 pounds for Ca and nil for Mg. These data indicate that the underlain acidic soil adsorbed the leachate Ca more extensively than it did the Mg, especially as it pertains to the Onslow soil.

The repeat 3570-pound input of dolomite in series B of the Cumberland soil during the 2nd 4-year period resulted in the leachings of 5314 pounds of calcium and 4176 pounds of magnesium as 20-year totals, and respective net losses of 1133 pounds and 2401 pounds, which comprised 30.9 percent and 70.0 percent of the respective inputs.

The net outgo of the leachings from series B of the Cumberland soil showed a Mg/Ca ratio of 2.13:1, which was almost identi-

cal with the one found for the single input of dolomite in series A. The repeat integral input of dolomite on the Onslow soil produced 20-year outgo totals of 3046 pounds and 3308 pounds for Ca and Mg, respectively. So far as known to the writers, this is the first instance of lysimeter leachings in which the concentration of magnesium ions from an unlimed or non-magnesium-limed soil was greater than that of the Ca ions. The net losses of Ca and Mg were 1028 pounds and 2437 pounds, and was respectively equivalent to 28.0 percent and 71.1 percent of inputs. The Mg/Ca ratio in the leachings of series B of the Onslow soil was 2.38:1.

The 8 quarterly incorporations of dolomite in series E of both soils during the first 8 years gave results that were similar to those of series B. The 20-year outgo of Ca and Mg from series E of the Cumberland soil was identical with that from series B, although in the early stages of the experiment the rate of outgo from series E was somewhat behind that from series B. The 20-year outgoes of Ca and Mg from series E of the Onslow soil were slightly lower than those from series B, a fact which may be accounted for by the delay in the effects of the factional inputs, as compared with the integral inputs at the beginning of each 4-year period.

The progressive changes in the relative losses of Ca and Mg, as affected by soil type and dolomite incorporation, are of interest. The data bearing on these aspects are given in the quadrennial summaries in table 11, and graphically in figures 3 and 4. It appears that during the 4-year period after the liming incorporation, the net outgo of Ca from series A and from series B of the dolomited Cumberland soil was about 4 percent of the input. The calcium outgo dropped to 2 percent in the last 4-year period, whereas the magnesium outgo continued at a rate of 2 to 2.5 times as high as that of the calcium, each expressed in relation to respective inputs. The Mg/Ca outgo ratio from the dolomited Onslow soil holds equally true in general, except that the Mg was leached at a rate much faster than that of Ca in the earlier stages. In the advanced stages of the experiment the trend in the Mg/Ca outgo shows a tendency to change, in that the net outgo of Ca equals and even exceeds that of Mg. The total annual losses of Ca and Mg from the controls and from the dolomited series A and F are shown in figures 3 and 4. These graphs register the differences in the outgo of Ca in relation to that from the control, and a similar relationship for the outgo of Mg. The outstanding fact is that although the outgo of calcium from the dolomited Cumberland soil (figure 3A) was not much more, and occasionally less, than that from the control, the outgo of Mg continued greater than that from the control throughout the 20 years. The difference in the outgo of Ca and Mg from the dolomited Onslow soil in relationship to that from the control is shown in figure 4. The meager outgo of Mg during the last stages of the experiment is no doubt due to the exhaustion of Mg supply in the soil.

The relatively high rate of outgo of Mg from the incorporations of dolomite in the Cumberland clay loam at Knoxville, Tennessee, and the Onslow fine sandy loam at Blacksburg, Virginia, is in opposition to the conclusion arrived at by Prince and Toth (33) to the effect that incorporations of dolomite in a Sassafras loam during 28 years resulted in the fixation of magnesium "in a form which is not very soluble."

The present and previous findings as to the outgo of magnesium from incorporations of dolomite should not be confused with the extensive fixations of magnesium resulting from heavy incorpora-

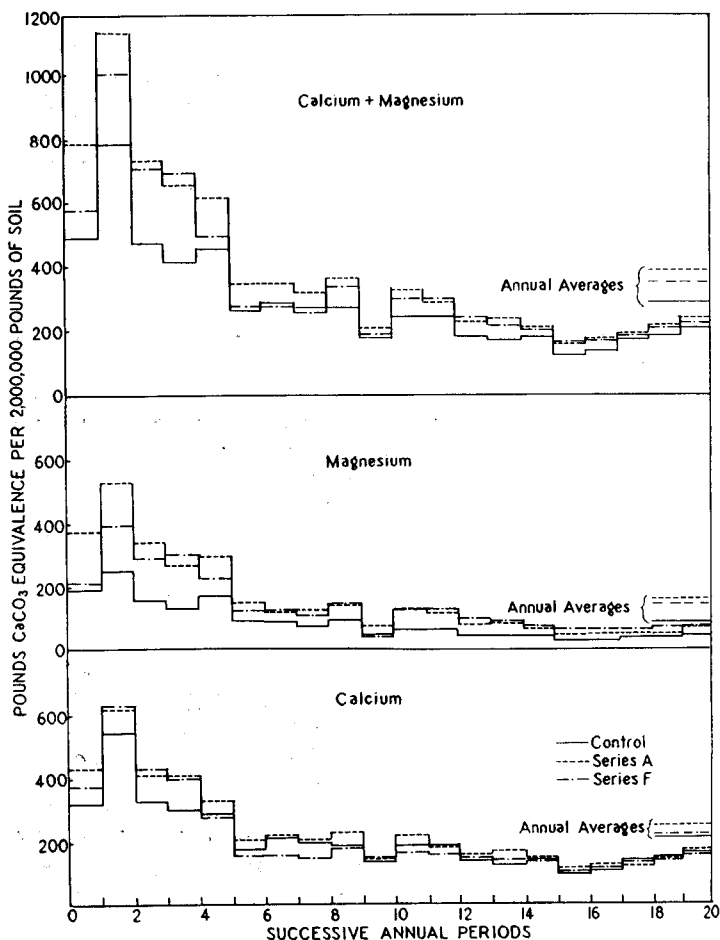


Fig. 3—Comparisons of annual Ca, Mg, and Ca + Mg outgo from (A) control, (B) dolomited series A, and (C) dolomited series F, of a Cumberland clay loam at Knoxville.

tions of the highly soluble hydroxy and normal forms of magnesium carbonate (12, 13). The high concentrations of magnesium and the high pH values of the leachings resulting from the 32-ton and 100-ton incorporations of magnesium carbonate and MgO do not obtain in the leachings from heavy inputs of dolomitic limestone. The extensive fixations of magnesium from the soil solutions of $\text{Mg}(\text{HCO}_3)_2$ at pH above 10 were chiefly in the non-exchangeable form (27). Under such circumstances the magnesium ions may enter the lattice layer of the exchange complexes in exchange for aluminum, a possibility that is suggested in a discussion of crystalline silicates by Hendricks (5).

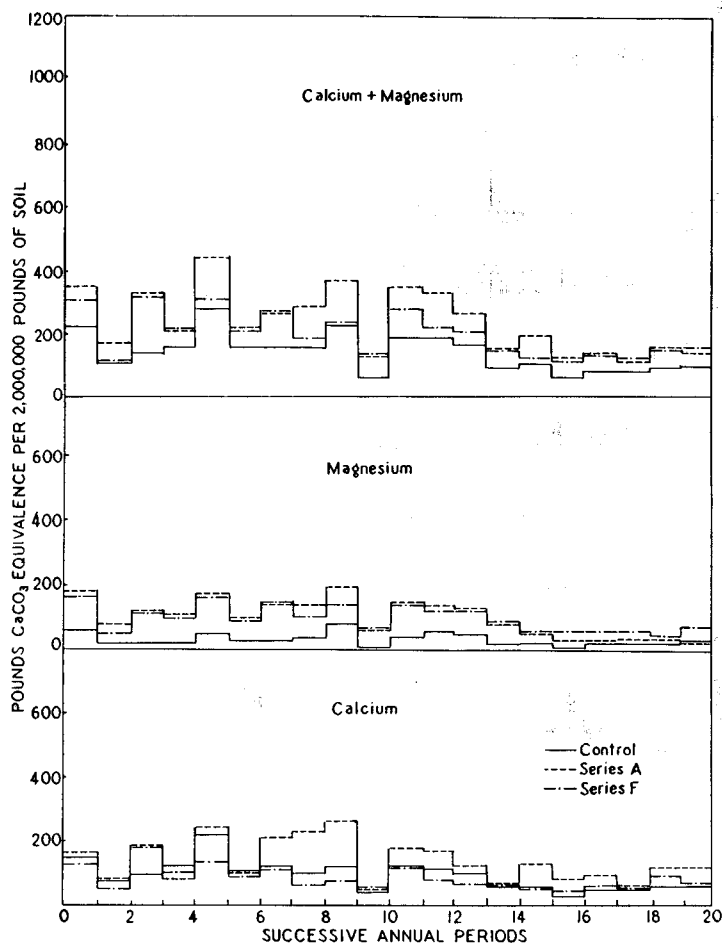


Fig. 4—Comparisons of annual Ca, Mg, and Ca + Mg outgo from (A) control, (B) dolomited series A, and (C) dolomited series F, of an Onslow fine sandy loam at Blacksburg.

TABLE 12A—Data as to status of Ca, Mg, and K in the control and the variously limed Cumberland clay loam in pounds of CaCO_3 -equivalence per 2,000,000 pounds of soil after 20-year exposure to leaching at Knoxville.

Experimental series	Liming material	Total input ¹			Total outgo			Balance			Net gain or loss ²		
		Ca	Mg	K	Ca	Mg	K	Ca	Mg	K	Ca	Mg	K
A	Burnt lime.....	9544	2112	In soil at start=375; in rainwater=181; total=556 pounds	6125	1707	298	3419	405	258	-181	-715	-117
	Limestone.....	9459	2197		6065	1692	277	3394	505	279	-206	-615	-96
	Dolomite.....	7909	3747		4829	3194	272	3080	553	284	-520	-567	-91
	Dica-silicate.....	9359	2297		5749	1924	272	3610	373	284	10	-747	-91
B	Burnt lime.....	13035	2191		7565	1593	241	5470	598	315	1870	-522	-60
	Limestone.....	12865	2361		7644	1610	223	5221	751	333	1621	-369	-66
	Dolomite.....	9765	5461		5345	4201	247	4420	1260	309	820	140	-66
	Dica-silicate.....	12665	2561		6923	2110	280	5742	451	276	2142	-669	-99
C	Burnt lime.....	13035	2191		7648	1639	227	5387	552	329	1787	-568	-46
	Limestone.....	12865	2361		7499	1626	230	5366	735	326	1766	-385	-49
	Dolomite.....	9765	5461		5413	4298	243	4352	1163	313	752	43	-62
	Dica-silicate.....	12665	2561		7056	2097	256	5609	464	300	2009	-656	-75
D	Burnt lime.....	9544	2112		6035	1736	298	3509	376	258	-91	-744	-117
	Limestone.....	9459	2197		5919	1732	298	3540	465	258	-60	-655	-117
	Dolomite.....	7909	3747		4650	3195	276	3259	552	280	-341	-568	-95
	Dica-silicate.....	9359	2297		5644	2018	298	8715	279	258	115	-841	-117
E	Burnt lime.....	13035	2191		7639	1768	254	5396	423	302	1796	-657	-73
	Limestone.....	12865	2361		7805	1772	244	5060	539	312	1460	-531	-63
	Dolomite.....	9765	5461		5330	4116	267	4435	1345	289	835	225	-86
	Dica-silicate.....	12665	2561		7030	2095	290	5635	466	266	2035	-654	-109
F	Burnt lime.....	9544	2112		5481	1635	271	4063	477	285	463	-643	-90
	Limestone.....	9459	2197		5434	1665	281	4025	532	275	425	-588	-100
	Dolomite.....	7909	3747		4359	2900	277	3550	847	279	-50	-273	-96
	Dica-silicate.....	9359	2297		5133	1817	296	4226	480	260	626	-640	-115
G	Burnt lime.....	9544	2112		5381	1626	283	4163	486	273	563	-634	-102
	Limestone.....	9459	2197		5267	1725	294	4192	472	262	592	-648	-113
	Dolomite.....	7909	3747		4238	3052	287	3671	695	269	71	-425	-106
	Dica-silicate.....	9359	2297		5179	1877	314	4180	420	242	580	-700	-133
Control.....	None.....	6053	2033		4216	1788	317	1837	245	239	-1763	-875	-136
Control.....	None.....	6053	2033		4145	1761	331	1908	272	225	-1692	-848	-150
Average.....		6053	2033		4181	1775	324	1872	258	232	-1728	-862	-143
Rainwater.....					2453	913	181						

¹Total input comprises the original contents of exchangeable cations (given in table 1), plus rainwater increments, plus the Ca and Mg introduced by the respective liming incorporations (given in table 2).

²In relation to original contents of exchangeable Ca, Mg, and K in soil, respectively.

TABLE 12B—Data as to status of Ca, Mg, and K in the control and the variously limed Onslow fine sandy loam in pounds of CaCO_3 -equivalence per 2,000,000 pounds of soil after 20-year exposure to leaching at Blacksburg.

Experimental series	Liming material	Total input ¹			Total outgo			Balance			Net gain or loss ²		
		Ca	Mg	K	Ca	Mg	K	Ca	Mg	K	Ca	Mg	K
A	Burnt lime	6043	958		3921	1013	274	2122	-55	57	962	-195	-37
	Limestone	5958	1043		3633	915	226	2325	128	128	1165	-12	11
	Dolomite	4408	2593		2582	2211	231	1826	382	100	666	242	6
	Dica-silicate	5858	1143		3178	1063	227	2608	80	104	1520	-60	10
B	Burnt lime	9534	1037		5193	833	225	4341	204	106	3181	64	12
	Limestone	9364	1207		5562	916	219	3802	284	112	2642	144	18
	Dolomite	6264	4307		3045	3308	224	3119	999	107	2059	859	13
	Dica-silicate	9164	1407		4840	1231	235	4324	176	96	3164	36	2
C	Burnt lime	9534	1037		5273	927	216	4261	110	115	3101	-30	21
	Limestone	9364	1207		5101	977	229	4263	230	102	3103	90	8
	Dolomite	6264	4307		3150	3323	227	3114	984	104	1954	844	10
	Dica-silicate	9164	1407		4397	1130	217	4757	277	114	3607	137	20
D	Burnt lime	6043	958		3816	1005	248	2227	-47	83	1067	-187	-11
	Limestone	5958	1043		3535	921	256	2423	122	75	1263	-18	-19
	Dolomite	4408	2593		2547	2332	257	1861	261	74	701	121	-20
	Dica-silicate	5858	1143		3256	1071	255	2602	72	76	1442	-68	-18
E	Burnt lime	9534	1037		4948	920	232	4586	117	99	3426	-23	5
	Limestone	9364	1207		4721	993	243	4643	214	88	3483	74	-6
	Dolomite	6264	4307		2884	3143	248	3380	1164	83	2220	1024	-11
	Dica-silicate	9164	1407		4370	1152	236	4794	255	95	3634	115	1
F	Burnt lime	6043	958		3288	840	232	2755	118	99	1585	-22	5
	Limestone	5958	1043		3133	884	236	2825	159	95	1665	19	1
	Dolomite	4408	2593		1875	2140	222	2533	453	109	1373	313	15
	Dica-silicate	5858	1143		2830	920	227	3028	223	104	1868	83	10
G	Burnt lime	6043	958		3219	843	231	2824	115	100	1664	-25	6
	Limestone	5958	1043		3382	843	227	2576	200	104	1416	60	10
	Dolomite	4408	2593		2308	2160	237	2100	433	94	940	293	0
	Dica-silicate	5858	1143		3047	1066	240	2811	77	91	1650	-63	-3
Control	None	2552	879		2162	906	280	393	-27	51	-167	-167	-43
Control	None	2552	879		1873	836	273	679	43	58	-481	-97	-36
Average		2552	879		2018	879	277	536	8	54	-624	-132	-40
Rainwater					1392	739	237						

In soil at start=94 pounds; In rainwater=237.
Total=331 Pounds

¹Total input comprises the original contents of exchangeable cations (given in table 1), plus rainwater increments, plus the Ca and Mg introduced by the respective liming incorporations (given in table 2).

²In relation to original contents of exchangeable Ca, Mg, and K in soil, respectively.

STATUS OF EXCHANGEABLE Ca, Mg, AND K, AND OF N AND S CONTENT OF THE SOILS AFTER TWENTY YEARS OF LYSIMETER LEACHINGS

Attention was focused upon the losses of Ca+Mg and of K, N, and S. The derived "net outgo" was taken as a measure of the effectiveness of a given material or a given method of incorporation, and correlated with the respective inputs of Ca and Mg. The calculations of the lysimeter data were in relation to control outgo. This procedure is convenient for the canceling out of the factors of rainwater increments and of native contents of the respective elements in the control soil. It is emphasized, however, that the "net outgo" of Ca, Mg, and K is not an actual value, since it does not represent equilibrium concentrations or proportions of the respective elements in the intermicellar soil solution. Moreover, neither the total nor the net outgo in the leachings gives, in itself, direct information as to the status of certain nutrient elements at the end of the 20-year exposure to lysimeter leachings from the various incorporations. To obtain such information, it was necessary to integrate the original soil content of exchangeable cations and other nutrients, the rainwater increments, and the elements supplied through the incorporations of the several liming materials in relation to the outgo in the leachings. Such information in regard to Ca, Mg, and K is presented in tables 12A and 12B, whereas that in regard to N and S is given in table 13.

Changes in Exchangeable Cation Content.—Four main columns of data are given in tables 12A and 12B. The column for *total input* represents original content plus rainwater increment for the 20-year period plus the quantities of Ca and Mg carried by incorporations of liming materials; the column for *outgo* presents the 20-year outgo of the respective elements; the column for *balance* represents the difference between input and outgo and expresses the status of the soils with respect to those elements at the end of the 20th year. The column for *net gain or net loss* gives the status of the soil in relation to original contents of Ca, Mg, and K.

The final status of each experimental soil is affected by a common constant of initial content and rainfall increment, and by the variables of quantities and manner of input. The last-mentioned value is distinguished by the series designation, and, within each series, by the kind of material. After 20 years of exposure, the Cumberland control soil had lost 1700 pounds of Ca and retained 1900 pounds. The Mg loss was 861 pounds against a retention of 259 pounds. The corresponding values for losses and retention of K were 143 pounds and 232 pounds. In each instance the algebraic difference of "balance" minus "loss or gain" equals original content. In view of this relationship, reference is made henceforth only to the expressions of net gain or loss from the initial content of a particular element in the soil. The net loss of Ca from calcic limestone incorporations of series A was 200 pounds; the loss from

TABLE 13—Data as to status of N and of S in the variously limed soils after 20-year lysimeter exposure at Knoxville, and at Blacksburg, in pounds per 2,000,000 pounds of soil.

Experimental series	Liming material	Cumberland clay loam								Onslow fine sandy loam							
		Input		Output		Balance		Net Loss ¹		Input		Output		Balance		Net Loss ¹	
		N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
A	Burnt lime	8064	1746	1038	858					1227.5	884	704	381				
	Limestone			984	860							630	362				
	Dolomite			961	866							584	365				
	Dica-silicate			1020	866							564	355				
	Average			1001	863	2063	883	817	97			621	366	607	518	533	42
B	Burnt lime			1052	883							691	372				
	Limestone			1004	887							598	362				
	Dolomite			1013	895							588	368				
	Dica-silicate			1067	880							606	379				
	Average			1034	886	2030	860	850	120			596	370	632	514	508	46
C	Burnt lime			1062	905							714	388				
	Limestone			1027	902							711	389				
	Dolomite			1071	919							669	380				
	Dica-silicate			1081	943							688	379				
	Average			1060	917	2004	829	876	151			696	384	532	500	608	60
D	Burnt lime			975	876							666	366				
	Limestone			982	862							647	373				
	Dolomite			928	866							688	376				
	Dica-silicate			992	878							628	373				
	Average			969	869	2095	877	785	103			657	372	571	572	569	48
E	Burnt lime			1059	902							754	381				
	Limestone			1147	905							734	373				
	Dolomite			965	896							663	379				
	Dica-silicate			1031	928							754	397				
	Average			1051	908	2013	838	867	142			726	383	502	501	638	59
F	Burnt lime			919	827							615	361				
	Limestone			907	836							541	386				
	Dolomite			909	849							464	363				
	Dica-silicate			901	865							504	377				
	Average			909	844	2155	902	725	78			531	372	677	512	463	48
G	Burnt lime			923	845							536	390				
	Limestone			900	850							546	362				
	Dolomite			877	865							604	377				
	Dica-silicate			942	872							643	403				
	Average			911	859	2153	887	727	93			582	383	646	501	494	59
Control	None			893	798							504	339				
Control	None			827	851							513	362				
Average				860	822	2204	924	676	56			509	351	719	533	421	27

¹In relation to original content of N and S, respectively.

series D was 75 pounds, against gains of 500 pounds from series F and G, and 1800 pounds from the double incorporations, series B, C, and E.

Series B, C, and E showed average net gains of only 140 pounds for magnesium from the double incorporations of dolomite, whereas the single integral dolomite incorporations of series A and D registered an absolute loss of 568 pounds of Mg at the end of 20 years.

The losses from the Onslow controls were 624 pounds of Ca, 132 pounds of Mg, and 40 pounds of K, after the 20 years of exposure, the results for the Ca and Mg from the 2 controls being wide apart. The soil still contained 536 pounds of Ca, whereas the magnesium residue was practically nil. The unit incorporations of calcic limestone resulted in an average net gain of 1200 pounds of calcium in the Onslow soil, whereas the double rates caused a Ca build-up of 3000 pounds. The unit rate of dolomite incorporation resulted in an over-all gain of 200 pounds of Mg, whereas the double inputs of dolomite caused a gain of 900 pounds. Small but significant differences in the outgo of Ca and Mg from the calcic materials can be traced to differences in the composition of those products.

Changes in Contents of N and S.—A general view of the status of initial and final contents of N and S is given in table 13, and the relationships between the various values are obvious from an examination of that table. The initial contents, as given in table 1, plus rainwater increments during the 20 years, are reckoned as *input*, and the 20-year data given in the appendix are presented as *outgo*. The *balance* is the computed contents of the elements present in the soil after the 20 years of exposure, and the *net loss* is in relation to original contents of the respective elements in each soil.

The losses of nitrogen from the several series of the Cumberland soil were as follows: The control soils lost 676 pounds; the soils with single rate of liming (Average of A and D) lost 801 pounds; the soils that received single-rate liming in the upper zone (average of F and G) lost 726 pounds; the soils that received the double-rate liming (average of B, C, and E) lost 864 pounds. These losses represent respective percentages of 23, 28, 25, and 30 of the initial content of nitrogen. Hence, both rate of input of the liming materials and the zone of their incorporation exerted distinct effects upon the *net loss* of nitrogen from the Cumberland soil.

The loss of nitrogen from the unlimed Onslow soil was 421 pounds; that induced by the single integral of liming was 551 pounds; that induced by double integral of liming was 584 pounds. The losses from series B were not concordant with those from series C and E, but were included in the foregoing averages for nitrogen losses. The losses from the Onslow soil were respectively equivalent to percentages of 37, 48, 51, and 42 of the initial content of nitrogen.

The loss of sulfur from the unlimed Cumberland soil was 56 pounds, that from the single-integral liming (average of A, D, F, and G, was 93 pounds and the loss resultant of the double-integral of limings was 138 pounds. These quantities are not large, yet they register a significant effect of the rate of liming upon the loss of sulfur. Upon the basis of original content of sulfur, the percentage losses were 5.7, 9.5, and 14.0, respectively. The over-all loss of S from the Onslow control was 27 pounds, against a loss of 53 pounds as the average for all of the limings, these losses being 2.3 percent and 4.6 percent, respectively, of the initial content of sulfur in the Onslow soil.

RATES OF DEPLETION OF EXCHANGEABLE Ca AND Mg FROM CERTAIN LIMESTONED AND DOLOMITED SOILS AND CONTROLS

In the preceding section, the status of the cations in variously limed soils was presented solely at the point of expiration of the 20th year of the experiment. Through the same method of accounting for the various increments of input and outgo, the findings were computed to show the status of Ca and Mg in 5 typical experimental units of both soils for each year of the experiment, as in tables 16 to 25 inclusive. The principal objective was to plot the progression in soil's content of Ca and Mg in relation to time. Equally important, however, is the fact that the data afforded opportunity for the computation of the ratios of Mg-to-Ca in the annual outgo, expressed as percentage of supply of these elements in the soils for the respective annual periods. Changes in the status of Ca and Mg in the soils are shown in graphs, figures 5, 6, 7, and 8. Sections A, B, and C of figure 5 depict the rate of depletion of Ca and Mg of the Cumberland clay loam, at various levels of base saturation, that was effected by the incorporated liming materials. Each pair of curves in these figures represents 2 sets of values for Ca and Mg. The values that read upward from the base line of the graph represent the cumulative decline in the soil's content of Ca and Mg over 20 years. The values marked on the right-hand side of the graph read in the opposite direction from the points of initial contents of Ca and Mg. These values may be regarded as the cumulative loss from each experiment whose Ca and Mg contents, including the immediate liming incorporations, are defined as "initial contents". The "cumulative loss" values are not identical with either the expression "outgo" or "net outgo" used in the discussion of leaching data. "Net outgo" is merely a comparative value in relation to outgo from the unlimed soil, whereas "outgo" is not an actual loss, since the term does not include accretion to the soil of Ca and Mg through rainwaters. "Cumulative loss" represents an absolute and independent value that can be applied alike to the limed and unlimed soils. The difference between these values can be shown by use of the *outgo* and *net outgo* of Ca and Mg from the dolomite in series A of the Cumberland soil, as given in table 12A. Total *outgo*

of calcium was 4829 pounds, and of magnesium, 3194 pounds. When corrected for control, the net outgo from the above experiment becomes 648 pounds and 1419 pounds, against *cumulative losses* of 2380 pounds and 2280 pounds for Ca and Mg, respectively, according to the plotted values of figure 7B. The values for "cumulative loss" and the "residual" content are complementary values, and at a selected point the summation of the 2 readings on the curve repre-

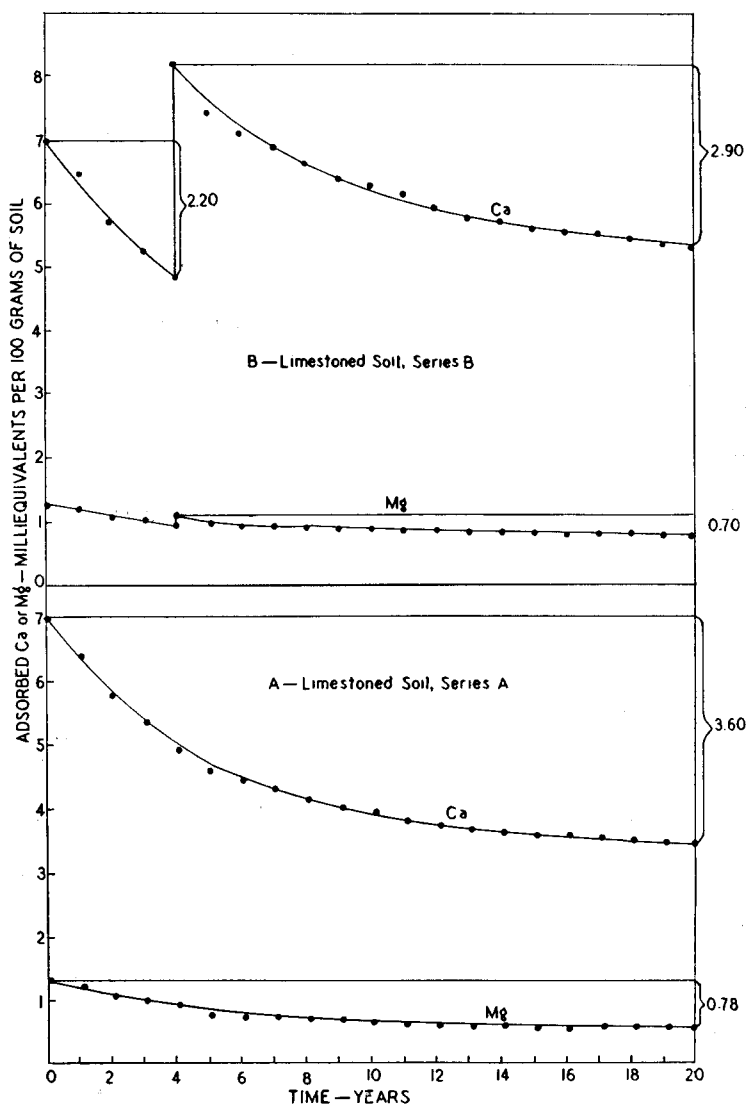


Fig. 5—Progressive depletion of calcium and magnesium from a limested Cumberland clay loam: (A) limested with 3570 pounds of CaCO_3 -equivalence at beginning; (B) limested at beginning of first and second 4-year periods with 3570 pounds of CaCO_3 -equivalence in each incorporation.

sents the "initial content" of the soil, inclusive of liming incorporations.

Two aspects are indicated by the depletion curves of figures 5 to 8. One is the rate of Ca and Mg depletion at various points on the time scale, and the other is the relationship between the contained Ca and Mg and the respective rates of their outgo. The net loss of Ca from the Cumberland soil was at maximal rate in the early

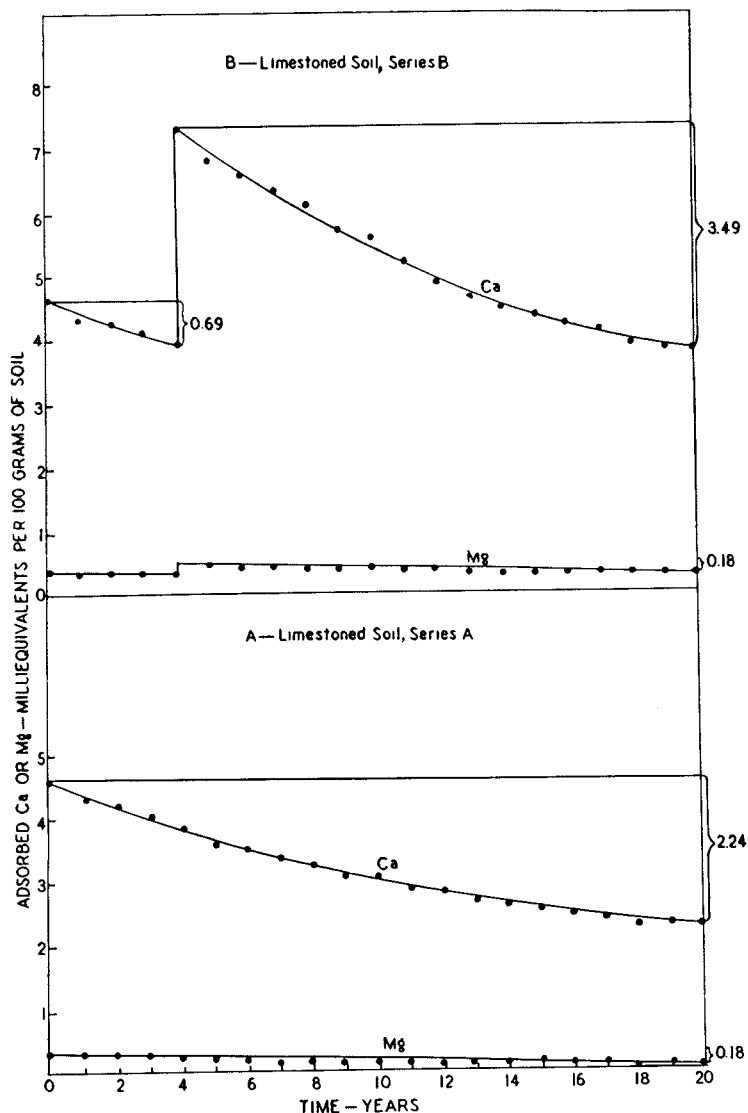


Fig. 6—Progressive depletion of calcium and magnesium from a limested Onslow fine sandy loam: (A) limested with 3570 pounds of CaCO_3 -equivalence at beginning; (B) limested at beginning of first and second 4-year periods with 3570 pounds of CaCO_3 -equivalence in each incorporation.

stages of the experiment, and decreased rapidly in the successive periods, as shown in figures 5 and 7.

Readings from the curves 5B, 5C, and 7A give the following net losses of calcium from the Cumberland soil by 4-year periods as pounds per 2,000,000 pounds of soil:

	1st	2nd	3rd	4th	5th
Control (fig. 7A)	1100	400	150	50	20
Limestoned (fig. 5B)	2000	800	450	200	100
Limestoned (fig. 5C)	2200	1600	700	380	200

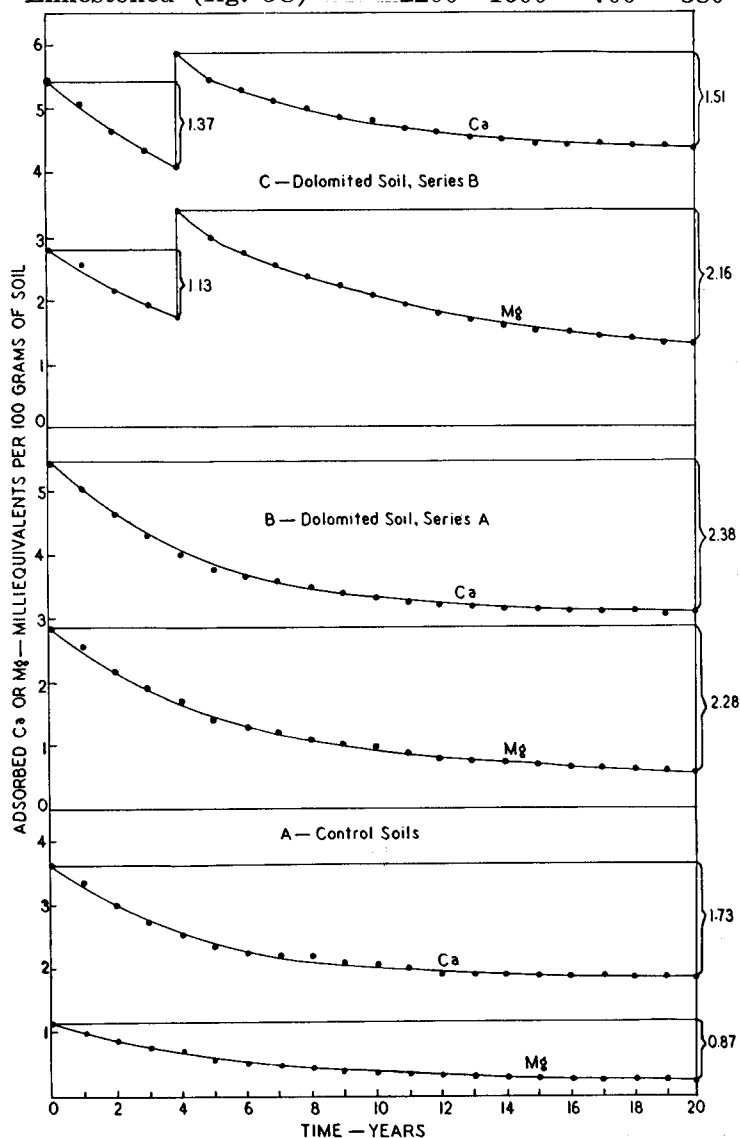


Fig. 7—Progressive depletion of calcium and magnesium from (A) the control, (B) once-dolomited, and (C) twice-dolomited Cumberland clay loam.

In a comparison of these values and corresponding values in table 7, the distinction between "outgo" and "net loss" is apparent. The marked diminution in rate of outgo through rainwater leachings has been attributed to "aging" or "mineralization" of the added calcium that had entered the complexes (19). Without any attempt to develop a theoretical explanation of the phenomenon, the findings can be integrated in relation to normal soil processes. It

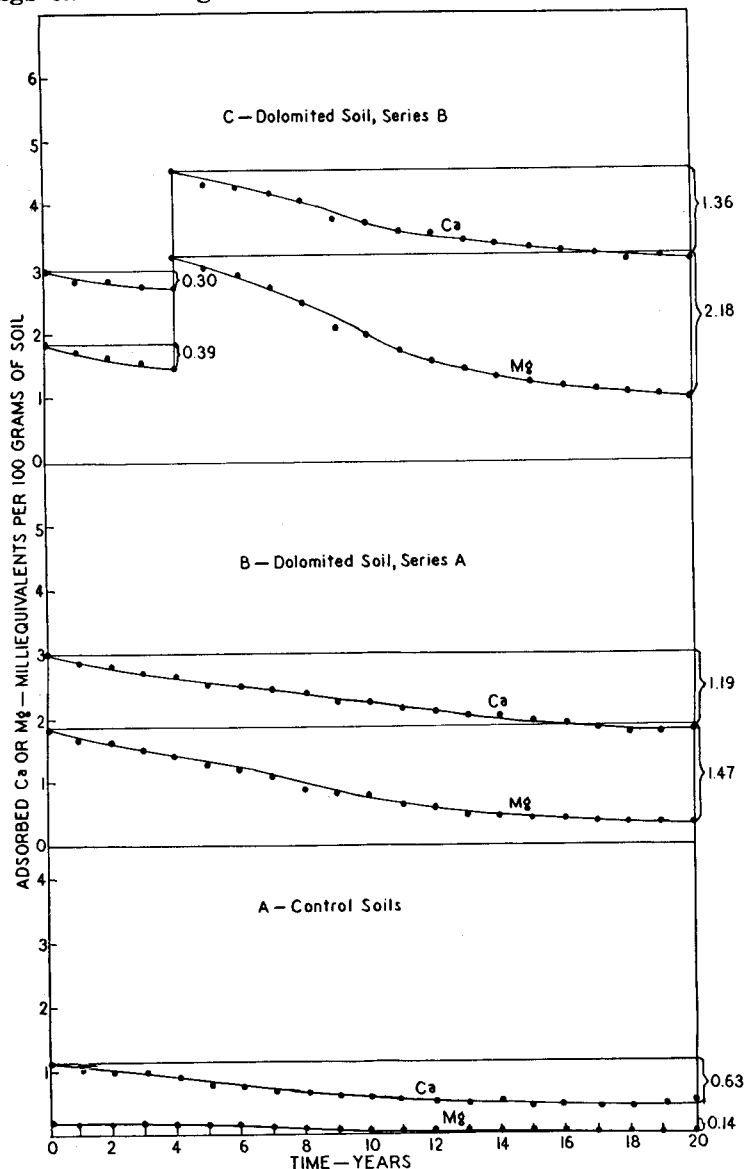


Fig. 8—Progressive depletion of calcium and magnesium from (A) the control, (B) once-dolomited, and (C) twice-dolomited Onslow fine sandy loam.

has not been established that after its adsorption by the soil the added Ca loses its ability to function in cation interchange or to effect the neutralization of H-ions that are generated in the soil. The phenomenon of decreasing leachability of the additive Ca after the sorption under natural conditions may be regarded as a consequence of an adjustment in the chemical and biochemical activities of the limed soil without any particular change in the nature of the Ca-complex. Certain concomitant phenomena serve to explain the high rate of outgo of Ca and Mg at the early stages of an experiment. One of these is the bacterial activation that ensues as an effect of the aeration that occurs when the bulk of soil is screened and mixed to assure uniformity in the several portions for placement in the lysimeters. Moreover, the decomposition of incorporated carbonates effects an enrichment in the CO_2 content of the soil system, with resultant early increase in capacity to dissolve bases into the drainage waters.

The annual leachings of nitrates as graphed in figure 1, show that the nitrate outgo accounts for nearly 50 percent of the outgo of Ca+Mg from the unlimed as well as the limed Cumberland clay loam, series A. The heavier rates of liming which induced the larger outgo of Ca+Mg produced larger proportions of bicarbonate in the leachings. This relationship is indicated by the wider spaces between the (SO_4 plus NO_3) lines and those for Ca+Mg in figures 1 and 2. The disappearance of bicarbonate indication on these graphs coincides with the experimentally determined cessation in the losses of Ca+Mg from the soil; that is, outgo is in balance with the increment supplies by rainwaters, as exemplified by curves for Ca and Mg from the control in figure 5A.

The fact that the unlimed soil and the limed soils undergo similar progressive diminutions in outgo militates against the postulation that "aging" accounts for a lessening in the dissolubility of the Ca content of the soil complex.

The net losses of calcium from the limestoned Virginia soil did not show the sharp decline that was registered by the Tennessee soil during the early stages of the experiment. The differential behavior of the 2 soils is attributed to their distinctive chemical characteristics. As noted in the earlier publication (28), the organic matter in the Cumberland soil was readily decomposable, whereas that of the Virginia soil was more stable and included peanut-hull residues. The course of the depletion of Ca and Mg in the Virginia soil is given in figures 6 and 8. The outgo of Ca and Mg, and consequently the net losses of those elements from the Virginia soil, were affected by serious annual fluctuations, as can be seen from the scattering of the experimental values of the curves in figures 6 and 8. The curve for Ca in figure 6A shows a gradual decreasing rate of loss of Ca from the limestoned soil of series A, whereas the losses of Ca from the limestoned soil series B start at a much higher rate and fall off faster. This difference may mean that the degree of Ca-saturation in the Virginia soil is an important factor

governing the rate of outgo of calcium. The net losses of Ca from the single and double limestone incorporations in the Virginia soil for the five 4-year periods as pounds per 2,000,000 pounds of soil were as follows:

	<u>1st</u>	<u>2nd</u>	<u>3rd</u>	<u>4th</u>	<u>5th</u>
Limestoned, series A -----	700	500	400	250	180
Limestoned, series B -----	690	1400	1000	700	400

In the 2nd 4-year intervals, 3.5 m.e. and 6.5 m.e. represented the mean Ca contents for the 2 series, against corresponding m.e. values of 2.3 and 3.9 in the 5th 4-year periods. The contents of Ca in those series of the Cumberland soil were 4.4. m.e. and 7.2 at the early period, and 3.5 m.e. at the 5th 4-year period of the experiment. The rate of loss of Ca at near the end of the 20-year period was greater for the Virginia soil than for the Tennessee soil, although the Ca content of the Virginia soil had been diminished to a much lower level. Series A and B of the Virginia soil showed 42 and 72 percent Ca-saturation near the close of the experiment, whereas the singly and doubly limestoned Tennessee soils were 35 and 54 percent Ca-saturated. Near the close of the experiment, the single-limestoned Tennessee and Virginia soils showed almost the same degree of Ca-saturation, yet the rate for net loss from the Virginia soil was nearly twice as high as that from the Tennessee soil. Thus, the limestoned Virginia soil started with a slower rate of calcium loss than the limestoned Tennessee soil. The losses of calcium from the Cumberland soil, however, decreased sharply past the mid-point of the experiment, whereas those from the Virginia soil were maintained at a uniform rate and had overtaken the losses from the Tennessee soil at the end of 20 years.

It is logical to assume that the exchangeable supply of calcium of a soil, or its degree of Ca-saturation, will affect the rate of losses of that element through rainwater leachings. Base-exchange investigations have demonstrated that the degree of cation saturation of clay particles of a given base governs the extent of replacement by other cations (10, 2). As pointed out by Bray, (2, p. 962), however, "It is unsafe to predict what the final over-all effect will be under soil conditions where factors outside the ones included in the laboratory experiment are present." The data of table 14 were compiled to establish relationship between degree of calcium saturation of the Tennessee and Virginia soils and the rate of loss of calcium through rainwater leachings. The tabulated data were obtained from the curves in figures 5, 6, 7, and 8 for net loss of calcium in the 4-year periods and for the mean content of calcium of each period.

The 3 ranges of Ca-saturation are supplied by the unlimed, once-limestoned, and twice-limestoned soils, although the values in these 3 liming categories do not overlap to an extent sufficient to furnish many points for intercomparisons. The unlimed Tennessee soil was 30-percent Ca-saturated in the initial 4-year period and showed a net loss of 850 pounds for that period, whereas, the Ca-

TABLE 14—*Relation of calcium content and degree of Ca-saturation to net loss of Ca through 20 years of rainwater leachings from Cumberland and Onslow soils.*

Soil	Liming	Successive 4-year periods	Ca in soil ¹		Net loss per period per 100 grams
			Per 100 grams	Degree of Ca-saturation	
			M.e.	Percent	M.e.
Cumberland clay loam	Unlimed	1	3.00	30	0.85
		2	2.25	22	0.50
		3	2.00	20	0.25
		4	1.90	19	0.10
		5	1.85	18	0.02
Cumberland clay loam	Limestoned series A	1	5.80	57	2.05
		2	4.45	44	0.80
		3	3.95	39	0.43
		4	3.60	36	0.22
		5	3.45	34	0.10
Cumberland clay loam	Limestoned series B	1	5.70	56	2.20
		2	7.20	71	1.60
		3	6.20	61	0.90
		4	5.70	56	0.38
		5	5.40	53	0.20
Onslow fine sandy loam	Unlimed	1	1.00	19	0.25
		2	0.80	15	0.25
		3	0.60	11	0.10
		4	0.50	9	0.10
		5	0.40	7	0.05
Onslow fine sandy loam	Limestoned series A	1	4.10	76	0.70
		2	3.50	65	0.50
		3	3.00	55	0.40
		4	2.70	50	0.25
		5	2.30	43	0.18
Onslow fine sandy loam	Limestoned series B	1	4.20	78	0.69
		2	6.50	120	1.40
		3	5.40	100	1.00
		4	4.40	81	0.70
		5	3.90	72	0.40

¹Mid-point values for each period were taken from graphs in figures 5, 6, 7, and 8, as representative of average content of each period.

saturation nearest thereto was the 34-percent saturation of the once-limestoned soil in the 5th period, with a corresponding net loss of calcium for that period of only 100 pounds. In the initial period, the twice-limestoned soil was 56 percent Ca-saturated and had a net Ca loss of 2200 pounds; yet in the 4th period, when the same degree of Ca-saturation prevailed as a consequence of an intervening incorporation, the loss of calcium was only 380 pounds. However, substantial differences in the leaching rates of calcium when the degrees of Ca-saturation were near-equal need not be taken as complete refutation of the principle of rate of outgo, or replacement, as a function of the degree of saturation. Instead, the indicated discrepancies should serve to emphasize the fact that, under natural and normal soil conditions, the rate of loss of calcium is governed largely by the microbiological activities, and of the quantity of readily decomposable organic matter, rather than by differences in degree of Ca-saturation. Only when the soils have attained more or less uniformity in microbiological activity, and in resultant uniformity in the generation of CO₂, will the degree of Ca-saturation govern the rate of outgo. For example, the losses of calcium from series B in the 5th period can be related to the losses

from series A. Series B showed 34 percent saturation degree and a 100-pound loss of calcium, whereas series A was 53 percent saturated and had a 200-pound loss of calcium. Similar relationships between degree of Ca-saturation and outgo are indicated in the data from the Virginia soil, except that there are fewer common points for intercomparison.

PROPORTIONS OF NITRATE, SULFATE, AND BICARBONATE IN TOTAL CATION LOSSES FROM EXPERIMENTAL SOILS

Although the leachings of nitrates and sulfates have been integrated with outgo of Ca+Mg in preceding sections of the text, this aspect is deemed of sufficient importance to justify special consideration. The present discussion will attempt to show: (a) the proportions of anions to total cation outgo from the 2 unlimed soils; (b) the effects of single and repeated incorporations of the liming materials upon proportions established in (a); (c) the effect of time on the proportions of the anions under the several conditions. Data that relate to these aspects appear in table 15, in form somewhat different from the presentation in figures 1 and 2. The data in table 15 are given by 4-year periods for the unlimed soils and for certain limestoned soils, whereas the charted data from representative series are given as annual averages for the several liming materials. The values in table 15 represent net losses, whereas the plotted values of figures 1 and 2 represent actual outgo. The corrections for rainwater content were applied in table 15, because it was desired that the corrected values point the relationships that would be obtained under natural conditions, where the soil would not be affected by atmospheric pollution.

Of the 2773-pound cation loss from the Cumberland control soil during 20 years, 87 percent was accounted for by nitrates and the remainder was shared equally by sulfate and bicarbonate. The single 3570-pound limestone full-depth incorporation induced an increased cation outgo of 1744 pounds over that from controls, and concomitant increases in anion outgo as follows: Nitrate, 443 pounds; sulfate, 119 pounds; and 1182 pounds ascribed to bicarbonate. The large increase in bicarbonate proportion due to liming has resulted in a rearrangement in the percentage distribution of anions in the leachings, decreasing the nitrate loss from 87 to 64 percent and increasing the bicarbonate loss from 7 to 31 percent of the total cation loss. An additional incorporation of limestone in series B the 5th year caused an increased cation loss of 3182 pounds, which was accounted for in part by a 514-pound increase in nitrate outgo and a 203-pound increase in sulfate outgo, the remainder of 2455 pounds being ascribed to bicarbonate.

Series F, which is comparable to series A, except that the incorporation of limestone in F was made in the upper 1/3 of the soil column, suffered a total cation loss of 3863 pounds, or a 1090-pound increase over that in control, which was accounted for by a 168-pound increase as nitrate, 45-pound increase as sulfate, and

TABLE 15—*The proportions of NO₃, SO₄, and HCO₃ of total cation leached from Cumberland clay loam and Onslow fine sandy loam, as affected by liming and time.*

Experimental series	Cation or anion	CaCO ₃ equivalence as pounds per 2,000,000 pounds of soil, and as percent of total cation by periods in years											
		1-4		5-8		9-12		13-16		17-20		1-20	
		Lbs.	Pct.	Lbs.	Pct.	Lbs.	Pct.	Lbs.	Pct.	Lbs.	Pct.	Lbs.	Pct.
CUMBERLAND CLAY LOAM													
Controls	Ca+Mg+K	1555	100	757	100	326	100	50	100	85	100	2773	100
	NO ₃	1335	86	700	93	314	96	85	170	-7	-	2413	87
	SO ₄	22	1	38	5	65	20	19	38	50	59	174	6
	HCO ₃	208	13	19	2	-53	-16	-54	-	42	-	186	7
Limestoned Series A	Ca+Mg+K	2538	100	1048	100	539	100	220	100	172	100	4517	100
	NO ₃	1624	64	739	71	385	71	114	52	-7	-5	2856	63
	SO ₄	125	5	37	4	49	9	25	11	56	32	293	6
	HCO ₃	789	31	272	25	105	20	81	37	123	73	1368	31
Limestoned Series B	Ca+Mg+K	2626	100	1822	100	754	100	423	100	330	100	5955	100
	NO ₃	1585	60	914	50	289	38	146	35	-7	-2	2927	49
	SO ₄	122	5	97	5	50	7	34	8	75	23	377	6
	HCO ₃	919	35	811	45	415	55	243	57	262	79	2651	45
Limestoned Series F	Ca+Mg+K	2256	100	720	100	484	100	193	100	210	100	3863	100
	NO ₃	1553	69	582	81	324	67	103	53	14	7	2581	67
	SO ₄	116	5	22	3	46	10	-10	-4	45	21	219	6
	HCO ₃	587	26	116	16	114	23	100	51	151	72	1063	27
Rainwater	Ca+Mg+K	828	-----	671	-----	730	-----	687	-----	682	-----	3598	-----
	NO ₃	43	-----	107	-----	154	-----	179	-----	175	-----	657	-----
	SO ₄	559	-----	431	-----	394	-----	425	-----	584	-----	2394	-----
ONSLow FINE SANDY LOAM													
Controls	Ca+Mg+K	330	100	293	100	183	100	76	100	-73	100	809	100
	NO ₃	328	99	357	122	329	180	318	418	186	-----	1505	186
	SO ₄	-16	-5	62	21	31	17	47	62	-38	-----	84	10
	HCO ₃	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Limestoned Series A	Ca+Mg+K	837	100	625	100	560	100	382	100	104	100	2421	100
	NO ₃	367	44	424	68	411	73	478	125	253	243	1937	80
	SO ₄	-1	-1	69	11	59	11	50	13	-50	-48	118	5
	HCO ₃	-----	47	-----	21	-----	16	-----	-----	-----	-----	366	15
Limestoned Series B	Ca+Mg+K	749	100	1283	100	1268	100	679	100	357	100	4333	100
	NO ₃	211	28	414	32	522	41	446	66	229	64	1823	42
	SO ₄	-25	-3	74	6	81	6	37	5	-28	-8	118	3
	HCO ₃	-----	75	-----	62	-----	53	-----	29	-----	44	2392	55
Limestoned Series F	Ca+Mg+K	570	100	480	100	368	100	353	100	172	100	1876	86
	NO ₃	336	59	371	77	340	92	364	103	221	128	1619	10
	SO ₄	-19	-3	71	15	72	20	75	21	-6	-3	194	4
	HCO ₃	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Rainwater	Ca+Mg+K	386	-----	556	-----	556	-----	413	-----	514	-----	2434	-----
	NO ₃	25	-----	79	-----	46	-----	32	-----	132	-----	312	-----
	SO ₄	250	-----	169	-----	147	-----	147	-----	300	-----	1013	-----

877-pound increase as bicarbonate. The 654-pound decrease in loss from series F, as against that from series A, was shared equally by the decreases in the leachings of nitrate and bicarbonate.

The effect of increased calcium saturation of the Cumberland soil upon the cation and anion losses may be summarized as follows: At the 50-percent base-saturation of the control soil, the cation losses were 90 percent as nitrates. Increases in calcium saturation through liming resulted in large increases in cation losses that were balanced only in part by increases in the outgo of nitrates and sulfates, with attendant decreased percentage of nitrate and continual increases in the bicarbonate proportion.

The 20-year net loss of cations from the unlimed Virginia soil was 809 pounds. The nitrate loss was 186 percent and the sulfate loss was equivalent to 10 percent of the cation loss. These values, however, do not represent the actual proportions in outgo from control soil, because the added effect from the rainwater increments was not included. The total cation outgo from the control exceeded the equivalences of NO_3 , plus SO_4 , except during the last 6 years, as shown in figure 2. One integral liming caused increase of 1612 pounds in cation outgo over that from control, of which 432 pounds was accounted for as nitrates and 34 pounds as sulfates. The anion losses as nitrate, sulfate, and bicarbonate, respectively, accounted for 80, 5, and 15 percent of the total cation loss from the once-limestoned Virginia soil. The twice-limestoned Virginia soil gave a 3524-pound increase in cation outgo, of which 318 pounds was accounted for as nitrates, 34 pounds as sulfates, and 2392 pounds as bicarbonate. The 545-pound decrease in cation outgo from the single incorporation of limestone in the upper third of the Virginia soil, as against that from full-depth liming of series A, was shared equally by decreased losses of nitrate and bicarbonate. Hence, the conclusions drawn for the Tennessee soil in regard to the effects of increases in base saturation upon proportions of anions in leaching, are likewise applicable to the Virginia soil.

The large outgo of $\text{Ca}+\text{Mg}$ from the Tennessee soil in the initial stages of the experiment and from the Onslow soil in the middle stages, raises the question of relative losses of anions and cations at various stages of the experiment. The unlimed Tennessee soil starts with a 1355-pound loss of cations in the first 4 years, but in each of the succeeding 4-year periods the losses decrease approximately one-half of the loss in the preceding period, whereas the losses in the 4th and 5th periods were meager. The nitrate ion was predominant throughout the 12 years during which there were substantial losses of cations; the sulfate outgo showed only slight increases, whereas significant amounts of bicarbonates appeared only in the initial 4-year period.

The single incorporation of limestone in the first 4-year period caused a 1027-pound average increase in loss of cations from series A and B. That increase was accounted for by 240 pounds, as nitrates, 100 pounds as sulfates, and 677 pounds as bicarbonates. Dur-

ing the 2nd 4-year period, series A showed a 291-pound increase in cation loss, 39 pounds of which was accounted for as nitrates, none as sulfate, and 253 pounds as bicarbonates. During the 3rd period there was a 213-pound increase in loss of cations, 71 pounds being due to nitrates, nil to sulfates, and 142 pounds to bicarbonates. The 170-pound loss in the 4th period was accounted for by 39 pounds as nitrates and 131 pounds as bicarbonate. The minus value for nitrate outgo in the 5th period probably is due to the high correction for the unusual incidence of nitrates in the rainwaters of that particular period.

The increase in cation outgo from series B of the limestoned in the second period was 1065 pounds, 214 being accounted for as nitrates, 4 pounds as sulfates, and 847 pounds, or 80 percent, as bicarbonates. The cation increase in the 3rd period was 428 pounds, which was accounted for entirely as bicarbonate. In the 4th period, the increase in outgo was 373 pounds, 61 pounds being accounted for as nitrates, 15 pounds as sulfates, and 292 pounds, or 78 percent, as bicarbonate. The increase in the 5th-period outgo was 245 pounds, all of which was accounted for as bicarbonate. Thus, the 80 to 100 percent of the increases in cation outgo resultant from increased calcium supply was accounted for as bicarbonate. This conclusion is different from the one indicated for the anion percentages in table 15. The difference is due to the method of approach, in which the total loss was the basis for computation, whereas the basis in the above discussion was the increased outgo over that from control.

As previously indicated, the net loss of nitrate from unlimed Virginia soil exceeded the total loss of cations from that soil. The progressive decrease in cation outgo, while the nitrate outgo continued nearly constant, is reflected by the decrease in percentage of the excess in loss of nitrates. The increases in loss of cations from the limestoned Virginia soil, as registered by the first four of the five 4-year periods, were 507, 332, 377, and 306 pounds, in succession, whereas the corresponding nitrate increases were: 39, 67, 82, and 160 pounds, with virtually no increases for sulfate outgo. Respective proportions of 92, 80, 80, and 52 percent were attributed to the outgo of bicarbonates in the successive 4-year periods.

The increases in loss of cations from series B of the limestoned Virginia soil during the 2nd, 3rd, and 4th 4-year periods were: 990, 1085, and 603 pounds, respectively, in relation to increases in nitrate losses of 67, 193, and 128 pounds, whereas bicarbonates accounted for successive increases of 99, 82, and 95 percent of the cation loss.

The course of the percentage losses of nitrogen by 4-year periods is of interest. The total loss of 676 pounds from the unlimed Tennessee soil was distributed through percentages of 54, 29, 13, 3, and 1 for the succession in 4-year intervals, as against corresponding percentages of 57, 26, 124, and 1 for the 800-pound loss suffered by the limestoned soil. In series B the limestoned soil had a total loss

of 820 pounds, which was distributed as 53, 32, 11, 5 and 1 percent of total loss for the successive 4-year periods. The loss of nitrogen from the Tennessee soil, limed or unlimed, was virtually nil during the final 4-year period, although the computed residual nitrogen was 2060 pounds of N per 2,000,000 pounds of soil, or 71 percent of its original content of 0.1440 percent of N.

The net losses of nitrogen from the unlimed Virginia soil, from the limestoned series A and B, were 421, 542, and 510 pounds, with the respective losses distributed as follows for the successive 4-year periods:

Unlimed soil	22, 24, 22, 21, and 12 percent
Series A limestoned	19, 22, 21, 25, and 13 percent
Series B limestoned	12, 23, 29, 24, and 13 percent

The 542-pound loss amounted to a 48-percent loss of the original 0.057 percent N of the soil.

The distribution of the N losses from the Virginia soil is in decided contrast to that from the Tennessee soil. It is notable that although the Virginia soil continues to yield appreciable quantities of N, even after 20 years of leaching had removed 48 percent of its initial content of nitrogen, the Tennessee soil had ceased to yield any N in the leachates after a loss of only 29 percent of its total N content.

The distribution of the losses of sulfur from the unlimed soils in 4-year periods is somewhat irregular. The highest percentage of losses from the limed Tennessee soil occurred during the period of liming. The outgo of sulfates from the Virginia soil was too irregular for the drawing of generalizations on the distribution of losses. The net losses of S from the Tennessee soil, unlimed and limestoned A and B were 56, 94, and 121 pounds, respectively, which corresponded to 6, 10, and 12 percent of the original sulfur content of .049 percent. The net losses from the corresponding values for the unlimed and limestoned series A and B of the Virginia soils were 27, 38, and 38 pounds, which represented percentages of 5, 7, and 7 percent respectively, of the initial sulfur content of 560 pounds per 2,000,000 pounds of soil.

CATION INTERRELATIONSHIPS IN THE LYSIMETER OUTGO

Since Way (37) in 1850 discovered the power of soils to adsorb potassium from KCl with concomitant release of calcium equivalence as CaCl_2 the subject of base exchange, or cation interchange, has held an important position in soil research. Soils now are characterized according to base-exchange capacity and content of specific cations. Losses of Ca, Mg, and K through rainwater leaching are regarded as exchange phenomena through which the H-ions of the carbonic acid of the percolating water replace the metal cations of the soil. The reverse order obtains when a soil is limed, inasmuch as the incorporated Ca or Mg replaces the hydrogen ions of the

soil complex. When the principles of cation exchange are applied to certain types of soil analyses and soil amelioration, the properties of the specific cations are recognized as affecting flocculation, soil reaction, and degree of adsorption. The particular properties of cations that bear upon the outgo of Ca, Mg, and K in the rainwater leachings are those that pertain to intensities of exchange adsorption and ease of replacement. These properties have been investigated by Jenny and co-workers (5, 6, 8, 9) and more recently by Bray (2). Through investigations of the replaceability of potassium from clay suspensions, as such is influenced by the degree of K saturation and type of the complementary ion, Jenny and Ayers (10) developed the following relationships: If the complementary C ions are held more tenaciously than the B ions, the replacing W ions favor the B ions, but when the complementary C ions are held less tightly than the B ions, the replacing agent will favor the C ions rather than the B ions. Their conclusion that "as a matter of fact, neutralizing an acid soil with Ca should render K more available . . ." (10:457), is inconsistent with their own generalizations on exchangeability as affected by complementary ions.

Bray (2) established the cation release by 1.66 m.e. HCl per 100 grams of soil on a number of Illinois soils, and has computed average f-values of Mg, K, and H, in which f is the ratio of the percentage of the exchangeable supply of each base released, in relation to that of Ca, which is taken as unity. The f-Mg ranged from 1.10 to 1.98, or an average of 1.60; the f-K ranged from 1.56 to 3.18, with an average value of 2.20; and f-H was calculated as =0.35. It was assumed that the ratio of a given cation released when a small quantity of an electrolyte is added to the system is proportional to (a) the relative amount present and (b) the "relative ease of release." Both Jenny and Bray formulated an equation which led to the generalization: *Where a cation of higher tenacity is replaced by one with a lower tenacity, the proportionate release of other cations present will be decreased.*

The cation releases from our 2 experimental soils through the rainwater leachings are not subject to exact computation of constants such as might be feasible under laboratory experimentation. It would be advantageous, however, if the determined long-range effects exerted by the inputs of calcic and magnesian materials upon outgo of Ca, Mg, and K could be correlated with the cited principles of cation interchange.

The various and long-time lysimeter experiments that embraced calcic, magnesian, and dolomitic materials, and a wide range in rate and manner of incorporation, have led to certain observations as to cation interrelationships in leachings which may be summarized as follows: (a) Incorporations of the several calcic liming materials effect a diminution of the quantity of magnesium present in the rainwater leachings from the zone of incorporation; (b) incorporation of magnesian oxides and precipitated carbonates effect substantial diminution in the outgo of calcium in the leachings as

they pass directly from the zone of incorporation; (c) the incorporation of a calcic or magnesian or dolomitic material represses outgo of K from the zone of incorporation. (The first two relationships were designated as the phenomena of "Reciprocal repression"—17, 19, 21, 23); (d) the percolates from a Ca-fortified soil effects replacements of Mg from underlying strata of unlimed soil or subsoil; (e) the percolates from a soil fortified with either oxides or carbonates of magnesium will effect a replacement of Ca from underlying zones of either soil or subsoil; (f) additions of sodium nitrate effected slightly smaller releases of Ca and Mg than the reciprocal releases of Mg and Ca effected by additions of the nitrates of calcium or magnesium, (26) and (g) inputs of nitrate, chloride, and sulfate of potassium effected some releases of Ca and Mg (29).

The relationships cited in (d) to (g) conform to accepted principles of cation interchange. However, the first three relationships have been presented as exceptions to, or negations of, the rules of cation interchange. The repressive effect that calcic and magnesian liming exerts upon the release of other cations in the zone of incorporation has been attributed particularly to incidence of bicarbonate of Ca or Mg from residues of liming materials as such, or as Ca complexes, which function to preclude basic interchange (19, p. 496). It is important to observe that the phenomena of "reciprocal repression" is not limited to the relatively brief period during which rational-rate incorporations of Ca or Mg carbonate may continue as such or to the period of their decomposition in the soil system, since these phenomena are registered by the leaching long after the Ca or Mg has been fixed in the soil complex.

REPRESSIVE EFFECT OF CALCIC LIMING UPON OUTGO OF MAGNESIUM

In the present experiment the repressive effect of additive Ca upon Mg outgo was effected by 3 types of calcic materials, whereas repression upon outgo of K was induced by each of the 4 liming materials. The outgo from the incorporated dolomite affords a comparison as to Mg/Ca ratios that are affected by rate of incorporation in relation to supplies of Ca and Mg native to the soil. The outgo of magnesium from the burnt lime, limestone, and Ca-silicate incorporations was considerably below the outgo from the unlimed soil, as shown in table 12. Actual repressions were greater than those indicated, however, since all of the calcic materials carried increments of magnesium which may have boosted the Mg outgo to some extent. The averages for the 20-year leachings of Mg from the 4 single-rate incorporations of calcic material in the Tennessee soil were 1676 pounds for burnt lime, 1704 pounds for limestone, and 1909 pounds for the silicate, against 1775 pounds from the unlimed soil; whereas, corresponding values of 1667, 1669, and 1767 pounds were shown for the double-rate liming. The increase of 158 pounds for the single input of the silicate and no gain from double input

can be accounted for by respective increments of 264 pounds and 528 pounds of magnesium thru the dicalcium silicate incorporations. When allowance is made for the Mg content of the silicate, its calcium content of the single and double incorporations effected repressions in the outgo of magnesium of 106 pounds and 528 pounds. The inputs of magnesium through single-rate incorporations of burnt lime and limestone were 79 and 164 respectively. When corrections are applied for those 2 increments, the repressions in outgo of magnesium will be 178 pounds and 235 pounds for burnt lime and limestone, respectively, against corresponding repressions of 266 pounds and 434 pounds for the double limings.

After like corrections for the magnesium in the calcic materials, the 20-year leachings of Mg from the single inputs of lime, limestone, and silicate on the Virginia soil were 744, 727, and 766 pounds, respectively, against a control outgo of 879 pounds; whereas, the double-rate inputs of same calcic materials caused respective leachings of 725, 630, and 643 pounds of magnesium. Hence, the repressions upon outgo of Mg for the 20-year period for the respective calcic materials at single rate were 135, 152, and 113 pounds; and for the double rate, 154, 249, and 236 pounds, respectively. Such repressions appear to be somewhat greater in the Tennessee soil than in the Virginia soil.

REPRESSIVE EFFECT OF LIMING UPON OUTGO OF POTASSIUM

The potassium outgo is given by annual periods in tables IX and X, and with corrections for control outgo for quadrennial periods, in table 8. The unlimed Tennessee soil yielded 328 pounds of K during the 20 years, whereas leachings of 288, 288, 298, and 295 pounds came from the single-rate of liming for the burnt lime, limestone, dolomite, and calcium silicate, respectively. The corresponding leachings from the 4 double-rate limings were 241, 232, 252, and 275 pounds, respectively. Therefore, the average repression in outgo of K resultant from the single limings was 37 pounds, and that induced by the double limings was 74 pounds. As can be seen from the bottom line of each series in table 8, however, the repressive effect on K outgo was not sustained through the entire 20 years. In certain series of the Tennessee soil the repressive effect diminished with progress of time. It is also clear that some potassium release of K was effected in the lower unlimed zone of series F and series G of the Tennessee soil during the downward passage of the leachings from the limed upper zone, which is in accord with previous observations (23) under similar conditions.

The 20-year outgo of potassium from unlimed Virginia soil was 277 pounds, the average outgo from the single rate of liming was 239 pounds, and that from the double rate of liming, 222 pounds. The repression in outgo of K for the entire 20 years was 38 and 55

pounds for the single and double rates of liming, respectively. No particular pattern developed as to the influence of lime upon the extent of repression in K outgo, although the most significant repression seemed coincidental with the higher concentration of calcium or of Ca+Mg in the leachings. In accord with the behavior of the Tennessee soil, the Virginia soil also shows vanishing influence of liming upon the diminution in the outgo of K during the final 4 years of the 20-year experiment. The observed results are in accord with the previous observations as to the repressive effects of liming upon the occurrence of K in the free water of the soil (14, 17, 23, 29).

MAGNESIUM/CALCIUM OUTGO RATIOS, IN RELATION TO CONTENT OF THESE ELEMENTS IN THE SOIL

The leachability of adsorbed calcium and magnesium resultant from dolomite incorporations was considered as to the total and net outgo, and as to the Mg/Ca ratios as these were influenced by rate and zone of liming incorporation. Based on data of table 11, the ratios of Mg/Ca in the outgo appear in the following range: 0.66:1, 0.78:1, and 0.42:1 for the once-dolomited, twice-dolomited, and untreated series of the Tennessee soil, respectively; whereas, values for the corresponding series of the Virginia soil were: 0.82:1, 1.08:1, and 0.43:1, respectively. The fault with the foregoing expressions lies in the fact that they fail to establish any constant ratio and that unless the initial contents of the elements are taken into account, these values give an inaccurate impression as to relative rate of losses of Mg and Ca from the soil. The proper approach seemed to lie in a correlation of the Mg/Ca ratio, as of percentage outgo of the supplies of each element in the soil, rather than as of actual outgo. This could not be done on a 20-year basis, since the supplies of Ca and Mg in the soil vary with time, as is shown by figures 5 to 8. Computations of the percentages of Ca and Mg outgo upon the basis of annual balances of these elements in the controls and in 2 typically limed and 2 typically dolomited soils are given in tables 16 to 25.

A mere inspection of the outgo values "as percentage of supply" gives a clear indication that the soil's content of Mg is lost at a rate much faster than that of Ca. It was hoped, moreover, that computations of the annual percentage of Mg/Ca ratios might develop some constant relationship that otherwise would not become obvious because of fluctuations in absolute outgo and in percentage outgo from year to year. It should be noted that in the computations of the Mg/Ca ratios, as given in tables 16 to 25, the data were subjected to a severe test. The percentage outgo for the initial year was based upon the content of exchangeable Ca and Mg, as determined through extraction by means of ammonium acetate, plus rainwater increments, plus Ca and Mg added through a specific liming; and upon the quantities of the Ca and Mg outgo in the leachings for each annual period. Any error in the factors — Ca and

TABLE 17—Twenty-year annual balances of supply and outgo of Ca and Mg as m.e. per 100 grams of soil; outgo as percentages of supply, and Mg/Ca ratios of such outgo.

ONSLow FINE SANDY LOAM CONTROL

Years—	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg
	1		2		3		4		5	
In soil at beginning of each year.....	1.160	0.140	1.044	0.105	1.015	0.106	0.991	0.102	0.911	0.101
In rainwater increment during year.....	0.037	0.034	0.049	0.031	0.080	0.023	0.051	0.032	0.086	0.037
Total supply.....	1.197	0.174	1.093	0.136	1.095	0.134	1.042	0.134	0.997	0.138
Outgo in leaching during year.....	0.153	0.069	0.078	0.030	0.104	0.032	0.131	0.033	0.226	0.057
Outgo, in percentage of supply.....	12.8	40.0	7.2	22.0	9.4	24.0	12.6	24.6	22.6	42.0
Mg/Ca ratio of percentage outgo.....	3.1		3.1		2.6		2.0		1.9	
Years—	6		7		8		9		10	
In soil at beginning of each year.....	0.771	0.081	0.768	0.072	0.703	0.064	0.672	0.048	0.598	0.011
In rainwater increment during year.....	0.113	0.035	0.061	0.030	0.081	0.036	0.053	0.051	0.046	0.039
Total supply.....	0.884	0.116	0.829	0.102	0.784	0.100	0.725	0.099	0.644	0.050
Outgo in leaching during year.....	0.116	0.044	0.126	0.038	0.112	0.052	0.127	0.088	0.049	0.022
Outgo, in percentage of supply.....	13.1	38.0	15.2	37.2	14.3	52.0	17.5	88.0	7.6	44.0
Mg/Ca ratio of percentage outgo.....	2.9		2.5		3.6		5.0		5.8	
Years—	11		12		13		14		15	
In soil at beginning of each year.....	0.595	0.028	0.549	0.019	0.552	0.011	0.514	0.001	0.517	0.020
In rainwater increment during year.....	0.090	0.045	0.126	0.060	0.069	0.047	0.073	0.053	0.035	0.021
Total supply.....	0.685	0.073	0.675	0.079	0.621	0.058	0.587	0.052	0.552	0.041
Outgo in leaching during year.....	0.136	0.054	0.123	0.068	0.107	0.059	0.070	0.032	0.071	0.035
Outgo, in percentage of supply.....	20.0	74.0	18.2	86.0	17.2	10.0	12.0	61.5	12.9	85.4
Mg/Ca ratio of percentage outgo.....	3.7		4.7		5.9		5.1		6.6	
Years—	16		17		18		19		20	
In soil at beginning of each year.....	0.481	0.006	0.478	0.004	0.448	0.012	0.416	0.022	0.494	0.009
In rainwater increment during year.....	0.039	0.018	0.029	0.016	0.025	0.024	0.146	0.047	0.103	0.055
Total supply.....	0.520	0.024	0.507	0.020	0.473	0.012	0.562	0.025	0.597	0.046
Outgo in leaching during year.....	0.042	0.020	0.059	0.032	0.057	0.034	0.068	0.034	0.067	0.043
Outgo, in percentage of supply.....	8.1	83.3	11.6	1	---	---	---	---	---	---
Mg/Ca ratio of percentage outgo.....	10.0		---		---		---		0.530	
In soil at end of year.....									0.003	

¹Where the Mg outgo exceeded or was equal to the total supply, computations of percentage outgo for either Ca or Mg were considered useless from the standpoint of accuracy of result.

Mg content, rainwater increments, and leachate value — will affect the percentage outgo of each element for the year, and will also affect the Mg/Ca ratio for that year. An error in the analysis of Ca or of Mg in the rainwater, or in the leachates, for any year will distort all subsequent computations, since a given balance of the elements at the end of each year is taken as the initial content of Ca and Mg of the following year. Moreover, the lower the supply of an element in the soil, the more seriously both the percentage outgo, and the Mg/Ca ratio will be affected by a slight error in analysis. The Mg/Ca percentage ratios for the unlimed and the dolomited Tennessee soil are given in tables 16, 22, and 24, and graphically in figure 9A. The average of the 20 annual results for the control and the once-and twice-dolomited Cumberland soils are $1.82 \pm .18$, $1.88 \pm .16$, and $1.75 \pm .11$, respectively. The grand average Mg/Ca ratio of 60 annual values is $1.82 \pm .15$. The 3 Tennessee series represented in the plotted values of figure 9A, exhibit a wide range in degree of saturation and in ratios for exchangeable Mg/Ca content. The trend shown by distribution of experimental points in figure 9A fails to reveal any influence of degree of base saturation or Mg/Ca content ratio upon the percentage Mg/Ca outgo ratio of the Cumberland soil.

The percentage Mg/Ca outgo ratios of the Virginia soil are given in tables 17, 23, and 25, and graphically in figure 9B. Because of the wide scattering of experimental points, it is not possible to establish the Mg/Ca outgo ratio for the unlimed Onslow soil. The low content of bases, magnesium in particular, militates against analytical accuracy. The wide scattering of points after the 9th and 10th years is evident in figure 9B. In the 9th year the "total supply" of 99 pounds in the unlimed soil yielded an outgo of 88 pounds, which was unusually high in relation to the outgo of magnesium in previous years and also in relation to the outgo of Ca in the same year. This resulted in a high percentage Mg/Ca ratio for the year and also diminished the supply of Mg for the 10th year. Although the outgo of Mg in the 10th year did not appear abnormal, it was proportionately high, especially in relation to the percentage for Ca in that year, and resulted in a ratio of 5.8, the highest in 10 years. If the near-normal outgo of 44 pounds were assigned for the 9th year, the Mg/Ca ratio for that year would be 2.5 instead of 5.0, and the ratio for the 10th year would be 3.1 instead of 5.8. The foregoing is given as an example of how an unaccountable error in the results for one year will affect the true Mg/Ca outgo ratio of that year and distort subsequent results.

The enhancement in the content of Ca and Mg in the Virginia soil through dolomite incorporations resulted in some improvement in the distribution of the plotted values in figure 9B. Although these values are somewhat more scattered than those from the Tennessee soil (fig. 9A), they show a distinct trend for Mg/Ca outgo ratio. The greater number of points lies chiefly between 2.0 and 2.5. The average percentage Mg/Ca outgo ratio of 40 annual results

of the dolomited Virginia soil is 2.24. Again, as was shown for the Tennessee soil, the plotted values are free of any influence from variations in base-saturation degree or in the changing of Mg/Ca content ratio for the Virginia soil. The differences between the Mg/Ca percentage-outgo ratio of 1.82 from the Tennessee soil and that of 2.24 for the Virginia soil may be ascribed to difference in the types of adsorption complex. The adsorption complex in the Tennessee clay loam is mostly of kaolinitic type, whereas, that of Virginia fine sandy loam is of organic nature.

CORRELATION BETWEEN LYSIMETER FINDINGS AND PRESENT-DAY CONCEPTS OF CATION INTERCHANGE

In harmony with past findings, the results now reported registered a repression in the outgo of magnesium wherever a calcic material had been incorporated, and a diminution in the outgo of potassium wherever calcic and dolomitic limestones had been incorporated. We have also established Mg/Ca outgo constants for each soil upon the basis of outgo as percentage of content, rather than on straight outgo. The question now arises: Can the phenomena that are demonstrated by lysimeter results — those of

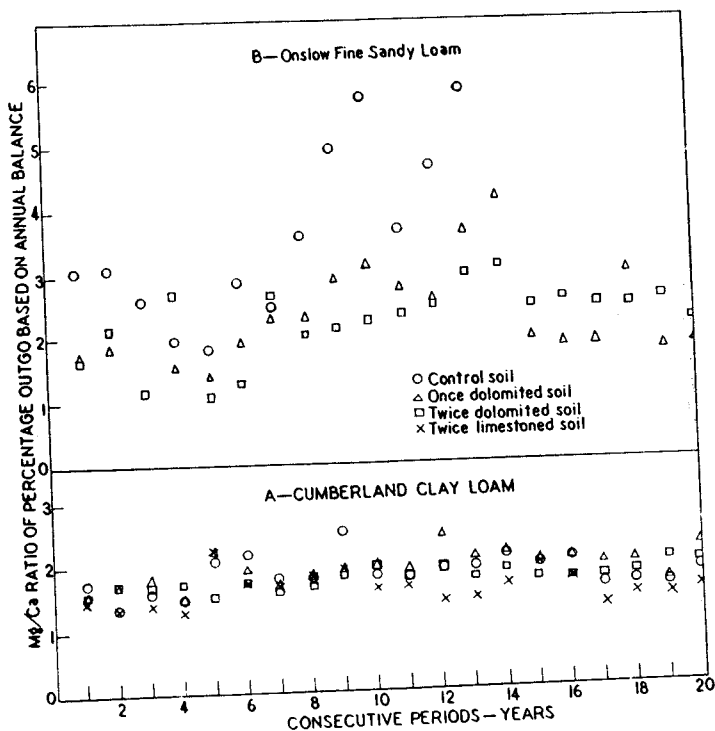


Fig. 9—Mg/Ca outgo ratios, as percentages of annually balanced supplies of these elements in the soil, from controls and dolomited soils: (A) Cumberland clay loam, (B) Onslow fine sandy loam. (Data taken from tables 16-25).

TABLE 19—Twenty-year annual balances of supply and outgo of Ca and Mg as m.e. per 100 grams of soil; outgo as percentages of supply, and Mg/Ca ratios of such outgo.

ONSLow FINE SANDY LOAM, LIMESTONED SERIES A

Years—	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg
	1		2		3		4		5	
In soil at beginning of each year	4.566	0.304	4.247	0.286	4.133	0.279	3.981	0.265	3.797	0.256
In rainwater increment during year	0.037	0.034	0.049	0.031	0.080	0.028	0.051	0.032	0.086	0.037
Total supply	4.603	0.338	4.296	0.317	4.213	0.307	4.032	0.297	3.883	0.293
Outgo in leaching during year	0.356	0.052	0.163	0.038	0.232	0.042	0.235	0.041	0.354	0.043
Outgo, in percentage of supply	7.7	15.4	3.8	12.0	5.5	13.7	5.8	13.8	9.1	14.7
Mg/Ca ratio of percentage outgo	2.0		3.4		2.5		2.3		1.6	
Years—	6		7		8		9		10	
In soil at beginning of each year	3.529	0.250	3.468	0.266	3.338	0.211	3.239	0.171	3.075	0.121
In rainwater increment during year	0.113	0.035	0.061	0.030	0.081	0.036	0.053	0.051	0.046	0.039
Total supply	3.642	0.285	3.529	0.296	3.419	0.247	3.292	0.222	3.121	0.160
Outgo in leaching during year	0.174	0.059	0.191	0.045	0.180	0.076	0.217	0.101	0.083	0.026
Outgo, in percentage of supply	4.8	20.7	5.4	17.6	5.3	30.8	6.6	45.4	2.7	16.2
Mg/Ca ratio of percentage outgo	2.2		3.3		5.8		6.1		6.9	
Years—	11		12		13		14		15	
In soil at beginning of each year	3.038	0.134	2.893	0.130	2.827	0.132	2.707	0.101	2.637	0.117
In rainwater increment during year	0.090	0.045	0.126	0.060	0.069	0.047	0.073	0.053	0.035	0.021
Total supply	3.128	0.179	3.019	0.190	2.896	0.179	2.780	0.154	2.672	0.138
Outgo in leaching during year	0.235	0.049	0.192	0.053	0.189	0.078	0.143	0.037	0.136	0.028
Outgo, in percentage of supply	7.5	27.4	6.4	30.5	6.5	43.6	5.1	24.0	5.1	20.3
Mg/Ca ratio of percentage outgo	3.6		4.7		6.7		4.8		4.0	
Years—	16		17		18		19		20	
In soil at beginning of each year	2.536	0.110	2.473	0.103	2.399	0.092	2.316	0.084	2.323	0.109
In rainwater increment during year	0.039	0.018	0.029	0.016	0.025	0.024	0.146	0.047	0.103	0.055
Total supply	2.575	0.128	2.502	0.119	2.424	0.116	2.462	0.131	2.426	0.164
Outgo in leaching during year	0.102	0.025	0.103	0.027	0.108	0.032	0.139	0.022	0.101	0.036
Outgo, in percentage of supply	4.0	19.5	4.1	22.7	4.5	27.6	5.6	16.8	4.2	22.0
Mg/Ca ratio of percentage outgo	4.9		5.5		6.1		3.0		5.2	
In soil at end of year									2.325	
									0.128	

"reciprocal repression" in particular — be reconciled with the accepted concepts in regard to cation interchange?

In the studies on base exchange in soils a neutral salt solution, usually an ammonium salt, has been employed in effecting interchange whereby the NH_4 ion replaces the adsorbed Ca-, Mg-, and K-ions. Theoretically, and also by experiment, it can be shown that solutions of $\text{Ca}(\text{NO}_3)_2$ and CaSO_4 will function in a similar manner. Since liming accelerates nitrification and sulfonation in the soil, the concept that liming serves to liberate potassium has long persisted and is still being taught, as shown by the citation from Lyon and Buckman (11, p. 358): "The liberation of mineral nutrients, particularly potassium, by the addition of lime is somewhat uncertain although it evidently must occur, at least to some extent." From their findings as to the effect of degree of saturation upon cation replaceability, Jenny and Ayers (10, p. 457) concluded that "As a matter of fact, neutralizing an acid soil with Ca should render K more available. . ." If that is true, how can we account for the multiple findings that separate incorporations of CaO , $\text{Ca}(\text{OH})_2$, MgO , MgCO_3 , $\text{Mg}(\text{OH})_2$, limestone, dolomite, and slag invariably cause a diminution in the potassium present in the rainwater leachings? And how can we account for the two parallels, that an input of an oxide or carbonate of calcium represses the outgo of magnesium and that an incorporated oxide or carbonate of magnesium induces a repression in the leachings of calcium.

Differentiating between direct chemical effects of added CaCO_3 in sterile soils and effects from such additions in normal soils, Jenny and Shade (7, p. 168) concluded ". . . that CaCO_3 incorporated in the soil indeed liberates adsorbed K which in turn — provided that conditions are favorable — may be readsorbed by micro-organisms, the activity of the latter apparently having become favored by the treatment." And they designated the repressive effect exerted by CaCO_3 upon outgo of K as an "abnormal" phenomenon.

As noted by Bray (2, p. 962), the conclusions drawn by Jenny and Ayers are contrary to the principles of complementary ion effects upon cation exchangeability, as developed by Jenny and Ayers (10), and as expressed by Bray, namely, that ". . . the substitution of calcium for hydrogen on a clay colloid, as is accomplished by liming, will decrease the relative release of the other ions. . ." In reference to findings of Jenny and Ayers through CO_2 -water extractions of K from a K-H system, Bray conceded that "It is unsafe to predict what the final over-all effect will be under soil conditions where factors outside the ones included in the laboratory experiment are present." The experiments reported by Jenny and Ayers do not warrant their conclusion that "neutralizing an acid soil with Ca should render K more available." Their studies included such systems as K-Na, K- NH_4 , K-H, and K-Ca, but the system that would bear most directly on the problem, namely, that of Ca-H, which would also provide for a natural level or levels of K-saturation,

was not considered. In the humid regions where liming is a major problem, the exchangeable cations are made up mostly of hydrogen and Ca, with minor proportions of K and Mg. The problem then is, How will the availability or replaceability of the normal supplies of K and Mg be affected by the drainage waters after various degrees of hydrogen replacement are effected through liming? Jenny and Ayers maintained a constant quantity of K-clay in their K-Ca systems and varied the ratios of K/Ca by means of increasing additions of Ca-clay to the system, whereas the HCl that provided the replacing H-ion was maintained constant in equivalence of the K content in the entire series. Although this procedure satisfied the ratio requirement, yet through the increase in the quantity of clay with decreasing K-saturation, the effect was as if a clay constant were treated with varying quantities of replacing H-ions. As pointed out by Wiklander (38, p. 126) "Consequently such an experimental method cannot answer the question whether a diminishing degree of saturation also implies decreasing exchangeability or not." Moreover, such an experimental procedure does not conform to the natural chemical and biochemical processes that operate with regularity in the soil adsorption complex irrespective of small changes in K/Ca ratio. Seatz and Winters (34) studied the release of K from a number of Tennessee soils at varying Ca-H proportion in systems to which K was added at 3 rates. They found more K released from the Ca-soil than from the hydrogen soil. However, they concluded that their findings are not in conflict with the findings obtained in lysimeter studies, since "... the ionic concentration of the replacing solution, natural carbonated rainwater, is of an entirely different order of magnitude than the replacing solutions used in the laboratory. . ." Peech and Bradfield (32, p. 46) accorded qualified support to the conclusions arrived at by Jenny and Shade in stating that "In the absence of neutral salts, the addition of lime will invariably liberate the adsorbed potassium. . ." But they also noted that lime will effect a decrease of the potassium in soil solution after the addition of KCl, and that this should be equally valid for soils devoid of additive KCl, provided the soils contain neutral salts. They made no reference to the postulate relative to micro-organic fixation of released K. No satisfactory explanation has been advanced to account for repeatedly observed repression registered by the lysimeter leachings of K from either that native or that added to soils limed with any calcic, magnesian, or dolomitic material, and the corollary findings that liming decreases the uptake of K by plants, and that the liming of a soil usually requires a supplemental input of potassium for various non-legumes.

Indeed, Bray, as well as Jenny and Ayers, could have derived substantial support for their theoretical deductions in regard to replaceability of a particular ion under natural soil conditions in the findings embodied in papers based on the lysimeter experiments on liming at the Tennessee Station during the past 35 years. Conversely, it is believed that the long-time observations of repression

TABLE 20—Twenty-year annual balances of supply and outgo of Ca and Mg as m.e. per 100 grams of soil; outgo as percentages of supply, and Mg/Ca ratios of such outgo.

CUMBERLAND CLAY LOAM, LIMESTONED SERIES B

	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg
Years—	1		2		3		4		5	
In soil at beginning of each year	7.006	1.284	6.456	1.189	5.706	1.084	5.262	1.001	8.207	1.083
In rainwater increment during year	0.060	0.088	0.195	0.124	0.074	0.066	0.088	0.064	0.115	0.029
Total supply	7.066	1.372	6.651	1.313	5.780	1.150	5.350	1.065	8.322	1.112
Outgo in leaching during year	0.610	0.183	0.945	0.229	0.518	0.149	0.549	0.146	0.909	0.169
Outgo, in percentage of supply	8.6	13.3	14.2	17.4	9.0	13.0	10.3	13.7	10.9	15.2
Mg/Ca ratio of percentage outgo	1.55		1.23		1.44		1.33		1.40	
Years—	6		7		8		9		10	
In soil at beginning of each year	7.413	0.943	7.091	0.911	6.892	0.913	6.618	0.884	6.378	0.853
In rainwater increment during year	0.115	0.029	0.150	0.059	0.101	0.033	0.132	0.062	0.109	0.043
Total supply	7.528	0.972	7.241	0.970	6.993	0.946	6.750	0.946	6.487	0.896
Outgo in leaching during year	0.437	0.061	0.549	0.057	0.375	0.062	0.372	0.093	0.217	0.038
Outgo, in percentage of supply	5.8	6.3	4.8	5.9	5.4	6.6	5.5	9.8	3.3	4.2
Mg/Ca ratio of percentage outgo	1.10		1.23		1.22		1.80		1.24	
Years—	11		12		13		14		15	
In soil at beginning of each year	6.270	0.858	6.100	0.841	5.923	0.818	5.773	0.799	5.676	0.805
In rainwater increment during year	0.122	0.037	0.157	0.030	0.128	0.025	0.145	0.050	0.124	0.037
Total supply	6.392	0.895	6.257	0.871	6.051	0.843	5.918	0.849	5.800	0.842
Outgo in leaching during year	0.292	0.054	0.334	0.053	0.278	0.044	0.242	0.044	0.227	0.053
Outgo, in percentage of supply	4.6	6.0	5.3	6.1	4.6	5.2	4.0	5.2	3.9	6.3
Mg/Ca ratio of percentage outgo	1.30		1.15		1.13		1.33		1.61	
Years—	16		17		18		19		20	
In soil at beginning of each year	5.573	0.789	5.524	0.791	5.474	0.785	5.403	0.777	5.321	0.763
In rainwater increment during year	0.102	0.032	0.124	0.022	0.128	0.026	0.145	0.030	0.139	0.027
Total supply	5.675	0.821	5.648	0.813	5.602	0.811	5.548	0.807	5.460	0.790
Outgo in leaching during year	0.151	0.030	0.174	0.028	0.199	0.034	0.227	0.044	0.239	0.039
Outgo, in percentage of supply	2.7	3.7	3.1	3.4	3.6	4.2	4.1	5.5	4.4	4.9
Mg/Ca ratio of percentage outgo	1.31		1.10		1.17		1.34		1.10	
In soil at end of year									5.221	0.751

in Mg and K outgo of Mg and K induced by calcic liming may be explained readily through proper application of modern concepts of complementary ion effects upon cation interchange. To establish even a qualitative relationship between the observed effect of liming and the known exchange properties of Ca- and H-ions, it will be necessary to take into consideration some of the facts regarding cation interchange, especially as they apply to replacements by addition of a small quantity of electrolyte:

(a) When a soil is suspended in neutral salt solutions containing equivalent quantities of Na, K, Ca, and Mg, it will be found that these cations possess different capacities to replace the soil hydrogen; their relative replacing powers show the following order: $\text{Ca} > \text{Mg} > \text{K} > \text{Na}$. Since the quantities of cation exchanged will be governed by the type of adsorbed ion, the type of colloid, and the concentration of the replacing electrolyte, Jenny and Reitemeier (8) proposed the use of "symmetry value" as a quantitative expression for the relative replacing powers of the several cations in relation to a Ca-clay. They defined "symmetry value" as "the magnitude of exchange expressed in percentage for the symmetry concentration equal to one" (8, p. 593). The symmetry concentration was further defined as the concentration of the replacing electrolyte in which the number of ions added is made equal to the number of exchangeable ions in the colloid. According to Gieseking and Jenny (4), the symmetry values for a number of cations are as follows: Ba=52.96, Ca=50, Mg=47.53, Na=12.74, K=28.80, NH_4 =29.35, and H=77.80. These values serve as measures of the relative intensities of exchange adsorption of the several cations in competition with calcium ions on a Putnam clay colloid.

As indicated earlier, Bray (2) made use of the opposite property of cations — their relative tendencies to free themselves from the colloid and enter into solution — and designated this property as "relative ease of release." For the several cations, Bray gave the following ease of release, or f-values: $f\text{K}=2.2$, $f\text{Mg}=1.6$, $f\text{Ca}=1$, and $f\text{H}=0.35$.

(b) The relative ease of release of an adsorbed ion will be affected by the nature of the complementary ion; that is, an adsorbed ion which presently is not considered in the release. When K is chosen as the ion to be released, the extent of its release by a relatively low concentration of an electrolyte will be influenced by the type of the other adsorbed ions; that is, whether these are mostly H, Ca, or Mg. Through his equations, Bray established several generalizations, of which the following is most important for the present objective: "When a cation of a lower f-value has been replaced by one with a higher f-value, the proportionate release of the other cations present on the colloid will be decreased" (2).

A NEW CONCEPT OF THE LYSIMETER SOIL AS AN INTERCHANGE SYSTEM

For a proper integration between lysimeter findings and the principles of ionic exchange, it is necessary to recognize the functional parts of a lysimeter system that correspond to the essential elements of a cation replacement system. In an ion-exchange system we recognize the following parts: (a) the "exchanger"—the adsorption complex, (b) the adsorbed cations, which may be either hydrogen or metal cations, singly or jointly, and (c) the electrolyte that supplies the replacing cation. In the lysimeter system, the soil is the exchanger and generally consists of a mixture of organic and inorganic colloids. The adsorbed cations are chiefly H and Ca, with small proportions of Mg and K. It remains to be determined what constitutes the replacing electrolyte in the lysimeter system. This is a matter of prime importance, since upon it will depend the acceptance or rejection of "reciprocal repression" as a normal consequence of cation exchange. Admittedly, rainwater charged with atmospheric CO_2 and carrying minute quantities of nitrates and sulfates is the universal replacing electrolyte in natural soil systems. It is a fact, however, that relatively pure water possesses limited capacity to effect cation-replacement, as can be demonstrated by the low values obtained through the leaching of a Ca-soil with distilled water, and by the low electrolyte content of lysimeter leachings that come through during the winter months. The replacing power of the rainwater is an acquired property, which it gains during its contact with the soil. Relatively high concentrations of nitrate, sulfate, and bicarbonate are acquired by the soil waters after the rainwater has entered the soil system. The rapidity with which the electrolytes will be acquired is governed by the organic-matter content and general fertility of the soil, and by seasonal temperature and moisture conditions. It is important to recognize the fact that only relatively meager quantities of electrolytes have reached the soil as components of rainwaters, and that the solutes of $\text{Ca}(\text{HCO}_3)_2$, $\text{Ca}(\text{NO}_3)_2$, and CaSO_4 in the soil systems were generated through nitrification and sulfonation within the soil. The cations of Ca and Mg found in the soil solution are pictured here not as the attacking or replacing ions in the zone of their formation, but as the products of the exchange with hydrogen of the biologically engendered HNO_3 , H_2SO_4 , and H_2CO_3 acids. This hydrogen exchange is viewed as taking place whether the soil is acidic or has been neutralized through liming. The only difference between the two systems is that in the limed soil the nitrification is promoted by the continual exchange of H-ions for the Ca-ions in the soil complex, whereas, in the soil of low Ca-content the H-ions, not finding enough Ca or Mg for interchange, produce a harmful accumulation of H-ions in the soil. In this particular respect, the rainwaters function, first, to supply proper moisture conditions for biological activities in the soil, and, second, to dilute or leach away the accumulations of the biochemical end-products, so that the cycle of hydrogen interchange may repeat itself.

In view of the above-described concept of cation interchange, the removal of bases from a biologically active soil through rain-water leachings may be considered as comparable to the processes of intermittent extractions with relatively minute quantities of a mixture of HNO_3 , H_2SO_4 , and H_2CO_3 acids — conditions essentially the same as those observed by Bray in the previously described experiments. If that be true, the generalizations presented by Bray, upon the basis of his investigation as to the effect of complementary ions, should also apply to the cation interrelationships in lysimeter leaching as affected by liming.

Jenny and Ayers (10) and Bray (2) have arrived at the same conclusion as to theoretical effect of the kind of complementary ion upon the exchangeability of other ions on the exchange complex. These conclusions are to the effect that where a cation with a lower f-value is replaced by one with a higher f-value, the proportionate release of the other cations present on the colloid will be decreased. If we take the cation substitutions as applying to Ca for H, then the outgo of the "other ions" could be made to apply to the outgo of K. It is obvious that liming results in the substitution of Ca-ions, or of Ca-and Mg-ions, for H-ions, on the soil colloid; and by both the "symmetry value" ($\text{Ca}=50$, $\text{H}=77.80$) and the "relative ease of release" concepts ($\text{Ca}=1$, $\text{H}=0.35$), the Ca-ion is regarded as being held more loosely than the H-ion on the colloid. Moreover, Bray's conclusion that "... the substitution of calcium for hydrogen on a clay colloid, as is accomplished by liming, will decrease the relative release of the other ions..." which, as above deduced, could be either K or Mg, is in accord with Bray's theoretical deductions, as well as with those of Jenny and Ayers. Although the cited conclusions were derived from laboratory experiments and based on theoretical considerations of cation exchange, they are substantiated through their integration with the lysimeter findings conducted at the Tennessee Experiment Station since 1914 and through the 20-year findings at the Virginia Station. Through acceptance of the concept of a lysimeter soil as a *cation interchange system, with internally generated H-ions as the prime replacing cation*, all the previously observed phenomena that were registered by the lysimeter experiments become logical deductions of the accepted theories of cation interchange.

The repression in the outgo of magnesium from the calcic lime incorporations is explainable through the reasoning relative to the analogous effect on K outgo. When Mg is taken for Ca as complementary ion, the repressive effect on the outgo of Ca and of K can be explained in like manner. The previously reported instances of interchange by lysimeter leachings in the underlying strata of unlimed soil or subsoil represent a normal consequence of the leaching of neutral solutes of either Ca or Mg from the zone of their formation down into unlimed zones.

Besides applying the principles of cation interchange to present findings for lysimeter leachings, we found it possible to establish

definite and constant Mg/Ca outgo ratios from each experimental soil. These ratios, given in tables 16 to 25, and in figure 9, correspond to the f-value established by Bray by a single equilibration with a small quantity of HCl. The present results and computations are believed to represent the first observations of Mg and Ca releases and ratios where supply and outgo were controlled under natural conditions of exposure during a period of 20 years.

SUMMARY

This bulletin presents findings obtained in parallel at the Tennessee and Virginia Experiment Stations in a 20-year lysimeter study of the fate of, and effects induced by, equivalent quantities of burnt lime, limestone, dolomite, and dicalcium silicate in a Cumberland clay loam at Knoxville, and in an Onslow fine sandy loam at Blacksburg. The two soils had respective exchange capacities of 10 m. e. and 5.4 m. e. and their base saturations were 50 percent and 26 percent, respectively. Every integral-rate incorporation was equivalent to 2000 pounds of CaO, or 3570 pounds of CaCO_3 , per 2,000,000 pounds of soil, in lysimeters of 1/20,000 acre, each of which contained 100 pounds of soil, moisture-free basis. The experiment comprised seven 4-unit series, A to G and had as its objective the determination of the differential outgo, or conservation of Ca and Mg and other nutrient elements, as the result of the following essential variants of liming practices:

- (a) Type of liming material
- (b) Zone of incorporation
- (c) Integral quadrennial incorporations versus 4 fractional incorporations.
- (d) Repeated quadrennial incorporations versus 8 fractional incorporations

The occurrences of Ca, Mg, K, nitrate, sulfate, and bicarbonate in the rainwater leachings were determined and presented in tabulations for annual outgo and respective 20-year totals for 28 liming treatments, for 2 soil controls, and for rainwater collections at both Stations. Summaries are given for the 5 quadrennial periods, and certain relationships not readily apparent from the basic data are presented in special tables and graphs. Throughout the text, the values for Ca, for Mg, and for Ca+Mg are expressed in pounds of CaCO_3 per 2,000,000 pounds of soil.

The annual rainfalls at the Tennessee and Virginia Stations for the 20-year experimental period were 48.23 and 36.38 inches, respectively, whereas corresponding percolations were from 43 to 50 percent of the rainfall at Knoxville and from 40 to 60 percent at Blacksburg. In general, over-all rainfall governs the extent of nutrient outgo, although seasonal distribution may become the dominant factor.

The relative effectiveness of the 4 liming materials was on the basis of 20-year outgo of Ca+Mg as averages of series A, B, and C. The burnt lime and limestone proved of equal effectiveness in each soil. The outgo from the dolomite incorporation in each soil exceeded somewhat the outgo from the 2 calcic materials, whereas the outgo of Ca+Mg from the dicalcium silicate was appreciably less, particularly that from the Onslow soil.

The incorporation of the liming materials in the upper third of of the 2 soils resulted in an over-all conservation of 20 percent of input in comparison with full-depth incorporation. This conservation was effected largely during the initial 8 years of the experiment and was paralleled by a lesser outgo of nitrates.

Although outgo of Ca+Mg induced by annual fractional-rate limings was less than such outgo from the integral incorporation in the Tennessee soil during the first 4-years, and during the first 8 years in the Virginia soil, larger outgo from this mode of lime application during the later years served to equalize the outgo for the 20-year period.

The second integral incorporation was made in the 5th year and caused a 1500-pound increase in the outgo of Ca+Mg over that from the single incorporation of the Tennessee soil, as an average for the 4 liming materials during the subsequent 16 years. The corresponding increase resultant from the additional integral incorporation in the Virginia soil was as large as that from the Tennessee soil, but the increase in outgo from the 8 fractional incorporations of series E, as compared with that from 4 such incorporations in series D, was smaller, only 1165 pounds of Ca+Mg.

Rates of outgo of Ca and Mg from incorporations of dolomite were influenced by the quantities and forms of the native supplies of these elements in the soil. The 20-year totals for outgo of Ca and Mg from the dolomite in series A of the Tennessee soil were 4829 pounds for calcium and 3194 pounds for magnesium. The corresponding totals for the Virginia soil were 2582 pounds for calcium and 2111 pounds for magnesium. The Mg/Ca ratios in total outgo from single incorporations of dolomite in the Tennessee and Virginia soil were 0.55:1 and 0.82:1, respectively. The repeated integral incorporation of dolomite in the Tennessee soil resulted in proportionately greater increase in Mg than Ca outgo. As of total outgo, the calcium ions in the leachings still exceeded the Mg ions. The repeated incorporation of dolomite in the Virginia soil caused a 10-percent increase in the total for Mg outgo over the total for Ca outgo. As noted, the Mg/Ca ratio is influenced by soil reserves of these elements, by rate of dolomite incorporations, and by duration of the experiment.

The final status of the experimental soil, after 20-year lysimeter exposure, with regard to the several nutrient elements was determined by balancing of outgo against the several sources of intake. As compared with its original status, the unlimed Tennes-

see soil had suffered a net loss of 1700 pounds of Ca and 861 pounds of Mg. The corresponding net losses from the soils which received one integral of calcic lime, average of A and D, were 160 pounds of Ca and 682 pounds of Mg. From soils with double incorporations of those calcic materials, there was a 1735-pound gain of Ca and a 471-pound loss of Mg, as averages of series B, C, and E. The once-dolomited Tennessee soils showed a net gain of 431 pounds of Ca and a net loss of 568 pounds of Mg from series A, whereas the double incorporations of dolomite induced net gains of 802 pounds of Ca and 102 pounds of Mg, as averages for series B, C, and E.

The unlimed Virginia soil lost 624 pounds of its original Ca content and all exchangeable Mg content. In the soils with single calcic liming, averages of A and D, there was a 1114-pound gain of Ca and a 103-pound loss of Mg. In the soils with double calcic liming, averages of B, C, and E, there were gains of 3182 pounds of Ca and 82 pounds of Mg. The Virginia soils with single dolomite incorporation, averages of series A and D showed gains of 666 pounds of Ca and 182 pounds of Mg. The soils which had received 2 dolomite incorporations, averages of B, C, and E, showed gains of 2131 pounds of Ca and 909 pounds of Mg.

The net losses of N from the Tennessee soil were 676, 801, 726, and 864 pounds, as respective averages for the unlimed soil and for series A, F, and B, against respective net losses of 421, 551, and 584 as averages for the unlimed Virginia soil and its limed series A and B. The losses of sulfur from the Tennessee soil were 56, 93, and 138 pounds, as averages for the unlimed soil and its series A and B, respectively; whereas, the losses of sulfur from the Virginia soil were 27 and 53 pounds, as respective averages for the unlimed soil and all of the liming incorporations.

The rates of depletion during the 20-year period of Ca and Mg from the controls and from certain limed and dolomited series are shown graphically in figures 5 to 8. The net loss of calcium from the Tennessee soil was highest in the initial 4 years and dropped rapidly during the succession of 4-year periods, whereas the loss of calcium from the Virginia soil began at a moderate rate and decreased gradually. Although the degree of Ca-saturation was a factor, it alone did not account for the decrease in the rate of Ca outgo from the Tennessee soil. The slow-down of microbiological activities in the soil because of the depletion of the most readily decomposable fraction of organic matter of that soil is suggested as a plausible explanation for decreased cation outgo.

The proportions of nitrate, sulfate, and bicarbonate ions were computed in relation to total cation loss from the unlimed soil, in relation to additional Ca losses induced through liming, and in relation to time. Nitrate outgo accounted for 87 percent of net loss of cations from the unlimed Tennessee soil, and the other 13 percent was due equally to sulphates and bicarbonates. The net loss of

nitrate from the unlimed Virginia soil was equivalent to 186 percent of the computed net loss of cations. In the actual outgo from the 2 controls, the proportion of nitrate was much smaller because of the higher proportion of cations contributed by the rainwater. The increases in the outgo of Ca from the single and double incorporations of the liming materials, over those from the controls, were only partly balanced by increases in the outgo of nitrates, and from 70 to 90 percent of such increases were accounted for as bicarbonate.

The 20-year net loss of N from the unlimed Tennessee soil showed a distribution through the 5 successive 4-year periods of 55, 29, 13, 3, and 0 percent of that loss. The Tennessee soil still contained 77 percent of its original nitrogen content after nitrate outgo had ceased. The net losses of N from the unlimed, once-limestoned, and twice-limestoned Virginia soil were 421, 542, and 510 pounds, respectively. The progression in the losses was more uniform; 22 percent occurred during each 4-year interval of the first 4 quadrennial periods and 12 percent during the final period, without evidence of effects from liming.

Under "Cation Interrelationship", the subject of cation interchange and the observed phenomena "reciprocal repression" were reviewed. The present findings substantiated previous observations as to the repression that limestone incorporations exert upon the leaching of magnesium and as to the repression that incorporations of both calcic and dolomitic limestone exert upon the outgo of potassium. The repressions in Mg outgo from one integral incorporation of burnt lime, and of limestone in the Tennessee soil effected respective repressions of 178 pounds and 235 pounds in the outgo of magnesium, whereas corresponding repressions induced by the double inputs of lime and of limestone were 266 pounds and 434 pounds. The repression in outgo of magnesium from the Virginia soil were 135 and 152 pounds from integral full-depth inputs of lime and limestone, respectively, and 154 pounds and 249 pounds from the corresponding double incorporations. As an average for all limings of the Tennessee soil, the repressions in outgo of K were 37 pounds from the single-rate incorporations and 74 pounds from the double-rate, whereas corresponding averages for the repressions exerted by all single-rate and double-rate limings in the Virginia soil amounted to 38 pounds and 55 pounds of K, respectively.

Neither total outgo nor net outgo exhibited any constant relationship for losses of Ca and Mg, as an effect of variation in the type of liming materials. A fairly constant ratio of Mg/Ca outgo was obtained, however, when the annual outgo of Ca and Mg was expressed as percentages of the supply of each element in the soil during that interval. As a grand average of 60 pairs of values for the Tennessee soil, a Mg/Ca outgo ratio of 1.82 was obtained which held true for the outgo from the unlimed soils and for the

outgo from the several limestoned and dolomited series. The Mg/Ca outgo ratio for the Virginia control soil, because of low magnesium content, was not so well defined. The average of 40 values for outgo from the dolomited Virginia soil gave a Mg/Ca outgo ratio of 2.24. These Mg/Ca outgo ratios demonstrate that the Mg-ion is released more readily than the Ca-ion from both the Tennessee and the Virginia soils. The above-determined ratios are similar in character to Bray's f-Mg values, except that our values were based on leachings under natural conditions of 20-year duration.

An analogy was drawn between the functional parts of a lysimeter soil and those of cation interchange system in the laboratory, with a view to reconciling the apparent inconsistencies between the "repressive effects" registered by lysimeter leachings and the expected enhancements in outgo according to the principles of cation interchange. It is believed that the proper recognition of what constitutes the replacing agent in the lysimeter soil system holds the key to the correct interpretations of lysimeter leaching results. The soil and its adsorbed cations of H, Ca, Mg, etc. are readily recognizable as the 2 of the 3 functional parts in the lysimeter system. The replacing electrolyte, which is the subject of a new concept, is presented as consisting primarily of the hydrogen generated within the soil as a result of biochemical activities. According to this new concept, the bicarbonates, nitrates, and sulfates of calcium that are formed in the limed soils should not be regarded as a replacing agent which has the power to liberate other cations from the soil. Rather, the Ca-, Mg-, and K-ions in the soil solution of the limed zone, as well as in the unlimed soil, are to be regarded as the "products" of an exchange with the biochemically generated hydrogen ions, each under its respective cation combination. When this concept of hydrogen as the prime replacing cation is integrated with the principle of complementary ion effect, as enunciated by Jenny and Ayers (10) and by Bray (2), the replacement of hydrogen by calcium as is accomplished by liming should decrease the replaceability of K and Mg in the zone of liming. The present interpretations of the leaching data from the Tennessee and Virginia Stations warrant the new concept which brings into accord the phenomena of "reciprocal repression" in outgo with the fundamental rules of cation interchange.

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APPENDIX¹TABLE I—*Rainfall and annual percolation volumes from the variously limed Cumberland clay loam at Knoxville.*

Experimental series	Liming material	Kilograms per lysimeter in successive annual periods																				20-Year
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
A	Burnt lime	75	121	161	133	160	108	87	139	134	107	159	168	118	132	155	82	68	96	149	100	2453
	Limestone	74	120	158	134	165	120	89	144	140	111	160	171	122	136	166	85	71	98	154	104	2514
	Dolomite	74	124	158	133	166	114	93	146	140	110	158	172	121	134	163	84	70	98	154	105	2515
	Dica-silicate	75	121	164	133	164	113	91	145	138	109	158	165	118	132	164	84	70	97	158	106	2507
B	Burnt lime	74	121	159	128	163	110	89	139	134	109	164	167	119	132	163	84	70	97	155	105	2488
	Limestone	72	118	155	128	159	109	88	138	131	105	159	166	118	130	160	81	67	95	150	103	2430
	Dolomite	72	123	163	132	182	119	104	149	140	116	168	176	121	143	166	88	73	98	159	98	2587
	Dica-silicate	77	128	164	134	188	121	106	154	143	120	180	178	122	147	154	97	74	98	162	109	2656
C	Burnt lime	73	119	160	129	166	108	81	122	132	99	150	161	108	115	150	70	58	88	144	98	2330
	Limestone	75	119	159	128	168	105	80	121	130	95	138	162	110	119	156	72	60	90	143	92	2323
	Dolomite	74	120	161	128	170	110	86	130	134	101	161	165	113	125	157	76	57	92	142	95	2398
	Dica-silicate	74	123	160	131	178	113	90	131	133	102	150	164	107	122	158	75	64	94	141	99	2409
D	Burnt lime	74	113	157	140	188	118	92	146	139	106	156	172	119	130	162	79	68	94	150	103	2506
	Limestone	76	119	159	131	182	115	87	142	137	105	151	165	116	126	161	76	65	94	145	100	2450
	Dolomite	73	118	160	136	185	120	96	148	146	110	157	169	116	128	157	82	66	88	139	102	2497
	Dica-silicate	74	113	155	129	185	120	96	136	139	106	160	169	114	125	158	78	63	94	146	99	2457
E	Burnt lime	76	117	156	130	180	115	94	136	139	109	166	172	115	127	155	73	62	94	147	95	2460
	Limestone	71	114	167	128	189	122	105	148	143	119	180	180	118	129	162	77	66	95	153	98	2555
	Dolomite	72	115	154	133	178	117	98	140	140	111	159	170	120	131	157	81	67	96	155	101	2495
	Dica-silicate	76	116	157	136	186	120	102	142	141	114	167	175	122	137	165	82	70	97	160	106	2568
F	Burnt lime	74	118	159	136	177	117	98	150	146	109	162	169	122	141	170	86	72	99	159	107	2572
	Limestone	74	121	159	134	175	113	88	146	143	112	168	172	121	136	169	85	68	99	157	104	2544
	Dolomite	73	117	159	132	174	115	100	151	141	108	163	171	121	134	166	84	70	98	152	101	2530
	Dica-silicate	70	117	158	130	174	115	92	136	141	105	158	163	124	135	166	83	70	98	150	104	2490
G	Burnt lime	69	116	155	128	168	114	86	138	134	107	164	165	119	131	162	83	68	96	151	103	2456
	Limestone	75	121	159	131	171	115	95	143	139	108	160	167	120	132	163	82	68	96	150	103	2499
	Dolomite	77	120	156	132	176	115	91	146	139	112	167	170	122	135	165	85	70	98	153	105	2534
	Dica-silicate	73	112	155	127	172	114	89	143	136	109	163	165	118	132	164	82	69	97	151	100	2467
Control	None	72	114	155	124	147	100	76	138	139	96	133	157	109	119	153	73	61	86	138	93	2283
	None	78	122	161	135	172	117	88	136	140	106	158	167	123	135	165	83	70	98	156	101	2512
Rainwater		160	271	286	295	316	155	186	224	206	255	279	268	227	284	308	188	173	240	232	227	4782
Rainfall, inches		31	53	56	57	62	30	36	44	58	49	58	49	49	57	58	39	36	46	58	40	964

¹The data given in tables I to XIV represent the compilation of original analytical results from both Stations, and were used as the basis for computations in many of the tables presented throughout the text. Because these data were double-checked, they will make possible the verification of any values that may be questioned, or the evaluation of relationships not given in this bulletin.

TABLE II—*Rainfall and annual percolation volumes from the Onslow fine sandy loam at Blacksburg.*

Experimental series	Liming material	Kilograms per lysimeter in successive annual periods																			20-Year	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
A	Burnt lime	63	48	95	69	108	74	58	95	108	50	114	105	106	123	80	60	63	81	109	69	1678
	Limestone	59	46	93	69	108	74	58	97	108	50	115	105	103	122	80	60	63	79	107	69	1663
	Dolomite	63	47	98	69	108	74	57	97	112	51	116	110	110	125	87	63	67	84	109	70	1715
	Dica-silicate	64	49	94	69	108	74	58	93	109	49	116	95	95	121	70	59	64	69	106	69	1631
B	Burnt lime	67	47	96	69	108	74	58	96	107	49	112	104	103	122	80	61	66	78	107	70	1674
	Limestone	60	47	94	68	108	74	57	97	111	50	114	108	107	126	81	63	66	85	109	70	1693
	Dolomite	60	45	98	67	108	74	61	98	112	49	114	107	105	126	82	64	66	81	108	70	1696
	Dica-silicate	60	44	96	68	108	74	58	96	109	50	113	103	102	123	82	60	65	82	108	70	1671
C	Burnt lime	60	45	97	68	108	74	58	96	108	50	115	104	104	124	84	63	65	83	108	70	1684
	Limestone	65	46	97	67	108	74	58	95	109	50	114	105	104	125	83	64	66	86	109	70	1693
	Dolomite	64	48	98	68	109	74	58	97	113	50	113	107	106	127	83	63	69	89	109	70	1713
	Dica-silicate	58	48	97	69	108	74	58	95	110	51	112	106	106	128	84	63	67	89	109	70	1701
D	Burnt lime	62	52	97	68	109	74	58	97	114	51	114	106	106	127	84	62	66	88	107	70	1710
	Limestone	60	50	98	68	108	74	58	95	110	51	116	106	106	127	84	63	66	88	107	70	1706
	Dolomite	63	50	97	68	108	74	58	96	108	50	114	106	104	121	77	62	62	85	102	70	1676
	Dica-silicate	64	51	97	67	108	74	58	96	109	50	111	105	103	121	77	62	63	86	101	70	1672
E	Burnt lime	62	43	95	68	108	73	58	91	108	50	111	104	102	121	76	62	62	85	106	70	1657
	Limestone	58	45	97	67	108	74	58	92	102	51	112	100	101	119	74	61	61	75	103	69	1626
	Dolomite	59	44	96	68	108	74	58	92	103	50	112	103	100	120	74	60	62	76	106	69	1636
	Dica-silicate	62	45	97	67	108	74	58	92	102	51	113	101	100	120	77	61	61	75	100	69	1632
F	Burnt lime	57	43	97	66	108	73	58	89	102	51	110	100	98	119	72	56	60	69	95	69	1591
	Limestone	58	44	96	67	108	74	58	89	102	52	113	100	99	118	71	60	67	95	69	69	1596
	Dolomite	58	43	95	67	108	74	58	90	103	51	113	101	101	118	70	60	60	68	97	68	1600
	Dica-silicate	59	44	92	67	107	74	58	90	104	51	110	102	100	118	72	57	63	64	94	69	1596
G	Burnt lime	59	44	98	67	106	74	58	91	102	51	109	101	95	118	74	57	59	66	94	69	1589
	Limestone	55	40	92	66	107	74	58	92	104	49	110	100	101	117	75	57	58	64	97	69	1585
	Dolomite	58	40	95	67	107	74	58	92	102	51	109	100	99	119	73	56	60	68	95	69	1591
	Dica-silicate	52	36	95	66	108	74	58	92	102	50	110	100	98	120	75	57	61	66	96	66	1582
Control	None	58	55	97	69	106	73	58	92	115	44	108	111	119	128	86	57	69	87	111	70	1715
Control	None	64	46	95	66	105	73	58	87	100	48	106	100	93	117	74	58	58	71	96	70	1585
Rainwater		56	133	217	184	209	127	135	174	168	128	237	239	174	215	111	84	120	122	199	192	3324
Rainfall, inches		30	27	42	36	41	25	26	34	45	28	48	38	43	49	31	38	37	29	46	35	727.6

TABLE III—Annual outgo of calcium from the variously limed Cumberland clay loam at Knoxville, as pounds of CaCO_3 -equivalence per 2,000,000 pounds of soil.

Experimental series	Liming material	In successive annual periods																		20-year outgo			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Net
A	Burnt lime	510	843	519	569	455	262	339	270	280	169	258	256	188	168	158	131	150	174	200	226	6125	1944
	Limestone	645	827	503	544	409	259	287	284	282	171	251	246	205	179	177	125	138	148	181	204	6065	1884
	Dolomite	429	620	411	405	334	210	221	207	231	140	222	183	160	167	152	116	127	143	173	178	4829	648
	Dica-silicate	549	747	497	501	421	271	284	238	265	174	249	230	210	182	171	132	140	147	157	184	5749	1568
B	Burnt lime	490	901	518	516	957	431	416	396	361	220	301	323	282	242	236	155	171	195	221	233	7565	3384
	Limestone	610	945	518	549	909	437	349	375	372	217	292	334	278	242	227	151	174	199	227	239	7644	3463
	Dolomite	423	634	359	379	550	285	278	255	269	169	228	217	207	191	170	129	136	139	152	175	5345	1164
	Dica-silicate	512	777	450	502	831	372	434	365	330	220	260	267	291	281	195	155	157	175	183	216	6923	2742
C	Burnt lime	512	907	579	533	532	374	445	493	509	240	323	364	276	262	224	159	197	224	236	259	7648	3467
	Limestone	618	807	556	541	520	359	472	470	439	230	356	366	277	241	239	173	182	202	223	228	7499	3318
	Dolomite	430	620	403	370	394	272	326	331	333	169	233	248	192	173	160	114	127	156	178	184	5413	1232
	Dica-silicate	529	806	526	515	459	365	426	433	421	221	350	329	251	241	242	172	177	192	177	224	7056	2875
D	Burnt lime	355	726	640	624	448	311	335	277	259	177	247	219	174	190	202	143	158	171	188	191	6035	1854
	Limestone	395	752	592	641	423	279	326	269	261	174	245	257	179	168	179	124	140	163	157	195	5919	1738
	Dolomite	342	605	487	485	303	209	250	185	188	126	203	201	157	143	125	98	103	129	132	179	4650	469
	Dica-silicate	428	687	592	562	417	285	308	252	254	159	203	229	181	183	165	107	140	167	133	192	5644	1463
E	Burnt lime	352	704	607	630	579	376	483	533	510	269	343	347	255	280	273	188	201	215	222	272	7639	3458
	Limestone	388	704	643	635	550	365	489	478	457	272	410	400	305	322	310	210	198	210	205	254	7805	3624
	Dolomite	336	585	491	478	389	246	315	265	333	166	244	235	179	175	143	119	136	163	161	171	5530	1149
	Dica-silicate	344	667	598	629	519	337	462	420	447	240	315	316	229	232	238	181	180	204	221	251	7030	2849
F	Burnt lime	370	713	504	538	371	224	177	201	264	158	249	285	189	192	188	133	146	167	193	219	5481	1300
	Limestone	411	750	501	442	340	212	228	238	263	148	236	274	193	182	173	128	150	176	183	206	5434	1253
	Dolomite	376	631	429	401	281	163	162	149	201	109	185	182	150	137	133	105	117	139	145	164	4359	178
	Dica-silicate	388	692	474	476	324	193	220	187	220	153	242	261	181	132	155	122	145	165	195	208	5133	952
G	Burnt lime	330	635	433	459	344	217	179	249	284	160	251	272	209	231	184	135	178	196	215	220	5381	1200
	Limestone	346	639	472	403	356	211	171	241	280	157	246	254	216	212	178	128	162	185	195	215	5267	1086
	Dolomite	338	613	385	369	276	165	156	175	202	103	168	181	151	138	140	109	122	135	152	160	4238	57
	Dica-silicate	341	614	434	461	333	217	216	240	228	148	219	264	196	196	182	137	153	178	196	226	5179	998
Control	None	309	515	319	273	325	179	216	211	183	150	204	204	151	138	160	99	115	142	162	161	4216	
Rainwater	None	319	572	346	321	259	180	208	195	186	124	179	175	139	126	127	99	115	144	149	182	4145	
		60	195	74	88	115	115	150	101	132	109	122	157	128	145	124	102	124	128	145	139	2453	

TABLE IV—*Annual outgo of calcium from the variously limed Onslow fine sandy loam at Blacksburg, as pounds of CaCO₃-equivalence per 2,000,000 pounds of soil.*

Experimental series	Liming material	In successive annual periods																			20-year outgo		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Net
A	Burnt lime.....	354	136	228	217	366	181	186	249	284	88	311	154	201	136	186	112	148	135	144	105	3921	1903
	Limestone.....	356	163	232	235	354	174	191	180	217	83	235	192	189	143	136	102	103	108	139	101	3633	1615
	Dolomite.....	165	78	194	85	255	107	123	142	169	58	190	184	129	77	137	95	103	74	120	97	2582	564
	Dica-silicate.....	221	78	145	150	359	169	181	194	232	82	215	193	165	138	108	88	122	101	137	100	3178	1160
B	Burnt lime.....	268	116	212	230	630	308	324	347	410	134	329	344	244	255	206	141	176	188	186	145	5193	3175
	Limestone.....	372	102	214	222	636	317	317	298	452	166	471	450	310	227	161	150	176	198	177	146	5562	3544
	Dolomite.....	187	60	185	75	304	143	167	203	345	100	219	196	132	139	103	87	90	111	95	104	3045	1027
	Dica-silicate.....	210	88	143	156	642	301	276	269	398	148	426	348	283	244	162	120	147	173	150	156	4840	2822
C	Burnt lime.....	306	106	228	214	386	246	139	324	512	202	586	448	279	274	192	139	167	165	171	189	5273	3255
	Limestone.....	291	92	229	215	387	251	141	229	473	221	506	465	258	269	222	156	160	171	172	193	5101	3083
	Dolomite.....	156	78	189	89	231	153	135	140	327	149	335	250	127	152	102	81	91	149	100	116	3150	1132
	Dica-silicate.....	245	77	146	157	376	251	117	258	393	153	368	382	297	238	198	120	153	174	158	136	4397	2379
D	Burnt lime.....	219	121	249	217	367	191	216	186	237	74	206	286	190	185	150	120	134	178	135	155	3816	1798
	Limestone.....	190	107	252	214	287	194	165	157	230	76	212	251	218	184	152	97	107	164	137	141	3535	1517
	Dolomite.....	135	74	184	86	216	99	93	112	157	59	140	148	132	153	141	104	126	130	97	161	2547	529
	Dica-silicate.....	186	102	140	155	326	200	156	167	189	72	207	186	225	161	125	106	121	153	120	159	3256	1238
E	Burnt lime.....	174	93	248	214	436	236	252	288	351	191	381	305	312	252	226	177	157	273	197	185	4948	2330
	Limestone.....	284	106	244	210	352	242	256	235	289	200	382	266	283	226	212	162	149	230	188	205	4721	2703
	Dolomite.....	126	70	176	113	281	177	139	128	137	87	187	180	180	118	141	93	152	141	134	124	2884	866
	Dica-silicate.....	165	89	152	142	369	251	256	194	270	144	382	288	301	219	228	154	181	247	155	183	4370	2352
F	Burnt lime.....	206	126	237	215	257	171	183	161	167	90	198	208	183	135	132	94	127	128	142	128	3288	1270
	Limestone.....	159	108	241	216	264	177	185	147	175	88	189	162	178	123	118	91	112	129	136	135	3133	1115
	Dolomite.....	132	59	191	105	139	100	121	71	85	61	128	89	83	75	62	56	66	65	107	80	1875	-145
	Dica-silicate.....	167	73	148	140	263	156	183	114	177	89	170	146	166	109	132	90	100	125	148	134	2830	812
G	Burnt lime.....	197	86	246	209	259	172	213	149	199	77	178	146	188	176	105	102	105	124	144	144	3219	1201
	Limestone.....	146	88	247	210	270	181	172	151	171	84	243	312	217	177	97	93	123	118	138	144	3382	1364
	Dolomite.....	140	56	197	86	159	100	90	67	80	55	124	177	106	147	114	105	142	115	107	141	2308	290
	Dica-silicate.....	180	55	156	138	248	165	161	128	156	86	156	261	201	172	161	93	149	126	131	124	3047	1029
Control	None.....	162	93	106	128	240	111	128	125	146	50	167	130	109	73	87	45	66	52	74	70	2162	
Control	None.....	144	63	101	135	212	121	124	99	107	47	104	116	104	67	54	38	51	61	61	64	1873	
Rainwater.....		37	49	80	51	86	113	61	81	53	46	90	126	69	73	35	39	29	25	146	103	1392	

TABLE V—Annual outgo of magnesium from the variously limed Cumberland clay loam at Knoxville, as pounds of CaCO_3 -equivalence per 2,000,000 pounds of soil.

Experimental series	Liming material	In successive annual periods																		20-year outgo			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Net
A	Burnt lime	193	224	141	152	165	74	92	71	95	44	72	57	42	43	51	29	30	38	44	50	1707	-68
	Limestone	191	231	140	142	166	74	78	80	92	45	67	57	45	45	55	34	28	35	40	47	1692	-83
	Dolomite	367	529	337	264	297	148	137	126	144	80	126	118	82	86	65	52	51	55	57	73	3194	1419
	Dica-silicate	223	260	163	163	181	93	93	78	100	51	82	63	54	56	58	39	34	40	45	48	1924	149
B	Burnt lime	186	242	138	138	169	65	63	55	88	36	53	48	43	45	54	30	26	33	40	41	1593	-182
	Limestone	183	229	149	146	169	61	57	62	93	38	54	53	44	44	53	30	28	34	44	39	1610	-165
	Dolomite	364	535	281	287	501	252	232	221	230	144	179	173	146	132	103	74	77	76	97	97	4201	2426
	Dica-silicate	209	274	160	180	246	95	107	99	104	65	74	70	69	64	61	47	38	43	55	50	2110	335
C	Burnt lime	190	243	151	131	166	78	75	75	93	38	68	50	38	41	46	28	24	29	39	36	1639	-136
	Limestone	188	224	164	134	168	74	82	72	86	41	59	55	38	40	48	30	23	29	37	34	1626	-149
	Dolomite	372	548	316	281	344	212	267	273	282	137	188	199	148	142	111	83	80	97	105	113	4298	2423
	Dica-silicate	201	278	192	171	179	114	109	100	116	59	88	79	58	57	70	43	36	45	52	50	2097	322
D	Burnt lime	187	265	192	164	142	83	80	70	87	43	64	49	34	41	57	35	29	33	40	41	1736	-39
	Limestone	185	265	185	163	154	73	85	66	89	50	57	55	40	42	50	30	26	34	37	41	1732	-43
	Dolomite	238	440	350	367	311	151	171	132	147	80	128	122	92	90	74	52	53	60	63	74	3195	1420
	Dica-silicate	185	274	214	213	181	97	106	84	101	53	62	65	52	61	63	36	36	43	44	48	2018	243
E	Burnt lime	188	283	196	171	179	75	87	77	100	40	49	49	33	40	48	27	23	31	35	37	1768	-7
	Limestone	171	256	192	167	168	79	87	76	97	46	64	63	42	49	61	34	24	29	32	35	1772	-3
	Dolomite	225	419	337	370	365	207	270	231	287	141	194	200	145	145	90	90	94	103	97	106	4116	2341
	Dica-silicate	178	269	220	196	192	95	114	97	126	63	72	78	51	56	69	43	35	42	47	52	2095	320
F	Burnt lime	217	275	163	140	146	60	49	51	88	42	46	51	37	48	52	30	27	33	38	42	1635	-140
	Limestone	248	271	153	136	126	54	57	59	90	42	50	65	39	41	56	32	28	37	41	40	1665	-110
	Dolomite	214	390	296	304	227	122	122	116	152	88	131	129	101	89	84	61	63	62	77	72	2900	1125
	Dica-silicate	220	283	173	158	153	64	66	62	91	52	66	65	45	50	58	37	33	43	51	47	1817	42
G	Burnt lime	179	289	157	159	146	71	53	64	87	41	47	49	32	38	54	29	26	32	39	34	1626	-149
	Limestone	191	287	180	197	157	69	59	64	88	36	48	55	37	37	54	29	26	34	43	34	1725	-50
	Dolomite	197	338	232	259	440	127	119	137	180	86	134	144	111	111	84	65	65	72	79	72	3052	1275
	Dica-silicate	206	284	173	175	160	81	73	79	91	46	82	67	48	56	43	38	32	42	51	50	1877	102
Control	None	197	248	157	127	175	93	90	84	104	54	71	70	46	46	42	32	29	38	41	44	1788	
Control	None	180	255	160	140	177	98	84	80	99	46	61	62	46	48	47	31	29	36	37	45	1761	
Rainwater		88	124	66	64	29	29	59	33	62	43	37	30	25	50	37	32	22	26	30	27	913	

TABLE VI—Annual outgo of magnesium from the variously limed Onslow fine sandy loam at Blacksburg, as pounds of CaCO_3 -equivalence per 2,000,000 pounds of soil.

Experimental series	Liming material	In successive annual periods																			20-year outgo		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Net
A	Burnt lime	82	35	44	39	49	58	46	60	103	33	72	83	69	35	40	18	37	41	31	38	1013	142
	Limestone	52	38	42	41	43	59	45	76	101	26	49	58	78	37	28	25	27	32	22	36	915	44
	Dolomite	185	91	133	124	186	111	150	148	205	68	163	152	138	85	62	39	41	47	43	40	2211	1340
	Dica-silicate	77	29	40	45	69	56	49	65	130	23	96	83	70	38	30	19	30	41	37	36	1063	192
B	Burnt lime	39	16	48	37	43	63	31	41	51	26	50	69	84	52	23	23	28	28	43	38	833	-38
	Limestone	49	19	44	39	67	59	38	52	60	28	69	75	90	52	26	23	19	31	42	34	916	41
	Dolomite	194	82	124	118	232	123	237	248	454	133	270	227	175	184	97	83	77	95	82	73	3308	2437
	Dica-silicate	66	14	38	41	146	57	69	62	98	40	120	108	87	66	40	29	34	33	36	47	1231	360
C	Burnt lime	56	17	54	35	48	56	39	44	80	33	67	68	80	65	23	18	23	54	26	41	927	56
	Limestone	50	29	58	39	58	56	38	42	77	31	74	80	82	85	26	23	26	42	19	42	977	106
	Dolomite	211	91	143	116	92	110	184	187	420	149	406	247	241	173	119	67	86	116	83	82	3323	2452
	Dica-silicate	67	22	37	47	52	55	52	61	126	55	101	54	81	97	41	27	30	49	38	38	1130	259
D	Burnt lime	84	22	44	37	114	53	36	49	81	26	67	23	79	63	36	22	24	50	46	49	1005	134
	Limestone	69	20	44	35	82	54	38	39	71	23	50	79	85	47	30	19	20	30	46	40	921	50
	Dolomite	127	85	163	109	170	143	161	146	200	74	162	118	199	96	81	54	51	66	63	64	2332	1461
	Dica-silicate	63	39	71	49	58	61	50	46	93	37	65	85	86	48	37	29	30	37	29	58	1071	200
E	Burnt lime	68	16	69	37	68	56	30	45	73	25	30	64	63	106	22	23	52	20	20	33	920	49
	Limestone	90	18	49	35	149	58	37	47	66	30	39	53	61	105	34	22	24	19	24	33	993	113
	Dolomite	123	53	170	106	202	147	213	193	281	141	264	166	233	183	146	98	74	138	99	113	3143	2272
	Dica-silicate	61	19	57	53	90	52	30	58	103	50	104	87	78	76	39	34	34	38	43	46	1152	281
F	Burnt lime	84	20	48	40	36	51	47	34	61	35	49	68	65	38	28	19	23	22	41	31	840	-31
	Limestone	63	17	38	37	63	55	44	37	66	29	59	102	70	36	25	20	24	22	36	41	884	13
	Dolomite	172	57	126	107	169	112	151	114	147	72	151	127	130	86	70	67	71	69	55	87	2140	1269
	Dica-silicate	64	30	62	46	46	48	46	44	67	26	61	88	66	34	29	26	27	30	33	47	920	49
G	Burnt lime	64	29	65	40	54	53	37	45	64	27	48	54	74	36	24	15	24	24	29	37	843	-28
	Limestone	52	25	67	37	58	51	39	35	81	24	47	35	84	45	25	23	30	22	26	37	843	-28
	Dolomite	120	41	147	107	173	140	164	101	158	73	151	109	181	95	113	62	32	45	51	97	2160	1289
	Dica-silicate	62	22	57	46	85	55	48	67	95	33	106	56	83	48	37	31	28	33	38	36	1066	195
Control	None	70	38	34	35	50	43	40	56	88	20	56	67	61	32	40	21	36	43	34	42	906	
Control	None	67	23	29	31	65	44	37	48	87	23	52	68	56	31	29	18	27	24	34	43	836	
Rainwater		34	31	28	32	37	35	30	36	51	39	45	60	47	53	21	18	16	24	47	55	739	

TABLE VII—Annual outgo of Ca+Mg from the variously limed Onslow fine sandy loam at Blacksburg, as pounds of CaCO_3 -equivalence per 2,000,000 pounds of soil.

Experimental series	Liming material	In successive annual periods																20-year outgo					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Net
A	Burnt lime	703	1067	660	721	620	336	431	341	375	213	330	313	230	211	209	160	180	212	244	276	7832	1877
	Limestone	836	1058	643	686	575	323	365	364	374	216	318	303	250	224	232	159	166	183	221	251	7747	1792
	Dolomite	796	1149	748	669	631	358	358	333	375	220	340	301	242	253	217	168	178	198	230	251	8023	2068
	Dica-silicate	772	1007	660	664	602	364	377	316	365	225	331	293	264	238	229	171	174	187	202	232	7673	1718
	Average	777	1070	678	685	607	345	383	339	372	219	332	303	247	232	222	165	175	195	224	253	7820	1865
B	Burnt lime	676	1143	656	654	1126	490	479	451	449	256	354	371	325	287	290	185	197	228	261	274	9158	3203
	Limestone	793	1174	667	695	1078	498	406	437	465	255	346	387	322	286	280	181	202	233	271	278	9254	3299
	Dolomite	787	1169	640	666	1051	537	510	476	499	313	407	390	353	323	273	203	213	215	249	272	9490	3535
	Dica-silicate	721	1051	610	682	1077	467	541	464	434	285	334	337	360	345	256	202	195	218	188	266	9033	3078
	Average	744	1134	643	674	1083	500	484	457	462	277	360	371	340	360	321	215	224	246	257	309	9234	3279
C	Burnt lime	702	1150	730	664	698	452	520	568	602	278	391	414	314	303	270	187	221	253	275	295	9287	3332
	Limestone	806	1031	720	675	688	433	554	542	525	271	415	421	315	281	287	203	205	231	260	262	9125	3170
	Dolomite	802	1168	719	651	738	484	593	604	615	306	421	447	340	315	271	197	207	253	283	297	9711	3756
	Dica-silicate	730	1184	718	686	638	479	535	533	537	280	438	408	309	298	312	215	213	237	229	274	9253	3298
	Average	769	1133	722	669	691	462	551	562	570	284	416	423	320	299	285	201	212	244	262	282	9319	3364
D	Burnt lime	542	991	832	788	590	494	415	347	346	220	311	268	208	231	259	178	187	204	228	232	7871	1916
	Limestone	580	1017	777	804	577	357	411	335	350	224	302	312	219	210	229	154	166	197	194	236	7651	1696
	Dolomite	580	1045	837	852	614	360	421	317	335	206	331	323	249	233	199	150	156	189	195	253	7845	1890
	Dica-silicate	613	961	806	775	598	382	414	386	355	212	265	294	233	244	228	143	176	210	177	240	7662	1707
	Average	579	1004	813	805	595	398	315	334	347	216	302	299	227	229	228	156	171	200	199	240	7757	1802
E	Burnt lime	540	987	803	801	758	451	570	610	610	309	392	396	288	320	321	215	224	246	257	309	9407	3452
	Limestone	559	960	835	802	718	444	576	554	564	318	474	463	347	371	371	244	222	239	237	289	9577	3622
	Dolomite	561	1004	828	848	754	453	585	496	620	307	438	435	324	320	233	209	230	266	258	277	9446	3491
	Dica-silicate	522	936	818	825	711	432	576	517	573	303	387	394	280	288	307	224	215	246	268	303	9125	3170
	Average	546	972	821	819	735	448	577	544	589	309	423	422	313	325	308	223	223	225	255	295	9389	3434
F	Burnt lime	587	988	667	678	517	284	226	252	352	200	295	336	226	240	240	163	173	200	231	261	7116	1161
	Limestone	659	1021	654	578	466	266	285	297	353	190	286	339	232	223	229	160	178	213	224	246	7099	1144
	Dolomite	590	1021	725	705	507	285	284	265	353	197	316	311	251	226	217	166	180	201	222	236	7260	1305
	Dica-silicate	608	975	647	634	477	257	286	249	311	205	308	326	226	182	213	159	178	208	246	255	6950	995
	Average	611	1001	673	649	492	273	270	266	342	198	351	328	233	218	226	162	177	206	231	250	7106	1151
G	Burnt lime	509	924	590	618	490	288	222	313	371	201	298	321	241	269	238	164	204	228	254	254	6997	1042
	Limestone	537	926	652	600	413	280	230	305	368	193	294	309	253	249	232	157	188	219	238	249	6892	937
	Dolomite	535	951	617	628	521	292	275	312	382	189	302	325	262	249	224	174	187	207	231	232	7095	1140
	Dica-silicate	547	898	607	636	493	298	289	319	319	194	301	331	244	249	225	175	185	220	247	276	7053	1098
	Average	535	925	617	621	479	290	254	312	360	194	299	322	250	254	239	168	191	219	243	253	7009	1054
Control	None	506	763	476	400	500	272	306	295	287	204	275	274	197	184	202	131	144	180	203	205	6004	
Control	None	499	827	506	461	436	278	292	275	285	170	240	237	185	174	174	130	144	180	186	227	5906	
Average		503	795	491	432	468	275	200	285	286	187	258	256	191	179	188	131	144	180	195	216	5955	

TABLE VIII—Annual outgo of Ca+Mg from the variously limed Onslow fine sandy loam at Blacksburg, as pounds of CaCO₃-equivalence per 2,000,000 pounds of soil.

Experimental series	Liming material	In successive annual periods																			20-year outgo		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Net
A	Burnt lime	436	171	272	256	415	239	232	309	387	122	383	236	270	171	226	130	185	176	175	142	4933	2047
	Limestone	408	201	274	276	397	233	236	256	318	109	285	250	267	180	163	127	130	139	160	137	4546	1660
	Dolomite	350	169	327	209	441	218	273	290	374	126	353	335	267	163	198	134	144	121	163	137	4792	1906
	Dica-silicate	298	107	185	195	428	225	230	259	362	106	311	276	235	176	137	107	152	142	174	136	4239	1353
	Average	373	162	265	234	420	229	243	279	360	116	344	274	260	173	181	125	153	145	168	138	4628	1742
B	Burnt lime	307	132	260	267	673	371	355	388	461	160	379	413	328	307	229	164	205	216	228	183	6026	3140
	Limestone	421	121	258	261	703	376	355	350	511	194	540	525	400	279	187	173	195	229	219	180	6477	3591
	Dolomite	381	142	309	193	536	266	404	451	799	233	490	423	307	323	200	169	167	206	177	177	6353	3467
	Dica-silicate	276	102	181	197	788	358	345	331	496	188	546	456	370	311	202	149	181	206	186	203	6172	3286
	Average	346	124	252	230	675	343	364	380	567	194	489	450	351	305	205	164	187	214	203	186	6257	3371
C	Burnt lime	362	123	282	249	434	302	178	368	593	235	654	516	359	339	214	157	190	219	197	230	6201	3315
	Limestone	341	121	287	254	445	307	179	271	551	252	579	544	340	354	249	180	187	214	191	235	6081	3195
	Dolomite	367	169	332	205	323	263	319	327	747	298	741	497	368	325	221	148	176	265	183	198	6472	3586
	Dica-silicate	312	99	193	204	428	306	169	319	519	209	469	436	378	335	240	147	183	224	196	174	5540	2654
	Average	346	128	274	228	408	295	211	321	603	249	561	498	361	338	231	158	184	231	192	209	6099	3213
D	Burnt lime	303	143	293	254	481	244	252	235	318	100	272	309	269	247	186	142	158	228	181	203	4818	1932
	Limestone	259	127	296	249	369	248	203	196	301	98	262	330	303	231	181	116	127	194	182	180	4451	1565
	Dolomite	262	159	347	195	386	242	254	258	357	133	302	266	330	248	222	159	177	196	160	225	4878	1992
	Dica-silicate	249	141	211	204	384	261	206	213	282	108	272	270	311	209	161	135	151	190	149	217	4324	1438
	Average	268	143	287	226	405	249	229	226	315	110	277	294	303	234	188	138	153	202	168	206	4618	1732
E	Burnt lime	242	146	317	251	504	292	282	333	425	216	410	369	375	358	248	200	209	293	217	218	5868	2982
	Limestone	374	124	293	245	501	300	293	282	355	230	422	319	344	331	246	184	173	248	213	238	5715	2829
	Dolomite	249	123	346	219	483	324	252	321	418	228	451	346	414	301	287	191	226	280	233	237	6029	3143
	Dica-silicate	226	108	209	195	459	303	286	352	373	194	486	375	379	295	267	188	215	285	198	229	5522	2636
	Average	273	125	266	228	487	305	278	297	393	267	442	352	378	321	262	191	206	277	215	230	5784	2898
F	Burnt lime	290	146	285	255	293	222	230	195	228	125	247	275	248	173	159	112	150	150	182	159	4224	1338
	Limestone	222	125	279	253	327	232	229	184	241	118	248	264	248	159	143	112	137	152	173	176	4022	1136
	Dolomite	304	116	317	212	308	212	272	185	232	133	279	216	213	161	133	123	137	134	162	167	4016	1130
	Dica-silicate	231	103	210	186	309	204	229	158	244	115	231	234	232	143	161	116	127	155	181	181	3750	864
	Average	262	123	273	227	309	218	240	181	236	123	251	247	235	159	149	116	138	148	175	171	4003	1117
G	Burnt lime	261	115	311	249	313	225	250	194	264	104	226	200	263	212	128	118	128	148	173	181	4063	1177
	Limestone	198	113	314	247	328	232	211	186	252	108	290	347	301	222	122	116	154	139	164	181	4225	1339
	Dolomite	260	97	344	193	332	240	254	168	239	128	275	286	287	242	226	167	173	160	158	238	4467	1581
	Dica-silicate	242	77	213	184	333	220	209	195	251	119	262	317	284	219	198	124	177	159	169	161	4113	1227
	Average	240	101	296	218	327	229	231	186	252	115	263	288	284	224	169	131	158	152	166	190	4217	1331
Control Control	None	232	131	140	163	290	154	168	181	233	70	223	197	170	105	127	66	102	95	107	112	3066	
	None	211	86	130	166	277	165	161	147	194	69	156	184	160	98	83	56	78	84	94	107	2706	
Average		222	108	136	164	283	160	164	164	214	70	190	191	165	102	105	61	90	90	101	110	2886	

TABLE IX—Annual outgo of potassium from the variously limed Cumberland clay loam at Knoxville, as pounds of K per 2,000,000 pounds of soil.

Experimental series	Liming material	In successive annual periods																		20-year outgo			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Net
A	Burnt lime	25	39	24	23	23	21	14	14	16	10	16	12	9	9	12	6	5	7	8	7	298	
	Limestone	26	46	24	22	24	20	9	9	10	7	13	10	8	9	10	5	5	6	8	6	277	
	Dolomite	22	40	25	21	24	18	11	9	12	8	13	10	8	9	11	5	5	7	9	5	272	
	Dica-silicate	20	48	25	18	21	20	9	9	11	9	12	12	8	9	11	5	5	7	8	5	272	
	Average	24	44	25	21	23	20	11	10	12	9	13	11	8	9	11	5	5	7	8	6	280	
B	Burnt lime	15	40	20	19	18	18	11	7	9	7	9	10	8	9	14	4	4	6	8	5	241	
	Limestone	14	39	19	21	16	19	8	7	10	6	8	10	6	7	10	4	4	6	5	4	223	
	Dolomite	11	41	21	20	23	19	10	9	9	6	11	12	6	9	12	5	5	7	7	5	247	
	Dica-silicate	20	48	23	21	32	19	13	9	10	8	10	12	10	10	10	5	4	5	7	4	280	
	Average	15	42	21	20	22	19	10	8	9	7	9	11	8	12	11	5	4	6	7	5	248	
C	Burnt lime	15	43	23	18	16	20	11	7	9	4	10	11	6	7	8	3	3	4	6	3	227	
	Limestone	11	41	23	19	18	18	10	7	8	5	10	11	7	8	10	4	4	6	6	4	230	
	Dolomite	14	46	24	18	20	18	8	7	10	6	11	12	8	9	8	5	4	7	6	5	243	
	Dica-silicate	17	53	27	17	28	21	10	6	9	5	9	9	6	6	8	4	4	5	7	5	256	
	Average	15	46	24	17	21	19	10	7	9	5	10	11	7	8	9	4	4	6	6	4	239	
D	Burnt lime	36	47	23	17	21	23	13	11	12	8	15	11	8	9	12	5	5	7	9	6	298	
	Limestone	37	47	20	17	18	20	12	12	13	9	17	12	9	10	14	5	5	7	8	6	298	
	Dolomite	15	43	23	16	21	24	11	10	12	9	15	13	9	10	10	6	5	7	7	6	276	
	Dica-silicate	21	50	25	18	24	23	12	10	12	9	16	13	11	9	13	5	5	7	9	6	298	
	Average	27	47	23	17	21	23	12	11	13	9	16	12	9	10	12	5	5	7	8	6	293	
E	Burnt lime	21	46	22	18	22	19	11	8	12	7	13	9	6	7	8	4	4	5	7	5	254	
	Limestone	16	41	19	18	22	22	12	9	12	7	14	10	5	9	7	4	3	5	6	3	244	
	Dolomite	22	48	23	21	22	20	12	9	12	7	11	10	6	8	8	4	4	6	8	5	267	
	Dica-silicate	24	56	30	23	27	21	13	8	12	7	11	10	8	8	9	4	4	5	6	4	290	
	Average	21	48	24	20	23	21	12	9	12	7	12	10	6	8	8	4	4	5	7	4	264	
F	Burnt lime	27	52	28	22	17	23	8	9	12	5	10	10	5	7	8	5	5	5	8	5	271	
	Limestone	30	56	32	18	20	22	9	10	11	5	10	10	6	8	7	5	4	5	8	5	281	
	Dolomite	27	47	34	22	21	23	6	9	10	6	10	8	6	8	9	5	5	7	9	5	277	
	Dica-silicate	31	62	26	22	21	25	11	8	10	6	10	11	6	8	7	5	5	7	9	6	296	
	Average	29	54	30	21	20	23	10	9	11	6	10	10	6	8	8	5	5	6	9	5	281	
G	Burnt lime	33	59	33	23	19	24	8	9	9	5	9	7	5	8	7	4	4	6	7	4	283	
	Limestone	46	59	31	21	22	24	8	8	9	5	8	7	5	7	9	4	3	6	7	5	294	
	Dolomite	50	60	28	20	20	23	6	8	7	6	7	8	6	7	7	4	4	6	7	5	287	
	Dica-silicate	53	58	34	23	27	22	11	8	7	5	9	8	6	7	9	4	4	6	8	5	314	
	Average	48	59	32	22	22	23	8	8	8	5	8	8	6	7	8	4	4	6	7	5	294	
Control	None	29	44	29	20	27	18	13	17	16	11	15	13	10	11	14	6	5	6	8	5	317	
Control	None	23	57	31	22	25	29	13	14	15	9	17	13	9	9	11	6	5	7	10	6	331	
Average	None	26	51	30	21	26	24	13	16	16	10	16	13	10	10	13	6	5	7	9	6	324	
Rainwater		11	24	11	8	11	10	8	7	11	8	6	6	8	11	10	5	9	7	8	8	181	

TABLE X—Annual outgo of potassium from the variously limed Onslow fine sandy loam at Blacksburg, as pounds of K per 2,000,000 pounds of soil.

Experimental series	Liming material	In successive annual periods										20-year outgo										Total	Net
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Net
A	Burnt lime	22	14	21	14	13	14	12	12	21	8	11	13	8	11	18	14	10	7	11	9	274	-37
	Limestone	17	6	19	13	11	12	11	10	16	8	14	8	8	11	12	12	8	7	11	15	226	
	Dolomite	18	9	19	12	11	12	9	9	18	7	15	12	8	13	13	8	6	11	11	10	231	
	Dica-silicate	11	10	19	12	12	15	11	9	15	7	16	8	8	11	9	15	7	10	11	12	227	
	Average	17	10	19	13	12	13	11	10	17	8	14	10	8	11	13	12	8	9	11	12	240	
B	Burnt lime	16	8	18	12	12	12	12	8	16	8	13	8	6	14	15	8	9	7	12	9	225	-51
	Limestone	10	12	18	14	11	12	9	9	15	8	14	10	9	12	10	9	7	10	12	11	219	
	Dolomite	14	6	20	16	13	12	10	6	15	8	12	12	6	10	13	8	7	9	12	13	224	
	Dica-silicate	14	22	20	12	16	12	11	6	15	8	11	11	9	13	12	11	5	5	11	10	235	
	Average	14	12	19	14	13	11	11	7	15	8	12	10	7	12	13	9	7	8	12	11	226	
C	Burnt lime	18	4	19	13	13	11	10	10	15	8	12	10	6	12	12	10	7	7	11	9	216	-55
	Limestone	21	3	20	12	11	12	9	11	17	8	12	10	9	14	12	13	6	5	12	12	229	
	Dolomite	20	6	19	12	13	11	10	10	17	8	11	10	8	7	11	9	7	7	12	18	227	
	Dica-silicate	18	4	20	12	13	11	12	7	16	8	10	8	7	12	11	15	7	4	13	8	217	
	Average	19	4	20	10	13	11	10	10	16	8	11	10	8	11	12	12	7	6	12	12	222	
D	Burnt lime	32	14	19	12	12	11	12	8	19	8	12	10	8	13	10	10	7	9	13	11	248	-23
	Limestone	30	12	20	13	20	11	12	7	16	8	12	10	9	11	13	14	7	6	12	13	256	
	Dolomite	24	11	20	12	17	12	12	8	17	8	12	12	6	13	16	9	12	12	11	13	257	
	Dica-silicate	37	9	20	12	19	11	12	9	16	8	14	10	6	12	13	4	9	11	12	13	255	
	Average	31	12	20	12	17	11	12	8	17	8	12	10	7	12	13	9	9	9	12	13	254	
E	Burnt lime	22	6	18	13	14	12	12	8	17	8	15	9	6	12	11	7	9	10	11	12	232	-37
	Limestone	25	6	18	12	20	12	12	9	17	8	13	10	8	11	11	8	9	10	11	11	243	
	Dolomite	18	6	20	13	19	11	12	10	16	8	14	12	8	11	11	11	12	10	12	14	248	
	Dica-silicate	26	7	20	12	16	12	12	10	16	7	15	12	6	8	11	8	7	10	11	10	236	
	Average	23	6	19	12	17	12	12	9	16	8	14	11	7	11	11	9	9	10	11	12	240	
F	Burnt lime	24	8	20	12	16	12	12	9	16	8	13	10	7	11	10	7	6	10	11	10	232	-48
	Limestone	26	10	20	13	11	11	11	9	15	8	15	13	7	10	14	7	6	9	11	10	236	
	Dolomite	11	9	19	12	14	11	11	9	17	8	14	13	7	8	10	6	6	8	12	17	222	
	Dica-silicate	17	8	18	12	13	11	10	9	16	8	15	10	8	8	12	9	9	11	11	12	227	
	Average	20	9	19	12	14	11	11	9	16	8	14	12	7	9	11	7	7	9	11	12	229	
G	Burnt lime	20	11	18	12	10	11	12	6	16	8	15	15	8	11	15	6	6	9	11	11	231	-43
	Limestone	21	10	19	11	11	12	12	7	16	8	14	11	9	11	12	8	7	8	11	9	227	
	Dolomite	20	13	16	12	11	11	12	8	17	8	13	15	7	10	12	9	9	9	11	14	237	
	Dica-silicate	28	9	18	12	12	11	12	7	19	8	14	15	6	11	11	4	7	10	11	15	240	
	Average	22	11	18	12	11	11	12	7	17	8	14	14	8	11	13	7	7	9	11	12	234	
Control	None	25	18	13	13	16	13	13	16	24	10	23	10	11	10	15	11	11	10	9	9	280	
	None	27	13	13	12	23	13	12	16	23	11	22	10	9	11	14	8	8	10	9	11	273	
	Average	26	16	13	13	20	13	13	16	26	11	23	10	10	10	15	10	10	10	9	10	277	
Rainwater		8	13	11	2	26	9	10	15	11	8	8	17	10	10	16	9	23	11	8	12	237	

TABLE XI—Annual outgo of nitrate nitrogen from the variously limed Cumberland clay loam at Knoxville, as pounds of N per 2,000,000 pounds of soil.

Experimental series	Liming material	In successive annual periods																			20-year outgo		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Net
A	Burnt lime.....	89	190	98	94	93	51	84	41	48	25	45	36	31	17	16	15	11	17	15	22	1038	146
	Limestone.....	109	170	99	89	81	51	64	41	48	28	39	36	33	18	18	13	9	12	16	10	984	
	Dolomite.....	100	187	104	75	89	47	61	37	44	23	37	28	27	19	15	15	14	18	13	8	961	
	Dica-silicate.....	106	200	103	98	92	53	64	34	46	29	38	31	36	17	18	15	10	13	11	6	1020	
	Average.....	101	187	101	89	89	51	68	38	47	26	40	34	32	18	17	15	11	15	14	12	1001	
B	Burnt lime.....	85	206	84	90	140	57	69	41	38	25	35	37	41	20	20	13	10	19	14	8	1052	174
	Limestone.....	93	191	85	87	137	58	52	39	37	20	29	38	38	24	17	12	9	16	13	9	1004	
	Dolomite.....	102	202	78	81	109	61	70	38	48	26	38	30	32	24	18	13	13	13	11	6	1013	
	Dica-silicate.....	99	196	83	81	128	60	86	50	46	31	36	29	43	26	17	14	10	15	11	6	1067	
	Average.....	95	199	83	85	129	59	59	69	42	25	35	36	39	24	18	13	10	16	12	7	1034	
C	Burnt lime.....	90	188	98	89	102	65	87	61	59	21	33	35	38	21	13	14	14	14	11	9	1062	200
	Limestone.....	91	183	94	81	98	58	89	55	57	22	41	35	37	17	14	17	11	12	9	6	1027	
	Dolomite.....	97	211	96	81	96	60	93	67	56	20	37	33	32	20	14	14	10	13	15	6	1071	
	Dica-silicate.....	99	224	99	78	87	58	92	63	53	22	40	36	30	17	18	16	13	15	14	7	1081	
	Average.....	94	202	97	82	96	60	90	62	56	21	38	35	34	19	15	15	12	14	12	7	1060	
D	Burnt lime.....	75	186	108	94	81	53	75	41	42	27	36	27	25	17	21	18	12	16	14	7	975	109
	Limestone.....	76	189	113	90	87	52	77	40	44	27	32	35	27	16	17	16	9	13	16	6	982	
	Dolomite.....	76	179	110	89	72	53	74	29	35	20	37	36	29	17	14	11	9	11	16	8	928	
	Dica-silicate.....	86	195	118	95	80	44	73	48	47	23	31	28	31	22	16	11	13	13	12	6	992	
	Average.....	78	187	112	92	80	51	75	40	42	24	34	32	28	18	17	14	11	13	15	7	969	
E	Burnt lime.....	71	199	114	88	88	50	95	60	58	25	38	25	30	24	20	18	13	17	15	11	1059	191
	Limestone.....	71	192	118	103	94	61	89	51	55	29	56	50	36	33	27	25	14	19	14	10	1147	
	Dolomite.....	73	197	114	88	81	49	83	33	53	20	34	27	26	18	10	15	10	15	10	9	965	
	Dica-silicate.....	75	170	111	90	93	56	99	54	60	25	41	31	29	17	18	16	8	17	12	9	1031	
	Average.....	73	190	114	92	89	54	92	50	57	25	42	33	30	23	19	19	11	17	13	10	1051	
F	Burnt lime.....	78	208	102	82	75	37	40	32	41	23	37	37	25	19	18	16	10	15	16	8	919	49
	Limestone.....	82	194	98	74	66	37	54	36	40	19	35	40	29	19	16	15	12	17	16	8	907	
	Dolomite.....	93	193	107	87	75	32	51	27	44	19	32	30	29	14	15	14	12	13	14	8	909	
	Dica-silicate.....	87	198	102	82	66	26	55	29	34	22	39	36	25	15	16	15	12	17	18	8	901	
	Average.....	85	198	102	81	71	33	50	31	40	21	36	36	27	17	16	15	12	16	16	8	909	
G	Burnt lime.....	80	187	99	79	74	31	36	42	49	19	36	40	30	20	15	16	17	24	19	9	923	51
	Limestone.....	84	182	98	70	71	33	37	45	48	21	35	38	34	20	16	14	15	17	15	7	900	
	Dolomite.....	81	179	94	75	74	43	49	38	45	14	31	32	26	19	15	14	12	15	14	8	877	
	Dica-silicate.....	87	197	98	84	76	40	55	40	36	18	34	36	29	21	19	17	13	15	17	10	942	
	Average.....	83	186	97	77	74	37	44	41	45	18	34	37	30	20	16	15	14	18	16	9	911	
Control	None.....	63	179	64	75	89	35	72	37	38	36	39	34	28	15	20	16	16	14	14	9	893	
Control	None.....	70	182	76	63	63	38	69	46	37	20	29	27	25	13	13	16	10	12	10	8	827	
Average	None.....	67	181	70	69	76	37	71	42	38	28	34	31	27	14	17	16	13	13	12	9	860	
Rainwater		2	5	3	2	6	2	12	11	15	11	10	7	10	18	16	6	13	11	12	13	184	

TABLE XII—Annual outgo of nitrate nitrogen from the variously limed Onslow fine sandy loam at Blacksburg, as pounds of N per 2,000,000 pounds of soil.

		In successive annual periods																				20-year outgo	
Experimental series	Liming material	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Net
A	Burnt lime	37	8	8	47	53	29	45	27	71	20	27	26	29	33	84	30	41	41	31	17	704	112
	Limestone	51	8	9	42	51	22	45	23	58	20	28	22	29	35	55	24	29	37	27	15	630	
	Dolomite	7	10	5	42	47	22	45	24	56	18	28	23	30	39	74	21	20	30	28	15	584	
	Dica-silicate	2	8	8	44	49	21	45	27	62	17	28	18	26	30	32	39	26	23	39	20	564	
	Average	24	9	8	44	50	24	45	25	62	19	28	22	29	34	41	29	29	33	31	17	621	
B	Burnt lime	2	8	11	43	51	22	45	27	61	20	28	23	23	32	68	24	29	31	30	13	591	87
	Limestone	2	11	11	42	48	15	45	30	66	29	28	36	31	32	42	29	25	30	27	19	598	
	Dolomite	1	8	11	42	54	20	45	30	80	37	28	31	23	30	35	21	25	29	26	12	588	
	Dica-silicate	12	7	10	42	53	22	45	27	76	28	28	36	38	32	32	19	22	28	29	20	606	
	Average	4	8	11	42	52	21	45	29	71	29	28	32	29	32	44	23	25	29	28	16	596	
C	Burnt lime	13	8	9	50	53	20	45	29	102	38	28	41	37	37	64	22	34	33	29	22	714	187
	Limestone	0	10	8	44	48	24	45	27	102	36	28	43	30	37	72	29	32	44	27	25	711	
	Dolomite	2	11	12	40	60	20	45	27	108	38	28	36	37	33	52	27	24	30	25	14	669	
	Dica-silicate	18	8	13	43	57	20	45	29	86	28	28	40	38	35	68	28	30	33	29	12	688	
	Average	8	9	11	44	55	21	45	28	100	35	28	40	36	36	64	27	30	35	28	18	696	
D	Burnt lime	21	38	19	45	53	20	45	27	62	18	25	21	28	34	56	36	30	47	30	21	666	148
	Limestone	13	25	23	43	52	20	45	24	53	16	31	22	28	34	71	22	27	48	31	19	647	
	Dolomite	11	33	36	40	50	24	45	26	53	19	28	20	26	32	87	37	36	28	29	28	688	
	Dica-silicate	9	38	30	42	58	17	45	28	45	19	27	18	28	29	51	23	29	37	27	28	628	
	Average	14	34	27	43	53	20	45	26	53	18	20	20	28	32	66	18	31	40	29	24	657	
E	Burnt lime	2	33	76	47	60	17	45	33	49	35	27	36	42	29	74	36	28	42	29	14	754	217
	Limestone	2	40	67	45	63	19	45	30	47	34	28	29	35	28	76	31	29	38	28	20	734	
	Dolomite	2	20	33	44	58	22	45	27	48	36	27	24	34	28	74	30	37	28	28	18	663	
	Dica-silicate	6	59	28	46	59	15	45	30	47	37	28	32	42	28	86	43	42	39	27	15	754	
	Average	3	43	51	46	60	17	45	30	48	36	28	30	38	28	78	35	34	37	28	17	726	
F	Burnt lime	6	96	14	41	51	19	45	18	42	19	25	20	26	25	46	20	34	27	26	15	615	22
	Limestone	8	25	23	41	46	18	45	17	42	22	25	19	27	21	42	21	30	32	23	14	541	
	Dolomite	31	16	13	38	46	14	45	16	42	23	25	20	21	22	20	21	21	22	19	17	464	
	Dica-silicate	13	20	13	39	46	15	45	16	46	17	25	21	24	23	22	20	22	32	26	19	504	
	Average	15	39	17	40	47	17	45	17	43	20	25	20	25	23	33	21	27	28	24	16	531	
G	Burnt lime	8	20	25	39	45	14	45	19	45	45	24	21	26	21	30	19	26	26	25	13	536	73
	Limestone	4	20	30	39	45	14	45	19	43	40	28	29	34	25	25	19	27	21	24	13	546	
	Dolomite	6	17	29	39	46	15	45	20	43	25	29	23	22	27	77	33	34	24	24	25	604	
	Dica-silicate	33	19	42	39	46	14	45	24	43	15	27	37	32	28	43	20	34	25	24	53	643	
	Average	13	19	32	39	46	14	45	21	44	32	27	28	29	25	44	23	30	24	24	26	582	
Control	None	16	10	8	38	46	22	36	21	54	14	22	14	31	27	37	15	22	26	28	17	504	
Control	None	9	44	26	45	45	19	36	16	41	19	22	22	17	18	34	15	18	36	16	15	513	
Average	None	13	27	17	42	46	21	36	19	48	17	22	18	24	23	36	15	20	31	22	16	509	
Rainwater		.04	2	3	1	12	2	2	6	4	1	6	2	1	3	3	2	3	7	25	2	88	

Note. — The nitrogen in the rainwater for the 19th year is abnormally high, and can be accounted for only by contamination from an unknown source.

TABLE XIII—Annual outgo of sulfate sulfur from the variously limed Cumberland clay loam at Knoxville, as pounds of S per 2,000,000 pounds of soil.

Experimental series	Liming material	In successive annual periods																			20-year outgo		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Net
A	Burnt lime	49	63	50	58	47	30	37	38	34	29	42	39	31	41	37	30	37	48	55	63	858	
	Limestone	54	58	49	58	48	27	35	40	36	25	39	39	32	44	38	30	37	47	54	67	860	
	Dolomite	56	62	52	55	48	30	34	36	35	29	41	39	30	42	40	30	37	49	56	65	866	
	Dica-silicate	61	58	49	58	49	28	34	36	32	30	40	37	34	45	36	31	39	49	53	67	866	
	Average	55	60	50	57	48	29	35	38	34	29	41	39	32	43	38	30	37	48	55	64	863	41
B	Burnt lime	48	64	49	56	67	33	42	37	36	30	36	39	36	38	35	34	41	45	53	64	883	
	Limestone	54	58	49	57	64	31	38	36	36	32	36	38	34	38	42	33	43	48	53	67	887	
	Dolomite	55	62	49	57	65	35	42	34	41	32	39	39	37	37	41	36	42	43	53	62	895	
	Dica-silicate	60	61	48	55	70	34	45	35	33	34	36	35	34	37	35	37	38	43	48	62	880	
	Average	54	61	49	56	67	33	42	36	37	32	37	38	31	44	44	34	46	45	52	64	886	64
C	Burnt lime	49	60	50	57	52	33	45	44	39	30	38	43	30	46	38	32	45	53	51	70	905	
	Limestone	54	58	49	57	51	32	46	41	38	33	42	43	30	40	41	33	45	49	55	65	902	
	Dolomite	56	62	49	55	54	33	49	44	41	33	40	44	33	39	43	34	44	49	55	62	919	
	Dica-silicate	63	60	48	57	54	38	49	43	41	33	41	42	33	44	46	37	47	48	52	67	943	
	Average	56	60	49	57	53	34	47	43	40	32	40	43	32	42	42	34	45	50	54	66	917	95
D	Burnt lime	36	61	53	65	47	30	39	39	34	32	41	37	28	46	44	31	44	48	53	68	876	
	Limestone	43	60	55	63	45	28	38	37	35	31	39	38	28	43	43	27	40	49	51	69	862	
	Dolomite	39	64	58	64	47	30	42	32	33	31	42	41	29	43	41	29	37	46	44	74	866	
	Dica-silicate	44	62	58	62	49	31	41	37	37	33	39	34	30	45	42	29	40	49	51	68	873	
	Average	41	62	56	63	47	30	40	36	35	34	40	38	29	44	43	29	40	48	50	70	869	47
E	Burnt lime	38	61	58	62	52	34	46	40	39	33	36	36	31	44	44	34	46	48	52	68	902	
	Limestone	35	60	60	62	50	34	48	37	39	33	38	37	32	49	47	37	45	47	49	66	905	
	Dolomite	40	61	60	65	48	34	50	33	43	30	41	42	33	39	36	33	45	49	49	65	896	
	Dica-silicate	40	63	64	66	53	36	52	42	42	32	37	38	33	41	41	39	45	48	48	68	928	
	Average	38	61	60	61	51	34	49	38	41	32	38	38	32	43	42	36	45	48	49	67	908	86
F	Burnt lime	35	66	55	60	43	27	29	31	38	29	40	40	29	39	38	30	39	47	50	62	827	
	Limestone	40	67	54	55	44	28	34	39	36	28	37	40	32	36	36	29	39	49	51	62	836	
	Dolomite	40	65	59	62	44	29	33	32	37	30	38	38	31	39	40	30	38	49	51	64	849	
	Dica-silicate	47	65	55	61	44	28	35	32	43	31	41	40	33	39	37	31	40	47	52	64	865	
	Average	41	66	56	60	44	28	33	34	39	30	39	40	31	38	39	30	39	48	51	63	844	22
G	Burnt lime	36	56	54	63	45	30	31	38	41	31	39	37	32	36	37	30	40	51	55	63	845	
	Limestone	34	61	60	60	45	28	30	36	40	31	42	38	34	35	39	29	40	51	52	65	850	
	Dolomite	38	59	56	65	48	30	35	38	41	31	38	41	33	39	39	32	41	48	51	62	865	
	Dica-silicate	35	61	59	66	44	31	34	38	38	30	41	41	32	42	43	31	39	49	53	65	872	
	Average	36	59	57	64	46	30	33	38	40	31	40	39	33	38	40	31	40	50	53	64	859	37
Control	None	31	38	66	43	48	31	25	45	35	23	41	41	30	39	43	22	26	49	57	60	793	
	None	32	51	52	56	43	30	33	42	36	31	42	42	32	42	45	29	38	50	53	72	851	
	Average	32	45	59	50	46	31	29	44	36	27	42	42	31	41	44	26	32	50	55	66	822	
Rainwater		28	46	51	54	36	35	41	26	38	30	31	27	29	34	37	36	40	42	49	56	766	

TABLE XIV—Annual outgo of sulfate sulfur from the variously limed Onslow fine sandy loam at Blacksburg, as pounds of S equivalence per 2,000,000 pounds of soil.

Experimental series	Liming material	In successive annual periods																				20-year outgo	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	Net
A	Burnt lime	26	19	24	17	26	11	24	20	18	10	19	19	22	14	18	9	17	20	20	28	381	15
	Limestone	26	16	22	13	27	11	21	17	16	10	16	24	20	18	14	11	17	19	20	24	362	
	Dolomite	28	17	24	13	23	9	19	17	16	11	20	20	20	18	18	10	17	19	21	26	365	
	Dica-silicate	30	17	22	13	31	12	18	17	16	8	15	17	22	16	13	9	18	14	18	29	355	
	Average	26	17	23	14	24	11	21	18	17	10	18	20	21	16	16	10	17	18	20	27	366	
B	Burnt lime	22	16	22	13	28	10	26	17	15	10	17	22	20	18	16	11	17	21	26	25	372	19
	Limestone	25	13	22	12	31	8	22	17	16	10	24	23	18	19	11	11	17	22	24	24	362	
	Dolomite	27	18	23	12	27	10	26	20	16	10	18	22	15	17	16	10	17	18	23	23	368	
	Dica-silicate	29	15	22	12	29	10	21	20	16	9	23	26	16	17	14	12	18	17	24	29	379	
	Average	26	16	22	12	29	10	24	19	16	10	21	24	17	18	14	11	17	18	24	25	370	
C	Burnt lime	21	16	21	13	31	9	23	20	17	10	23	25	16	18	16	10	24	18	24	28	388	33
	Limestone	24	14	22	12	28	11	26	20	16	10	23	30	16	18	19	12	19	15	22	32	389	
	Dolomite	26	18	23	12	28	8	25	19	15	10	21	29	16	17	14	12	17	17	22	30	380	
	Dica-silicate	26	15	22	13	24	9	25	19	16	11	21	29	17	19	16	13	18	18	23	25	379	
	Average	24	16	22	13	28	9	25	20	16	10	23	28	16	18	16	12	20	17	23	29	384	
D	Burnt lime	25	17	21	13	27	9	20	19	17	10	18	23	17	18	15	13	18	19	20	27	366	21
	Limestone	23	16	22	15	29	9	25	19	16	10	17	30	16	17	17	14	15	16	21	26	373	
	Dolomite	25	17	22	14	28	10	24	16	17	10	15	24	16	19	18	15	15	16	21	33	375	
	Dica-silicate	24	16	20	13	24	11	24	17	15	10	17	24	16	19	17	20	16	17	21	32	373	
	Average	24	17	21	14	27	10	23	18	16	10	17	25	16	18	17	16	16	17	21	30	372	
E	Burnt lime	22	13	26	12	25	11	24	18	16	10	21	22	18	18	18	14	16	22	21	34	387	32
	Limestone	21	15	24	12	27	11	24	18	14	10	20	21	17	16	18	14	15	18	21	37	373	
	Dolomite	26	14	25	13	27	9	24	19	15	10	24	18	16	15	15	13	17	19	23	37	379	
	Dica-silicate	22	13	25	12	27	9	25	17	16	10	26	28	17	16	20	16	18	20	23	37	397	
	Average	23	14	25	12	27	10	24	18	15	10	23	22	17	16	18	14	17	20	22	36	383	
F	Burnt lime	17	17	19	12	27	7	24	16	15	10	23	18	21	17	13	12	16	19	22	36	361	21
	Limestone	24	15	23	12	27	8	25	17	15	10	28	18	23	17	14	16	16	21	22	35	386	
	Dolomite	26	16	23	12	22	10	24	14	15	10	18	14	22	16	14	15	17	14	23	38	363	
	Dica-silicate	26	21	23	12	24	11	25	13	16	10	21	17	23	17	14	11	16	16	24	37	377	
	Average	24	17	22	12	24	9	25	15	15	10	23	17	22	17	14	14	16	18	23	36	372	
G	Burnt lime	22	16	22	12	28	11	25	15	15	10	39	19	22	16	13	11	17	18	28	31	390	32
	Limestone	18	15	21	12	25	11	25	14	17	10	19	23	21	16	15	15	18	15	22	30	362	
	Dolomite	22	17	21	12	30	11	25	16	15	10	27	16	23	17	14	12	16	15	25	33	377	
	Dica-silicate	26	16	23	11	27	11	25	15	15	11	30	29	23	17	18	15	17	16	21	37	403	
	Average	22	16	22	12	28	11	25	15	15	10	29	22	22	17	15	13	17	16	24	33	383	
Control Control	None	21	14	20	19	24	11	18	19	17	8	13	22	21	14	13	10	14	19	23	19	339	32
	None	21	16	19	19	28	10	19	18	15	8	16	14	21	16	17	12	14	23	21	35	362	
	Average	21	15	20	19	26	10	19	19	16	8	15	18	21	15	15	11	14	21	22	27	351	
Rainwater		14	24	26	16	17	12	15	10	12	11	17	7	9	20	9	9	6	14	33	43	324	