

THE UNIVERSITY OF TENNESSEE
AGRICULTURAL EXPERIMENT STATION

BULLETIN No. 152*

APRIL, 1934

THE CONSERVATION OF BURNT LIME, LIMESTONE,
DOLOMITE, AND CALCIUM SILICATE IN
SOIL AS INFLUENCED BY METHODS
OF INCORPORATION

By

W. H. MACINTIRE, W. B. ELLETT, W. M. SHAW, AND H. H. HILL



KNOXVILLE, TENNESSEE

*Presented also as Technical Bulletin 54 of the Virginia Agricultural Experiment Station.

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THE CONSERVATION OF BURNT LIME, LIMESTONE, DOLOMITE, AND CALCIUM SILICATE IN SOIL AS INFLUENCED BY METHODS OF INCORPORATION*

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INTRODUCTION

To insure a rational scheme for liming, it is essential that the activities of liming materials in the soil be fully understood. Many facts have been developed in regard to the liming of soils, but much is still to be learned. This is true of both the theory and the practice. Many of the older beliefs and teachings were deductions, and some of these have been shown to be incorrect. Certain of the virtues formerly attributed to liming materials in general have been shown to be nonexistent. Likewise, it has been shown that some of the supposed harmful effects, such as the "burning" of organic matter by caustic lime, do not occur (13).

There are many ramifications in the judicious use of lime under humid conditions. In general, liming is beneficial, and the benefits have been attributed to chemical, bacterial, mechanical, and nutritive effects with varying emphasis. Under some circumstances, however, liming may induce conditions favorable to the development of noxious organisms and bring about certain chemical activities detrimental to plant growth, especially in the case of specific crops. It is essential, therefore, to recognize the possibility of harmful effects from the injudicious use of a valuable agency of soil fertility.

The optimal economic rate of an initial liming, and frequency and rate of repetitions, will vary with the nature of the soil and the crop. The form of lime—oxide, hydroxide, and carbonate—and the type of material—high-calcic, high-magnesian, or dolomitic—are likewise factors of importance. Caustic forms become a part of the soil system more rapidly than do the natural carbonates, and the degree of fineness determines the speed with which solution and fixation of a limestone takes place (15,16,21,34). The rapidity of solution and disintegration of limestone particles is a function of the season (24), and the conservation of added lime is materially influenced by the zone of incorporation (16,21). These points are of especial importance in comparisons between limestone and dolomite. The former is dissolved more rapidly than the latter in the solvents that function in the soil, but in heavy types of soil the difference may be minimized to an academic degree when finely-ground products are compared (34).

When liming to correct acidity and its corollary condition—insufficiency of bases—two broadcasting methods of procedure may be followed to supply the same amount of lime to a soil during a given period. The first method calls for an initial treatment to bring the soil quickly to an optimal condition.

*An 8-year lysimeter study conducted jointly by the Tennessee and Virginia Experiment Stations.

The second method calls for the addition of successive fractions of a full treatment. In the first method, for example, one 2000-pound addition of CaO-equivalence would be made as a treatment to cover a 4-year period, or longer, whereas the same total addition might be made by a 500-pound initial treatment with repetitions at the end of the first, second, and third years. The first procedure calls for a larger initial financial outlay, with probability of greater immediate plant response. The second procedure calls for a smaller initial outlay with probable delay in the obtaining of maximal crop response. When single light limings are adequate, the second procedure admits of the simultaneous drilling in of mixtures of fertilizers, with either limestone or dolomite. In both cases the initial betterment would be maintained by further additions to offset the depletion factors of (a) leaching outgo, which includes neutralization of biologically engendered acids; (b) assimilation by plants; and (c) decreased availability through progressive decrease in the solubility of the absorbed lime. The ameliorating factors of full-depth and surface-zone incorporations and the comparative activities of chemically equivalent quantities of the several liming materials also needed to be considered.

Objective: The primary intent was to study the conservation of four liming materials in the soil by determining the specific activities and relative merits of full and divided initial treatments, full and divided repetitions, and full-depth and surface-zone incorporations. Especial consideration will therefore be given to the outgo of calcium and magnesium. Information thus obtained should have a distinct value as guidance in the planning of plat experiments relating to the judicious use of different liming materials in the economic practice of liming.

Taking as a background some of the results obtained in the many years of research of the lime problem at the Tennessee Station, summarized by Mooers (36), and those at the Virginia Station (7,8), a lysimeter study was instituted to determine the fate and chemical activities of, and the bacterial effects induced by, four different liming materials incorporated in full and fractional quantities in typical Tennessee and Virginia soils over an 8-year period.

PLAN OF EXPERIMENT

Duration: The project was inaugurated simultaneously at Knoxville and Blacksburg during the first week of August, 1924, to extend over an 8-year period.

Soils: The Tennessee soil was a brown Cumberland clay loam of moderate fertility and had a relatively low content of bases. It was chiefly derived *in situ* from dolomite, but in part from an ancient alluvial deposit, and has been found well adapted to general farm crops, and also to alfalfa, when limed. For about 30 years it had been in bluegrass sod, which was skimmed off before the required amount of soil was taken. The Virginia soil, previously described (3), is a gray-black Onslow fine sandy loam, slightly heavier than the Norfolk series, not so fertile nor so well drained, and responds to heavy applications of complete fertilizers. The quantity of soil used in each lysimeter was equivalent to 100 pounds, moisture-free basis. The analyses of the two soils are given in table 1.

Lysimeters: The 62 lysimeters were each of 1/20,000-acre area. They were of identical construction, of 14-gauge "Ingot" iron, painted with asphaltum paint and provided with ground-quartz filter beds, upon which the soils

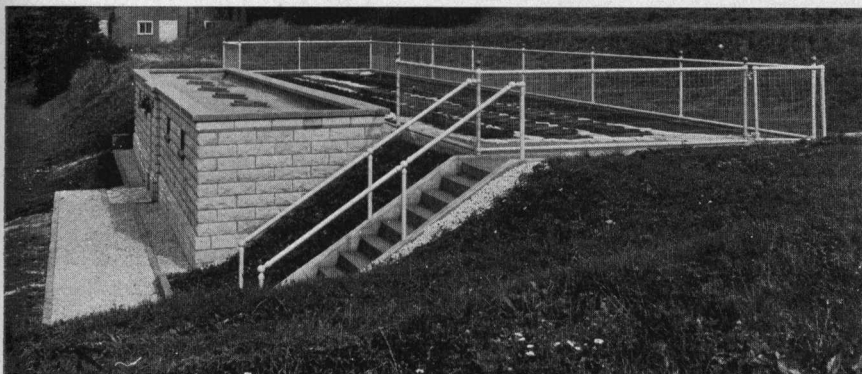


Plate I.—Exterior and interior views of the lysimeter equipment at the Tennessee Agricultural Experiment Station

were laid. It should be emphasized that the contents of leachings therefore represent *the actual losses from the surface soil*, since the leachings passed directly to the containers, unaffected by subsoil.

Liming Materials: Chemically equivalent quantities of high-calcic burnt lime, limestone, dolomite, and leached “di-calcium silicate,” each of 100-mesh fineness, were used in each comparison at the unit rate of 2000 pounds CaO-equivalence, or 3570 pounds CaCO_3 -equivalence, and at the fractional rate of 500 pounds of CaO, or 893 pounds of CaCO_3 . The neutralizing value against standard acid and the calcium and magnesium contents were determined for

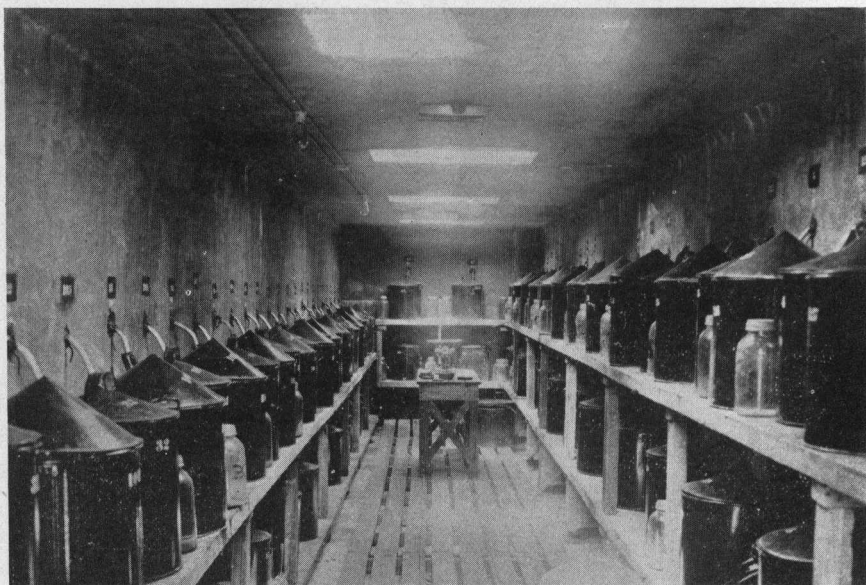
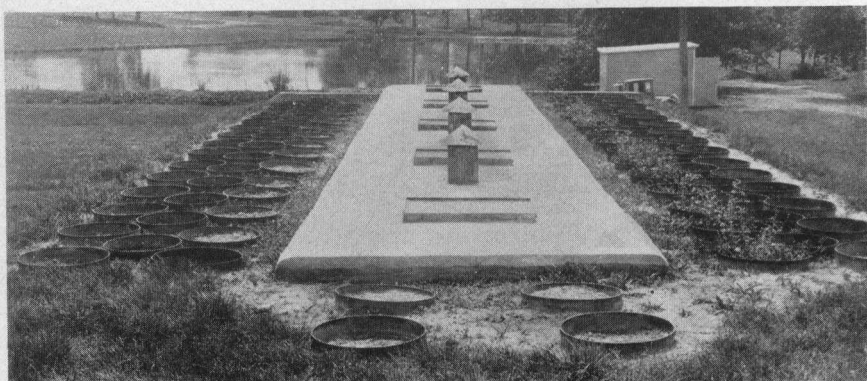


Plate II.—Exterior and interior views of the lysimeter equipment at the Virginia Agricultural Experiment Station

each material. The burnt lime had a CaO value of 93.78 per cent, and a magnesia content equivalent to 2.07 per cent CaCO_3 . The limestone contained 92.52 per cent CaCO_3 , and MgCO_3 equivalent to 4.50 per cent CaCO_3 . The Knox dolomite contained 49.85 per cent CaCO_3 and 38.63 per cent MgCO_3 , an equivalent ratio of 1.08:1. The "di-calcium silicate" was a by-product material obtained from the Electric Smelting and Aluminum Company, of Sewarren, New Jersey. This product was leached to remove soluble salts, and the free lime content was thereby reduced. The leached material contained 43.37 per cent CaO , magnesia equivalent to 3.48 per cent CaO and 14.39 per

cent silica. The lime and magnesia content gives a total CaO-equivalence of 46.85 per cent, against the computed value of 48.3 per cent for the normal silicate, CaSiO_3 . All of the liming materials required for the 8-year period at both stations were analyzed, and each full charge and each fraction was segregated in a sealed individual container before the project was begun.

Methods of Incorporation: There were seven group comparisons, designated as series A to G, inclusive.

Series A: The full unit treatments of 2000 pounds of CaO-equivalence, or 3570 pounds of CaCO_3 , were incorporated throughout the entire body of soil in August, 1924, and left undisturbed until August, 1928, at which time each unit was removed, and without additional liming the soil was given the same handling required for the re-liming of series B and C. This series was therefore identical with series B and C for the first four years; and, save for the repetition of the liming treatments, identical with series B thereafter.

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

Series C: This series was parallel with series A and B for the first four years. It then received annual quarter-additions of 500 pounds CaO-equivalence, mixed throughout the soil. Hence, it differed from series A and B in the aeration incident to the last three incorporations made during the second 4-year period.

Series D: This series received the quarter-additions, mixed throughout the soil initially and again at the beginning of each of the next three years. There were no further additions during the next four years, but the soil was taken up and given the same aeration required for the treatments of series E.

Series E: This series was identical with series D for the first four years, but it received during the 8-year period twice the liming given series D, since series E received a quarter-addition annually during the second four years.

Series F: This series received single full additions mixed throughout the upper third of the soil, without further additions or aeration during the second 4-year period. Both upper and lower zones were removed and mixed 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: In this series the liming materials were incorporated with only the upper third of the soil. During the first four years, the total amounts

TABLE 1.—*Chemical analyses of the Tennessee Cumberland clay loam and the Virginia Onslow fine sandy loam*

Soil	pH, 1-5 aqueous suspension	Car- bon- ate CO ₂	Total nitro- gen	Total sul- fur	Acid soluble (c)			Exchangeable (a), per cent CaCO ₃ -equivalence					Un- sat- uration, per cent
					CaCO ₃ ⇌		K	Ca	Mg	K	H	Capac- ity (b)	
					Ca	Mg							
Tennessee	6.4	.020	.144	.049	.234	.628	.197	.180	.056	.024	.230	.490	48
Virginia	5.2	.003	.057	.028	.073	.076	.026	.058	.007	.006	.199	.270	74

(a) Hissink method; (b) by ammonium acetate; (c) 1.115 HCl digestion.

incorporated were the same as the single initial additions in series F, but the additions to series G were divided into four equal annual additions. The soils were not disturbed during the second 4-year period, as in the case of series F.

Controls: Controls were afforded to correspond to the manipulations given for single treatments and repetitions. Rainfall was collected in blank containers and analyzed to determine increments derived from that source.

PROPORTIONS OF RAINFALL LEACHED

The soils received no water, except rainfall. The amounts of rainfall and the proportions that passed through the soils of the several groups are given for the Tennessee and Virginia soils in tables 2a and 2b, respectively.

The rainfall at the Tennessee Station was equivalent to 197.1 inches and 171.8 inches for the first and second 4-year periods. The amounts that passed from the control for series A, B, and C were 45.8 per cent and 51.3 per cent during the first and second 4-year periods. At the Virginia Station corresponding drainage values of 41.2 per cent and 51.1 per cent were obtained from rainfall totals of 135.3 inches and 125.4 inches. The leachings from series A-E of the heavy Tennessee soil were increased over the untreated soil for both 4-year periods. The reverse was consistently true for the Virginia soil during the first 4-year period, but during the second 4-year period the lime treatments gave a slight increase in the volumes of the leachings. There were no marked nor consistent differences indicated for the different liming materials for either soil in the series A-E.

The more frequent manipulation of the unlimed soil caused a greater leaching volume for the heavy Tennessee soil during the first 4-year period, but a reverse effect was shown for the sandy Virginia soil. The differences due to manipulation in the unlimed soil were small for both soils during the second 4-year period. The surface-zone incorporations showed no appreciable effect upon the leachings from either soil during the first four years, whereas there was some enhancement in the volumes from both soils during the second 4-year period.

Liming is supposed to exert a material effect upon the physical structure of a soil and thus to influence its drainage; but on the whole, no marked effect on the volumes leached was shown by the liming materials. It should be remembered, however, that the vitiating effects of varying quantities of organic matter from plant residues were not encountered, since the soils were kept fallow during the 8-year period. Although the factor of variations in leachate volumes was not a primary objective, the comparisons by groups demonstrate the uniformity of the leaching volumes from a constant quantity of soil obtained from a well-mixed bulk and placed in identical free-draining containers.

OUTGO OF CALCIUM

The amounts of calcium leached from the two soils each year are given in tables 3a and 3b. All values for calcium, magnesium, and carbonates will be expressed throughout in terms of CaCO_3 -equivalence.

The analyses of the rainwaters at each Station show an income of calcium that represents a considerable fraction of the calcium leached from the untreated soil. This increment is derived mainly from calcium sulfate carried

TABLE 2a.—Amounts of percolates from the Tennessee Cumberland clay loam, as influenced by four liming materials and different methods of incorporation during an 8-year period

Treatments			Percolates—pounds per tank										Total 8-year period
	Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period					
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	353	598	631	650	2232	696	343	410	495	1944	4176
	.....	None	158	251	342	272	1023	325	221	167	305	1018	2041
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	166	267	355	293	1081	352	239	193	307	1091	2172
		Limestone	163	264	349	295	1071	365	247	197	317	1126	2197
		Dolomite	164	273	348	293	1078	367	250	204	321	1142	2220
Series B	Same as series A for first four years; 2000-pound full-depth additions re- peated at beginning of 5th year.	Calcium silicate	166	266	361	294	1087	362	248	200	321	1131	2218
		Burnt lime	164	267	351	281	1063	359	244	196	307	1106	2169
		Limestone	159	260	343	281	1043	350	241	194	305	1090	2133
		Dolomite	159	271	359	290	1079	401	261	228	326	1216	2295
		Calcium silicate	169	283	362	297	1111	415	268	233	340	1256	2367
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	161	263	348	284	1056	367	237	180	269	1053	2109
		Limestone	165	262	350	282	1059	371	232	176	268	1047	2106
		Dolomite	164	264	355	281	1064	375	243	190	287	1095	2159
		Calcium silicate	162	272	354	288	1076	392	250	197	288	1127	2203
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment, and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	163	250	347	308	1068	414	260	202	323	1199	2267
		Limestone	167	262	350	289	1068	402	254	192	313	1161	2229
		Dolomite	161	260	352	299	1072	409	265	212	326	1212	2284
		Calcium silicate	162	250	342	285	1039	409	264	211	300	1184	2223
Series E	Same as series D for first four years; 500-pound full-depth additions at be- ginning of 5th, 6th, 7th, and 8th years.	Burnt lime	166	258	345	288	1059	396	253	208	300	1157	2214
		Limestone	157	252	346	282	1037	416	270	231	326	1243	2280
		Dolomite	158	254	340	292	1044	392	259	216	309	1176	2220
		Calcium silicate	167	256	346	299	1068	410	264	224	312	1210	2278
Series F	.....	None	171	269	355	297	1092	380	257	194	299	1130	2222
	2000-pound CaO-equivalent mixed with upper three inches of soil at be- ginning of experiment. No further additions.	Burnt lime	162	261	351	299	1073	389	258	216	332	1195	2268
		Limestone	164	267	350	297	1078	386	249	194	321	1150	2228
		Dolomite	161	258	351	292	1062	384	254	219	332	1189	2251
		Calcium silicate	156	259	349	288	1052	385	254	204	299	1142	2194
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	152	255	341	281	1029	369	252	191	304	1116	2145
		Limestone	165	267	351	288	1071	378	254	209	316	1157	2228
		Dolomite	169	264	345	291	1069	388	254	200	321	1163	2232
		Calcium silicate	161	247	342	280	1030	378	253	197	315	1143	2173
Rainfall, acre inches.....			31.1	52.9	55.7	57.4	197.1	61.5	30.3	36.2	43.8	171.8	368.9

TABLE 2b.—Amounts of percolates from the Virginia Onslow fine sandy loam as influenced by four liming materials and different methods of incorporation during an 8-year period

Treatments			Percolates—pounds per tank										
Amounts and methods of incorporation		Material	First 4-year period					Second 4-year period					Total 8-year period
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	345	294	478	406	1523	461	280	297	383	1421	2944
	.....	None	142	121	213	152	628	234	161	127	204	726	1354
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	138	107	210	152	607	237	162	127	209	735	1342
		Limestone	130	101	206	152	589	238	162	128	213	741	1330
		Dolomite	138	104	215	152	609	238	162	128	214	742	1351
Calcium silicate		141	108	207	152	608	239	162	128	205	734	1342	
Series B	Same as series A for first four years; 2000-pound full-depth additions repeated at beginning of 5th year.	Burnt lime	147	104	212	153	616	238	163	128	211	740	1356
		Limestone	132	103	208	149	592	238	162	128	213	741	1333
		Dolomite	133	100	216	148	597	239	163	134	215	751	1348
		Calcium silicate	132	96	212	150	590	239	163	128	211	741	1331
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	133	99	213	149	594	239	163	128	212	742	1336
		Limestone	143	102	213	148	606	237	162	128	210	737	1343
		Dolomite	142	107	217	149	615	241	162	128	213	744	1359
		Calcium silicate	128	107	213	152	600	239	162	128	209	738	1338
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	136	114	213	149	612	240	163	128	213	744	1356
		Limestone	133	110	215	150	608	239	163	128	210	740	1348
		Dolomite	138	111	214	150	613	237	164	128	211	740	1353
		Calcium silicate	141	112	213	148	614	237	162	128	212	739	1353
Series E	Same as series D for first four years; 500-pound full-depth additions at beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	137	95	209	149	590	238	161	128	201	728	1318
		Limestone	129	99	213	148	589	239	162	128	202	731	1320
		Dolomite	130	98	212	149	589	237	162	128	203	730	1319
		Calcium silicate	136	100	214	148	598	237	162	128	202	729	1327
Series F	.....	None	129	102	210	145	586	232	160	127	192	711	1297
	2000-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment. No further additions.	Burnt lime	125	95	213	146	579	237	161	128	197	723	1302
		Limestone	127	97	212	147	583	237	162	128	197	724	1307
		Dolomite	128	94	209	147	578	237	162	128	199	726	1304
		Calcium silicate	130	96	204	147	577	236	162	128	199	725	1302
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	130	97	215	147	589	235	163	128	200	726	1315
		Limestone	122	88	202	146	558	236	162	128	202	728	1286
		Dolomite	127	88	209	147	571	236	162	128	204	730	1301
		Calcium silicate	114	80	210	146	550	238	162	128	203	731	1281
Rainfall, acre inches			30.5	26.7	42.2	35.9	135.3	40.7	24.7	26.2	33.8	125.4	260.7

by smoke and from the carbonates and silicates of road dust, and it may amount to a considerable part of the outgo. The larger amount of total calcium found in the rainwater at Knoxville is attributable to the proximity of commercial industries and railroads. The absolute, or net, losses of calcium from the unlimed soils are therefore the differences between the losses shown for the controls and the amounts carried by the rainwaters. In the interpretation of lysimeter data this point is often ignored. It should therefore be stressed that the *outgo* of calcium, and also that of magnesium, is different from the *net loss*. When the annual increment from this source is subtracted from the 2374 pounds of calcium leached from the unlimed controls, the net loss from the unlimed Tennessee soil is reduced to 1476 pounds, or 185 pounds per annum. In the discussion of the amounts of calcium and magnesium leached from the limed soils, the term *outgo* will be used to designate the actual amount leached, whereas the *net loss* will be the amount in excess of that leached from the unlimed soil.

The exchangeable calcium from the clay loam, 47 per cent unsaturated, is equivalent to 77 per cent of the total calcium content, and from parallel studies with the same soil it was known that most of the first year was required for the complete transformation of the full carbonate treatments into fixed soil combinations. At the Tennessee Station the minimal annual rainfall of the first 4-year period came during the first year. Hence, if only limestone and dolomite were involved, the smaller losses of calcium for the first year from the full treatments of series A, B, and C, as compared with the losses for the second year, would be attributable to the two factors, speed of limestone disintegration and a smaller rainfall. But the losses from the three burnt-lime units that were known to be fixed within 10 days (13) and the losses from the three calcium silicate units showed the same relationships for the first two years. Hence, it is evident that the dominant factor in the greater outgo of calcium during the second year was that of greater rainfall, with the attendant greater bacterial activities recorded for the second year in tables 6a and 9a. For the first 4-year period, the losses from the calcium silicate were comparable with, although somewhat less than, those from burnt lime and from high-calcic limestone.

The repetition of the full treatments of burnt lime and of limestone gave decided increase in calcium outgo during the second 4-year period, the totals from the two materials being almost identical. The repetition of the calcium silicate treatment also enhanced the outgo of calcium, but the losses from this treatment continued somewhat less than those from the caustic and carbonate forms. The effects of full and divided additions, and zone of their incorporations, upon cumulative outgo of calcium from the silicate are shown for both soils in Fig. 4. The natural silicate Wollastonite was compared with calcium carbonate in chemical and plant-growth studies by MacIntire and Willis (19) and similar comparisons have since been made by other workers. The present by-product silicate has been studied most extensively by Barnette (3,4,5). Recently, Midgely (35) reported that calcium silicate served to counteract the toxicity induced in a heavy soil by large additions of calcium carbonate.

Each of the seven dolomite additions induced an outgo of calcium somewhat greater than that from the untreated soil during the first four years,

TABLE 3a.—*Outgo of calcium from the Tennessee Cumberland clay loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

	Treatments	Material	Pounds CaCO ₃ -equivalent per 2,000,000 pounds of soil										Total 8-year period
	Amounts and methods of incorporation		First 4-year period					Second 4-year period					
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	60	195	74	88	417	115	115	150	101	481	898
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	None	309	515	319	273	1416	325	179	216	211	981	2347
		Burnt lime	510	843	519	569	2441	455	262	339	270	1326	3767
		Limestone	645	827	503	544	2519	409	259	287	284	1239	3758
		Dolomite	429	620	411	405	1865	334	210	221	207	972	2837
Series B	Same as series A for first four years; 2000-pound full-depth additions repeated at beginning of 5th year.	Calcium silicate	549	747	497	501	2294	421	271	284	238	1214	3508
		Burnt lime	490	901	518	516	2425	957	431	416	396	2200	4625
		Limestone	610	945	518	549	2622	909	437	349	375	2070	4692
		Dolomite	423	634	359	379	1795	550	285	278	255	1368	3163
		Calcium silicate	512	777	450	502	2241	831	372	434	365	2002	4243
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	512	907	579	533	2531	532	374	445	493	1844	4375
		Limestone	618	807	556	541	2522	520	359	472	470	1821	4343
		Dolomite	430	620	403	370	1823	394	272	326	331	1323	3146
		Calcium silicate	529	806	526	515	2376	459	365	426	433	1683	4059
	Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	355	726	640	624	2345	448	311	335	277	1371	3716
		Limestone	395	752	592	641	2380	423	279	326	269	1297	3677
		Dolomite	342	605	487	485	1919	303	209	250	185	947	2866
		Calcium silicate	428	687	592	562	2269	417	285	308	252	1262	3531
Series E		Same as series D for first four years; 500-pound full-depth additions at beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	352	704	607	630	2293	579	376	483	533	1971	4264
		Limestone	388	704	643	635	2370	550	365	489	478	1882	4252
		Dolomite	336	585	491	478	1890	389	246	315	265	1215	3105
		Calcium silicate	344	667	598	629	2238	519	337	462	420	1738	3976
	Series F	2000-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment. No further additions.	None	319	572	346	321	1558	259	180	208	195	842	2400
		Burnt lime	370	713	504	538	2125	371	224	177	201	973	3098
		Limestone	411	750	501	442	2104	340	212	228	238	1018	3122
		Dolomite	376	631	429	401	1837	281	163	162	149	755	2592
		Calcium silicate	388	692	474	476	2030	324	193	220	187	924	2954
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	330	635	433	459	1857	344	217	179	249	989	2846
		Limestone	346	639	472	403	1860	356	211	171	241	979	2839
		Dolomite	338	613	385	369	1705	276	165	156	175	772	2477
		Calcium silicate	341	614	434	461	1850	333	217	216	240	1006	2856
		Rainfall, acre inches	31.1	52.9	55.7	57.4	197.1	61.5	30.3	36.2	43.8	171.8	368.9

TABLE 3b.—*Output of calcium from the Virginia Onslow fine sandy loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

Treatments			Pounds CaCO ₃ -equivalent per 2,000,000 pounds of soil										
	Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period					Total 8-year period
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	37	49	80	51	217	86	113	61	81	341	558
	.....	None	162	93	106	128	489	240	111	128	125	604	1093
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	354	136	228	217	935	366	181	186	249	982	1917
		Limestone	356	163	232	235	986	354	174	191	180	899	1885
		Dolomite	165	78	194	85	522	255	107	123	142	627	1149
Calcium silicate		221	78	145	150	594	359	169	181	194	903	1497	
Series B	Same as series A for first four years; 2000-pound full-depth additions repeated at beginning of 5th year.	Burnt lime	268	116	212	230	826	630	308	324	347	1609	2435
		Limestone	372	102	214	222	910	636	317	317	298	1568	2478
		Dolomite	187	60	185	75	507	304	143	167	203	817	1324
		Calcium silicate	210	88	143	156	597	642	301	276	269	1488	2085
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	306	106	228	214	854	386	246	139	324	1095	1949
		Limestone	291	92	229	215	827	387	251	141	229	1008	1835
		Dolomite	156	78	189	89	512	231	153	135	140	659	1171
		Calcium silicate	245	77	146	157	625	376	251	117	258	1002	1627
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	219	121	249	217	806	367	191	216	186	960	1766
		Limestone	190	107	252	214	763	287	194	165	157	803	1566
		Dolomite	135	74	184	86	479	216	99	93	112	520	999
		Calcium silicate	186	102	140	155	583	326	200	156	167	849	1432
Series E	Same as series D for first four years; 500-pound full-depth additions at beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	174	93	248	214	729	436	236	252	288	1212	1941
		Limestone	284	106	244	210	844	352	242	256	235	1085	1929
		Dolomite	126	70	176	113	485	281	177	139	128	725	1210
		Calcium silicate	165	89	152	142	548	369	251	256	194	1070	1618
Series F	.....	None	144	63	101	135	443	212	121	124	99	556	999
	2000-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment. No further additions.	Burnt lime	206	126	237	215	784	257	171	183	161	772	1556
		Limestone	159	108	241	216	724	264	177	185	147	773	1497
		Dolomite	132	59	191	105	487	139	100	121	71	431	918
		Calcium silicate	167	73	148	140	528	263	156	183	114	716	1244
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	197	86	246	209	738	259	172	213	149	793	1531
		Limestone	146	88	247	210	691	270	181	172	151	774	1465
		Dolomite	140	56	197	86	479	159	100	90	67	416	895
		Calcium silicate	180	55	156	138	529	248	165	161	128	702	1231
Rainfall, acre inches			30.5	26.7	42.2	35.9	135.3	40.7	24.7	26.2	33.8	125.4	260.7

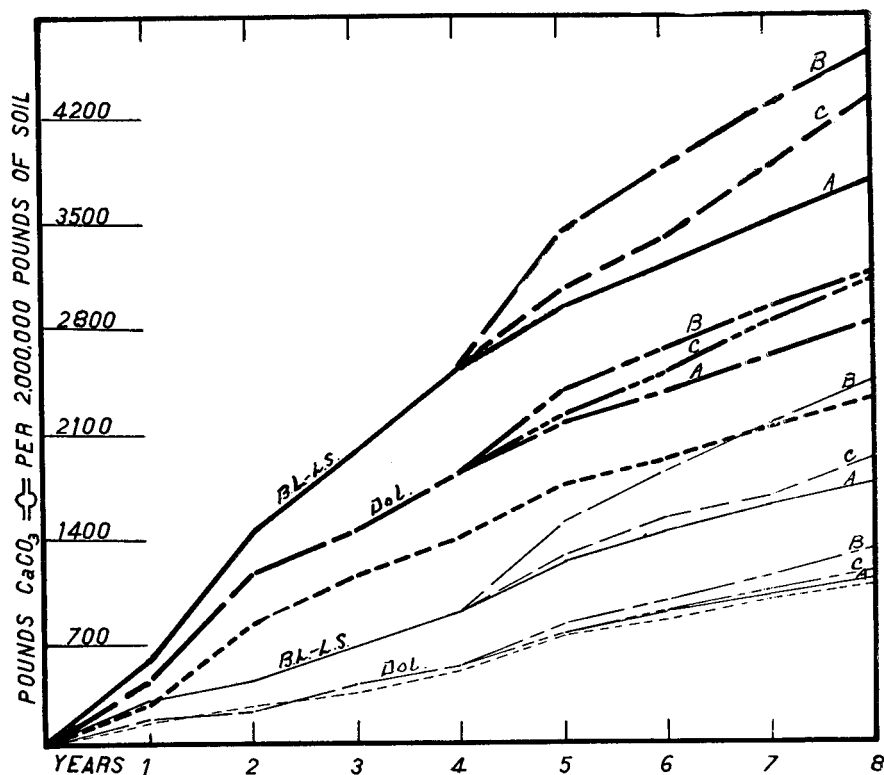


Fig. 1.—Cumulative outgo of calcium from burnt lime and limestone, averaged, and from dolomite, full-depth incorporations.

Series A, 3570-pound CaCO_3 $\diamond$, 1924; no further treatment.

Series B, 3570-pound CaCO_3 $\diamond$, 1924 and 1928.

Series C, 3570-pound CaCO_3 $\diamond$, 1924, and four annual quarter-additions, 1928-1932.

Heavy lines, Cumberland clay loam.

Light lines, Onslow fine sandy loam.

Unlimed soil - - - - -

but materially less than each loss induced by the corresponding high-calcic treatments. On the contrary, no increase in calcium outgo was found for full-depth incorporations of dolomite made in another experiment with the same soil after its supply of exchangeable calcium had been materially reduced by cropping and cultivation. In that experiment dolomite additions were found to give no increases, and even decreases, in the outgo of calcium (29). In the case of series A, D, F, and G, where no additions were made after the first 4-year period, dolomite failed to show an increase in calcium outgo, an actual depression being evidenced by the surface-zone incorporations of series F and G.

The eight annual additions of the high-calcic materials in series E showed calcium losses slightly less than those found for the full initial and subsequent fractional-treatment repetitions of series C, and considerably less than those of series B, in which full incorporations were made at the beginning of the first and the fifth year. The losses from the eight incorporations of series E

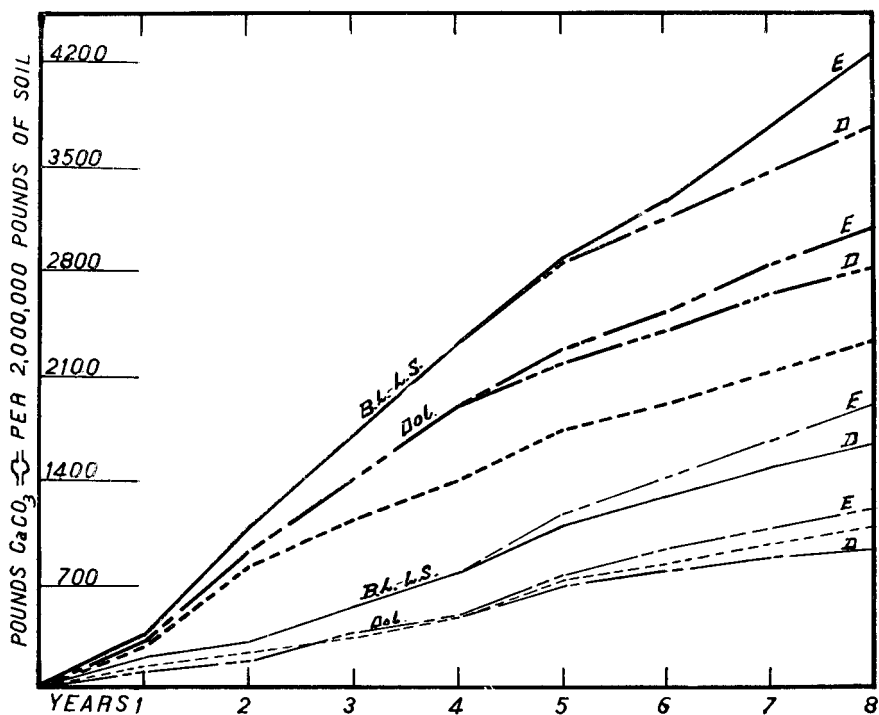


Fig. 2.—Cumulative outgo of calcium from burnt lime and limestone, averaged, and from dolomite, full-depth incorporations.

Series D, 3570-pound CaCO_3 $\diamond$, in four quarter-additions, 1924-1928.

Series E, 7140-pound CaCO_3 $\diamond$, in eight quarter-additions, 1928-1932.

Heavy lines, Cumberland clay loam.

Light lines, Onslow fine sandy loam.

Unlimed soil - - - - -

were greater than those from the four quarter-additions given series D, but not proportionate to the double treatment.

In comparison with the full-depth incorporations of series A, the surface-zone full additions of series F showed, for each liming material, a somewhat smaller outgo of calcium for each annual period. During the first four years each of the four annual quarter-incorporations of series G showed consistently a smaller calcium outgo than was found for the corresponding unit of series F; but there was a close parallel between the two series thereafter. From comparisons between series A and F and between series D and G, it is evident that the outgo of calcium from incorporations in the surface zone was materially less than the outgo of calcium from the full-depth incorporations for both the full units and quarter fractions.

Since the losses from burnt lime and limestone were so concordant, they were averaged and given jointly against the calcium outgo from dolomite in the graphic showing of the cumulative outgo in Figs. 1, 2, and 3. The speed of the outgo of calcium from the burnt lime, limestone, and dolomite units of series A, B, and C, and from the untreated soils, is shown in Fig. 1; for series D and E in Fig. 2; and for series F and G in Fig. 3, for both soils. The

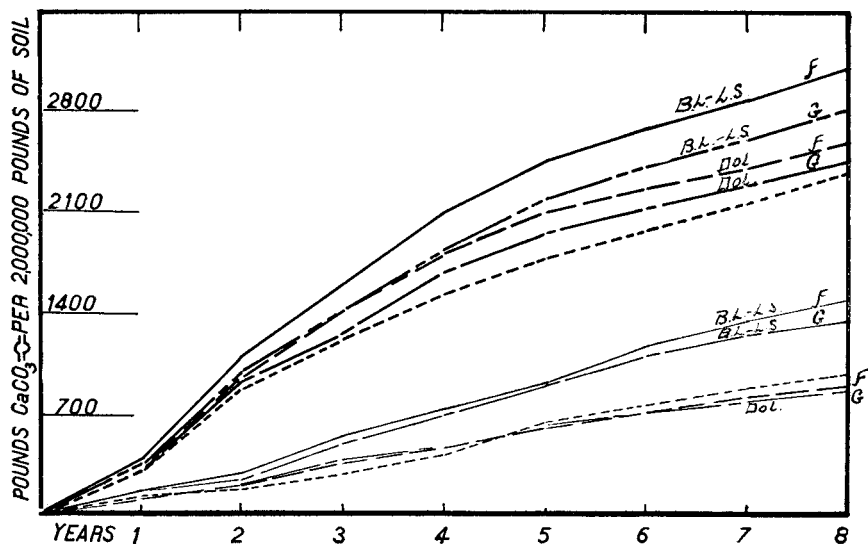


Fig. 3.—Cumulative outgo of calcium from burnt lime and limestone, averaged, and from dolomite, surface-zone incorporations.

Series F, 3570-pound CaCO_3 $\circ$, single addition 1924; no further treatment.

Series G, 3570-pound CaCO_3 $\circ$, four quarter-additions, 1924-1927; no further treatment.

Heavy lines, Cumberland clay loam.

Light lines, Onslow fine sandy loam.

Unlimed soil -----

cumulative losses from calcium silicate are given for all series and for both soils in Fig. 4.

The calcium results from the fine sandy loam differ in several particulars from those found for the heavy Tennessee soil that contained more than three times as much total and also exchangeable calcium. The unlimed Virginia soil, 74 per cent unsaturated, suffered an annual net loss of only 61 pounds CaCO_3 -equivalence, or one-third of the corresponding net loss from the unlimed Tennessee soil.

The volumes of the leachings and calcium losses for the second year were uniformly less than the corresponding values for the other three years of the first 4-year period. The calcium outgo from the silicate material was uniformly and materially less than that from each of the other two high-calcic materials. This difference was decidedly more pronounced during the first 4-year period. The increases of calcium outgo were small for the dolomite in each of the series A, B, and C, during the first 4-year period, and also for series A and C during the second 4-year period. For the 8-year period the maximal net loss of calcium from dolomite came from the two full treatments of series B, and was equivalent to 29 per cent of the average found for burnt lime and limestone in series A and C. The four supplemental quarter-additions of series C did not increase the total outgo of calcium over the amount for the single full-unit treatment of series A.

Differing from the Tennessee soil, the Virginia soil showed no marked increase in calcium outgo derived from the annual quarter-additions of dolomite incorporated at full depth during the second 4-year period. The calcium

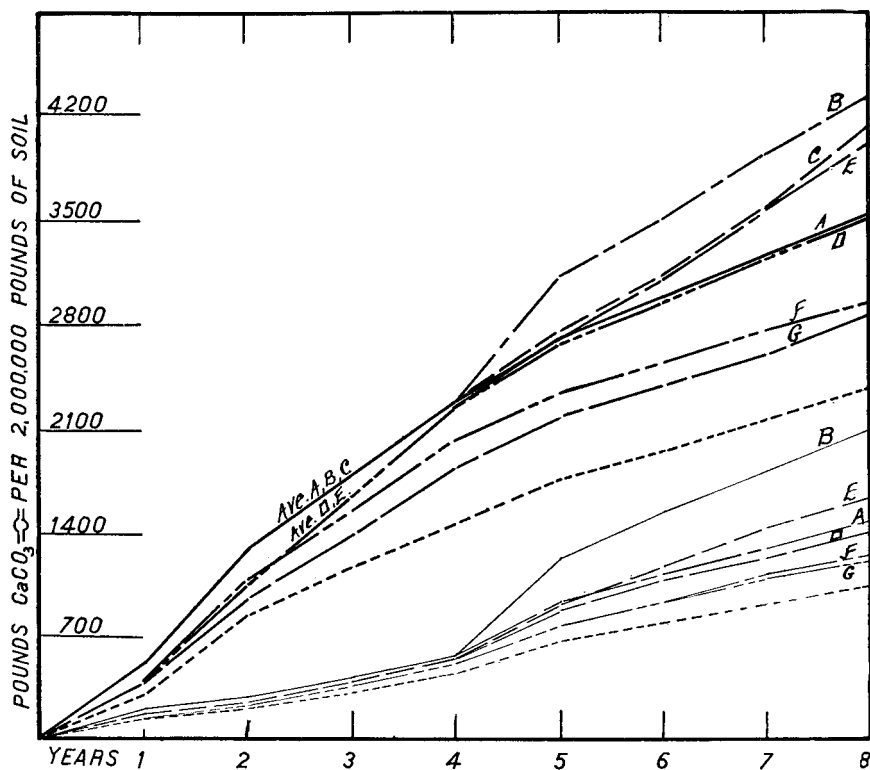


Fig. 4.—Cumulative outgo of calcium from calcium silicate, both full-depth and surface-zone incorporations.

Series A, B, and C averaged for first 4 years; series D and E likewise.

Series A, B, and C, 3570-pound CaCO_3 $\approx$, 1924, full-depth incorporations; series A, no further treatment; treatment repeated in series B, 1928, and by quarter-additions in series C, beginning 1928.

Series D and E, 3570-pound CaCO_3 $\approx$ in quarter-additions 1924-1928; series D, no further treatments; four additional quarter-additions in series E, 1928-1932.

Series F, 3570-pound CaCO_3 $\approx$ in upper third of soil, 1924; no further additions.

Series G, 3570-pound CaCO_3 $\approx$ in upper third of soil, in four quarter-additions, 1924-1928; no further additions.

Heavy lines, Cumberland clay loam.

Light lines, Onslow fine sandy loam.

Unlimed soil - - - - -

outgo from the full-depth quarter-additions of dolomite to series D, and also that of its duplicate series E, was practically the same as the outgo from the untreated soil during the first four years. During the second four years there was a depression in the outgo of calcium of series D, where no dolomite was added during the second 4-year period; but in series E the repetition of the four quarterly additions gave an average increase of 30 pounds per annum.

In a comparison of the surface-zone series F and G, there were practically no differences in the amounts of calcium lost from the respective materials added in full units and in four annual additions during the first four years. At the end of that period the upper third of the soil showed an absence of carbonates from the additions of burnt lime, limestone, and silicate to series F, but there was an increase of .08 per cent shown for the dolomite treatment. The

divided additions of series G showed carbonate residues from the burnt lime, limestone, and dolomite, at the end of the fourth year, the respective increases being .085 per cent, .080 per cent, and .195 per cent. During the second 4-year period the losses from series F and G were comparable for the respective treatments and considerably less than those from the full-depth fraction-incorporations of series D.

Differing from the results shown for the dolomite additions to the Tennessee soil with its large accumulation of exchangeable calcium, the dolomite additions gave only small increases in outgo of calcium from the Virginia soil, and in some cases actual deficiencies during the first 4-year period. Although the 3570-pound dolomite additions supplied 1780 pounds of calcium carbonate, the average increase in calcium outgo from all seven dolomitic treatments in the seven series was only 30 pounds for the first 4-year period. During the second 4-year period the amounts of calcium leached from the dolomite additions of the first four years were less than the calcium outgo from the untreated soil in three of the series. A similar relationship has been shown in some related studies (29). In general, subsequent dolomite additions, in full or in fractions, caused some increase in the amount of calcium leached during the 8-year period, but the largest increase, 278 pounds for series B, was equivalent to only 7.8 per cent of the calcium carbonate supplied by the 7140-pound treatment.

OUTGO OF MAGNESIUM

The question of available supplies of magnesium has attained considerable importance during recent years. Deficiencies of this element are registered by the plant through characteristic symptoms. Although especially important in the case of tobacco, magnesia deficiencies have reached such proportions as to be an important nutritive problem for many crops, including corn and cotton, in the Coastal Plain. It has been taught that one of the functions of high-calcic liming materials is to effect a liberation of soil magnesia. It has been definitely proved that the reverse may be true (18,28,29). Neutral salts of calcium, such as the sulfate carried by phosphatic fertilizers, may effect this liberation in the laboratory treatment of an acid soil, but not when the soil is limed and exposed to natural leaching (29). Hence, the long-continued use of the magnesia-free, acid-producing ammoniates and "standard" superphosphate tend to produce an actual deficiency of magnesium in the absence of lime; whereas high-calcic materials tend to conserve the soil's magnesium content by decreasing the amount that is present in the leachates. This has been found for both the native supplies of magnesium and additions of soluble magnesium salts.*

The amounts of magnesium leached from the Tennessee and Virginia soils each year are given in tables 4a and 4b, respectively. As in the case of calcium, magnesium is brought to the soil by rainwaters, and, in proximity to commercial activities, appreciable quantities may be derived from this source, although the magnesium increments are generally less than those of calcium (20). The amounts of both calcium and magnesium brought to the soil at Knoxville were considerably in excess of those washed down at Blacksburg.

*Unpublished data.

TABLE 4a.—*Outgo of magnesium from the Tennessee Cumberland clay loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

Treatments			Pounds CaCO ₃ -equivalent per 2,000,000 pounds of soil										
	Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period					Total 8-year period
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	88	124	66	64	342	29	29	59	33	150	492
	.....	None	197	248	157	127	729	175	93	90	84	442	1171
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	193	224	141	152	710	165	74	92	71	402	1112
		Limestone	191	231	140	142	704	166	74	78	80	398	1102
		Dolomite	367	529	337	264	1497	297	148	137	126	708	2205
Calcium silicate		223	260	163	163	809	181	93	93	78	445	1254	
Series B	Same as series A for first four years; 2000-pound full-depth additions repeated at beginning of 5th year.	Burnt lime	186	242	138	138	704	169	65	63	55	352	1056
		Limestone	183	229	149	146	707	169	61	57	62	349	1056
		Dolomite	364	535	281	287	1467	501	252	232	221	1206	2673
		Calcium silicate	209	274	160	180	823	246	95	107	99	547	1370
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	190	243	151	131	715	166	78	75	75	394	1109
		Limestone	188	224	164	134	710	168	74	82	72	396	1106
		Dolomite	372	548	316	281	1517	344	212	267	273	1096	2613
		Calcium silicate	201	278	192	171	842	179	114	109	100	502	1344
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment, and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	187	265	192	164	808	142	83	80	70	375	1183
		Limestone	185	265	185	163	798	154	78	85	66	383	1181
		Dolomite	238	440	350	367	1395	311	151	171	132	765	2160
		Calcium silicate	185	274	214	213	886	181	97	106	84	468	1354
Series E	Same as series D for first four years; 500-pound full-depth additions at beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	188	283	196	171	838	179	75	87	77	418	1256
		Limestone	171	256	192	167	786	168	79	87	76	410	1196
		Dolomite	225	419	337	370	1351	365	207	270	231	1073	2424
		Calcium silicate	178	269	220	196	863	192	95	114	97	498	1361
Series F	.....	None	180	255	160	140	735	177	98	84	80	439	1174
	2000-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment. No further additions.	Burnt lime	217	275	163	140	795	146	60	49	51	306	1101
		Limestone	248	271	153	136	808	126	54	57	59	296	1104
		Dolomite	214	390	296	304	1204	227	122	122	116	587	1791
		Calcium silicate	220	283	173	158	834	153	64	66	62	345	1179
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	179	289	157	159	784	146	71	53	64	334	1118
		Limestone	191	287	180	197	855	157	69	59	64	349	1204
		Dolomite	197	338	232	259	1026	440	127	119	137	823	1849
		Calcium silicate	206	284	173	175	838	160	81	73	79	393	1231
Rainfall, acre inches.....			31.1	52.9	55.7	57.4	197.1	61.5	30.3	36.2	43.8	171.8	368.9

The total magnesium content of the Tennessee soil was 2.7 times as great as its total content of calcium, but the exchangeable magnesium was only 8.9 per cent of the total. Hence, the net annual loss of magnesium was equivalent to only 85 pounds of CaCO_3 . The burnt lime and limestone showed consistently a repressive effect upon the magnesium leached from the Tennessee soil in the three series A, B, and C for both of the 4-year periods. The maximal repressive effect for the 8-year period was shown by the repetition of the full-depth incorporations of burnt lime and of limestone in series B. Since this effect was not registered during the first four years, by any of the seven treatments of calcium silicate, nor by any of the five full-depth incorporations of that material during the second 4-year period, it may be that the unleached fraction of the added calcium silicate continued in that form. It should be remembered also that the soil was enriched by 222 pounds and 444 pounds of magnesia, as CaCO_3 -equivalence in the single and double-unit incorporations of 3570 pounds and 7140 pounds, respectively, of calcium silicate, the added magnesia being in the readily available form of magnesium silicate. During the second 4-year period, however, the surface-zone incorporations of calcium silicate in series F and G exerted upon magnesium outgo the same repressive effect that was shown for burnt lime and for limestone. This can be attributed to the movement of the dissolved carbonates from the upper zone of treatment to the lower untreated zone and the stoppage of the dissolved carbonates and resultant accumulation of calcium in that zone, as well as to the decrease in the amount of magnesia derived from the calcium silicate.

During the first 4-year period the annual quarter-additions of series D and E did not show the repressive effect that was registered by the full single treatments, but they did show this ultimate effect during the second 4-year period. Hence, for the 8-year period the amounts of magnesium leached were about the same as those from the unlimed soil. In these two series, as in the case of the other full-depth incorporations, the calcium silicate failed to exert a repressive effect, but rather the reverse, upon outgo of magnesium. In addition to the previously suggested probability of the persistence of the silicate, and the fact that the calcium silicate contained more than 6 per cent CaCO_3 -equivalence of magnesia, it is also possible that there is in effect a buffering action exerted by the silica content of the added silicate.

During the first four years of identical treatment, the quantities of magnesium leached from the full-depth additions of dolomite in series A, B, and C were in accord. During the second four years, however, there was a divergence due to an increase in the magnesium leached from the further limings in both the full and the quarter additions.

In series F and G the liming materials were in direct contact with only the upper third of the soil, and the neutral salts engendered in that zone passed through the acid zone, where some exchange between calcium and magnesium occurred during the first two years. This effect was not noted in series F during the third and fourth years and only to a limited extent for the divided additions of series G. During the second 4-year period, however, the migration of dissolved carbonates from the upper to the lower zone had evidently progressed to such an extent that the repressive effect was definitely registered by all three of the high-calcic materials. The full initial incorporation of dolomite in series F gave an outgo of magnesium somewhat larger

TABLE 4b.—*Outgo of magnesium from the Virginia Onslow fine sandy loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

	Treatments		Pounds CaCO ₃ -equivalent per 2,000,000 pounds of soil										Total 8-year period
	Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period					
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	34	31	28	32	125	37	35	30	36	138	263
		None	70	38	34	35	177	50	43	40	56	189	366
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	82	35	44	39	200	49	58	46	60	213	413
		Limestone	52	38	42	41	173	43	59	45	76	223	396
		Dolomite	185	91	133	124	533	186	111	150	148	595	1128
		Calcium silicate	77	29	40	45	191	69	56	49	65	239	430
Series B	Same as series A for first four years; 2000-pound full-depth additions re- peated at beginning of 5th year.	Burnt lime	39	16	48	37	140	43	63	31	41	178	318
		Limestone	49	19	44	39	151	67	59	38	52	216	367
		Dolomite	191	82	124	118	518	232	123	237	248	840	1358
		Calcium silicate	66	14	38	41	159	146	57	69	62	334	493
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	56	17	54	35	162	48	56	39	44	187	349
		Limestone	50	29	58	39	176	58	56	38	42	194	370
		Dolomite	211	91	143	116	561	92	110	184	187	573	1134
		Calcium silicate	67	22	37	47	173	52	55	52	61	220	393
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment, and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	84	22	44	37	187	114	53	36	49	252	439
		Limestone	69	20	44	35	168	82	54	38	39	213	381
		Dolomite	127	85	163	109	484	170	143	161	146	620	1104
		Calcium silicate	63	39	71	49	222	58	61	50	46	215	437
Series E	Same as series D for first four years; 500-pound full-depth additions at be- ginning of 5th, 6th, 7th, and 8th years.	Burnt lime	68	16	69	37	190	68	56	30	45	199	389
		Limestone	90	18	49	35	192	149	58	37	47	291	483
		Dolomite	123	53	170	106	452	202	147	213	193	755	1207
		Calcium silicate	61	19	57	53	190	90	52	30	58	230	420
Series F	.....	None	67	23	29	31	150	65	44	37	48	194	344
	2000-pound CaO-equivalent mixed with upper three inches of soil at be- ginning of experiment. No further additions.	Burnt lime	84	20	48	40	192	36	51	47	34	168	360
		Limestone	63	17	38	37	155	63	55	44	37	199	354
		Dolomite	172	57	126	107	462	169	112	151	114	546	1008
		Calcium silicate	64	30	62	46	202	46	48	46	44	184	386
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	64	29	65	40	198	54	53	37	45	189	387
		Limestone	52	25	67	37	181	58	51	39	35	183	364
		Dolomite	120	41	147	107	415	173	140	164	101	578	993
		Calcium silicate	62	22	57	46	187	85	55	48	67	255	442
Rainfall, acre inches.....			30.5	26.7	42.2	35.9	135.3	40.7	24.7	26.2	33.8	125.4	260.7

than that from the divided additions of series G during the first four years. At the end of that period the dolomite additions in the two series had been equalized, and the disparity found for the first 4-year period was offset by the delayed increase in outgo of magnesium from series G during the second 4-year period. This gain in series G was accounted for almost entirely by leachings from the 61.5-inch rainfall of the fifth year. These comparisons indicate that the depth of the lime incorporations and the depth of root development are factors in determining the extent to which high-calcic liming materials will affect the supplies of nutrient magnesium.

The quantities of acid-soluble and exchangeable magnesium of the Virginia soil were both about one-eighth of the respective amounts present in the Tennessee soil, and the annual net loss of magnesium from the unlimed Virginia soil was equivalent to only 11.5 pounds of CaCO_3 . In general, the results from the burnt lime and limestone additions show either a slightly repressive effect or no effect upon the outgo of magnesium from the three full-depth series A, B, and C. On the other hand, the buffered calcium silicate again failed to register a repression. In the other two full-depth series, D and E, the results from the high-calcic materials, when averaged, were fairly comparable, and without marked effect as to either acceleration or repression of magnesium outgo during the first four years. During the second four years, and consequently for the 8-year period, the leachings of magnesium from series D and E were appreciably in excess of those found for the unlimed controls. The differences induced by the surface-zone additions of burnt lime and of limestone were not great for either of the 4-year periods. The relationship established for the effects induced by the two methods of incorporating the dolomite was also comparable with that found for the Tennessee soil.

OUTGO OF Ca+Mg

In an intra-comparison between caustic and carbonate high-calcic materials, the separate amounts of calcium and magnesium leached afford an adequate record of the conservation of the two elements. But when the comparison includes a dolomitic material, it becomes necessary to compare the total outgo of Ca+Mg found for each type of material. This is necessitated by the fact that the high-calcic materials may have either a neutral, a repressive, or an augmentative effect, dependent upon the type and also the amount of the added material and upon both the periodicity and the depth of incorporation, and especially upon the amounts of exchangeable native calcium and magnesium in the soil. The same factors determine whether an addition of either a true dolomite or a "near" dolomite will increase the outgo of calcium, exert a repressive effect, or show no effect upon calcium outgo.

The results for actual outgo of Ca+Mg, in terms of CaCO_3 -equivalence, are given in tables 5a and 5b for the Tennessee and Virginia soils, respectively. The wide difference between the respective capacities of the Tennessee and Virginia soils to conserve added Ca+Mg is readily observed by reference to the cumulative data curves of Fig. 5. These represent the actual increases over the controls in Ca+Mg outgo. Drawn to a scale twice that of Figs. 1-4, Fig. 5 affords a condensed comparison as to methods and periodicity of incorporation based on 12 values for the curves of series A, B, and C, eight for series D and E, and four each for series F and G, for the

TABLE 5a.—*Outgo of Ca+Mg from the Tennessee Cumberland clay loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

Treatments			Pounds CaCO ₃ -equivalent per 2,000,000 pounds of soil										Total 8-year period
	Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period					
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	148	319	140	152	759	144	144	209	134	631	1390
	.....	None	506	763	476	400	2145	500	272	306	295	1373	3518
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	703	1067	660	721	3151	620	336	431	341	1728	4879
		Limestone	836	1058	643	686	3223	575	323	365	364	1627	4850
		Dolomite	796	1149	748	669	3362	631	358	358	333	1680	5042
Calcium silicate		772	1007	660	664	3103	602	364	377	316	1659	4762	
Series B	Same as series A for first four years: 2000-pound full-depth additions re- peated at beginning of 5th year.	Burnt lime	676	1143	656	654	3129	1126	496	479	451	2552	5681
		Limestone	793	1174	667	695	3329	1078	498	406	437	2419	5748
		Dolomite	787	1169	640	666	3262	1051	537	510	476	2574	5836
		Calcium silicate	721	1051	610	682	3064	1077	467	541	464	2549	5613
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	702	1150	730	664	3246	698	452	520	568	2238	5484
		Limestone	806	1031	720	675	3232	688	433	554	542	2217	5449
		Dolomite	802	1168	719	651	3340	738	484	593	604	2419	5759
		Calcium silicate	730	1184	718	686	3318	638	479	535	533	2185	5503
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	542	991	832	788	3153	590	494	415	347	1846	4999
		Limestone	580	1017	777	804	3178	577	357	411	335	1680	4858
		Dolomite	580	1045	837	852	3314	614	360	421	317	1712	5026
		Calcium silicate	613	961	806	775	3155	598	382	414	336	1730	4885
Series E	Same as series D for first four years: 500-pound full-depth additions at be- ginning of 5th, 6th, 7th, and 8th years.	Burnt lime	540	987	803	801	3131	758	451	570	610	2389	5520
		Limestone	559	960	835	802	3156	718	444	576	554	2292	5448
		Dolomite	561	1004	828	848	3241	754	453	585	496	2288	5529
		Calcium silicate	522	936	818	825	3101	711	432	576	517	2236	5337
Series F	.....	None	499	827	506	461	2293	436	278	292	275	1281	3574
	2000-pound CaO-equivalent mixed with upper three inches of soil at be- ginning of experiment. No further additions.	Burnt lime	587	988	667	678	2920	517	284	226	252	1279	4199
		Limestone	659	1021	654	578	2912	466	266	285	297	1314	4226
		Dolomite	590	1021	725	705	3041	507	285	284	265	1341	4382
		Calcium silicate	608	975	647	634	2864	477	257	286	249	1269	4133
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	509	924	590	618	2641	490	288	222	313	1313	3954
		Limestone	537	926	652	600	2715	413	280	230	305	1228	3943
		Dolomite	535	951	617	628	2731	521	292	275	312	1400	4131
		Calcium silicate	547	898	607	636	2688	493	298	289	319	1399	4087
Rainfall, acre inches.....			31.1	52.9	55.7	57.4	197.1	61.5	30.3	36.2	43.8	171.8	368.9

first 4-year period. For the second 4-year period, the curve for each series was computed from a 4-unit average.

For the first 4-year period the amounts of calcium and magnesium brought to the unlimed Tennessee soil through rainfall were 35 per cent of the amounts lost by leaching and 46 per cent during the next four years. When compared within each series, the three high-calcic materials, burnt lime, limestone, and calcium silicate gave comparable results for total outgo of Ca+Mg. The grand average outgo from seven burnt lime and seven limestone treatments was 4945 pounds, whereas that from the seven calcium silicate treatments was only 42 pounds less. A similar comparison between dolomite and the three high-calcic materials shows that the amounts of Ca+Mg leached from the dolomite are slightly, yet consistently, in excess of the corresponding values found for the three high-calcic materials. The average for 21 high-calcic additions was 4931 pounds, against 5101 pounds for the seven additions of dolomite. This relationship has also been found for other soils of the same type (29,34) and may be explained on the assumption that the magnesium fixed by the soil complexes is more readily hydrolyzed than is the calcium fixed by the same agencies.

The total leachings of Ca+Mg from the burnt lime, limestone, and dolomite additions to the Virginia soil were generally comparable. The grand average of 14 units, seven each for limestone and burnt lime, was 2223 pounds, against a 2228-pound average for the seven dolomite units. On the other hand, the 7-unit calcium silicate average was only 1962 pounds. It is therefore evident that the conservation of Ca+Mg in this acid fine sandy loam is different from that found for the Tennessee clay loam.

The maximal outgo from each soil came from the two full 3570-pound CaCO_3 -equivalent full-depth additions of series B. In each case, the recovery from the full addition with the supplemental quarter-additions, series C, gave more rapid initial outgo, but a total recovery in accord with that of the eight full-depth quarter-additions of series E. Likewise, the outgo from the single 3570-pound full-depth additions of series A gave a greater initial speed of outgo than that found for the four annual full-depth quarter-incorporations of series D, but the totals for the two series were close together. It will be noted that the single 3570-pound CaCO_3 -equivalent full-depth incorporations of series A gave a much more rapid outgo than that found for the same treatment in the Virginia soil, and that the repetition of treatment, series B, in the Virginia soil gave an ultimate total almost identical with that found for the single full-depth incorporations, series A, in the Tennessee soil.

The losses from the full initial surface-zone additions to the Tennessee soil, series F, were greater than the losses from the quarterly surface-zone additions of series G, materially less than those shown for the corresponding full-depth incorporations of series A and also for those shown for the divided full-depth incorporations of series D. The losses from both series F and G were practically nil for the Tennessee soil during the second 4-year period, because of the fixation exerted by the lower untreated zone. On the other hand, the losses from series F and G of the Virginia soil were in close agreement among themselves, as to both speed and totals, but distinctly below the corresponding values found for F and G with the Tennessee soil. The largest actual loss from the full-depth 7140-pound CaCO_3 -equivalent additions to the

TABLE 5b.—*Outgo of Ca + Mg from the Virginia Onslow fine sandy loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

Treatments			Pounds CaCO ₃ -equivalent per 2,000,000 pounds of soil										
	Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period					Total 8-year period
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	71	80	108	83	342	123	148	91	117	479	821
	.....	None	232	131	140	163	666	290	154	168	181	793	1459
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	436	171	272	256	1135	415	239	232	309	1195	2330
		Limestone	408	201	274	276	1159	397	233	236	256	1122	2281
		Dolomite	350	169	327	209	1055	441	218	273	290	1222	2277
Calcium silicate		298	107	185	195	785	428	225	230	259	1142	1927	
Series B	Same as series A for first four years; 2000-pound full-depth additions repeated at beginning of 5th year.	Burnt lime	307	132	260	267	966	673	371	355	388	1787	2753
		Limestone	421	121	258	261	1061	703	376	355	350	1784	2845
		Dolomite	381	142	309	193	1025	536	266	404	451	1657	2682
		Calcium silicate	276	102	181	197	756	788	358	345	331	1822	2578
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	362	123	282	249	1016	434	302	178	368	1282	2298
		Limestone	341	121	287	254	1003	445	307	179	271	1202	2205
		Dolomite	367	169	332	205	1073	323	263	319	327	1232	2305
		Calcium silicate	312	99	193	204	798	428	306	169	319	1222	2020
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	303	143	293	254	993	481	244	252	235	1212	2205
		Limestone	259	127	296	249	931	369	248	203	196	1016	1947
		Dolomite	262	159	347	195	963	386	242	254	258	1140	2103
		Calcium silicate	249	141	211	204	805	384	261	206	213	1064	1869
Series E	Same as series D for first four years; 500-pound full-depth additions at beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	242	146	317	251	919	504	292	282	333	1411	2330
		Limestone	374	124	293	245	1036	501	300	293	282	1376	2412
		Dolomite	249	123	346	219	937	483	324	352	321	1480	2417
		Calcium silicate	226	108	209	195	738	459	303	286	252	1300	2038
Series F	.....	None	211	86	130	166	593	277	165	161	147	750	1343
	2000-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment. No further additions.	Burnt lime	290	146	285	255	976	293	222	230	195	940	1916
		Limestone	222	125	279	253	879	327	232	229	184	972	1851
		Dolomite	304	116	317	212	949	308	212	272	185	977	1926
		Calcium silicate	231	103	210	186	730	309	204	229	158	900	1630
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	261	115	311	249	936	313	225	250	194	982	1918
		Limestone	198	113	314	247	872	328	232	211	186	957	1829
		Dolomite	260	97	344	193	894	332	240	254	168	994	1888
		Calcium silicate	242	77	213	184	716	333	220	209	195	957	1673
Rainfall, acre inches.....			30.5	26.7	42.2	35.9	135.3	40.7	24.7	26.2	33.8	125.4	260.7

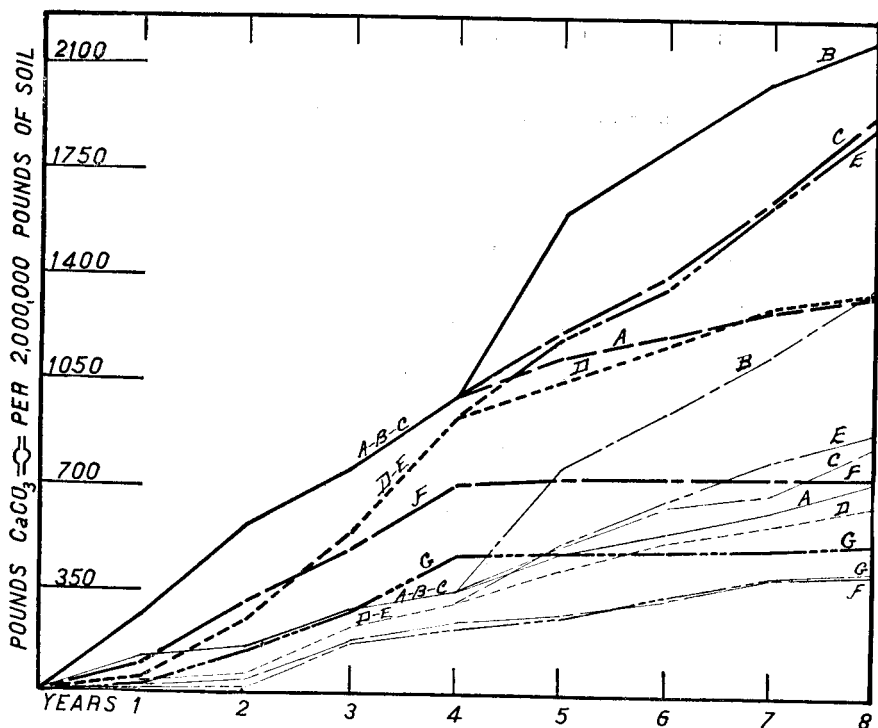


Fig. 5.—Cumulative net losses of Ca+Mg—those in excess of outgo from the unlimed soils—from all liming materials and all series.

Series A, B, and C averaged for first four years; series D and E likewise.

Series A, B, and C, 3570-pound CaCO_3 $\approx$, 1924, full-depth incorporations; series A, no further treatment; treatment repeated in series B, 1928, and by quarter-additions in series C, beginning 1928.

Series D and E, 3570-pound CaCO_3 $\approx$ in upper third of soil, 1924; series D, no further treatment; four additional quarter-additions in series E, 1928-1932.

Series F, 3570-pound CaCO_3 $\approx$ in upper third of soil, in four quarter-additions, 1924-1928; no further additions.

Series G, 3570-pound CaCO_3 $\approx$ in upper third of soil, 1924; no further additions.

Heavy lines, Cumberland clay loam.

Light lines, Onslow fine sandy loam.

Tennessee soil for the 8-year period was that of series B, which gave 30.4 per cent of the amount added in two units. Series C, which received a 7140-pound addition through one full treatment of 3570 pounds and four divided portions, showed a net loss of 28.05 per cent, whereas the eight divided additions of series E showed a loss of 29.6 per cent. The total outgo of Ca+Mg from the 7140-pound additions to the Tennessee soil was not materially influenced by the periodicity of incorporation in the full depth of soil.

The largest average net loss from 3570-pound full-depth additions, for the 8-year period was that of 37.4 per cent for series A, and the smallest, of 13.5 per cent, came from the divided surface-zone additions of series G. The average net loss from the full-depth additions of series A and D was 38.3 per cent of the 3570-pound addition, as against an average of 16.4 per cent for the surface-zone incorporations of series F and G. Although a net loss

of 19.3 per cent of the addition was found for the 8-year period in the case of series F, a 20.0 per cent net loss was shown for the first four years; that is, during the second 4-year period the average of the four units of series F ran 0.7 per cent less than the average of the unlimed controls. Again, the net loss from the four quarter-additions of series G for the 8-year period was 13.5 per cent of the added Ca+Mg, as against the 13.3 per cent net loss accounted for during the first four years.

The largest net loss of Ca+Mg from the full-depth, 7140-pound additions to the Virginia soil was that of 18.43 per cent for series B, which received full additions the first and fifth years. The net loss from the full initial addition and the four subsequent quarter-additions of series C was 11.28 per cent, as against 12.58 per cent for the eight quarter-additions of series E. The latter series showed a net loss practically identical with that found for the single full initial addition of series A for the 8-year period and a small difference for the first 4-year period. Full initial additions at the rate of 3570 pounds for series A showed net losses equivalent to 11.3 per cent and 22.5 per cent of the addition for the first and second 4-year periods, respectively, as against 8.2 per cent and 17.7 per cent for the four quarter-additions of series D. At the end of the 8-year period the full initial 3570-pound additions in the upper 3-inch zone, series F, and the divided additions of series G showed net losses equivalent to 12.07 per cent and 11.88 per cent of the common quantity added, the corresponding net losses for the first 4-year period being 7.11 per cent and 6.30 per cent, respectively.

Although the total amounts of calcium and magnesium supplied to the plant by addition of dolomite may be expected to equal, or to exceed, those furnished by high-calcic limes, the ratios of soluble calcium and magnesium will vary, as determined primarily by the nearness of the dolomitic material to true dolomite and by the occurrence of exchangeable calcium and magnesium in a specific soil. In most humid soils the available, or exchangeable, calcium far exceeds the amount of exchangeable magnesium, although the total quantity of the latter usually exceeds the amount of total calcium. The amount of calcium dissolved in the free soil water of an unlimed soil and present in the leachings usually exceeds the amount of magnesium. It is evident, therefore, that for soils of the types used in this experiment the ratio of solute magnesium to solute calcium cannot attain such proportions as to prove toxic to plant growth. Furthermore, after dolomite additions undergo disintegration in the soil, the fixed magnesium leaches out much more rapidly than the concomitant calcium. Hence, a soil treated with dolomite may be expected to show its greatest content of magnesium in leachates during an early period after the calcium and magnesium supplied by the dolomite become fixed as a part of the soil system. Alkalinity to a harmful degree may be induced by excessive additions of either calcareous or dolomitic limestone to poorly buffered soils, but if no detrimental effect occurs during this early period, none would be expected later.

OUTGO OF DISSOLVED CARBONATES

Of the total Ca+Mg outgo from the unlimed controls of the Tennessee soil, one-fourth was accounted for by dissolved carbonates. The carbonate outgo from the controls was, however, 213 pounds less than the content of

TABLE 6a.—*Outgo of carbonates from the Tennessee Cumberland clay loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

Treatments			Pounds CaCO ₃ -equivalent per 2,000,000 pounds of soil										
	Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period					Total 8-year period
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	112	168	133	146	559	175	76	156	151	558	1117
	.....	None	63	110	153	131	457	135	107	61	134	437	894
	2000 pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	90	172	202	164	628	180	111	84	164	539	1167
		Limestone	129	249	226	198	802	181	117	84	169	551	1353
		Dolomite	121	277	238	205	841	194	128	85	173	580	1421
Calcium silicate		133	186	199	186	704	180	120	92	167	559	1263	
Series B	Same as series A for first four years; 2000-pound full-depth additions repeated at beginning of 5th year.	Burnt lime	86	274	226	183	769	376	195	133	232	936	1705
		Limestone	125	255	198	197	775	376	196	139	227	938	1713
		Dolomite	121	277	205	194	797	437	188	141	241	1007	1804
		Calcium silicate	136	241	202	193	772	505	155	134	214	1008	1780
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	107	293	228	195	823	199	133	112	234	678	1501
		Limestone	141	227	206	180	754	199	148	125	241	713	1467
		Dolomite	115	278	204	165	762	203	159	124	234	720	1482
		Calcium silicate	132	256	215	174	777	229	147	126	235	737	1514
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	78	174	233	216	701	212	118	83	161	574	1275
		Limestone	74	177	200	245	696	186	110	75	151	522	1218
		Dolomite	70	179	222	270	741	205	110	83	178	576	1317
		Calcium silicate	66	172	183	245	666	198	117	86	131	532	1198
Series E	Same as series D for first four years; 500-pound full-depth additions at beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	70	185	224	269	748	259	147	125	277	808	1556
		Limestone	63	165	198	218	644	218	157	154	273	802	1446
		Dolomite	70	163	217	275	725	266	176	158	282	882	1607
		Calcium silicate	60	156	247	276	739	262	171	145	255	833	1572
Series F	.....	None	68	135	129	184	516	131	91	68	107	397	913
	2000-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment. No further additions.	Burnt lime	71	177	176	213	637	166	137	88	142	533	1170
		Limestone	73	216	185	199	673	172	121	73	149	515	1188
		Dolomite	78	164	178	191	611	170	131	80	138	519	1130
		Calcium silicate	87	170	148	182	587	172	126	74	130	502	1089
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	58	154	142	176	530	165	125	73	131	494	1024
		Limestone	67	155	160	187	569	178	131	83	136	528	1097
		Dolomite	57	164	143	166	530	172	116	82	139	509	1039
		Calcium silicate	60	162	171	168	561	153	129	74	142	498	1059
Rainfall, acre inches.....			31.1	52.9	55.7	57.4	197.1	61.5	30.3	36.2	43.8	171.8	368.9

TABLE 6b.—*Outgo of carbonates from the Virginia Onslow fine sandy loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

	Treatments		Pounds CaCO ₃ -equivalent per 2,000,000 pounds of soil										
	Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period					Total 8-year period
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	142	146	150	121	559	158	82	100	109	449	1008
	.....	None	276	83	113	59	531	104	45	36	73	258	789
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	178	79	140	91	488	156	91	54	130	431	919
		Limestone	219	74	132	96	521	157	74	54	123	408	929
		Dolomite	250	77	153	97	577	170	84	54	141	449	1026
Series B		Calcium silicate	263	104	145	97	609	162	88	59	126	435	1044
	Same as series A for first four years; 2000-pound full-depth additions repeated at beginning of 5th year.	Burnt lime	336	101	143	92	672	222	138	61	178	599	1271
		Limestone	256	85	141	90	572	243	125	61	170	599	1171
		Dolomite	211	92	146	98	547	195	108	61	207	571	1118
		Calcium silicate	247	89	146	98	580	265	155	66	176	662	1242
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	230	82	137	101	550	197	91	59	138	485	1035
		Limestone	261	86	140	92	579	179	98	59	140	476	1055
		Dolomite	247	99	149	95	590	189	88	61	151	489	1079
		Calcium silicate	259	112	143	87	601	180	98	61	138	477	1078
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	193	78	141	92	504	180	82	52	131	445	949
		Limestone	210	86	142	87	525	186	78	56	125	445	970
		Dolomite	148	101	139	101	489	183	115	56	133	487	976
		Calcium silicate	207	92	144	76	519	178	95	52	127	452	971
Series E	Same as series D for first four years; 500-pound full-depth additions at beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	199	75	134	85	493	197	115	61	134	507	1000
		Limestone	200	90	131	64	485	194	122	61	139	516	1001
		Dolomite	239	98	137	68	542	196	122	61	198	577	1119
		Calcium silicate	212	78	143	71	504	199	132	65	150	546	1050
Series F	.....	None	144	66	120	46	376	129	73	41	97	340	716
	2000-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment. No further additions.	Burnt lime	196	61	129	59	445	171	81	56	118	426	871
		Limestone	157	70	126	62	415	175	85	56	106	422	837
		Dolomite	184	85	138	63	470	196	105	61	122	484	954
		Calcium silicate	191	78	127	65	461	189	102	56	113	460	921
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	177	66	131	61	435	185	102	56	124	467	902
		Limestone	152	72	113	62	399	176	102	56	123	457	856
		Dolomite	177	77	126	67	447	179	102	56	122	459	906
		Calcium silicate	128	75	129	69	401	180	98	56	118	452	857
	Rainfall, acre inches.....		30.5	26.7	42.2	35.9	135.3	40.7	24.7	26.2	33.8	125.4	260.7

the rainwaters. The fact that a soil is of acid reaction does not mean that dissolved carbonates will not be present in the free soil water. The preponderant proportion of bases that leach from an acid soil will be in the form of neutral salts, but at certain periods there will be appreciable quantities of dissolved carbonates, derived from the hydrolytic breakdown of silicates and organic combinations. The presence of carbon dioxide in the solution and in the atmosphere of the soil induces equilibria that permit solutions of calcium and magnesium carbonates to remain in equilibrium with the soil acidoids.

In each of the 12 units of series A, B, and C, the minimal quantity of carbonates came from the clay loam during the first year, when the soil was richest in carbonates supplied by the single full additions. The carbonates leached from this group during the first four years averaged 8 per cent above the 8-unit average for the divided additions of series D and E. For the 8-year period, two full additions of series B gave more carbonates than the single additions and subsequent quarter-additions of series C and 400 pounds more than the average for the unit additions of series A. The 3570-pound divided additions of series D gave an outgo slightly less than that from the equal quantities added in the single additions of series A, for both the 4-year and the 8-year period. The full additions of the surface-zone series F gave 10 per cent more of carbonate leachings than the divided additions of series G for both of the 4-year periods, and both of the series ran considerably below any one of the five series A-E. At the end of the first four years the soils of the five full-depth series A-E were found to be devoid of residual carbonates.

The annual carbonate increment to the Virginia soil was 126 pounds, or 90 per cent as much as that for the Tennessee soil. In spite of a distinct acidity and a lower content of bases, and because of less nitrification and sulfication, the unlimed controls of the Virginia soil yielded 753 pounds of carbonates, or 83 per cent of the outgo from the Tennessee soil. The total 8-year average carbonate outgo of 753 pounds from this acid soil was 255 pounds less than the amount carried by the rainfall. In general, the order of magnitude of carbonate outgo from the different series was the same as that shown for the Tennessee soil. At the end of the first four years there were no residues of carbonates present in any of the series A-E, where the several materials were incorporated at full depth. In series F there were carbonate residues from the single addition of dolomite, but none from the other three materials. In series G there were equivalent residues from the burnt lime and limestone and approximately twice as much from the dolomite. A part of the added caustic lime, and also caustic magnesia, may react with colloidal silica in the soil to form simple silicates (22,31,37), such as the silicate material used in the present study, and a part may react to form more complex silicates. The ready hydrolysis of the simple silicates (12) is shown by the fact that, for both soils, the amounts of carbonates leached from the added silicate were as great as those derived from the other three liming materials.

REACTION VALUES OF LEACHINGS

The reaction of a residual soil is determined by the occurrence or the absence of alkaline-earth carbonates, or by the amount and solubility of readily hydrolyzed non-carbonate forms. A glaciated soil may contain considerable quantities of mineral forms of calcium and magnesium, and yet

TABLE 7a.—*Minimal-maximal pH values of periodic leachings from the Tennessee Cumberland clay loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

Treatments		1924	1925	1926	1927	1928	1929	1930	1931		
	Amounts and methods of incorporation	Material									
Series A		Rainwater		6.7-7.3	6.7-7.2	6.5-6.9	6.5-7.2	6.6-7.1	6.8-7.2	6.8-7.2	6.7-7.0
		None		6.5-7.2	6.9-7.2	6.8-7.3	7.1-7.3	6.7-7.3	6.9-7.5	6.8-7.3	7.0-7.4
		None		6.5-7.4	6.8-7.4	6.6-7.4	7.0-7.4	6.9-7.4	6.8-7.3	6.7-7.2	7.0-7.2
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	6.8-7.5	7.1-8.0	6.9-7.4	7.1-7.4	6.9-7.4	6.9-7.5	7.0-7.4	7.2-7.5	
		Limestone	7.2-7.6	7.1-7.6	7.1-7.4	7.1-7.4	6.9-7.4	6.9-7.5	6.9-7.4	7.2-7.6	
Dolomite		7.1-7.5	7.3-7.6	7.1-7.4	7.1-7.5	7.0-7.5	6.9-7.4	6.9-7.4	7.1-7.5		
Calcium silicate		7.1-7.5	7.0-7.5	7.0-7.4	7.0-7.5	7.0-7.5	7.0-7.4	6.9-7.4	7.0-7.4		
Series B	Same as series A for first four years; 2000-pound full-depth additions repeated at beginning of 5th year.	Burnt lime	7.0-7.5	7.1-7.7	7.1-7.4	7.1-7.5	7.2-7.8	7.0-7.8	7.1-7.6	7.3-7.8	
		Limestone	6.9-7.5	7.1-7.6	7.1-7.6	7.1-7.5	7.3-7.8	7.0-7.7	7.0-7.6	7.3-7.8	
		Dolomite	7.2-7.5	7.1-7.6	7.0-7.3	7.0-7.5	7.4-7.8	7.0-7.8	7.0-7.6	7.3-7.8	
		Calcium silicate	7.1-7.5	7.1-7.5	7.0-7.3	7.0-7.5	7.5-7.8	6.9-7.5	7.1-7.5	7.2-7.7	
		Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	7.1-7.5	7.2-7.7	7.3-7.4	7.1-7.5	7.3-7.4	6.8-7.6	7.1-7.6	7.6-7.9
Limestone	7.1-7.7			7.1-7.6	7.1-7.4	7.0-7.5	7.3-7.4	6.9-7.5	7.1-7.6	7.5-7.7	
Dolomite	7.2-7.5			7.1-7.7	7.0-7.4	7.0-7.5	7.3-7.7	7.0-7.6	7.1-7.6	7.3-7.7	
Calcium silicate	7.0-7.5			7.1-7.5	7.0-7.4	7.0-7.5	7.3-7.5	7.1-7.4	7.0-7.6	7.3-7.8	
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.			Burnt lime	6.7-7.5	7.0-7.5	7.0-7.4	7.1-7.5	7.2-7.4	7.0-7.3	6.8-7.4	7.0-7.4
		Limestone	6.6-7.4	6.9-7.3	6.8-7.4	7.1-7.7	7.3-7.4	6.9-7.5	7.1-7.6	7.5-7.7	
		Dolomite	6.6-7.4	7.1-7.6	7.0-7.3	7.1-7.6	7.1-7.4	7.0-7.2	6.7-7.4	7.0-7.4	
		Calcium silicate	6.6-7.3	6.9-7.4	6.8-7.3	7.0-7.6	7.2-7.4	6.9-7.2	6.7-7.4	7.0-7.2	
		Series E	Same as series D for first four years; 500-pound full-depth additions at beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	6.6-7.4	7.0-7.4	7.1-7.4	7.1-7.7	7.2-7.5	7.0-7.4	7.1-7.5	7.5-8.0
Limestone	6.5-7.4			6.9-7.4	7.0-7.3	7.1-7.6	7.2-7.5	7.0-7.4	7.0-7.4	7.4-8.0	
Dolomite	6.6-7.4			6.9-7.4	7.0-7.4	7.2-7.6	7.2-7.5	7.0-7.5	7.1-7.5	7.3-7.7	
Calcium silicate	6.5-7.4			6.9-7.3	6.8-7.4	7.0-7.6	7.2-7.5	6.8-7.5	7.1-7.5	7.2-7.6	
Series F	2000-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment. No further additions.			Burnt lime	6.5-7.4	7.0-7.3	6.9-7.5	7.1-7.4	6.9-7.3	6.8-7.4	6.8-7.4	7.0-7.3
		Limestone	6.6-7.4	7.0-7.4	6.8-7.4	7.0-7.4	7.0-7.4	6.9-7.4	6.8-7.3	7.0-7.4	
		Dolomite	6.6-7.5	7.0-7.3	6.8-7.4	7.0-7.5	7.1-7.4	6.8-7.4	6.7-7.3	6.8-7.3	
		Calcium silicate	6.7-7.4	7.0-7.4	6.9-7.4	7.0-7.4	7.0-7.4	6.9-7.4	6.8-7.3	7.0-7.3	
		Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and at beginning of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	6.5-7.4	6.8-7.3	6.8-7.3	7.0-7.4	7.1-7.3	6.7-7.4	6.7-7.3	7.1-7.3
Limestone	6.6-7.3			7.0-7.3	6.9-7.3	7.1-7.4	7.1-7.3	6.7-7.4	6.8-7.3	7.0-7.3	
Dolomite	6.5-7.4			7.0-7.3	6.9-7.3	7.0-7.4	7.1-7.4	6.8-7.4	6.8-7.3	6.9-7.3	
Calcium silicate	6.6-7.3			7.0-7.3	6.9-7.3	7.1-7.4	7.1-7.4	6.8-7.4	6.8-7.3	7.0-7.3	
Rainfall, acre inches.....				30.5	26.7	42.2	35.9	40.7	24.7	26.2	33.8

TABLE 7b.—*pH values of initial collections* of annual leachings from the Virginia Onslow fine sandy loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

Treatments			1924	1925	1926	1927	1928	1929	1930	1931
	Amounts and methods of incorporation	Material								
	.....	Rainwater	8.3	7.3	.....	6.8	6.8	6.6	6.8	7.1
	.....	None	8.3	7.3	7.7	6.8	7.0	7.0	6.8	7.2
	.....	None	8.3	7.4	7.7	7.0	7.0	7.2	6.8	7.2
Series A	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	8.4	7.4	7.9	7.0	7.3	7.0	7.0	7.3
		Limestone	8.3	7.4	7.6	7.3	7.4	7.4	6.8	7.3
		Dolomite	8.4	7.4	7.8	7.6	7.4	7.0	7.0	7.3
		Calcium silicate	8.4	7.7	7.8	7.5	7.4	7.8	7.0	7.3
Series B	Same as series A for first four years; 2000-pound full-depth additions repeated at beginning of 5th year.	Burnt lime	8.4	7.8	7.8	7.6	7.4	7.8	7.2	7.6
		Limestone	8.4	7.5	7.6	7.8	7.4	7.8	7.0	7.6
		Dolomite	8.4	7.7	7.8	7.7	7.4	7.2	7.0	7.6
		Calcium silicate	8.4	7.7	7.8	7.7	7.4	7.4	7.2	7.6
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	8.4	7.7	8.0	7.8	7.6	7.2	7.0	7.5
		Limestone	8.4	7.6	8.0	7.7	7.4	7.4	7.0	7.5
		Dolomite	8.4	7.5	8.0	7.6	7.8	7.6	7.0	7.5
		Calcium silicate	8.4	7.6	8.0	7.2	7.4	7.2	7.0	7.5
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	8.3	7.2	7.7	7.2	7.6	7.4	6.8	7.4
		Limestone	8.3	7.3	7.7	7.3	7.6	7.2	6.8	7.4
		Dolomite	8.3	7.5	7.8	7.6	7.6	7.6	6.8	7.5
		Calcium silicate	8.3	7.5	7.9	7.5	7.6	7.2	6.8	7.5
Series E	Same as series D for first four years; 500-pound full-depth additions at beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	8.2	7.6	7.6	7.5	7.4	7.2	7.0	7.6
		Limestone	8.2	7.6	7.6	7.3	7.3	7.2	7.0	7.6
		Dolomite	8.3	7.6	7.6	7.7	7.5	7.2	7.1	7.6
		Calcium silicate	8.3	7.6	7.6	7.8	7.4	7.2	7.1	7.6
Series F	2000-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment. No further additions.	Burnt lime	8.3	7.7	8.0	7.6	7.5	7.0	6.8	7.3
		Limestone	8.3	7.6	8.1	7.4	7.6	7.2	6.8	7.3
		Dolomite	8.2	7.6	8.1	7.7	7.5	7.4	7.2	7.3
		Calcium silicate	8.2	7.6	8.1	7.5	7.5	7.2	7.0	7.3
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	8.3	7.5	8.2	7.8	7.4	7.2	7.1	7.2
		Limestone	8.3	7.5	8.2	7.7	7.6	7.1	7.1	7.3
		Dolomite	8.3	7.8	8.2	7.8	7.4	7.2	7.0	7.3
		Calcium silicate	8.3	7.7	8.2	7.7	7.4	7.4	7.1	7.3
*Days intervening between "birthday" and collection of leachings			54	165	106	71	8	55	161	41

these materials may be so slightly soluble that the soil is strongly acid and capable of decomposing large quantities of added natural carbonates (22). This is not true of the old and well-leached residual soils of the temperate humid regions. Such soils have been leached to the point where the acidity found reflects the paucity of bases other than hydrogen. The acidity of extracts of such soils is expressed in terms of intensity, rather than total quantity, and stipulated by the Sorensen, or pH, values. The acidity of the Tennessee soil, determined by suspending one part of soil with five parts of distilled water, was 6.4.

In the discussion of the outgo of dissolved carbonates, it was pointed out that an acid soil may yield natural leachings that contain carbonates in solution, although the excess of dissolved carbon dioxide will cause the solution to register acidity. The pH values of the rainwater leachings for the 8-year period are given in table 7a. The determinations were made colorimetrically upon each collection of leachings, and with adequate checks by the electrometric method. The values given are the minimal and maximal for each year. The differences between the increases in alkalinity induced by the full initial full-depth additions of series A, B, and C, the divided full-depth additions of series D and E, and the surface-zone incorporations of series F and G, are shown in the leachings of the first year. In general, the values found for the first two years exceed those found during the third and fourth years. The repetitions of both full treatments and divided additions show a recurrent effect upon increase in pH values during the second 4-year period. Where no repetitions of additions were made the values came to a common level, without distinctive effect for any one of the four materials. In consonance with the reported outgo of dissolved carbonates, the pH values of the surface-zone incorporations of series F and G were less than those found for the full-depth incorporations of series A-E. In most cases the values found were on the alkaline side through the eighth year.

The values for the unlimed soils ranged from slight acidity to definite alkalinity. This range is registered as a function of seasons, the greater values coming during the periods of greater bacterial activity. It should be remembered that the intensity coefficient of a fractional unit increases as the values become distant from the neutral value of 7. A change of 0.2 of a pH has a different unit value in the 6-7 range as compared with the range 5-6. In a well-buffered soil, such as the Tennessee clay loam, the values found do not prove detrimental to plant growth. This has been demonstrated in practice by the addition of the 2000-pound CaO-equivalent or 3570-pound CaCO_3 -equivalent additions such as those used in the present study. For a sandy type of soil, however, the range found might prove to be excessive.

The 1-5 aqueous suspension of the Virginia fine sandy loam showed a pH value of 5.2, and although very much more acid, its total acid value, or exchangeable hydrogen, was only 86 per cent of that found for the Tennessee soil. The reaction values of the leachates from the Virginia soil were determined only in the first collections for each year. The values for the first year exceeded those found for the Tennessee soil and were the largest found for any of the eight years. The leachings from this soil showed no differences for the full-depth and surface-zone incorporations during the first 4-year period. Residues of carbonates were present in three of the units of

series G at the end of four years, but the underlying untreated zone brought all of the leachates to a common level of values. The repetition of full and divided additions showed, during the second 4-year period, higher values than those found for the corresponding single additions. The final values for the full-depth incorporations were slightly greater than those found for the surface-zone incorporations. During the first three years the leachings from the unlimed soils were distinctly alkaline, whereas those for the other five years were close to neutrality. So far as known to us, no previous systematic and extended record of the changes induced in the natural leachings as a result of liming has been reported. It is stressed that the present values are all for the free soil water of the surface soil, unaltered by underlying layers of subsoil.

OUTGO OF POTASSIUM

It is exceedingly difficult to overcome, or even modify, a theory that has become fixed by repetition in texts. This is true of the long-held belief that the liming of soils will induce a liberation of potassium. The belief was based upon the fact that this phenomenon can be effected readily when acid soils are suspended and agitated in solutions of neutral salts, or when acid soils are leached with solutions of either calcium or magnesium salts. In both cases the solutions will show enrichment in potassium content and equivalent decrease in the solute of the original solution. Several publications from the Tennessee Experiment Station have demonstrated that the liming of an acid soil will decrease the amount of potassium present in the free soil water and available to the plant (14,25,30,33), even in the presence of a high concentration of neutral salts of calcium and of magnesium. This holds true also for added potassium up to a certain point (25,32). Such a decrease in the amount of potassium present in the free soil water is reflected in a decreased potassium content of plants grown on a limed soil, as has been demonstrated in several studies (1,2,9,10,11).

The outgo of potassium from the two soils studied is given in tables 8a and 8b, the only additive source of potassium being the small amounts brought by rainwater and dust. The rainwater collections are fractioned periodically in the laboratory and kept in glass containers with a small amount of HCl to prevent hydrolytic action. It is probable that this very dilute acid will extract from any clay carried by the rainwater some potash that would not be water-soluble. It is probable, therefore, that the results given in tables 8a and 8b are greater than the actual water-soluble increments of potash, since some dust and pulverized clay washed from the blank rainwater tanks directly into the receivers where the rainwaters accumulated. Any amount of potassium from this source is identical for the unlimed controls and the limed soils.

Because of the extended growth of bluegrass sod, the quantity of exchangeable potassium in the Tennessee soil was one-tenth of that soluble in strong HCl. The amounts of potassium leached from this soil during the first four years were therefore considerably greater than those leached during the next four years. The average outgo from the 12 full additions of series A, B, and C was 104 pounds, against 128 pounds from the unlimed soil for the first four years, whereas the average of the eight divided additions of series D and E was 113 pounds. During the second 4-year period the 4-unit

TABLE 8a.—*Outgo of potassium from the Tennessee Cumberland clay loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

		Treatments		Pounds potassium per 2,000,000 pounds of soil										Total 8-year period
		Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period					
				1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A			Rainwater	11	24	11	8	54	11	10	3	7	31	85
			None	29	44	29	20	122	27	18	13	17	75	197
			Burnt lime	25	39	24	23	111	23	21	14	14	72	183
			Limestone	26	46	24	22	118	24	20	9	9	62	180
			Dolomite	22	40	25	21	108	24	18	11	9	62	170
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Calcium silicate	20	48	25	18	111	21	20	9	9	59	170	
Series B			Burnt lime	15	40	20	19	94	18	18	11	7	54	148
			Limestone	14	39	19	21	93	16	19	8	7	50	143
			Dolomite	11	41	21	20	93	23	19	10	9	61	154
			Calcium silicate	20	48	23	21	112	32	19	13	9	73	185
		Same as series A for first four years; 2000-pound full-depth additions repeated at beginning of 5th year.												
Series C			Burnt lime	15	43	23	18	99	16	20	11	7	54	153
			Limestone	11	41	23	19	94	18	18	10	7	53	147
			Dolomite	14	46	24	18	102	20	18	8	7	53	155
			Calcium silicate	17	53	27	17	114	28	21	10	6	65	179
		Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.												
Series D			Burnt lime	36	47	23	17	123	21	23	13	11	68	191
			Limestone	37	47	20	17	121	18	20	12	12	62	183
			Dolomite	15	43	23	16	97	21	24	11	10	66	163
			Calcium silicate	21	50	25	18	114	24	23	12	10	69	183
		500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.												
Series E			Burnt lime	21	46	22	18	107	22	19	11	8	60	167
			Limestone	16	41	19	18	94	22	22	12	9	65	159
			Dolomite	22	48	23	21	114	22	20	12	9	63	177
			Calcium silicate	24	56	30	23	133	27	21	13	8	69	202
		Same as series D for first four years; 500-pound full-depth additions at beginning of 5th, 6th, 7th, and 8th years.												
Series F			None	23	57	31	22	133	25	29	13	14	81	214
			Burnt lime	27	52	28	22	129	17	23	8	9	57	186
			Limestone	30	56	32	18	136	20	22	9	10	61	197
			Dolomite	27	47	34	22	130	21	23	6	9	59	189
		2000-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment. No further additions.	Calcium silicate	31	62	26	22	141	21	25	11	8	65	206
Series G			Burnt lime	33	59	33	23	148	19	24	8	9	60	208
			Limestone	46	59	31	21	157	22	24	8	8	62	219
			Dolomite	50	60	28	20	158	20	23	6	8	57	215
			Calcium silicate	53	58	34	23	168	27	22	11	8	68	236
		500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.												
Rainfall, acre inches.....				31.1	52.9	55.7	57.4	197.1	61.5	30.3	36.2	43.8	171.8	368.9

TABLE 8b.—*Outgo of potassium from the Virginia Onslow fine sandy loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

Treatments			Pounds potassium per 2,000,000 pounds of soil											Total 8-year period
	Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period						
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total		
Series A	.....	Rainwater	8	13	11	2	34	26	9	10	15	60	94	
	.....	None	25	18	13	13	69	16	13	13	16	58	127	
	2000 pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	22	14	21	14	71	13	14	12	12	51	122	
		Limestone	17	6	19	13	55	11	12	11	10	44	99	
		Dolomite	18	9	19	12	58	11	12	9	9	42	100	
		Calcium silicate	11	10	19	12	52	12	15	11	9	47	99	
Series B	Same as series A for first four years; 2000-pound full-depth additions re- peated at beginning of 5th year.	Burnt lime	16	8	18	12	54	12	12	12	8	44	98	
		Limestone	10	12	18	14	54	11	12	9	9	41	95	
		Dolomite	14	6	20	16	56	13	12	10	6	41	97	
		Calcium silicate	14	22	20	12	68	16	12	11	6	45	113	
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	18	4	19	13	54	13	11	10	10	44	98	
		Limestone	21	3	20	12	56	11	12	9	11	43	99	
		Dolomite	20	6	19	12	57	13	11	10	10	44	101	
		Calcium silicate	18	4	20	12	54	13	11	12	7	43	97	
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	32	14	19	12	77	12	11	12	8	43	120	
		Limestone	30	12	20	13	75	20	11	12	7	50	125	
		Dolomite	24	11	20	12	67	17	12	12	8	49	116	
		Calcium silicate	37	9	20	12	78	19	11	12	9	51	129	
Series E	Same as series D for first four years; 500-pound full-depth additions at be- ginning of 5th, 6th, 7th, and 8th years.	Burnt lime	22	6	18	13	59	14	12	12	8	46	105	
		Limestone	25	6	18	12	61	20	12	12	9	53	114	
		Dolomite	18	6	20	13	57	19	11	12	10	52	109	
		Calcium silicate	26	7	20	12	65	16	12	12	10	50	115	
Series F	.....	None	27	13	13	12	65	23	13	12	16	64	129	
	2000-pound CaO-equivalent mixed with upper three inches of soil at be- ginning of experiment. No further additions.	Burnt lime	24	8	20	12	64	16	12	12	9	49	113	
		Limestone	26	10	20	13	69	11	11	11	9	42	111	
		Dolomite	11	9	19	12	51	14	11	11	9	45	96	
		Calcium silicate	17	8	18	12	55	13	11	10	9	43	98	
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	20	11	18	12	61	10	11	12	6	39	100	
		Limestone	21	10	19	11	61	11	12	12	7	42	103	
		Dolomite	20	13	16	12	61	11	11	12	8	42	103	
		Calcium silicate	28	9	18	12	67	12	11	12	7	42	109	
Rainfall, acre inches.....			30.5	26.7	42.2	35.9	135.3	40.7	24.7	26.2	33.8	125.4	260.7	

averages of series A, B, and C were 64, 60, and 56 pounds, respectively, and those of series D and E were 66 pounds and 64 pounds, respectively, against 78 pounds from the controls. Hence, all of the full-depth incorporations of the liming materials caused a decrease in the solubility of the native supplies of soil potash throughout the 8-year period.

In series F and G, however, where the full and divided additions were incorporated with only the upper third of the soil, the migration of engendered neutral salts of calcium and magnesium from the upper zone caused a limited replacement, or liberation, of potassium from the lower unlimed acid zone. These two series gave leachings of 134 pounds and 158 pounds, respectively, against 128 pounds from the controls. During the second four years, the migration of bicarbonates had reached such an extent as to reverse the previous liberation-effect, the average leachings of 61 pounds and 62 pounds being consonant with those obtained from the full-depth incorporations of series A, B, C, D, and E for the second 4-year period.

There was no consistent difference in the repressive effects exerted by the several liming materials in the full-depth incorporations. In the surface-zone incorporations, the calcium silicate was less repressive than the other three materials upon potassium outgo.

The acid-soluble potassium content of the Virginia soil was one-eighth, and the exchangeable one-fourth, of the values found for the Tennessee soil. The actual outgo from the untreated soil amounted to 16 pounds per annum, with a net loss of 4.3 pounds of potassium. The average repressive effect for the 12 units of series A, B, and C of the Virginia soil was 17.5 per cent during the first four years, and still more during the second four years. During the first 4-year period the divided quarter-additions of series D and E showed the same average outgo as that found for the unlimed soils, but after the period required for the incorporation of all four annual quarter-additions, a definite repressive effect was evidenced by the four additions of series D and the eight of series E.

The outgo of potassium from the full initial additions and the quarter-additions in the surface-zone series F and G, respectively, was in each case only slightly less than that found for the unlimed soil during the first four years, but a definite repressive effect was recorded during the second 4-year period.

On the whole, it is evident that the different liming materials and different methods of incorporation effected a decrease in the amounts of water-soluble potassium. It is certain that no evidence was adduced to indicate any replacement of potassium by any of the several liming materials.

OUTGO OF NITRATE NITROGEN

Nitrate nitrogen determinations were made upon periodic collections, and are summarized for each annual period in tables 9a and 9b. There were five pounds, or less, of nitrogen precipitated per annum at Knoxville, except for the years 1930 and 1931. The Cumberland loam soil was fairly well supplied with readily oxidizable nitrogenous matter, following the long period in sod. The actual outgo from the untreated soil during the 8-year period was 21 per cent of the total nitrogen present initially. This rate would, of course, not be maintained after the depletion of the more readily oxidizable nitrog-

TABLE 9a.—*Outgo of nitrates from the Tennessee Cumberland clay loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

Treatments			Pounds nitrate nitrogen per 2,000,000 pounds of soil										
	Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period					Total 8-year period
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	2	5	3	2	12	5	2	12	11	30	42
	.....	None	63	179	64	75	381	89	35	72	37	233	614
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	89	190	98	94	471	93	51	84	41	269	740
		Limestone	109	170	99	89	467	81	51	64	41	237	704
		Dolomite	100	187	104	75	466	89	47	61	37	234	700
Calcium silicate		106	200	103	98	507	92	53	64	34	243	750	
Series B	Same as series A for first four years; 2000-pound full-depth additions repeated at beginning of 5th year.	Burnt lime	85	206	84	90	465	140	57	69	41	307	772
		Limestone	93	191	85	87	456	137	58	52	39	286	742
		Dolomite	102	202	78	81	463	109	61	70	38	278	741
		Calcium silicate	99	196	83	81	459	128	60	86	50	324	783
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	90	188	98	89	465	102	65	87	61	315	780
		Limestone	91	183	94	81	449	98	58	89	55	300	749
		Dolomite	97	211	96	81	485	96	60	93	67	316	801
		Calcium silicate	99	224	99	78	500	87	58	92	63	300	800
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	75	186	108	94	463	81	53	75	41	250	713
		Limestone	76	189	113	90	468	87	52	77	40	256	724
		Dolomite	76	179	110	89	454	72	53	74	29	228	682
		Calcium silicate	86	195	118	95	494	80	44	73	48	245	739
Series E	Same as series D for first four years; 500-pound full-depth additions at beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	71	199	114	88	472	88	50	95	60	293	765
		Limestone	71	192	118	103	484	94	61	89	51	295	779
		Dolomite	73	197	114	88	472	81	49	83	33	246	718
		Calcium silicate	75	170	111	90	446	93	56	99	54	302	748
Series F	.....	None	70	182	76	63	391	63	38	69	46	216	607
	2000-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment. No further additions.	Burnt lime	78	208	102	82	470	75	37	40	32	184	654
		Limestone	82	194	98	74	448	66	37	54	36	193	641
		Dolomite	93	193	107	87	480	75	32	51	27	185	665
		Calcium silicate	87	198	102	82	469	66	26	55	29	176	645
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	80	187	99	79	445	74	31	36	42	183	628
		Limestone	84	182	98	70	434	71	33	37	45	186	620
		Dolomite	81	179	94	75	429	74	43	49	38	204	633
		Calcium silicate	87	197	98	84	466	76	40	55	40	211	677
Rainfall, acre inches.....			31.1	52.9	55.7	57.4	197.1	61.5	30.3	36.2	43.8	171.8	368.9

enous residue. An increased nitrate outgo was induced by each of the materials during the first four years, and there seemed to be no consistent difference in the effects caused by the several materials. The average increase in annual outgo from series A, B, and C, identical as to treatment through the first four years, was 22.8 pounds of N, as against an 8-unit average of 21.8 pounds for the divided additions of series D and E. The surface-zone additions of series F gave an average increase in outgo of 19 pounds, but the divided surface-zone quarter-additions of series G showed an annual net loss of only 13 pounds. The average annual increase in outgo during the first four years for the 16 units of the four series, A, B, C, and F, to which 3570-pound-equivalent treatments were added initially, was 22 pounds of nitrogen, against a 20-pound average in outgo from the 12 units of series D, E, and G, which received the same liming equivalent in the aggregate, but in divided additions.

The single full additions of series A showed only a small effect during the second four years. The repetitions of series B gave marked accelerations during the fifth year, but totals less than those found for the separate quarter-additions of series C during the second four years. The average outgo from the single additions of series A was the same as that from the four divided additions of series D during the second 4-year period. The repetitions of the quarter-additions of series E gave a continuous accelerative effect during the second four years, and an increase of 39 pounds over series D. The smallest increase in nitrate outgo was found for the incorporations in the upper third of the soil, series F and G. This was true for the single full addition and also for the quarter-additions, and for both of the 4-year periods. In these two series, the actual contact of the soil and liming materials was restricted to a third of the soil, the zone of most active nitrification. Within this zone the rate of treatment was actually three times the extent of that in effect when the liming materials were in contact with the entire body of soil. Any accelerative influence upon the unlimed zone was, of course, limited to the effect of the quantities of lime transposed as dissolved carbonates and neutral salts.

The total native supply of nitrogen in the Virginia soil was only 40 per cent of that found in the Tennessee soil, and the nitrogen increments through rainfall were 69 per cent of those brought to the Tennessee soil.

There were wide discrepancies between the results induced by the incorporations of the several liming materials in the acid fine sandy loam during the first three years, and especially during the first year. This is particularly true of the identical series A, B, and C. As an example, the maximal outgo of 51 pounds and the minimal of 0 pounds were both found for the limestone additions. In these three series the vacillating results of the first year were followed by two years of meager production and outgo of nitrates, as compared with the undisturbed control soil. Concordance in outgo induced by each material in the triplicated units and in a comparison of one material against the others was observed, however, beginning with the fourth year. During the first year a similar condition prevailed where the divided additions of series D and E were incorporated with a coincidental aeration effect at the beginning of each year. During the second and third years these two series, progressively limed, gave an outgo of nitrates several times that found for the full initial additions of series A, B, and C. Similar results obtained for the

TABLE 9b.—*Outgo of nitrates from the Virginia Onslow fine sandy loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

Treatments			Pounds nitrate nitrogen per 2,000,000 pounds of soil										Total 8-year period
	Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period					
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	.04	2.3	3.4	.8	6.5	12	2.1	2.2	6	22	29
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	None	16	10	8	38	72	46	22	36	21	125	197
		Burnt lime	37	8	8	47	100	53	29	45	27	154	254
		Limestone	51	8	9	42	110	51	22	45	23	141	251
		Dolomite	7	10	5	42	64	47	22	45	24	138	202
Series B	Same as series A for first four years; 2000-pound full-depth additions re- peated at beginning of 5th year.	Calcium silicate	2	8	8	44	62	49	21	45	27	142	204
		Burnt lime	2	8	11	43	64	51	22	45	27	145	209
		Limestone	2	11	11	42	66	48	15	45	30	138	204
		Dolomite	1	8	11	42	62	54	20	45	30	149	211
		Calcium silicate	12	7	10	42	71	53	22	45	27	147	218
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	13	8	9	50	80	53	20	45	29	147	227
		Limestone	0	10	8	44	62	48	24	45	27	144	206
		Dolomite	2	11	12	40	65	60	20	45	27	152	217
		Calcium silicate	18	8	13	43	82	57	20	45	29	151	233
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	21	38	19	45	123	53	20	45	27	145	268
		Limestone	13	25	23	43	104	52	20	45	24	141	245
		Dolomite	11	33	36	40	120	50	24	45	26	145	265
		Calcium silicate	9	38	30	42	119	58	17	45	28	148	267
Series E	Same as series D for first four years; 500-pound full-depth additions at be- ginning of 5th, 6th, 7th, and 8th years.	Burnt lime	2	33	76	47	158	60	17	45	33	155	313
		Limestone	2	40	67	45	154	63	19	45	30	157	311
		Dolomite	2	20	33	44	99	58	22	45	27	152	251
		Calcium silicate	6	59	28	46	139	59	15	45	30	149	288
Series F	.....	None	9	44	26	45	124	45	19	36	16	116	240
	2000-pound CaO-equivalent mixed with upper three inches of soil at be- ginning of experiment. No further additions.	Burnt lime	6	96	14	41	157	51	19	45	18	133	290
		Limestone	8	25	23	41	97	46	18	45	17	126	223
		Dolomite	31	16	13	38	70	46	14	45	16	121	191
		Calcium silicate	13	20	13	39	85	46	15	45	16	122	207
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	8	20	25	39	92	45	14	45	19	123	215
		Limestone	4	20	30	39	93	45	14	45	19	123	216
		Dolomite	6	17	29	39	91	46	15	45	20	126	217
		Calcium silicate	33	19	42	39	133	46	14	45	24	129	262
Rainfall, acre inches.....			30.5	26.7	42.2	35.9	135.3	40.7	24.7	26.2	33.8	125.4	260.7

surface-zone incorporations of series F and G, and as was the case for series A-E, the uniformity in outgo that appeared within each group during the fourth year was followed by four years of concordant results. During the second 4-year period there was a surprising uniformity in the effects produced by the four liming materials within each group, and during the seventh year there was a common outgo of 45 pounds for each of the 28 units.

Taken as a whole, the several liming materials show no differences among themselves for any of the seven groups during the last 4-year period. Although differences in the total amounts of liming materials incorporated at full depth and differences in methods of their incorporation produced small differences in the outgo of nitrogen from series A-E during the second four years, the uniform outgo from these five series showed evidence of increased nitrification and losses in excess of those from the surface-zone incorporations of series F and G. The last two groups showed little evidence of enhanced nitrate outgo. It is evident that the cumulative additions are less repressive than the full additions upon nitrate outgo, but even the quarter-additions showed decidedly erratic results in the leachings of the first year.

The difference between the concordant results from the well-buffered and slightly acid heavy Tennessee clay loam and the discordant results from the distinctly acid fine sandy loam from Virginia may be due to several factors. The per cent unsaturation found for the Tennessee soil was 47, as against 74 for the Virginia soil, but the exchangeable hydrogen in the former soil exceeded that of the latter soil. The added liming materials were fully decomposed when incorporated throughout the full depth of both soils, but the resultant reaction values of the well-buffered Tennessee soil were not brought to the pH values that were found for the leachates from the sandy Virginia soil. Furthermore, the organic-matter residues of the Tennessee soil were largely due to the fine roots of bluegrass, whereas numerous particles of high-cellulose peanut hulls were found in the Virginia soil. The experiment was inaugurated during the first month of August, at which time it is known that extensive nitrification takes place in the Tennessee soil, whereas the nitrification transpiring in the Virginia soil is nugatory.

From the foregoing, it would appear that denitrification of varying degree has been in effect under the Virginia conditions. Excessive liming, especially of poorly buffered soils, is conducive to denitrification, and the double unit of 7140 pounds of CaCO_3 -equivalence, and even the single-unit of 3570 pounds, may be considered as an excessive liming for the Onslow fine sandy loam. Midgely (35) has recently presented the literature upon this undesirable aspect of liming. Any denitrification responsible for the discrepancies could have occurred either in the soil or in the collections of leachings, but the fact that a paucity of nitrates occurs in this soil in its native habitat indicates that either absence or meager and irregular occurrences of nitrates in the leachings were caused by denitrification within the soil. Determinations of nitrites, as well as those of free and albuminoid ammonia in the rainwater leachings, have been provided for in Tennessee lysimeter experiments for more than twenty years. The leachings have been collected with and without the presence of either toluene or chloroform. Except in certain instances where either ammoniacal materials or foreign soils have been added to the Tennessee soils, the small and rare occurrences of nitrites, and also those of free ammonia,

have been too meager to be considered. Because of the fact that no reasonable rate of liming had caused nitrites to appear in the leachates of previous experiments, the experimental outline did not call for nitrite determinations in the leachings obtained in the present study.

If it be true that the observed results are due to denitrification and are attributable to liming, it appears that the discordance as to nitrate production and outgo did not continue after the full 3570-pound addition had become fixed and aged in the soil. The flora had apparently become accustomed to the altered soil reaction, since neither full nor divided additions caused a continuation of the initial effect. On the other hand, the denitrification might be in evidence only so long as the high-cellulose peanut hulls persist as such in the soil. The variations between the mixed or aerated unlimed soil, and that unmixed or unaerated, may throw light upon this point. The mixing of the Tennessee soil, given as a control procedure for the soils that received the annual quarter-additions, caused only a small increase in the outgo of nitrates for the first 4-year period and none for the 8-year period. But the annual aeration of the Virginia soil control and the units of series D, E, F, and G, incident to incorporations of the several liming materials, caused a decided increase in nitrate outgo. Since this was true for all of the four full additions of series F, as well as the divided additions of series D, E, and G, it cannot be said that the progressive liming of the last three series was responsible for the apparent cessation of denitrification and the ascendancy of nitrification.

OUTGO OF SULFATE SULFUR

Differing from the outgo of nitrogen, a considerable part of a sulfate outgo may be offset by the amounts supplied by rainfall. The nearer the location to coal-consuming localities, the larger will be the increments of sulfur. A 317-pound precipitation of sulfate sulfur occurred during the 8-year period at the Tennessee Station, located on the outskirts of Knoxville, whereas the precipitation at the Virginia Station, on the edge of the small town of Blacksburg, was only 134 pounds.

There was no difference between the amount of sulfur derived from rainfall and the amount lost from the unlimed and unmixed Tennessee soil during the first four years, and only a 10-pound net loss for the 8-year period. The sulfur outgo from the unlimed Virginia soil was slightly more than the sulfur added by rainfall, the net loss for the 8-year period being only 14 pounds.

The total sulfur content of the Tennessee soil was 0.049 per cent. As in previous experiments, liming produced an acceleration in the outgo of sulfates from this type of soil (17,26,27,34). Usually this accelerative effect is not marked after the first year or two. The initial accelerative effect caused by the full additions of series A, B, and C, was somewhat greater than that found for the quarter-additions of series D and E, but for the first four years the results for these five series were in accord, and also in agreement with those for the surface-zone series, F and G. There seemed to be no consistent difference between the capacities of the several liming materials to accelerate the outgo of sulfates. Although the several materials were comparable among themselves within each group, there was evidence of further acceleration during the second four years as a result of the repetition of the full treatments of series B and also the divided additions of series C. For the 8-year period

TABLE 10a.—*Outgo of sulfates from the Tennessee Cumberland clay loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

Treatments			Pounds sulfate sulfur per 2,000,000 pounds of soil										Total 8-year period
	Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period					
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	28	46	51	54	179	36	35	41	26	138	317
	.....	None	31	38	66	43	178	48	31	25	45	149	327
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	49	63	50	58	220	47	30	37	38	152	372
		Limestone	54	58	49	58	219	48	27	35	40	150	369
		Dolomite	56	62	52	55	225	48	30	34	36	148	373
		Calcium silicate	61	58	49	58	226	49	28	34	36	147	373
Series B	Same as series A for first four years; 2000-pound full-depth additions re- peated at beginning of 5th year.	Burnt lime	48	64	49	56	217	67	33	42	37	179	396
		Limestone	54	58	49	57	218	64	31	38	36	169	387
		Dolomite	55	62	49	57	223	65	35	42	34	176	399
		Calcium silicate	60	61	48	55	224	70	34	45	35	184	408
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	49	60	50	57	216	52	33	45	44	174	390
		Limestone	54	58	49	57	218	51	32	46	41	170	388
		Dolomite	56	62	49	55	222	54	33	49	44	180	402
		Calcium silicate	63	60	48	57	228	54	38	49	43	184	412
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	36	61	53	65	215	47	30	39	39	155	370
		Limestone	43	60	55	63	221	45	28	38	37	148	369
		Dolomite	39	64	58	64	225	47	30	42	32	151	376
		Calcium silicate	44	62	58	62	226	49	31	41	37	158	384
Series E	Same as series D for first four years; 500-pound full-depth additions at be- ginning of 5th, 6th, 7th, and 8th years.	Burnt lime	38	61	58	62	219	52	34	46	40	172	391
		Limestone	35	60	60	62	217	50	34	48	37	169	386
		Dolomite	40	61	60	65	226	48	34	50	33	165	391
		Calcium silicate	40	63	64	66	233	53	36	52	42	183	416
Series F	.....	None	32	51	52	56	191	43	30	33	42	148	339
	2000-pound CaO-equivalent mixed with upper three inches of soil at be- ginning of experiment. No further additions.	Burnt lime	35	66	55	60	216	43	27	29	31	130	346
		Limestone	40	67	54	55	216	44	28	34	39	145	361
		Dolomite	40	65	59	62	226	44	29	33	32	138	364
		Calcium silicate	47	65	55	61	228	44	28	35	32	139	367
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	36	56	54	63	209	45	30	31	38	144	353
		Limestone	34	61	60	60	215	45	28	30	36	139	354
		Dolomite	38	59	56	65	218	48	30	35	38	151	369
		Calcium silicate	35	61	59	66	221	44	31	34	38	147	368
Rainfall, acre inches.....			31.1	52.9	55.7	57.4	197.1	61.5	30.3	36.2	43.8	171.8	368.9

TABLE 10b—*Outgo of sulfates from the Virginia Onslow fine sandy loam, as influenced by four liming materials and different methods of incorporation during an 8-year period*

Treatments			Pounds sulfate sulfur per 2,000,000 pounds of soil										
	Amounts and methods of incorporation	Material	First 4-year period					Second 4-year period					Total 8-year period
			1924	1925	1926	1927	Total	1928	1929	1930	1931	Total	
Series A	.....	Rainwater	14	24	26	16	80	17	12	15	10	54	134
	.....	None	21	14	20	19	74	24	11	18	19	72	146
	2000-pound CaO-equivalent mixed full depth at beginning of experiment. No further additions.	Burnt lime	26	19	24	17	86	26	11	24	20	81	167
		Limestone	26	16	22	13	77	27	11	21	17	76	153
		Dolomite	28	17	24	13	82	23	9	19	17	68	150
		Calcium silicate	30	17	22	13	82	31	12	18	17	78	160
Series B	Same as series A for first four years; 2000-pound full-depth additions repeated at beginning of 5th year.	Burnt lime	22	16	22	13	73	28	10	26	17	81	154
		Limestone	25	13	22	12	72	31	8	22	17	78	150
		Dolomite	27	18	23	12	80	27	10	26	20	83	163
		Calcium silicate	29	15	22	12	78	29	10	21	20	80	158
Series C	Same as series A & B for first four years; 500-pound full-depth additions repeated beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	21	16	21	13	71	31	9	23	20	83	154
		Limestone	24	14	22	12	72	28	11	26	20	85	157
		Dolomite	26	18	23	12	79	28	8	25	19	80	159
		Calcium silicate	26	15	22	13	76	24	9	25	19	77	153
Series D	500-pound CaO-equivalent mixed full depth at beginning of experiment and at beginning of 2nd, 3rd, and 4th years.	Burnt lime	25	17	21	13	76	27	9	20	19	75	151
		Limestone	23	16	22	15	76	29	9	25	19	82	158
		Dolomite	25	17	22	14	78	28	10	24	16	78	156
		Calcium silicate	24	16	20	13	73	24	11	24	17	76	149
Series E	Same as series D for first four years; 500-pound full-depth additions at beginning of 5th, 6th, 7th, and 8th years.	Burnt lime	22	13	26	12	73	25	11	24	18	78	151
		Limestone	21	15	24	12	72	27	11	24	18	80	152
		Dolomite	26	14	25	13	78	27	9	24	19	79	157
		Calcium silicate	22	13	25	12	72	27	9	25	17	78	150
Series F	.....	None	21	16	19	19	75	28	10	19	18	75	150
	2000-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment. No further additions.	Burnt lime	17	17	19	12	65	27	7	24	16	74	139
		Limestone	24	15	23	12	74	27	8	25	17	77	151
		Dolomite	26	16	23	12	77	22	10	24	14	70	147
Calcium silicate		26	21	23	12	82	24	11	25	13	73	155	
Series G	500-pound CaO-equivalent mixed with upper three inches of soil at beginning of experiment and of 2nd, 3rd, and 4th years. No further additions.	Burnt lime	22	16	22	12	72	28	11	25	15	79	151
		Limestone	18	15	21	12	66	25	11	25	14	75	141
		Dolomite	22	17	21	12	72	30	11	25	16	82	154
		Calcium silicate	26	16	23	11	76	27	11	25	15	78	154
Rainfall, acre inches.....			30.5	26.7	42.2	35.9	135.3	40.7	24.7	26.2	33.8	125.4	260.7

the results from the single full addition of series A, and those for the equal incorporations of series D, made in four annual treatments, were practically identical. The same was true of the single full incorporations with four subsequent quarter-additions, series C, in comparison with the eight annual quarter-additions of series E. During the second four years, the average outgo from each of the surface-zone series F and G was less than that from any one of the series in which the additions were incorporated at full depth, and practically identical with the losses from the untreated soils.

When sulfur income from the rainfall is subtracted from the average outgo found for the aerated and unaerated unlimed Tennessee controls, a net loss of only 16 pounds is shown for the 8-year period. A similar computation gives net losses of 55 pounds as the average for the four liming materials of series A; 81 pounds for series B and also for series C; 58 pounds for series D; 79 pounds for series E; and 43 pounds and 44 pounds for series F and G, respectively. Although the several liming materials do not differ greatly in their accelerative effects, the calcium silicate shows the highest outgo in every series, save one, whereas the dolomite results are slightly greater than those found as the averages for burnt lime and limestone in every series.

The total sulfur content of the Virginia soil was only 0.028 per cent, or 560 pounds per 2,000,000 pounds of soil. This small residue of sulfur had withstood extended oxidation and leaching, and no large increase in sulfur outgo would be expected from the liming materials. Such treatments have been found to be effective in enhancing the outgo of sulfur from heavier types of Virginia soils (7). In general, some accelerative effect was found for all the series during the first year, but the losses for the first 4-year period were comparable with those from the untreated soils and also with the amounts carried by the rainwaters. During the second 4-year period the rainwater sulfur was less than that found to have passed from the unlimed soils, and the average outgo from each series, except series F, was somewhat greater than that from the unlimed soils. The net loss from the average outgo of the five full-depth series A-E was 7 pounds, and that from the surface-zone series F and G was only one pound. As in the case of the Tennessee soil, the decidedly smaller sulfate leachings gave no indication of consistent differences in the capacities of the several liming materials to enhance sulfonation and outgo of sulfates.

SUMMARY

Results are given from an 8-year 62-unit lysimeter study of a well-buffered, slightly acid Tennessee Cumberland clay loam and a strongly acid Virginia Onslow fine sandy loam to determine the conservation of, and effects induced by, four liming materials—burnt lime, limestone, dolomite, and calcium silicate—in unit, double, and divided additions with full-depth and surface-zone incorporations. The unit addition was equivalent to 2000 pounds of CaO , or 3570 pounds of CaCO_3 , per 2,000,000 pounds of soil, and all calcium and magnesium data are expressed in terms of CaCO_3 .

With rainfall of 197 inches and 171.8 inches for the first and second 4-year periods at the Tennessee Station, the leachings from the control for series A, B, and C was 45.8 per cent during the first 4-year period and 51.3 per cent during the second. At the Virginia Station corresponding drainage values of

41.2 per cent and 51.1 per cent were obtained from totals of 135.3 inches and 125.4 inches. Rainwaters at both stations showed increments of calcium and magnesium that amounted to considerable fractions of the quantities leached from the unlimed soils. On the whole, no marked effect on the volumes leached was shown by the four liming materials.

The loss of calcium from each limed unit of the Tennessee soil was considerably less the first year than the second year. The same being true of the controls, this was attributed to the minimal annual rainfall of the first year rather than slow assimilation of the additions. In general, the Tennessee soil showed closely concordant losses of calcium from burnt lime and limestone within each group; the outgo from each silicate addition was comparable with, although uniformly somewhat less than, the burnt lime and limestone parallels.

The calcium outgo from each of the seven dolomite additions to the Tennessee soil was greater than that from the untreated soil but materially less than that from the corresponding high-calcic treatments during the first 4-year period; that is, before the initial supply of exchangeable calcium had been materially reduced. With no additions after the first 4-year period, dolomite showed no appreciable increase in calcium outgo from the full-depth series A and D, whereas a repression was evidenced by the surface-zone incorporations of series F and G.

The eight annual additions of the high-calcic materials of series E showed calcium losses only slightly less than those of the full initial and four supplemental fractions of series C, and considerably less than the two full additions, one the first and one the fifth year, of series B. The surface-zone full addition of each liming material showed uniformly a smaller outgo of calcium than the corresponding full-depth incorporation.

The unlimed Virginia Onslow fine sandy loam, containing one-third as much total and also exchangeable calcium as the Tennessee soil, and 74 per cent unsaturated, suffered an annual net loss of only 61 pounds of CaCO_3 , or one-third of the net loss from the Tennessee soil.

The calcium outgo from each full-depth unit of the Virginia soil was more the first year than during the succeeding three years, a result opposite to that found for the Tennessee soil. During the second 4-year period the largest outgo from each of the 28 limed units and controls came during the fifth year, and the burnt lime and limestone results were generally in accord. Each silicate addition yielded considerably less calcium than either of the corresponding additions of high-calcic materials. The calcium outgo from the surface-zone incorporation of each liming material was in every case less than the amount of calcium leached from the corresponding full-depth incorporation during the first 4-year period. For the first 4-year period the calcium outgo from each addition of dolomite was close to that from untreated Virginia soil. The maximal net loss of calcium from dolomite during the 8-year period was equivalent to only 3 per cent of the two full additions of series B, and in two of the other series the losses of calcium were even less than those from the unlimed soil. The small increases, or even decreases, in the outgo of calcium from the dolomite additions during the first 4-year period were in contrast to the higher and enhanced yields from the Tennessee soil of high exchangeable calcium content. The average enhancement in calcium

outgo from the 1780 pounds of calcium carbonate carried by the 3570-pound addition of dolomite was only 30 pounds for the first 4-year period. Neither the full repetitions nor quarter-additions of dolomite showed material increases in calcium outgoing during the second 4-year period.

Although the magnesium content of the Tennessee soil was 2.7 times as great as its total content of calcium, only 8.9 per cent of the total magnesium content was in exchangeable form, and the net loss of magnesium from that soil was only 85 pounds per annum.

Both burnt lime and limestone showed consistently a repressive effect upon the magnesium outgoing from the Tennessee soil in the three series A, B, and C during both 4-year periods, the maximal effect being shown by the full-depth incorporations of burnt lime and limestone in series B. The seven silicate treatments did not register this effect during the first four years, nor did any of the five full-depth treatments during the second four years; but the surface-zone additions did show a repressive effect during the second 4-year period.

The quantities of both total and exchangeable magnesium in the Virginia soil were about one-eighth of the respective amounts found in the Tennessee soil, and the annual net loss of magnesium from the unlimed Virginia soil was equivalent to only 11.5 pounds of calcium carbonate.

Full-depth incorporations of high-calcic materials gave results fairly comparable, when averaged, and were without marked effect as to either acceleration or repression of magnesium outgoing during the first four years. Each of the seven dolomite additions caused an enhancement in magnesium outgoing, but the average outgoing from the dolomite additions to the Virginia soil was less than the magnesium outgoing from the untreated Tennessee soil.

The Tennessee and Virginia soils showed wide differences in their ability to conserve added $\text{Ca} + \text{Mg}$. The amounts of the two elements brought to the Tennessee soil by the rainwaters were 34 per cent and 48 per cent of the amounts lost by leaching from the unlimed soil during the two four-year periods.

Within each Tennessee series the three high-calcic materials, burnt lime, limestone, and calcium silicate, gave comparable results for the total outgoing of $\text{Ca} + \text{Mg}$, and amounts slightly but consistently less than those leached from the dolomite additions. This relationship is accounted for by the fact that the magnesium fixed by the soil complexes is more readily hydrolyzed than the fixed calcium. The largest net loss of $\text{Ca} + \text{Mg}$ from the full-depth addition to the Tennessee Cumberland clay loam soil was 37.4 per cent in series A, whereas the smallest, or 13.5 per cent of the addition, came from the divided surface-zone additions.

The total outgoing of $\text{Ca} + \text{Mg}$ from the Virginia soil was uniform for burnt lime, limestone, and dolomite, whereas the outgoing from the added silicate was considerably less. The conservation of $\text{Ca} + \text{Mg}$ from equivalent quantities of the four materials therefore differed from that shown by the Tennessee clay loam.

The two full-depth additions of series B gave the maximal 8-year outgoing of $\text{Ca} + \text{Mg}$ from both soils. The net loss from the single 3570-pound addition to the Tennessee soil, series A, was more than twice that from the Virginia soil. The average net loss of $\text{Ca} + \text{Mg}$ from the two full additions, series B, to the Virginia soil was less than that found for the single full-depth treat-

ment, series A, of the Tennessee soil. For the 8-year period the average net loss of Ca+Mg from the two full-depth 3570-pound additions to the Virginia soil was 17.5 per cent of the amount added, against 10.5 per cent from full initial additions and four subsequent quarter-additions of series C and 13.4 per cent from the eight quarter-additions of series E, the latter series showing a net loss about 200 pounds in excess of that shown by the single full additions of series A. The net losses from the full additions of series A were equivalent to 10 per cent and 10.8 per cent of the addition for the first and second 4-year periods, respectively, as against 9.2 per cent and 10.0 per cent for four quarter-additions of series G. The net losses from the full 3570-pound additions and the divided additions in the upper 3-inch zone, series F, and series G, were equivalent to 8.1 per cent and 7.3 per cent of the quantity added during the first 4-year period. It is evident that added calcium and magnesium were fixed more tenaciously in the acid sandy Virginia soil than in the less acid heavy Tennessee soil.

The ratio of Ca:Mg in the total outgo from the unlimed Tennessee soil was 2.02:1, whereas that for the unlimed Virginia soil was 2.95:1. The grand averages found for the 21 high-calcic incorporations were 3.14:1 and 4.35:1 for the Tennessee and Virginia soils, respectively. As grand averages for the seven series, the dolomite additions gave ratios of 1.28:1 and 0.97:1 for the Tennessee and Virginia soils, respectively.

The carbonate content of rainwaters exceeded the carbonate outgo from the untreated Tennessee soil, and dissolved carbonates accounted for one-fourth of the total Ca+Mg outgo from the unlimed controls. The leachates from the two acid soils carried appreciable quantities of dissolved carbonates as the result of the hydrolytic breakdown of natural silicates. In every instance the quantity of carbonates leached from the clay loam during the initial year was the smallest outgo found for the first 4-year period, whereas the outgo of the seventh year was uniformly the lowest found for all units during the second 4-year period.

The annual carbonate increment to the Virginia soil was 126 pounds. The 8-year average outgo of 753 pounds from this acid soil was 255 pounds less than the amount carried by rainfall. Differing from the Tennessee soil, the Virginia soil yielded its maximal outgo of carbonates during the first year. In spite of its acidity, lower base content, poor nitrification and sulfonation, the unlimed controls of the Virginia soil yielded 753 pounds of carbonates, or 83 per cent of the outgo from the Tennessee soil. The order of magnitude of carbonate outgo from the different limed series corresponded to that shown for the Tennessee soil.

The reaction values of the leachates from the Tennessee soil did not differ greatly during the first 4-year period. Repetitions of full and also divided additions induced recurrent increases in pH values of the leachates during the second four-year period. Where the additions were not repeated, the values came to a common level.

The reaction values of the first year—the period of maximal carbonate outgo—were the largest found for the Virginia soil during the 8-year period. During the first three years the leachings from the unlimed acid units were quite alkaline, whereas those of the other five years were close to neutrality. Full-depth and surface-zone incorporations gave comparable pH values during

the first 4-year period. Carbonate residues were present in three of the units of series G at the end of four years, but the underlying acid zone brought the pH values of the leachates to uniformity.

The exchangeable potassium content of the Tennessee soil was one-eighth of that soluble in strong HCl, and the potassium outgo during the first four years was therefore considerably greater than that during the next four years. The average outgo of potassium from the 12 full additions of series A, B, and C was 104 pounds for the first 4-year period; the average outgo from the eight divided additions of series D and E was 113 pounds, and that from the unlimed soil was 128 pounds. The averages for series A, B, and C were 64, 60, and 56 pounds, respectively, for the second 4-year period; those of series D and E were 66 and 64 pounds, respectively, against 78 pounds for the controls. The full-depth incorporations of the three common liming materials therefore caused a decrease in solubility of the native supplies of soil potash throughout the 8-year period, with no consistent difference in repressive effects. The calcium silicate was less effective than the other three liming materials in the repression of potassium outgo.

The acid-soluble potassium content of the Virginia soil was one-eighth, and the exchangeable one-fourth of the values found for the Tennessee soil. The potassium outgo from the unlimed soil was 16 pounds per annum, but the net loss was only 4.3 pounds. The average repressive effect of the 12 units of series A, B, and C was 17.5 per cent during the first 4-year period, and still more during the subsequent four years. The potassium leachings from the quarter-additions of series D and E varied in their annual relationship to the outgo from the unlimed soils, but repressive effects were evidenced in the totals from both series. The outgo of potassium from the surface zone, series F and G, was not materially repressed during the first four years, but a definite repressive effect was in evidence during the second four years. In no case was evidence adduced to indicate, for either soil, any replacement of potassium by the calcium of the four liming materials in the zone in which an incorporation was made.

The average total nitrate nitrogen leached from the Tennessee soil during the 8-year period was 25 per cent of the nitrogen present initially. An increased outgo was shown for the four liming materials for the first 4-year period, with no consistent difference shown for the several forms of lime. The grand average outgo for the 20 full-depth incorporations was 747 pounds, against 645 pounds for the surface incorporations.

The differences between the concordant nitrate results from the well-buffered and slightly acid Tennessee soil and the discordant results from the strongly acid Virginia soil may be due to several factors. The per cent unsaturation of the Tennessee soil was less and the liming materials were completely decomposed when incorporated throughout the full depth of both soils, but the reaction values of the well-buffered Tennessee soil were not brought to the pH values found in the more acid sandy Virginia soil. Furthermore, the organic-matter residues of the Tennessee soil were largely due to fine roots of an extended growth of bluegrass, whereas numerous particles of high-cellulose peanut hulls were found in the previously cultivated Virginia soil. It would appear, therefore, that denitrification of varying extent has been induced under the Virginia conditions by the excessive liming represented

by the double-unit 7,140 pounds of CaCO_3 -equivalence, and also the single unit of 3,570 pounds. Aeration of the Tennessee soil did not materially enhance nitrate production, but aeration caused a decided increase in nitrate outgo from the unlimed Virginia soil and from the units of series D, E, F, and G.

No marked difference was shown between the amount of sulfur derived from rainfall and the amount lost from the unacrated Tennessee soil during the first four years, and only a 10-pound loss for the 8-year period. The unlimed Virginia soil gave a sulfur outgo only 14 pounds more than that added by rainfall during the 8-year period. The accelerative effects produced by the several liming materials did not differ greatly.

The Virginia soil contained only 0.028 per cent of sulfur, or 560 pounds per 2,000,000 pounds of soil. This small sulfur residue had already withstood extended oxidation and leaching, and no large increase of sulfur outgo would be expected from the additions of the four liming materials. Such treatments have been found to be effective for a time, however, in enhancing the outgo of sulfur from heavier types of both Tennessee and Virginia soils. Accelerative influences were registered by all additions in all series during the first year, but sulfur losses over a 4-year period were comparable with those from the unlimed soil and also with the amounts carried by the rainwaters. During the second 4-year period, the rainwater sulfur was less than the sulfur outgo from the unlimed soils, and the average outgo from each series, except series F, was somewhat greater than that of the unlimed soils. The Virginia Onslow fine sandy loam gave no indication of consistent differences in the capacities of the four liming materials to enhance sulfification and outgo of sulfates.

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