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WHAT HAPPENS TO THE LIME WHEN SOIL IS LIMED?[1]

by

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1. *Introduction.*

The object of this paper is to trace what happens to the lime when soil is limed. The lime applied to the soil, is

a) taken up by the crop;
b) washed out by rainwater;
c) adsorbed by the clayhumus-substance;
d) left behind in the soil in the form of $CaCO_3$.

In order to obtain accurate results it would be necessary to make an analysis not only of the soil, but also of the drainagewater and of the crop. I have no data at my disposal of the two latter analyses. I have simply, in the case of 7 experiment

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[1] This paper presents the substance of three other papers which appeared in the „Landbouwkundig Tijdschrift, 1925 and 1926". Owing to a different method of calculating and to the repetition of some of the tests, several figures differ somewhat from those, previously given.

fields, compared the composition of the limed plot (L) with that of the immediately adjacent unlimed plot (U). Six of these 7 fields had been limed shortly before the soil samples were taken. In this short period only very small quantities of CaO were taken up by the crop or washed out by rainwater, so that the differences in this respect between limed and unlimed were practically negligible. The soil of experiment field No. III where the lime was applied some years prior to the taking of soil samples, is a very heavy, impermeable clay soil and is moreover grassland. In this case too the differences (a) and (b) between L and U are negligible. I can therefore confine myself to determining the influence of liming on the soil, i. e. on the content of $CaCO_3$ and of clayhumus-lime (exchangeable CaO). But even this cannot be done exactly, since the composition of the soil of the limed plot was not determined before liming. I must therefore rest content with a comparison of the limed and unlimed plots at the moment of soil sampling. That I have ventured to publish the results, in spite of the resultant inaccuracy, is due to the fact that they throw a clear light on the great and indeed predominant influence of the degree of saturation of the clayhumus-substance with CaO on what happens to the lime, i. e., whether the lime is adsorbed by the clayhumus or whether it remains in the soil in the form of $CaCO_3$.

2. *Short description of the experiment fields.*

I. Experiment field — *Staal.* Heavy clay soil with little humus and practically free from $CaCO_3$ in the surface-soil; the subsoil (25—50 cm) contains 0,7 % $CaCO_3$. At a depth of about 70 cm the soil effervesces very distinctly with HCl. Arable land. The limed plot was manured in July 1924 with lime cake [1]) in a well dried condition to the amount of 50.000 KG per HA, containing about 12.000 KG CaO. The land was then ploughed four times to a depth of 20 cm. The soil sampling took place in April 1925. The lime cake was then scarcely visible.

II. Experiment field — *Dijkema.* Heavy clay soil with little humus and some $CaCO_3$ in the surface-soil. The subsoil (25—50 cm) contains already 2,5 % $CaCO_3$. Arable land. The

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[1]) Lime cake, i.e., filter-press cake from beet sugar manufacture (Kreideschlamm).

limed plot was manured in February 1923 with 10.000 KG slaked lime per HA, containing 7900 KG CaO. The lime was very wet and caked. The land was frozen so that the lime lay on the ground two or three weeks before it could be harrowed in lightly. In April the plots were still white with lime, which on investigation was found to consist largely of coarse-grained $CaCO_3$ (1).

III. Experiment field — *van der Grift*. Very heavy clay soil, relatively rich in humus; free from $CaCO_3$ in both surface- and subsoil. It is a very sticky soil, nearly impermeable to water. The limed plot was manured in 1915, 1920 and 1923, each time with 10.000 KG slaked lime per HA. Since it is grassland, the lime was not mixed with the soil. The soil sampling took place in March 1925. On the soil and in the upper 10 cm were found the remainder of the lime, which had been transformed into $CaCO_3$.

IV. Experiment field — *Atzema*. Heavy clay soil, relatively rich in humus; free from $CaCO_3$, in both surface- and subsoil. Under the subsoil is found peat at a depth of about 30 cm. Arable land. The limed part of the field was manured in autumn 1922 with 20.000 KG lime cake per HA. Two years later the soil sampling took place. No further trace of the lime cake was then to be seen.

V. Experiment field — *Wit*. Peat soil, very rich in humus, with no $CaCO_3$ (2). The limed plot was manured in March 1924 with lime cake, in a good dry condition, to the amount of 2300 KG CaO per HA. Immediately after the liming the soil was mixed with the lime. The soil sampling took place in January 1925. No trace of the lime cake was then to be found.

VI. Experiment field — *Wit*. Another part of the same field as V.

VII. Experiment field — *Weyer*. Peat soil, very rich in humus, with no $CaCO_3$ (2). Arable land. The limed plot was manured in October 1923 with lime cake, in a good dry condition, to the amount of 6000 KG CaO per HA. Immediately after liming the lime was worked into the upper layer of the surface-soil. The soil sampling took place in September 1924. No trace of the lime cake was then to be found.

The fields *Weyer* and *Wit* were laid out, sampled and limed under the supervision of Dr. Jac. van der Spek.

As can be seen from the above, the lime was put on 5 fields

I, IV—VII in the form of $CaCO_3$ (lime cake) and on field II and III in the form of slaked lime. As already stated the CaO on these two latter fields was speedily changed into $CaCO_3$, so that all the fields may be said to have been manured with lime in the form of $CaCO_3$.

3. *Composition of the soils (Table A).*

TABLE A.

Experiment field n⁰.	Soil sample n⁰. B	U = unlimed; L = limed	Percentages on dried soil (105° C)					pH (Biilmann) in watery suspension
			Humus	Clay	Sand	$CaCO_3$	Exchangeable CaO	
I	1946	U	1.8	56.8	40.8	0.57	0.608	7.6
	1944	L	2.2	54.3	42.2	1.29	0.665	7.8
II	1751/52	U	2.9	66.2	29.6	1.25	0.747	8.0
	1750/53	L	2.8	66.1	29.5	1.66	0.751	8.0
III	1939	U	8.8	73.2	17.8	0.19	0.849	6.3
	1937	L	8.5	70.0	20.0	1.49	1.139	7.2
IV	1697	U	12.6	63.7	23.7	0	0.366	4.8
	1698	L	9.7	59.2	31.1	0	0.791	6.8
V	1857/59	U	48.1	21.3	30.6	0.51	1.390	5.2
	1856/58	L	44.9	17.7	37.4	0.53	1.605	5.9
VI	1869/71	U	42.6	23.1	34.3	0.50	1.715	6.1
	1868/70	L	43.0	20.2	36.8	0.68	1.815	6.6
VII	1724	U	50.0	29.9	20.1	0.60	1.104	4.6
	1718	L	50.0	31.3	18.7	0.76	1.734	5.5

Table A shows the composition of the surface-soils (0—18 à 25 cm) of the limed plots and of the unlimed plots immediately adjacent thereto, per 100 parts of dried soil (105° C), and also the pH according to Biilmann (3). With the exception of plots IV and V there is very little difference in the humus- and clay⸗contents between the soils of the limed and unlimed plots of the same fields.

4. *Differences in CaO⸗content between limed and unlimed soils (Table B).*

TABLE B.

Experiment field n⁰.	Differences in gms CaO between limed (L) and unlimed (U) on 100 gms dried soil (105° C) in the form of			= in percentages	
	$CaCO_3$	exchangeable CaO	total	$CaCO_3$	exchangeable lime
I	0.403	0.057	0.460	88	12
II	0.230	0.004	0.234	98	2
III	0.728	0.290	1.018	72	28
IV	0.0	0.425	0.425	0	100
V	0.011	0.215	0.226	5	95
V	0.101	0.100	0.201	50	50
VII	0.090	0.630	0.720	12	88

Table B shows the differences in the content of CaO between limed and unlimed soils of each field, in the form of $CaCO_3$, and clayhumus⸗CaO respectively, and also their sum, per 100 parts dried soil (0,403 + 0,057 = 0,460). In table B are also shown the quantities of CaO, remaining as $CaCO_3$ and taken up by the soil as clayhumus⸗CaO in percentages. Here great differences are apparent. The soil of fields IV, V and VII fixed all or practically all lime as clayhumus⸗CaO (100 %, 95 %, 88 %). In the soil of fields I and II practically all the lime remained as $CaCO_3$ and very little was fixed as clayhumus⸗CaO (12 %, 2 %). The fields III and IV come between these two extremes (28 %, 50 %).

The factors which have an influence on what happens to the lime, when soil is limed are:

1/ the amount of CaO that the soil can take up;

2/ the amount of lime used for manuring;

3/ the form and the fineness of the lime, the thoroughness of the mixing of the lime with the soil and the time during which the soil is subjected to the action of the lime.

5. *The K(clay)- and K(humus)-values and the V-value (Table C).*

TABLE C.

Experiment field n^0.	Soil sample n^0. B	pH (table A)	CaO per 100 parts humus = K (humus)	gms on 100 gms dried soil (105° C)					CaO per 100 parts clay = K(clay)	Degree of saturation = V
				Humus (table A)	CaO in humus	CaO in clay + humus (table A)	CaO in clay (difference)	Clay (table A)		
CLAY SOILS: K (humus) estimated from the pH; CaO in humus calculated from K (humus) and humus.										
I	1946	7.6	5.2	1.8	0.094	0.608	0.514	56.8	0.90	52
	1944	7.8	5.2	2.2	0.114	0.665	0.551	54.3	1.01	53
II	1751/52	8.0	5.2	2.9	0.151	0.747	0.596	66.2	0.90	49
	1750/53	8.0	5.2	2.8	0.146	0.751	0.605	66.1	0.92	50
III	1939	6.3	4.0	8.8	0.352	0.849	0.497	73.2	0.68	40
	1937	7.2	5.2	8.5	0.442	1.139	0.697	70.0	1.00	50
IV	1697	4.8	2.3	12.6	0.290	0.366	0.076	63.7	0.12	17
	1698	6.8	4.8	9.7	0.466	0.791	0.325	59.2	0.55	38
HUMUS SOILS: all the CaO assumed to be in the humus; K(humus) calculated from CaO in humus and humus.										
V	1857/59	5.2	2.89	48.1		1.390				23
	1856/58	5.9	3.57	44.9		1.605				29
VI	1869/71	6.1	4.03	42.6		1.715				34
	1868/70	6.6	4.22	43.0		1.815				36
VII	1724	4.6	2.21	50.0		1.104				17
	1718	5.5	3.47	50.0		1.734				26

The amount of lime which the soil can take up in the form of clayhumus-CaO depends on the content of clay and humus in the soil and on the richness of this clay and humus in bases. Owing to lack of time only the content of exchangeable CaO was determined. Now CaO predominates amongst the exchangeable bases (4), so that one can draw fairly far-reaching conclusions simply from the content of exchangeable CaO.

The exchangeable lime is present, partly in the clay substance, partly in the humus. So far, we have no method of separately determining these two forms of lime. There exists, however, some relationship between the lime-content of the humus per 100 parts of humus [K (humus)] and pH. I have plotted the pH of a great number of humus soils against the K (humus). It is true that fairly large differences occur in the pH's of soils with the same K-values and vice versa, but a mean pH-K-curve can none the less be drawn, which at least approximately shows the K (humus) when the pH is known. So, for instance, with a pH of about 7, K (humus) = about 5; with a pH of about 6, K (humus) = about 4. These figures are of course only approximately correct, but with clay soils poor in humus we can use them — without any great risk of error — in calculating the percentage of exchangeable lime in the humus, after which the lime-content in the clay and the K (clay) can be calculated. This calculation may be illustrated by the following example (Table C, soil sample No. B 1946).

K (humus) B 1946 with pH = 7,6 is supposed to be 5,2. The humus-content being 1,8 % (Table A), there is per 100 gms soil 0,018 × 5,2 gms = 0,094 gms CaO in the humus, that is 0,608 — 0,094 = 0,514 gms CaO in the clay. The clay-content is 56,8 % (Table A), so that K (clay) = 100 × 0,514 : 56,8 = 0,90 (Table C).

In this manner the K (clay) is calculated for the clay soils of fields I and II poor in humus and also of those of fields III and IV with from 8,5 % — 12,6 % humus.

With the peat soils of fields V, VI and VII this method of calculation cannot be employed. With these soils the lime in the humus plays such a predominant part, that it is perhaps best to neglect the clay and simply to calculate the K (humus) from the content of exchangeable lime and humus. For instance in B 1718 with 1,734 % CaO and 50 % humus, both on dried soil, K (humus) = 100 × 1,734 : 50,0 = 3,468 (see Table C).

The V⸗values (5) are also included in table C. As already stated in my Faraday Society paper (6) there is a connection between the K⸗ and V⸗values.

As will be seen on comparing the figures in tables B and C, there is a relationship between the K⸗ and V⸗values of the soils on the one hand (Table C) and the percentage of the added lime that are adsorbed by the clayhumus⸗substance of the soils on the other hand (Table B). With low K⸗ and V⸗values of the unlimed plots (IV, V, VII) practically all the lime is fixed as clayhumus⸗CaO; with high K⸗ and V⸗values (I, II) very little lime is taken up by the clay and humus of the soil. The unlimed soils of fields III and VI are in both respects between these two extremes. I shall refer to this later.

6. *How much clayhumus⸗CaO did the limed soil contain before liming; how much CaO has the soil taken up in consequence of the liming, both as clayhumus⸗CaO (actual adsorption) and as $CaCO_3$? (Table D).*

TABLE D.

Experiment field n^0.	Soil sample n^0. B	On 100 gms dried soil (105° C)								Liming-ratio
		gms clayhumus-CaO which the soil of the limed plot					Amount of lime taken u in percentages of what could be taken up = coeffic. of utilization.	gms CaO that the soil of the limed plot has taken up		
		contained before liming	contains after liming (table A)	can contain	has taken up after liming (actual adsorption)	could take up (potential adsorption)		in the form of $CaCO_3$ (tableB)	total	
I	1944	0.603	0.665	0.712	0.062	0.109	57	0.403	0.465	4.3
II	1750/53	0.741	0.751	0.873	0.010	0.132	8	0.230	0.240	1.8
III	1937	0.816	1.139	1.212	0.323	0.396	82	0.728	1.051	2.7
IV	1698	0.294	0.791	1.156	0.497	0.862	58	0	0.497	0.6
V	1856/58	1.297	1.605	2.335	0.308	1.038	30	0.011	0.319	0.3
VI	1868/70	1.733	1.815	2.236	0.082	0.503	16	0.101	0.183	0.4
VII	1718	1.105	1.734	2.600	0.629	1.495	42	0.090	0.719	0.5

Table B shows amongst other things the difference in gms clayhumus-CaO between the limed and unlimed plots of the same field. Since these plots are not of the same composition, these figures do not represent exactly the amounts of CaO taken up as clayhumus-CaO by the limed plots.

Somewhat more accurate results may perhaps be obtained by determining, with the aid of the K-values of table C, how much clayhumus-CaO the soil of the limed plot contained prior to liming. Here I have assumed that the K-values of the limed and unlimed soils were the same before liming. The calculation is then as follows for field I.

The K-values of the unlimed soil B 1946 (see Table C) are 5,2 and 0,90. If B 1944 had these K-values before liming there was present per 100 gms dried soil: $(2{,}2 \times 5{,}2 + 54{,}3 \times 0{,}90) : 100 = 0{,}603$ gms clayhumus-CaO. Seeing that B 1944 now contains 0,665 gms clayhumus-CaO, the soil has taken up 0,062 gms CaO (Table D). This figure is introduced as the *actual adsorption*, i.e. gms. CaO adsorbed by the clayhumus-substance per 100 gms soil.

There is a slight discrepancy between the actual adsorption of table D and the equivalent figures of table B (0,057 gms, etc.). Great discrepancies are only found in the case of fields IV and V.

In table D are also inclused the $CaCO_3$-figures from table B, for instance for field I 0,403 gms CaO. The lime-content of B 1944 has thus increased by $0{,}403 + 0{,}062 = 0{,}465$ gms CaO (Table D) as a result of liming. As we have already noted, we may neglect the differences between the limed and unlimed plots in respect of the amounts of CaO taken up by the crops and washed out by rainwater, so that — always supposing that the K-values of the soils of the two plots before liming were the same — this increase (0,465 gms) must be equal to the rate of application of lime, expressed in gms CaO per 100 gms dried soil. This was found by calculation to be practically the case with fields I, II and III and approximately with fields V, VI and VII. With field IV there was a fairly great difference; a considerable difference must therefore also have existed between the K-values of the soils of the limed and unlimed parts of this fields before liming.

7. *How much CaO can the soil take up as clayhumus-CaO (potential adsorption)? Coefficient of utilization. Liming-ratio. (Table D).*

It is also of great importance to know the total amount of CaO that can be fixed by the clayhumus-substance under natural conditions. This figure depends on the one hand on the clay- and humus-contents of the soil, and on the other hand on the degree of saturation (V) of the clayhumus-substance and on the maximum V that it can reach.

I have calculated this amount assuming that the highest K-values under Dutch climatic conditions are: K (clay) = 1,1 and K (humus) = 5,2. The first value, K (clay) = 1,1, I found to be the average of young Dutch polder soils, heavy clay soils, poor in humus and rich in $CaCO_3$ (see also table VII and VII of my Faraday Society paper). The second value, K (humus) = 5,2, is deduced from the pH-K(humus)-curve mentioned in § 5 above. I may add here that we also found this K(humus)-value of about 5,2 by our potentiometric titrations of humus soils with $Ca(OH)_2$ and $Ba(OH)_2$ up to pH = 7. Further, some soils in a natural condition, rich in CaO, give with a K (clay) = 1,1 a K (humus) about 5, as shown in the following table.

Soil sample n⁰. B	gms on 100 gms dried soil (105° C)					K (humus) (calculated)
	clay	humus	clay-humus-CaO	CaO in clay, with K(clay) = 1,1	CaO remaining in humus	
885	53,0	12,7	1,22	0,58	0,64	5,0
1735	26,1	47,5	2,72	0,29	2,43	5,1

It should further be noted that it is especially the humus which adsorbs the CaO. In well-saturated soils in a natural condition 100 gms humus contain about 5,2 gms CaO and 100 gms clay about 1,1 gms CaO. Certain facts seem to show that the humus-CaO is more readily available for the crops.

The calculation of the amount of CaO that the soil can take up is now seen to be as follows (see Table D). With K-values respectively 5,2 and 1,1 100 gms dried soil B 1944 (with 2,2 % humus and 54,3 % clay) contain (2,2 × 5,2 + 54,3 × 1,1) : 100 = 0,712 gms CaO. Since B 1944 contained in the unlimed condition 0,603 % CaO, the clayhumus-substance of 100 gms soil can take up under the prevailing climatic conditions 0,712 — 0,603 = 0,109 gms CaO. This figure is introduced as the *potential adsorption.*

As shown in § 6 the actual adsorption is 0,665 — 0,603 = 0,062 gms CaO, so that the actual adsorption in percentages of the potential adsorption is 100 × 0,062 : 0,109 = 57 %. This figure is introduced as the *coefficient of utilization* of the lime applied to the soil.

Another factor, which finally plays a role in the fate of the lime is the ratio of the amount of lime applied to the amount of lime that the soil could have taken up, i.e., the potential adsorption, both quantities expressed in gms CaO per 100 gms soil. Thus for B 1944 this ratio = 0,465 : 0,109 = 4,3 (Table D). This figure is introduced as the *liming-ratio.* As table D shows, only in the case of the first three fields, is there a liming-ratio greater than 1; the other soils could have taken up more lime than was applied (ratio less than 1).

8. *Summary of results (Table E).*

We now have sufficient data to permit of a discussion of results. In order to facilitate this discussion the most important results are epitomized in table E. The last two columns of table E have been calculated from table D and differ, therefore, somewhat from the last 2 columns of table B.

It should be borne in mind that under Dutch climatic conditions the soils can reach K-values of about 5,2 and 1,1 at the most. For the V-values of well-saturated Dutch clay soils poor in humus we have found V-values of about 55 (Faraday Society paper, table VII); the V-value of well-saturated humus soils with little clay is about 40.

In table E we see the effect of liming on the four values: pH, K (humus), K (clay) and V; they increase on liming. The higher, however, the degree of saturation of the clayhumus-substance of the unlimed soil is, the smaller is the increase.

TABLE E.

Experiment field n°.	Soil sample n°. B	Values of the soil before and after liming (table C)				actual adsorption and potential adsorption	gms CaO applied per 100 gms soil. Liming-ratio	Results of the liming		
								Coefficient of utilization	Per 100 parts CaO of the lime-manure *)	
		pH	K (humus)	K (clay)	V				was adsorbed by the clayhumus-substance	remained as $CaCO_3$ in the soil
I	1946	7.6	5.2	0.90	52	0.062	0.465	57	13	87
	1944	7.8	5.2	1.01	53	0.109	4.3			
II	1751/52	8.0	5.2	0.90	49	0.010	0.240	8	4	96
	1750/53	8.0	5.2	0.92	50	0.132	1.8			
III	1939	6.3	4.0	0.68	40	0.323	1.051	82	30	70
	1937	7.2	5.2	1.00	50	0.396	2.7			
IV	1697	4.8	2.3	0.12	17	0.497	0.497	58	100	0
	1698	6.8	4.8	0.55	38	0.862	0.6			
V	1857/59	5.2	2.89		23	0.308	0.319	30	97	3
	1856/58	5.9	3.57		29	1.038	0.3			
VI	1869/71	6.1	4.03		34	0.082	0.183	16	45	55
	1868/70	6.6	4.22		36	0.503	0.4			
VII	1724	4.6	2.21		17	0.629	0.719	42	87	13
	1718	5.5	3.47		26	1.495	0.5			

*) Calculated from the figures of table D.

Differences in the V-values, such as for field I (52—53), II (49—50) and VI (34—36) are within the limits of error inherent in the method of determining V.

Experiment fields I and II. Heavy clay soils, poor in humus, with little or very little $CaCO_3$, with however high values (7,6 — 5,2 — 0,90 — 52; 8,0 — 5,2 — 0,90 — 49). They are clay soils of medium age (7). Notwithstanding their high clay-content these soils, owing to their high degree of saturation, cannot adsorb much CaO (potential adsorption: 0,109 and 0,132).

Both soils received an excess of lime (liming-ratio 4,3 — 1,8) which largely remained in the soil as $CaCO_3$ (87—96), only a small part (13 — 4) being fixed as clayhumus-CaO. In spite of their general agreement there is however some difference between I and II. The soil of field I took up 0,062 gms CaO, i.e., 57 % of the potential adsorption; the soil of field II 0,010 gms CaO, i.e., only 8 % of the potential adsorption.

Experiment field III. Very heavy clay soil, relatively rich in humus, free from $CaCO_3$, with rather low values (6,3 — 4,0 — 0,68 — 40). In view of these facts the soil can adsorb a good deal of lime (potential adsorption 0,396) and of this amount 82 % is adsorbed by the clayhumus-substance (actual adsorption 0,323 gms CaO). The soil received an excess of lime (2,7), 30 % of which was adsorbed and 70 % remained as $CaCO_3$.

Experiment field IV. Heavy clay soil, relatively rich in humus, free from $CaCO_3$, with low values (4,8 — 2,3 — 0,12 — 17). As a result the soil can adsorb a great deal of lime (potential adsorption 0,862). Less lime was used than could have been adsorbed (liming-ratio = 0,6) and the whole of this was fixed (100 %), nothing remaining as $CaCO_3$ (0 %). The amount of CaO adsorbed (actual adsorption 0,497) was 58 % of the potential adsorption (0,862).

Experiment field V. Peat soil, rich in humus, free from $CaCO_3$, with low values (5,2 — 2,89 — 23). The soil can accordingly adsorb a large amount of CaO (potential adsorption 1,038). Less lime was used than could have been adsorbed (liming-ratio = 0,3) and practically the whole of this was fixed (97 %), only 3 % remaining as $CaCO_3$. The actual adsorption (0,308) is 30 % of the potential adsorption (1,038).

Experiment field VI. Peat soil, rich in humus, free from $CaCO_3$, with fairly high values (6,1 — 4,03 — 34). Notwithstanding its high humus-content this soil, owing to its high degree of saturation, can adsorb comparatively little CaO (potential adsorption 0,503). Less lime was used than could have been adsorbed (liming-ratio 0,7). Of the amount of lime applied (0,183) only 0,082 gms (actual adsorption) was adsorbed, that is 45 %, whilst 55 % remained as $CaCO_3$. The actual adsorption (0,082) is 16 % of the potential adsorption (0,503).

Experiment field VII. Peat soil, very rich in humus, free from $CaCO_3$, with very low values (4,6 — 2,21 — 17). The soil was therefore able to adsorb a great amount of CaO (possible adsorption 1,495). Less lime was used than could have been adsorbed (liming-ratio = 0,5), most of this (87 %) being fixed, whilst 13 % remained as $CaCO_3$. The actual adsorption (0,629) is 42 % of the potential adsorption (1,495).

9. *Discussion of results and conclusions.*

As already stated on page 179, the factors which have an influence on what happens to the lime, when soil is limed, are — apart from the crops and the rainwater:

1) the potential adsorption of the lime by the soil;

2) the liming-ratio;

3) the form and the fineness of the lime, the thoroughness of the mixing of the lime with the soil and the time during which the soil is subjected to the action of the lime.

It is of course only possible to draw conclusions regarding the influence of one of these factors when the others are equal. Now my chief aim is to study the influence of factor 1, for which reason factors 2 and 3 must be equal. With the four fields IV—VII this may be assumed to have been approximately the case. The liming-ratio values are 0,6—0,3—0,4—0,5, average about 0,45. The lime was thoroughly mixed with the surface-soil and applied in the form of lime cake in good dry condition on fields V—VII and in fairly dry condition on field IV. But on the latter the time during which the soil was subjected to the action of the lime was two years and on the other three about one year.

As regards factor 1, the potential adsorption, great differences are apparant (0,862—1,038—0,503—1,495, Table E). Now, if the potential adsorption was the principal factor determining the amount of lime adsorbed by the clayhumus-substance (the actual adsorption), then the figures of the last three columns of table E — and especially of the last 2 columns — would be in proportion of the potential adsorption. This, however, is by no means the case. The figures for field IV, V and VII (100—0; 97—3; 87—13) are pretty well equal, but there is a great difference between the figures for these three fields on the one hand and the figures for field VI (45—55) on the other.

Now two factors affect the potential adsorption, viz. the humus-and clay-contents of the soil and the degree of saturation of the clayhumus-substance.

With regard to the clayhumus-substance the boundary line lies between IV on the one hand and V, VI, VII on the other; but with regard to the degree of saturation the boundary line runs precisely as above. Fields IV, V, VII have low values (pH, K, V) as against field VI with fairly high values. It seems a not unreasonable conclusion that it is this degree of saturation — and the other values related thereto (K, pH) — which primarily determine what will happen to the lime applied. With soils such as IV, V, VII, with low values (V, K, pH) most of the lime applied is adsorbed (100—97—87) within about 12 month's time, whilst little or nothing remains as $CaCO_3$ in the soil (0—3—13), always in the case that the liming-ratio is about 0,3—0,6. With the fairly well-saturated soil of field VI, only about half the lime applied (45 %) was adsorbed in about the same period, whilst the other half (55 %) remained as $CaCO_3$ in the soil.

What this means, that the V-K-values are the predominant factors, may be illustrated by an imaginary example. Imagine two humus sandy soils with equal potential adsorption, for instance 0,503 as in field VI, but with respectively 43 % (*a*) and 11 % (*b*) humus and let us assume that the K(humus)-values of both soils can be calculated in the same manner, then the K(humus) is:

a) $5{,}2 - 100 \times 0{,}503 : 43 = 4{,}03$ and

b) $5{,}2 - 100 \times 0{,}503 : 11 = 0{,}63$.

Soil *a* is thus seen to be fairly well-saturated, whilst soil *b* is very much undersaturated. Suppose further that both soils are limed with 0,251 gms CaO per 100 gms soil (liming-ratio = 0,5), all other conditions being the same and that a year after liming the amount of CaO adsorbed by the humus (actual adsorption) is determined. If now the potential adsorption was the principal factor, determining the actual adsorption, then this latter would be approximately equal for both soils. This will be seen to be by no means the case. Soil *a* with the high K-value will adsorb less CaO than soil *b* with the low K-value.

The 3 clay soils (I, II, III) vary pretty considerably with respect to the factors 2 and 3 (see page 185). Number I received a great excess of lime (liming-ratio = 4,3) in the form of lime cake; II a smaller excess (1,8) in the form of slaked lime which however at the moment of mixing with the soil had already changed to a great extent into fairly coarse-grained $CaCO_3$. Soil sampling took place in the case of I and II shortly after liming (9 and 19 months respectively); in the case of soil III, on the other hand, 10 years, 5 years and 2 years respectively (see page 175/176) after liming. The liming-ratio was here 2,7, while the lime was applied as slaked lime, which was not mixed with the soil (grassland).

As follows from this summary, factors 2 and 3 are far from equal. It will therefore scarcely be possible accurately to determine the influence of the potential adsorption on the actual. The coefficient of utilization of the fairly well-saturated soils I and II is lower (57 %—8 %) than that of the rather undersaturated soil III, which even reaches the very high value of 82 %. The long period during which soil III was exposed to the action of the lime doubtless had its effect, but it seems to me that it was above all the rather low value of soil III which contributed to this result.

With the well-saturated soils I and II the actual adsorption is resp. 57 % and 8 % of the potential adsorption. These are very instructive figures. Field I shows us that even this type of clay soil — with high K-V-values — can still adsorb a great deal of lime in a short time (9 months), when rationally limed (very fine grained lime immediately and thoroughly mixed with the soil). On field II the lime was not properly applied and here only 0,010 gms CaO were adsorbed of the 0,132 gms CaO which could have been adsorbed, whilst 0,240 gms CaO were applied. And this notwithstanding that the lime had in this case been acting on the soil for 19 months. This instance demonstrates the great importance of a good mixing with fine grained lime immediately after liming, especially on fairly well-saturated soils.

10. *Further research work.*

It further remains to determine what subsequently happens to the $CaCO_3$ left behind in soils I, II, III and VI. I imagine that this will only be adsorbed by the clayhumus-substance to a slight extent or within a long period.

The research will have further to be extended to sandy humus soils and to clay or loam soils with low values.

And finally the experiments will have to be repeated in a more accurate fashion. I hope to have the co-operation of my colleagues in this work.

Summary.

The object of liming is primarily to bring CaO into the clayhumus-substances of the soil (lime adsorption) and thereby to increase the K- and V-values of this substance. A change in the structure and the acidity (pH) of the soil goes hand in hand with this, which of course again may affect the yield of the crops. The lime which is not adsorbed is left behind as $CaCO_3$ or is very soon transformed into it. I have tried to obtain an answer to the question what factors influence this process of lime adsorption within a short time (from about one to two years).

The soils of the limed and unlimed plots of 7 experiment fields were examined some time (about one or two years) after liming. The values: pH, K(humus) = gms humus-CaO per 100 gms humus, K(clay) = gms clay-CaO per 100 gms clay, V = degree of saturation and lime remaining as $CaCO_3$ in the soil were determined.

The four following new figures have been introduced:

1) the actual adsorption, i.e., gms CaO adsorbed by the clayhumus-substance per 100 gms soil;

2) the potential adsorption, i.e., gms CaO that the clay-humus-substance per 100 gms soil can take up under the prevailing climatic conditions. This figure is calculated from the clay- and humus-contents and the K-values, assuming that the highest K-values under Dutch climatic conditions are 5,2 (for humus) and 1,1 (for clay);

3) the coefficient of utilization of the lime applied, i.e., the actual adsorption in percentages of the potential adsorption;

4) the liming-ratio, i.e. the ratio of gms CaO applied per 100 gms soil to the potential adsorption.

The above mentioned object of liming is therefore to obtain as large an actual adsorption as possible in the shortest possible time and with the smallest possible liming-ratio.

In spite of the fact that the experiments were not conducted with the highest accuracy, the following conclusions may be regarded as fairly near the mark:

1) The actual adsorption will be the greater, the finer grained is the lime that is applied and the more thoroughly it is mixed with the soil immediately after liming. This result was already known but, so far as I am aware, has never before been expressed in figures relative to the composition of the soil.

2) The potential adsorption, in other words the clay⸗ and humus⸗contents and the degree of saturation of the clayhumus⸗substance (V) — or their K⸗values — also have an influence on the actual adsorption.

The influence of the clay⸗ and humus⸗contents had already been pointed out by others, but these experiments have shown that the degree of saturation is the predominant factor determining the actual adsorption. Thus, when two soils with the same potential adsorption — all other conditions being the same — are limed, the soil with the lowest degree of saturation will adsorb the greatest amount of CaO in the shortest time.

In investigating, therefore, the question which part of the lime is adsorbed and which is left behind as $CaCO_3$, it is not sufficient to state merely the clay⸗ and humus⸗contents; it is above all essential to give the degree of saturation (V) and the other values related thereto (K, pH).

3) Soils IV, V and VII with very low K⸗ and V⸗values practically adsorb all the lime as clayhumus⸗CaO (100—97—87) within about a year, whilst little or nothing is left behind as $CaCO_3$ (0—3—13). Soils I and II with high K⸗ and V⸗values take up very little lime as clayhumus⸗CaO (13—4) nearly all the lime remaining as $CaCO_3$ (87—96). Soils III and VI with medium K⸗V⸗values are between these two extremes (30 and 45 adsorbed and 70 and 55 left behind as $CaCO_3$).

From this it may be concluded that the K⸗V⸗values are the predominant factors determining the actual adsorption. It should of course be borne in mind that the other factors (liming⸗ratio, etc.) also play a role.

4) It has been found, that even with a fairly great liming⸗ratio (1,8) and after 19 months, hardly any CaO (0,010 gms) was adsorbed by an irrationally limed (coarse grained $CaCO_3$ inadequately mixed with the soil) heavy clay soil (field II), which was practically free from $CaCO_3$ and had fairly high

K-values and on which lime had had to be used to improve the structure. On this field 0,240 gms CaO was applied and 0,010 gms adsorbed, nearly all the lime remaining in the soil as $CaCO_3$ (0,230), notwithstanding that the potential adsorption was 0,132.

Especially soils of the type of field II with fairly high K-V-values must be limed as rationally as possible.

WAS FINDET BEI EINER BEKALKUNG DES BODENS MIT DER KALKDÜNGUNG STATT?

Zusammenfassung.

Die Kalkdüngung hat in erster Linie den Zweck, CaO in die Ton-Humus-Substanz des Bodens zu bringen (Kalkadsorption) und dadurch die K- und V-Werte dieser Substanz zu erhöhen. Hiermit geht eine Aenderung der Struktur und der Azidität (pH) des Bodens Hand in Hand. Dadurch können natürlich wieder die Ernteerträge beeinflusst werden. Derjenige Teil der Kalkdüngung, welcher nicht adsorbiert worden ist, bleibt als $CaCO_3$ zurück, oder wird sehr bald in diese Form umgewandelt. Ich habe nun versucht, die Frage zu klären, welche Faktoren auf diesen Kalk-Adsorptionsvorgang in kurzer Zeit (von 1 bis 2 Jahre) einen Einfluss ausüben.

Die Böden der mit Kalk gedüngten und der ungedüngten Parzellen von 7 Versuchsfeldern wurden einige Zeit (ungefähr 1 bis 2 Jahre) nach der Kalkung untersucht. Bestimmt wurden die Werte: pH, K(Humus) = Humus-CaO in % auf Humus; K (Ton) = Ton-CaO in % auf Ton; V = Sättigungsgrad und die Menge Kalk, die als $CaCO_3$ im Boden zurückbleibt.

Die vier folgenden neuen Grössen wurden eingeführt:

1) die *aktuelle Adsorption,* d. h. die Menge CaO in g., die von der Ton-Humus-Substanz in 100 g. Boden adsorbiert werden;

2) die *potentielle Adsorption,* d. h. die Menge CaO in g., welche die Ton-Humus-Substanz in 100 g. Boden unter den herrschenden klimatologischen Verhältnissen aufnehmen kann. Diese Grösse wird errechnet aus dem Gehalt an Ton und Humus und aus den K-Werten, unter der Voraussetzung, dass die höchsten K-Werte unter den in Holland herrschenden

klimatologischen Bedingungen für Humus = 5,2 und für Ton = 1,1 sind;

3) der *Ausnutzungscoefficient* der angewandten Kalkmenge, d. h. die aktuelle Adsorption in Prozent von der potentiellen Adsorption;

4) das *Kalk-Verhältnis*, d. h. der Quotient aus der auf 100 g. Boden angewandten CaO-Menge in g. und der potentiellen Adsorption.

Der oben erwähnte Zweck der Kalkung ist also der, in kürzester Zeit und bei möglichst geringem Kalküberschusse eine aktuelle Adsorption zu erzielen, die so gross als irgend möglich ist.

Obgleich die Versuche nicht mit einer wünschenswerten Genauigkeit durchgeführt worden sind, kann man die folgenden Schlüsse mit ziemlicher Sicherheit daraus entnehmen:

1) die aktuelle Adsorption wird umso grösser sein, in je feinerer Verteilung die angewandte Kalkdüngung gegeben worden ist, und je inniger sie unmittelbar nach der Düngung mit dem Boden vermischt worden ist. Dies Ergebnis war schon bekannt, aber es ist, soweit ich orientiert bin, noch niemals in einem Zahlenverhältnis, bezogen auf die Zusammensetzung des Bodens, ausgedrückt worden.

2) die potentielle Adsorption, mit anderen Worten der Gehalt an Ton und Humus und der Sättigungszustand der Ton-Humus-Substanz (V) — oder ihre K-Werte —, haben ebenfalls einen Einfluss auf die aktuelle Adsorption.

Der Einfluss des Ton- und Humusgehaltes wurde auch schon von anderen Wissenschaftlern nachgewiesen; aber meine Versuche haben gezeigt, dass der Sättigungsgrad der wesentlichste Faktor ist, der auf die aktuelle Adsorption bestimmend einwirkt. Werden also z.B. zwei Böden mit der gleichen potentiellen Adsorption — unter sonst ganz gleichen Bedingungen — mit Kalk gedüngt, so wird der Boden mit dem niedrigsten Sättigungsgrad die grösste Menge CaO in kürzester Zeit adsorbieren.

Bei der Beleuchtung der Frage, welcher Teil des Kalkes adsorbiert wird, und welcher Teil als $CaCO_3$ zurückbleibt, genügt es also nicht, nur den Ton-Humus-Gehalt des Bodens anzugeben; sondern es ist sehr wesentlich, darüber hinaus noch den Sättigungszustand (V) und die damit zusammenhängenden Werte (K, pH) zu bestimmen.

3) Die Böden IV, V und VII mit sehr niedrigen K- und V-Werten adsorbieren praktisch nahezu allen Kalk als Ton-Humus-CaO (100—97—87) im Laufe eines Jahres, während wenig oder nichts als $CaCO_3$ zurückbleibt (0—3—13). Die Böden I und II mit hohen K- und V-Werten nehmen nur sehr wenig Kalk als Ton-Humus-CaO auf (13—4), während fast aller Kalk als $CaCO_3$ zurückbleibt (87—96). Die Böden III und VI mit mittleren K- und V-Werten stehen zwischen diesen beiden Extremen (Ton-Humus-CaO : 30—45; $CaCO_3$: 70—55) (Table E).

Hieraus ist die Schlussfolgerung zu ziehen, dass die K-V-Werte die wesentlichen Faktoren sind, welche auf die aktuelle Adsorption bestimmend einwirken. Allerdings muss man immer bedenken, dass auch die anderen Faktoren (Kalk-Verhältnis, Einwirkungsdauer der Kalkdüngung, etc.) eine Rolle spielen.

4) Ein schwerer Tonboden (Versuchsfeld II), welcher praktisch frei von $CaCO_3$ war und ziemlich hohe K-Werte hatte, und welcher zur Verbesserung seiner Struktur des Kalkes bedürfte, wurde in unangebrachter Weise mit Kalk gedüngt (grobkörniger Kalk, unzulänglich mit dem Boden vermischt). Es hat sich gezeigt, dass trotz eines ziemlich grossen Kalküberschusses (Kalk-Verhältnis = 1,8) nach 19 Monaten kaum etwas CaO (0,010 g.) aufgenommen worden war. Diesem Versuchsfelde wurde eine Düngung von 0,240 g. CaO gegeben; davon wurden 0,010 g. adsorbiert, während fast aller Kalk als $CaCO_3$ im Boden zurückblieb (0,230 g.), obgleich die potentielle Adsorption 0,132 war.

Besonders Böden vom Typus des Versuchsfeldes II mit ziemlich hohen K-V-Werten müssen also so rationell als irgend möglich gedüngt werden.

QUE DEVIENT LA CHAUX APPORTÉE AU SOL COMME FUMURE?

Résumé.

Le but d'une fumure de chaux est en premier lieu de fournir CaO à l'argile et à l'humus du sol (adsorption du CaO) et d'augmenter par cela les valeurs K et V de ces substances. Un changement dans la structure et l'acidité (pH) du sol en est la suite, lequel peut aussi influencer le rendement de la récolte. La chaux qui n'est pas adsorbée, reste comme $CaCO_3$ dans le sol ou elle est transformée rapidement en $CaCO_3$. J'ai essayé d'obtenir une réponse à la question: quels sont les facteurs qui influencent le procès de l'adsorption de la chaux dans un temps court (1 à 2 années).

Les sols des parcelles avec et sans chaux de 7 champs d'expérimentation sont examinés quelque temps (1 à 2 années environ) après avoir reçu de la chaux. Les valeurs pH, K(humus) = gr. CaO dans l'humus par 100 gr. humus, K(argile) = gr. CaO dans l'argile par 100 gr. argile, V = degré de saturation (V = 100 S : T) et CaO resté comme $CaCO_3$ dans le sol sont determinées.

Les quatre nouvelles quantités suivantes ont été introduites:

1) *l'adsorption actuelle,* c'est gr. CaO adsorbés par l'argile-humus par 100 gr. sol;

2) *l'adsorption potentielle,* c'est gr. CaO que l'argile et l'humus peuvent adsorber par 100 gr. sol sous les conditions climatologiques dominantes. Cette quantité est calculée d'après la teneur en argile et humus et d'après les valeurs K, en supposant que les valeurs K maximales sont sous les conditions climatologiques néerlandaises K(humus) = 5,2 et K(argile) = 1,1;

3) *le coefficient d'utilisation de la chaux donnée,* c'est l'adsorption actuelle en pourcentages de l'adsorption potentielle;

4) *la proportion en chaux,* c'est la proportion entre la chaux donnée (gr. CaO par 100 gr. sol) et l'adsorption potentielle.

Le but mentionné ci-dessus est donc d'obtenir une adsorption actuelle aussi grande que possible dans le temps le plus court et avec l'excès en chaux le plus petit.

Malgré que les expérimentations ne sont pas conduites avec toute la précision nécessaire, il est pourtant permis d'en tirer les conclusions suivantes.

1) L'adsorption actuelle sera d'autant plus grande que la chaux donnée sera plus fine et mélangée intimement avec le sol, immédiatement après la fumure. Ce résultat était déjà connu, mais, à ma connaissance, n'a jamais été exprimé numériquement par rapport à la composition du sol.

2) L'adsorption potentielle, autrement dit la teneur en argile et en humus et le degré de saturation de l'argile et de l'humus (V) — ou leurs valeurs K — a aussi une influence sur l'adsorption actuelle.

L'influence de la teneur en argile et en humus sur l'adsorption actuelle a été déjà indiquée par d'autres, mais mes experimentations ont prouvé que le degré de saturation est le facteur principal qui domine l'adsorption actuelle. Par conséquent, quand deux sols avec la même adsorption potentielle—toutes les autres conditions étant les mêmes — reçoivent de la chaux, le sol avec le degré de saturation le plus petit adsorbera la quantité de CaO la plus grande dans le temps le plus court.

En recherchant quelle partie de la chaux donnée est adsorbée et quelle partie reste sous la forme de $CaCO_3$ dans le sol, il ne suffit pas de mentionner seulement la teneur en argile et en humus, mais il est surtout essentiel d'indiquer le degré de saturation de cette argile-humus (V) et les autres valeurs qui s'y rapportent (K, pH).

3) Les sols IV, V et VII avec des valeurs K et V très petites adsorbent presque toute la chaux comme argile-humus-CaO (100—97—87) dans une année environ, tandis que presque rien (0—3—13) reste sous la forme de $CaCO_3$ dans le sol. Les sols I et II avec des valeurs K et V grandes adsorbent peu de CaO dans l'argile et l'humus (13—4), tandis que presque toute la chaux (87—96) reste sous la forme de $CaCO_3$ dans le sol. Dans les sols III et VI avec des valeurs K et V moyennes resp. 30 % et 45 % de la chaux sont adsorbés par l'argile-humus, resp. 70 % et 55 % restant sous la forme de $CaCO_3$ dans le sol (Table E).

Nous en tirons la conclusion que les valeurs K et V sont les facteurs pricipaux qui régissent l'adsorption actuelle. Il ne faut cependant pas oublier que les autres facteurs (l'excès en chaux, etc.) jouent aussi une rôle.

4) Le sol très argileux du champ no. II, sans $CaCO_3$ et avec des valeurs K et V assez grandes, a reçu une fumure de chaux pour améliorer sa structure. Même avec un excès en chaux assez grand (1,8) et après que la chaux eut agi dans le sol pendant 19 mois, il n'y eut qu'une très petite quantité de CaO d'adsorbée par l'argile-humus. Bien qu'on eût donné 0,240 gr. de CaO et que le sol pût en adsorber 0,132 gr. (adsorption potentielle), seulement 0,010 gr. CaO fut adsorbé (adsorption actuelle) en 19 mois, tandis que le reste (0,230 gr. CaO) restait dans le sol sous la forme de $CaCO_3$. La cause de ce résultat doit être recherchée dans la fumure de chaux irrationnelle; la chaux étant donnée sous forme de gros grains et mal melangée avec le sol.

Spécialement les sols du type du champs no. II avec des valeurs K et V assez grandes doivent recevoir la chaux d'une manière aussi rationnelle que possible.

The analyses were carried out by A. Dekker, M. Dekker and H. Oosterveld, partly under the supervision of Dr. Jac. van der Spek.

POSTSCRIPTUM.

With reference to the "Nachschrift" on page 39 of these Transactions (Volume A) it should be mentioned that the pH's given in this paper are about 0,1—0,2 too low. This, however, affects neither the given potential adsorption or one of the other values, nor the general results.

REMARKS.

1) There was a great difference between the fineness of the $CaCO_3$-particles from the slaked lime and those from the lime cake. Of the former 55 % was smaller than 20 microns, of the latter 88 %.
2) Table A shows the $CaCO_3$-content of the unlimed soils B 1857/59, 1869/71 and 1724 to be about 0,5 %. This cannot be the case. I am inclined to think that by the determination of $CaCO_3$ (boiling of the soil with HCl) in soils such as these which are very rich in humus, a small quantity of CO_2 must be formed by the oxidation of carbon, although Süchting states that such oxidation does not take place in an acid medium.
3) By „clay" is to be understood particles smaller than 20 microns diameter, i.e., fraction I + II. For the method of mechanical analysis, especially the preliminary treatment, see: Proceedings of the International Society of Soil Science, Vol. I, (1925). The degree of acidity (pH) is determined by the *Biilmann-elektrode* in watery suspensions.
4) Internationale Mitteilungen für Bodenkunde XII, 81—172 (1922); see table 9 on page 108. See also: Base Exchange in Soils, General Discussion held by the Faraday Society, December 1924, page 555.
5) Der Sättigungszustand des Bodens. A. Mineralböden (Tonböden), Zeitschr. für Pflanzenernährung und Düngung, Teil A, 4. Jahrg., Heft 3. See also my Faraday Society paper, Transactions of the Faraday Society, no. 60, Vol. XX, Part. 3, page 556.
6) Faraday Society paper, page 556.
7) Faraday Society paper, page 564 (table VIII).