Effect of Lime on Soil and Crop in Swedish Field Experiments

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Earlier liming experiments

Throughout the years a large number of liming experiments have been conducted in Sweden. More general results of lime effects can be found as early as the turn of the century when cooperation started between the Royal Swedish Agricultural Experiment Station and the Local Agricultural Societies. This cooperation led to greater uniformity in the experimental plans and also opportunities to make a more uniform basis for liming recommendations.

Until the Second World War more than one thousand liming experiments were conducted on mineral soils of varying acidity. The fertilization intensity was adapted to the standards at that time. On strongly acidic soils, with pH levels below 5.5 /H_2O/, a lime application of 3-4 tonnes/ha CaO gave an average yield increase of about 300 yield units /in kg grain of cereals/ per hectare and year. On moderately acid soils, pH/H_2O/ 5.5-6.0, the yield increase was about 140 yield units and on slightly acid soils, pH/H_2O/ 6.0-6.5, the yield increase was slightly below 100 kg/ha/year /EKMAN, 1956/. The pH value was considered to provide a good basis for the assessment of liming status on mineral soils and was widely used. These experiments also illustrated that the liming effect was greater on clay soils than on sandy and silty soils.

A relatively large number of liming experiments were also conducted on organic soils. Results from more than 300 such experiments showed that liming increased the yields by, on average, 200 yield units per hectare and year. However, the pH values did not provide any acceptable guidance for the estimation of lime requirement on these soils. The net amount of lime in the soil, and to some extent the base value proposed by EGNÉR /1960/ was used instead.

A few experiments on mineral soils from this period are still running. During the years 1936-1941 six factorial liming and fertilization experiments were started at Lanna in western Sweden. The topsoil was a light clay loam with pH/H_2O/ 5.0-5.5 and deficient in easily soluble P. 6000 kg CaO/ha, as slaked lime, was supplied at the start of the experiment and 17.5 kg P/ha as superphosphate annually.

Lime without P fertilizer gave, on average, a winter wheat yield increase of 600 kg/ha/year grain at the start of the experimental period and about 400 kg/ha/year 30 years later. The annual fertilizing with 17.5 kg P/ha reduced the liming effect to, on the average, 450 kg/ha/year at the start and to 130 kg/ha/year after 30 years. The interaction between lime and phosphorus was, as expected, negative mainly on account of the mobilizing effect of lime on soil phosphorus. On average, the negative interaction corresponds to 200 kg/ha/year. The effect of lime on other crops was somewhat less than that in winter wheat /OHLSSON, 1979/.

In the experiments the effect of a single application of 6000 kg lime per hectare at the start of the experiment - more than 50 years ago - can still be observed. In winter wheat experiments non-treated with phosphorus, on the average, a grain yield increase of 285 kg/ha/year was obtained during the period 1978-1986. These experiments provide good evidence of lime effect lasting for many years.

Thirty-six years after the start of the experiments, half of the plots, i.e. two replicates, were limed again with 6000 kg CaO/ha. This was done in order to investigate the yield promoting effect of liming on unlimed treatments as well as the effect of a repeated application of lime on plots already limed.

Liming of unlimed plots without phosphate fertilization resulted in a yield increase of 835 kg/ha/year of winter wheat grain as an average of 8 harvest years. The lime effect was of the same order of magnitude as at the start of the experiment. The second application of lime in treatments without phosphorus fertilization gave a yield increase of 1025 kg/ha/year, of which some originates from the effect of the first liming.

Experiments with combined liming, fertilization and plant residues

During a short period after the Second World War, the use of lime in Sweden decreased as a result of the anti-liming propaganda. One of the arguments against liming was that the lime effects measured in most liming experiments could just as well have been indirect nutrient effects which could probably be achieved less expensively by fertilizing than by liming. At the same time, agriculture found itself at the start of the period of restructuralization which led to the more specialized forms of management found today. In such a situation - with cash crop cultivation without organic manure and with a more intensive soil tillage and increased acidification - it was feared that soil fertility was on the way towards a slow deterioration. With such background, a series of experiments involving combined treatments with liming, fertilization and plant residues had been started in the early 1960's /JANSSON, 1979; PERSSON, 1974/. The experimental plan comprised three liming levels, three fertilization levels and two plant residue levels. The liming levels correspond to unlimed soil and liming to 70 and 100% of base saturation. The fertilization levels represent half, full and two-fold compensation for nutrient removal by harvested crops. Plant residue levels consist of removal and incorporation of yield residues. The experiments have now been running for 26 years. The average liming effect on different crops is given in Table 1.

Cereals were the dominating crop in the experiments. The liming effect is statistically very significant at all levels in this crop. Liming to 70 and 100% of base saturation increased the yield by 10.7% and 14%, respectively. Among the other crops, in particular, the one-year ley gave very good response to liming, with a 21% yield increase at 70% base saturation. The effects of fertilization were high in all crops and at all levels.

Fig. 1 illustrates the yield response to liming and fertilization in cereals. Yield in treatments without liming and with 50% replacement of removed nutrients /nutrient level 1/ forms the base. The figure illustrates

Table 1
Average annual liming effects on different crops during the period 1963-1986

Treatment	Cereals grain	Ley I	Ley II-IV	Oilseeds seed
		dry matter		
	kg/ha			
Unlimed	3210	4530	4580	1450
Lime effects at:				
70% base saturation	+343***	+937**	+557*	+191**
100% base saturation	+448***	+776**	+610*	+16
100-70% base saturation	+105***	-160	+55	-175
Number of experimental years	102	15	15	11

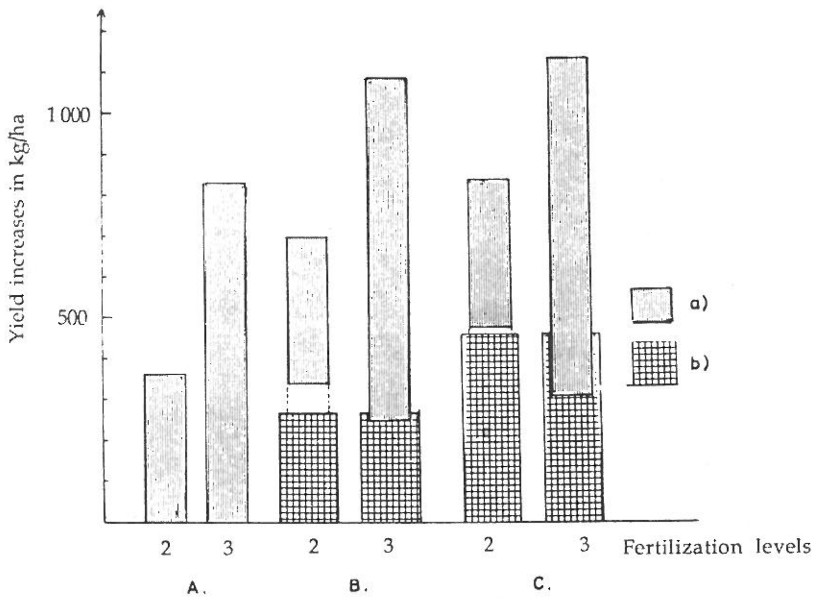

Fig. 1
Liming and fertilization effects in cereals. /Means of 102 harvest years./ a/ Fertilization effect; b/ liming effect. Fertilization levels: 2 = full; 3 = two-fold compensation of nutrient removal by harvested crops. Liming level: A = unlimed; Limed to B = 70% base saturation; C = 100% base saturation

that liming and fertilization largely had independent effects. This implies that fertilization cannot replace liming and that liming cannot replace fertilization /SIMÁN, 1985/.

Table 2
Analytical data for the soils and basic liming at the start of the experiments

No.	Code	Site	Soils: pH	Soils: Base saturation, %	Soils: Al-AS mg/100 ml	Basic liming /kg CaO/ha/ to 55% base saturation	70% base saturation	100% base saturation
1	B87	Åkersberga	5.5	41.3	2.5	1700	3950	8330
2	B86	Bro	5.6	50.1	2.1	1050	5610	13650
3	C113	Fjärdhundra	5.4	43.8	4.5	1800	6990	16410
4	E342	Vånga	5.4	38.2	3.6	5580	10540	20480
5	E343	Vikingstad	5.6	54.4	2.4	150	2690	10450
6	H152	Maden	5.8	49.3	1.1	1640	5980	14670
7	H153	Tomtabyholm	5.5	39.4	3.7	2540	4820	6990
8	K38	Nättraby	5.6	66.1	0.7	-	420	4320
9	L469	Påarp	5.9	53.9	1.0	70	1030	4160
10	M340	Pugerup	5.5	41.3	2.4	1190	2700	5440
11	M610	Hörby	5.5	50.8	1.5	380	2800	4450
12	O100	Svarteborg	6.1	54.0	0.3	110	1680	4830
13	O101	Tossemarken	5.6	46.5	1.2	1140	3150	7180
14	O102	Ljunbytorp	5.4	47.3	2.5	1630	4050	9260
15	P51	Eckerud	5.7	52.3	0.7	540	4110	10390
16	P1	Alingsås	5.2	21.4	9.9	3850	5560	9000
17	S90	Lundsholm	5.8	62.5	0.4	-	1980	7130
18	S91	Värmlands Säby	5.6	50.8	1.6	600	3600	9320
19	T112	Fällingsbro	5.7	34.6	2.1	3380	6290	12350
20	T113	Lindesberg	5.5	32.8	3.3	3250	6280	10850
21	U149	Östuna	5.4	41.3	3.4	2500	6000	10930
22	U150	Tärna prg, Sala	5.7	63.7	0.4	-	990	5670
23	Y7	Kalknäs	5.4	55.1	0.8	-	3620	9250
24	Y8	Sättna	5.3	47.0	1.6	1220	4130	9580
25	AC9	Röbäcksdalen	5.3	42.9	1.8	990	3010	5130
26	AC10	Lund	5.1	44.0	7.3	3790	5490	9800
27	BD11	Öjebyn	5.0	31.0	4.1	6850	12060	19670
28	BD12	Vojakkala	5.1	37.0	4.8	2940	5460	11240

Table 3
Effect of lime on different soil properties /Means of 28 experiments/

Treatment	pH/H_2O/	CEC	Base saturation	AL-P	AL-K	AL-Mg
				according to EGNÉR et al. /1960/		
Unlimed	5.63	19.5	50.3	7.3	14.1	14.7
Limed to						
55% base saturation	5.92	19.4	59.8	7.5	14.3	15.0
70% base saturation	6.21	19.5	67.2	7.8	13.7	15.6
100% base saturation	6.56	20.1	88.9	7.9	13.8	16.0

No statistically significant differences were found between the different levels of plant residues. The high stubble left, with modern harvesting techniques, limits the effect of the removal of harvest residues, which may explain the absence of treatment effects.

Since lime statuses were maintained, it is possible to calculate the continuous acidification and express it as an annual loss of lime. In order to maintain 70% base saturation in the topsoil, it was found necessary to supply 125 kg CaO per hectare and year, on the average, for all seven experiments. The corresponding supply for the maintenance of 100% base saturation was 360 kg CaO/ha/year.

An economic evaluation of liming shows that applications to 70% base saturation together with the maintenance of this level, were profitable in six out of seven experiments. Applications of lime to 100% base saturation were found profitable in four out of seven experiments.

New experimental series

It is well-known that the liming effect on crop yield may vary widely between different places even if the soil acidity degrees are similar. It is not unusual that an expected liming effect is not achieved or, in extreme cases, that liming results in yield decreases. This is discouraging for the farmer, the liming trade and last but not least for the scientists who are responsible for studying the relationships between different soil properties and growth. A major question is whether the pH level and/or the degree of base saturation in the soil can provide a suitable measure for the determination of lime requirement. What other parameters should be included? Another question which must be answered is: How should a suitable liming level on a given soil type be calculated when certain crops are grown? In the ongoing liming experiments the lowest liming level is generally directed at 70% base saturation. Can a lower liming level be justified in practical agriculture?

During 1983 about 30 simple liming experiments were established on mineral soils with the following experimental plan: a/ unlimed; b/ liming to 55% base saturation; c/ liming to 70% base saturation and d/ liming to 100% base saturation. The experimental sites are spread throughout Sweden and represent acid soils with large differences in their geological origin, texture and nutrient status. Consequently, it is probable that the liming effects will differ at the different sites. Some relevant properties of the soils are summarized in Table 2. Details of the lime requirement to reach 55%, 70% and 100% base saturation at different locations, respectively, are also given in Table 2.

Effect of lime on soil fertility

Table 3 shows the change in the base exchange capacity, the degree of base saturation, the pH /H_2O/, AL-P, AL-K and AL-Mg, as means of all experimental sites. The base exchange capacity and the potassium status have largely remained unchanged. The phosphorus status and, to some extent, the magnesium status too increased slightly following liming. The greatest effect was obtained, as expected, on the pH level and the degree of base saturation. In treatment b/ the degree of base saturation was about 5% higher, in treatment c/ about 3% lower and in treatment d/ about 11% lower than that was intended. The table values are based on analytical results from 1985, i.e. before adjustments were made with supplementary liming.

The change of 0.1 *M* $(NH_4)_2SO_4$ extractable aluminium /AS-Al/, in the experimental soils following liming is shown for each year individually in Fig. 2. Each column in the diagram is the mean of 28 treatments. The figure shows that AS-Al in the unlimed treatments was, on the average, about 1.6 mg/100 ml soil without any variation between years. The limed treatments,

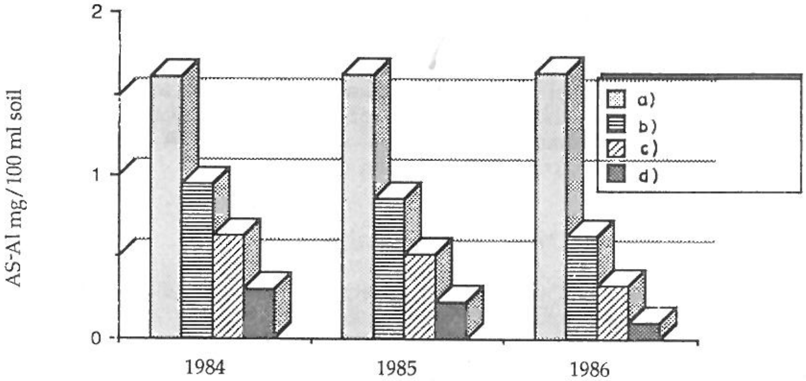

Fig. 2

Lime effect on 0.1 *M* $(NH_4)_2SO_4$ extractable aluminium. a/ Unlimed; Limed to b/ 55% base saturation; c/ 70% base saturation and d/ 100% base saturation.

however, the concentration of AS-Al decreased with time; the higher the dose of lime the stronger the decrease. The decreasing aluminium concentration with time reveals that a chemical equilibrium has not yet been achieved, probably depending on a heterogeneous admixture of lime with the soil.

Effect of lime on crop yield

The average response to liming during a three-year-period is given in Table 4. The values refer to basic yields in grain units in kg per hectare, as well as yield increases in relative values. The crops reacted positively to liming at all liming levels. The yield increases after liming to 55, 70 and 100% base saturation were 1, 4 and 5%, respectively. The two latter yield increases were highly significant.

The division of yields between individual years shows that the liming effect increased with time. The significance of the yield increases shows the same trend. The probable explanation of this is the more homogeneous admixture of lime in the topsoil layer with time.

The effect of lime on different crops, as averages during a three-year-period, is summarized in Table 5. The table shows that cereals were the dominating crop. Of a total of 84 experimental years, not less than 65 were in cereals, i.e. 77%.

On the average, all crops had a positive response to liming. The yield increases in cereals were statistically significant. The average yield increase in this crop at 55%, 70% and 100% base saturation corresponds to 1.7%, 3.6% and 3.9% yield increases, respectively.

The crops at the individual experimental sites reacted very differently to liming. At most sites, positive liming effects were obtained. However,

Table 4
Effect of lime on yield at different liming levels as an average of a 3-year period and during individual years

Year	Basic yield,	Relative yield at base saturation of			No. of exp. years
	50%	55%	70%	100%	
1984-1986	3950	101*	104***	105***	84
1984	4750	101	103	104	27
1985	3510	101	104*	103*	84
1986	3620	103	105**	107**	28

The basic yield is given in cereal units, kg/ha and in relative yields.

Table 5
Average liming effects on different crops
/Results from 28 experiments during 1984-1986/

Treatment	Cereals grain	Ley hay, dry matter	Oilseeds seed	Forage rape dry matter
	kg/ha			
Unlimed /50% base saturation/	3960	7890	2130	6370
Liming effects at				
55% base saturation	+68	+88*	+72	-427
70% base saturation	+144**	+188	+122	+1160
100% base saturation	+154**	+358	+206	+1483
Number of experimental years	65	6	5	3

at some sites the crop reacted negatively during all three years, while at other sites liming had no effect at all. This is illustrated by Table 6. Significantly positive liming effects can be noted at seven experimental sites. At one site, treated below, the liming effect was significantly negative.

The main conclusion is that neither the pH, the degree of base saturation, the easily soluble aluminium nor their combination provide a satisfactory explanation of liming effects on some soils.

Table 6
Average liming effects at 28 experimental sites

No.	Code	Basic yield	Relative yield at base saturation of			No. of experimental years
			55%	70%	100%	
1	B87	3220	105	100	105	2
2	B86	4500	99	104	100	3
3	C113	4690	106*	108	109	3
4	E342	4570	104	101	103	3
5	E343	4870	99	97	97	3
6	H152	3850	100	99	94	2
7	H153	4570	106	101	101	2
8	K38	4520	103*	104	105	3
9	LA69	4060	98	98	102	3
10	M340	4440	112*	111	110*	3
11	M610	5060	101	101	105	3
12	O100	4400	97	83	81	3
13	O101	3950	103	108	110	3
14	O102	4320	105	107**	107*	3
15	P51	2830	107	104	112	1
16	P1	4440	91	93*	93	3
17	S90	4400	99	102	102	3
18	S91	2900	102	119*	122	3
19	T112	4630	101	103	99	3
20	T113	4100	103	108	106	3
21	U149	3850	113	117	119	3
22	U150	5730	100	103	108	3
23	Y7	3230	104	108	112	3
24	Y8	2380	97	105	105	3
25	AC9	3110	98	109	113	3
26	AC10	1740	101	106	114	3
27	BD11	4180	95	116	115	3
28	BD12	2130	102	106*	116	3

Causal analysis of negative liming effects

One of the experiments with negative response to liming was studied in detail. The experiment has the code P1 and is situated at Alingsås in the province of Västergötland. The soil is a sandy silt. It is a very acidic soil with an initial pH/H_2O/ of 5.4 and a base saturation of 21.4%. The content of easily soluble aluminium was highest at this site, AS-Al = 9.9 mg/100 ml soil. In other words, it was the most acidic soil and had the highest aluminium concentration. According to the current opinion, liming on this soil should have been profitable. In fact, liming at all levels led to yield losses. The analysis showed that this soil is deficient in micro-nutrients as well as in magnesium /See Table 7/. The most growth-limiting factor appears to be copper. The concentration of EDTA-soluble copper and the concentration of copper in the crop at flowering provide evidence of this opinion.

Table 7

Causal analysis of diverging liming effects /Experiment P1 at Alingsås/

Variable	Liming levels				Variation in all experiment	Mean
	Unlimed	55%	70%	100%		
Yield level	4440	4030	4130	4120	1740-6210	4060
		Soil analyses				
pH	5.4	5.9	6.0	6.4	5.4-6.7	6.1
AS-Al	7.5	0.7	0.4	0.1	0.0-7.5	0.67
Base saturation %	21.4	38.6	46.4	77.5	13.2-100	66.6
AL-P	6.5	6.8	6.8	7.5	1.8-27.8	7.6
AL-K	11.6	13.9	11.1	13.4	4.4-27.6	14.0
AL-Mg	2.0	4.0	4.0	5.0	2.0-37.0	15.3
AL-Ca	40	110	135	215	40-1100	240
Mn-Mg$(NO_3)_2$	11.2	7.5	6.0	5.2	1.8-52.9	13.3
Cu-EDTA	0.25	0.25	0.25	0.25	0.25-7.9	3.3
Fe-EDTA	192	178	192	175	157-1674	570
Zn-EDTA	1.45	1.27	1.16	1.20	0.42-8.6	2.0
Plant analyses /Oats/ at flowering stage /Elements in % or ppm of dry matter/						
N %	1.3	1.4	1.4	1.6	0.7-3.4	1.6
P %	0.22	0.23	0.27	0.27	0.11-0.41	0.23
K %	3.1	3.1	3.5	3.4	1.0-4.0	2.0
Ca %	0.27	0.28	0.35	0.37	0.12-0.78	0.30
Mg %	0.10	0.11	0.13	0.13	0.05-0.22	0.13
Mn ppm	113	80	79	78	9-128	44
Cu ppm	3	3	3	3	3-9	4.6
Zn ppm	21	20	24	25	10-51	24
B ppm	3	3	4	3	2-6	3.8

Remarks

The results of the new experimental series show that it is impossible to determine which liming status is profitable on the basis of only individual factors such as soil pH, degree of base saturation, content of aluminium, etc. When the positive effect of liming does not occur on soils which "require lime", an already serious deficiency of one or more nutrients is generally exacerbated by the application of lime. Consequently, it is essential to define the level of, and the balance between, certain growth factors and to identify the ones which appear most growth limiting and, in addition, those which are negatively affected by liming. The conformity of the effect of growth factors on crop yields is relatively well-known in theory. However, we have not been able to utilize this knowledge in practice at full strength. By the development of quicker and less expensive analytical methods through improved apparatus, this situation has now changed. In Sweden, we are attempting to do this through coordinated plant and soil analysis. We anticipate that we will be able to reveal the cause of negative or non-existent liming effects and that we will be able to recommend the additional measures needed for profitable liming on lime deficient soils.

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