Effects on soil chemical properties in Swedish arable soils of different lime products

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Abstract
In field experiments the effects on soil pH and base saturation of different lime products were investigated. Product property hardness depending on geological origin of the raw material was compared in two groups, soft and hard. Crystalline dolomites *e.g.* were regarded as hard products and sedimentary lime-stones as soft ones. Also particle size and particle size distribution in the products were compared. Two classes were used, fine graded (<1 mm) and coarse graded (<3 mm), respectively. All material used was ordinary commercial products. Twelve experiments were run for 8 years. Tested factors *i.e.* hard/soft and fine/coarse increased pH and base saturation (BS) significantly. Soft products resulted in 4% higher BS than hard products. Fine graded products increased BS with 5% relative coarse grades ones. The lime effect on BS was the highest the 2nd after lime application. After that the effect declined. Eight years after lime application treatments with minor rates the first 4 years were superior concerning BS to treatments with full rate the first year and then nothing. On average for the last 4 years over the 8-year period the split application treatment gave 6% higher BS than the single rate treatment.

Key Words
Geological origin, particle size, soil pH, base saturation, single application, split application.

Introduction
Liming is a well recognized method to control and correct soil acidification in arable soils (Johnston 2004). Total consumption of liming material for Swedish arable soils is approximately 260 Mkg/yr (SCB 2009). It is well known that particle size and geological origin are important factors for the reactivity of the products (Ohlsson and Torstensson 1956; Persson 1985; Erstad 1992). There are many products for liming available on the Swedish market. They differ in properties and effects, which makes it difficult to evaluate products with respect to their soil chemical effectiveness. Rules and advice for liming have been elaborated (Albertsson 2008). These rules take into account the raw material for the lime products on the one hand and particle size distribution for the final product on the other. The scope for the present investigation was to evaluate these rules under field conditions.

Material and methods
Twelve Swedish experimental sites, both sandy soils and clay soils were chosen. The chosen sites were located between 55 and 64 °N in agricultural areas with organic matter contents from 1 to 10%. pH-values varied from 5.5 to 6.3 and CEC from 7 to 39 cmol/kg with exchangeable bases from 3 to 25 cmol/kg. It gave base saturation (BS) values from 22 to 68% (Table 1).

Lime calculated to give 70% BS was applied once. Target BS was 85% in some experiments due to regional adaptations. A specific comparison was made between lime applied in a single rate calculated to give 100% BS or eventually 120% and the same amount split on 4 consecutive applications during the first 4 years. All lime rates were based on CaO equivalents and ranged from 0.3 to 6.2 tonnes /ha to target the lower BS and 4.3 to 11.5 tonnes /ha to target the higher level. Lime was autumn applied and incorporated in the top soil (0-20 cm) before the experiments started. The split applications the following years were always spring applied. Randomised block experiments with four replicates and plot size 6 x 12 m were used.

The experiments were run and harvested at least four years. In nine instances they were run for eight years. Top soils (0-20 cm) were sampled the 1st, 2nd, 4th, 6th and the 8th year. All samples were pooled treatment wise. Error variance estimation was calculated from the interaction between sites and treatments. Used lime products were characterized and grouped as hard or soft depending on the geological origin of the raw material. Crystalline lime stones and dolomites were considered as hard, while sedimentary lime stones were considered as soft ones. Products with a particle size distribution falling below <1 mm were characterized as fine graded products, while products with fractions in the 0-3 mm interval were considered coarse.

Table 1. Relevant soil parameters for the experimental sites. Targets for the base saturation (BS %) and rates of CaO equivalents to achieve the target.

Site	pH	Exch. bases	CEC	Base saturation	Organic matter	Clay content <0.002 mm	BS target	CaO
		(------cmol/kg------)		(-----------------------%------------------------)				(tonnes /ha)
AC-87-1999	5.5	2.7	12.4	21.8	5.3	4	70/100	4.2/6.8
L-106-1999	5.6	1.6	6.5	24.6	1.4	2	85/120	2.7/4.3
W-1-2000	5.6	7.0	19.3	36.3	5.0	22	70/100	4.6/8.6
O-12-1999	5.8	8.9	25.3	35.2	8.7	34	70/100	6.2/11.5
P-35-1999	5.8	7.4	21	35.2	6.2	36	70/100	5.1/9.5
C-21-1999	5.9	24.6	38.5	63.9	10.4	6	70/100	1.6/9.7
D-117-1999	6.0	16.1	30.2	53.3	6.0	6	70/100	3.5/9.9
N-321-1999	6.0	4.1	11.6	35.3	4.2	10	70/100	2.8/5.3
M-417-2000	6.1	6.6	11.4	57.9	3.6	10	85/120	2.1/5.0
Y-86-1999	6.1	12.7	21.3	59.6	4.8	21	70/100	1.5/6.0
L-303-1999	6.3	4.2	8.8	47.7	2.2	6	85/120	2.3/4.5
U-111-1999	6.3	13.6	20.0	68.0	2.1	40	70/100	0.3/4.5

Soil analyses results

Both soft and hard lime products affected pH values clearly and significantly compared to the control (Table 2). Similar effects were obtained also for exchangeable bases and BS. A small but statistically significant pH difference was also measured between the products. Base saturation increased from 50 to more than 60% when limed. There was a relative difference, although not at a statistically significant level, in BS of 4% in favour for the soft products

Table 2. Effects on pH, exchangeable bases and base saturation (BS) after liming with products with varying hardness. Means of year 1, 2 and 4 from start. One, two or three asterisks denotes significant levels p<0.05, <0.01 and <0.001, respectively.

Treatment, type of product	pH	Exch. bases (cmol/kg)	BS %
No lime	6.0	9.3	50.3
Hard	6.3	11.0	60.6
Soft	6.4	11.2	63.1
Effect			
H-N	0.3***	1.7***	10.3***
S -N	0.4***	1.8***	12.0***
H-S	-0.1**	-0.2	-2.5

The comparison of coarse and fine graded products showed that fine graded products gave 0.1 pH-units higher pH-values than the coarse ones (Table 3). Exchangeable bases were 0.7 cmol/kg higher in the fine graded group and base saturation was 63% compared with 60% in the coarse graded treatments, a difference of 5% on a relative base. The latter was not at a significant level. The effects on pH and exchangable bases were statistically significant.

Table 3. Effects on pH, exchangeable bases and base saturation (BS) of liming products with varying particle size distributions. Means of year 1, 2 and 4 from start. One, two or three asterisks denotes significant levels p<0.05, <0.01 and <0.001, respectively.

Treatment, type of product	pH	Exch. bases (cmol/kg)	BS (%)
No lime	6	9.3	50.3
Fine graded	6.4	11.5	63.3
Coarse graded	6.3	10.8	60.1
Effect			
F -N	0.4***	2.1***	13.0**
C-N	0.3***	1.5***	10.5**
F-C	0.1**	0.7*	2.5

Yield results

A box-plot for relative (control=100) annual yields of spring cereals shows that variation both between and within years was considerable. Some experiments gave generally positive and some generally negative yield effects of liming, probably attributable to micro nutrient effects. An analysis of the data showed that the yield effects were most consistent the 2nd year after liming. On average yield increases with 5-7% compared with un-limed treatments were observed this year with the higher value for winter cereals.

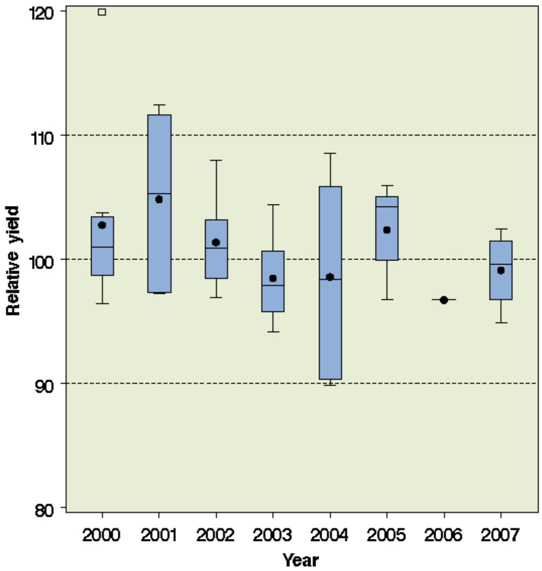

Figure 1. Box-plot for spring cereal yields. The boxes include the 25th and 75th percentile, horizontal line within the boxes represent the median value, dots are means, and squares are outliers (>1.5 the distance between 25 and 75 percentile).

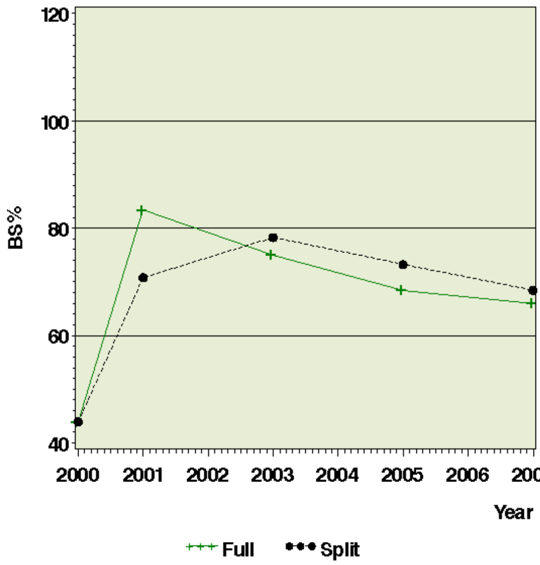

Figure 2. Base saturation response after liming with full single rate or with annual rates the first 4 years. Total rate of CaO equivalents similar in both variants. Fine graded sedimentary lime stone used.

Applying lime in a full large rate has a quick effect, which is not fully obtainable with split annual applications, but on the other hand the effect declines and the 3rd year after lime application the BS in treatments with split rates has reached slightly higher levels. The difference maintains the rest of the period.

Discussion

It was confirmed that products produced from soft raw materials reacted faster than those from hard ones. Fine graded products were more reactive than coarse graded. This was expected and in accordance with other investigations (Ohlsson and Torstensson 1955; Persson 1985; Erstad 1992). Measurements in field experiments cannot give similar precision as laboratory methods used by Erstad (1992). The results indicated that annual minor rates appear to be more effective and beneficial than single large rates over a 5 year period. Observed and measurable differences confirm that the principles which form the basis for comparing lime products for Swedish agricultural soils are valid under field conditions.

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