Int. Agrophysics, 2001, 15, 67-72

INTERNATIONAL
Agrophysics
www.ipan.lublin.pl/int-agrophysics

Influence of long-term liming on aggregate stability of a loess-derived soil

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Received August 9, 2000; accepted November 6, 2000

Abstract. Results of a long-term field trial on a silt loam soil near Freising (Upper Bavaria) show that evaluating the meliorative effect of liming on soil structural properties depends on the initial homogeneity of the soil within the study area as well as on the method of determination. In a percolation test, liming increased stability of aggregates 1-2 mm in size and, thus, decreased sealing hazard of the top soil (0-4, 4-10, 10-20, 20-30 cm). In the test of soil settling, stability of aggregates 5-8 mm in size was not affected. The decreased sealing, observed also in the field, enhanced emergence.

Keywords: liming, aggregate stability, settlement, loessial soil, surface sealing

INTRODUCTION

Fertilizing a soil with calcium carbonate or slaked lime (= liming in the following text) is a means to reduce the effect of soil acidification not only in agriculture (Diercks and Heitefuss, 1994; Kiener, 1987; Schuhbauer, 1981), but also in forestry (Kreutzer and Göttlein, 1991; Weyer, 1993), to overcome a well-known unfavourable chemical soil properties (Baeumer, 1978; Scheffer and Schachtschabel, 1998). In contrast to the above, the effect of li me as a conditioner for soil physical properties such as stability of aggregates or structure, is often controversially (Becher and Schwertmann, 1973; Kiener, 1987; Le Bissonnais *et al.,* 1993) as there are no definite results (Bohne, 1991). For instance, field observations often show that the tendency of a soil surface to seal is decreased by liming and this promotes emergence especially of fine seedlings (Behr, 1965; Callebaut *et al*., 1994; Hoyt, 1981). In most cases, however, this visual finding cannot be confirmed by common soil physical measurement methods, since variation in the measured values is relatively high in contrast to the results of common chemical determinations. Hence, demonstration of differences in the soil physical parameters is complicated (Becher, 1986). This paper presents effects of liming on two soil physical parameters and their statistical analysis.

MATERIALS AND METHODS

In 1978, a field study was initiated by Institute of Plant Nutrition, about 2 km west of Freising (Upper Bavaria) on a slope facing north. The soil was a Dystric Cambisol derived from loess (at least 50 cm thick) underlain by Tertiary fine sand. Properties of the loessial topsoil (0-25 cm) were as follows: texture 20% <2 μm, 70% 2-63 μm, 10% 63-2000 μm; organic matter content ca. 2.5%; bulk density 1.52 g cm^{-3} and 1.43 g cm^{-3}, pore volume 42% and 45%, pores >10 μm 6% and 11%, for unlimed and limed plots, respectively (Personal communication Dr. R. Gutser, Institute of Plant Nutrition). Eight plots (5×8 m) each separated by strips of about 50 cm in width, were installed. Four plots were limed with $CaCO_3$ in the springtime before seedbed preparation according to Table 1, the other 4 were not limed. pH-values determined in July 1987 were also given in Table 1. Ploughing depth was 30 cm, seedbed preparation by chiseling was done to 10 cm depth. Crop rotation consisted of wheat (*Triticum* sp. L.), barley (*Hordeum* sp. L.), corn (*Zea mays* L.), and sugar beets (*Beta vulgaris* var. alt.). The plots were checked visually for surface sealing several times each year.

In September 1987, the year with sugar beets as the crop, partly disturbed soil samples were taken from each plot at the following depths: 0-4, 4-10, 10-20, 20-30 cm. The samples were air-dried and sieved to get aggregate fractions of 1-2 and 5-8 mm in each sample. Stability to percolation (Becher and Kainz, 1983) was determined in the 1-2 mm-aggregate fraction using 3 replicates and each time 10 g of aggregates. The procedure given by Becher and Kainz

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T a b l e 1. Liming history and pH-values (means)*

Liming		pH-values ($CaCl_2$)		
Year	$CaCO_3$ calculated as CaO (dt ha^{-1})	depth (cm)	unlimed	limed
1978	40	0-4	4.8	5.7
1982	5	4-10	5.1	6.3
1984	4	10-20	5.4	6.4
1986	10	20-30	5.5	6.4
1987	5			

*Personal communication Dr. R. Gutser, Institute of Plant Nutrition.

(1983) was modified so that not an outflow, but the inflow is registered directly by a computer via a top-loading balance at predetermined time intervals. To put it briefly, 1-2 mm of washed sand was filled about 1 cm high into Perspex (Plexiglas) tubes of 1 cm ∅ closed at the bottom by a rubber stopper in which some plastic tubing was inserted; 10 g of the aggregates were filled into such tubes. The tubes were subsequently filled up with about 1 cm of sand and gently pressed and closed by the top rubber stopper which was connected to a Mariotte bottle (on the top-loading balance) through plastic tubing. Distilled H_2O was allowed to percolate with a constant hydraulic head of 20 cm for 10-11 min. The tendency to subside was determined according to Hartge (1969) on the 5-8 mm-aggregate fraction using 3 replicates and each time 50 g of aggregates. Then, 50 g per subsample were filled into a Perspex tube with a 3.6 cm ∅ the bottom closed by brass wire gauze (1.5 mm aperture). After wetting by the capillary rise with distilled H_2O, the height of the sample in the tube was measured (= initial height). Then the whole tube was knocked vertically against a horizontal metal plate over a distance of 1 cm (= knock). The remaining height of the sample after predetermined numbers of knocks was recorded and the percentage of settlement was calculated with respect to the initial height. The curves of cumulative inflow as well as the settling curves were fitted by the least squares regression and the coefficients of the resulting equations of regression were analysed statistically.

RESULTS AND DISCUSSION

Visual evaluation of the soil surfaces during the cropping period of 1987 clearly showed that the soil surfaces of the limed plots were less sealed and that the sugar beet seedlings emerged more uniformly than on the unlimed plots.

Stability to percolating water

The cumulative volume of the percolating inflow increased with the time elapsed, but its rate decreased monotonically (Fig. 1). The natural heterogeneity observed even within one soil sample may lead to a considerable variation of the cumulative inflow curves as demonstrated by Fig. 1 for 2 soil samples, although the reproducibility of the applied method was good. The linear correlation between the sum of percolating water volume and time of percolation is usually poorer ($r^2 \approx 0.98$) than between sum of percolating water volume and square root (time of percolation) ($r^2 \approx 0.99$). The coefficients **a** and **b** of the general Eq. (1):

$$y = \mathrm{a} + \mathrm{b}\sqrt{x} \qquad (1)$$

were analysed statistically with respect to liming, sampled plot and sampling depth. There existed, however, a better quadratic correlation between the sum of percolating water volume and square root (time of percolation) ($y = \mathrm{a} + \mathrm{b}\sqrt{x} + \mathrm{c} \cdot x$; $r^2 \approx 0.9999$) (Fig. 2), but this kind of correlation

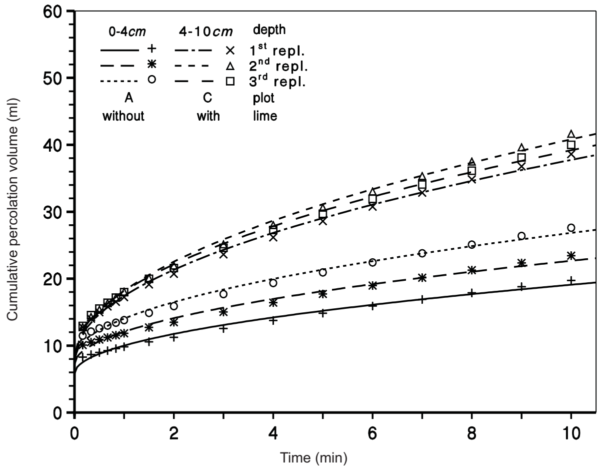

Fig. 1. Variability of cumulative percolation volumes for two soil samples.

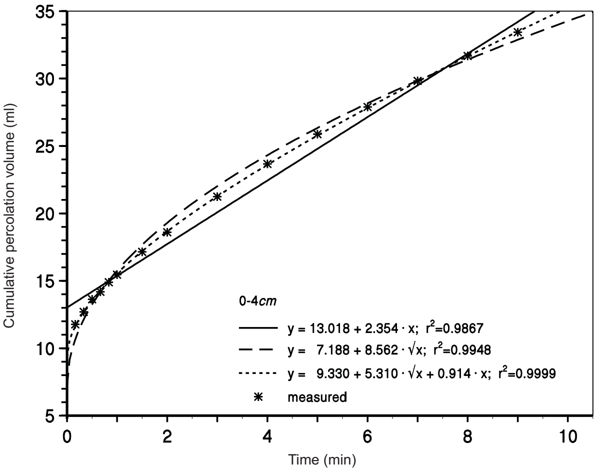

Fig. 2. Example of different curve fittings of the time-dependent cumulative percolation volumes.

was abandoned because of difficulties when interpreting the linear coefficient together with quadratic one.

The three-way analysis of variance (ANOVA) (Table 2) showed that significant differences exist among sampling depths and among plots for the intercept **a** (IC) as well as for the coefficient of regression **b** (CR). Due to this analysis liming affects only the coefficient of regression. However, applying an extensive one-way analysis of variances, it was possible to check whether a definite depth or a definite plot was always responsible for the unexpected significant effects of depth and plot, respectively. Table 3 shows that IC was more often not significantly affected by depth within each plot (the same lower case letter within this column) as well as by the plot within each sampling depth (the same upper case letter within the line) than CR. Only liming more often affected IC and CR (31 and 69%, respectively) as indicated by significantly greater values given in **bold** letters.

If the topsoil (0-30 cm) of the study area was homogeneous, i.e., there did not exist any differences in the soil properties (which may be due to parent material and/or soil tillage practice), no significant differences should be observed over depth within a plot or within limed or unlimed plots for the same depth. However, as was found out in another study area (Becher, 1995), even small soil heterogeneities make it difficult to demonstrate the effect of liming.

Table 2. Percolation: Significance and ranking due to three-way analysis of variance (ANOVA) for all variants considering **a** and **b** of the equation of regression $y = \mathrm{a} + \mathrm{b}\sqrt{x}$

Variant	Intercept **a**			Coefficient of regresion **b**		
	Significance					
Depth (D)	*			***		
Plot (P)	***			***		
Liming (L)	n.s.			***		
D x P	*			***		
D x L	n.s.			n.s.		
P x L	n.s.			***		
D x P x L	**			***		
	Ranking					
		mv.	sign.		mv.	sign.
	Depth					
	20-30	8.29	a	0-4	8.10	a
	10-20	7.94	ab	4-10	7.17	b
	4-10	7.86	ab	10-20	6.71	c
	0-4	7.60	b	20-30	4.78	d
	Plot					
	D	8.49	a	C	7.13	a
	B	7.88	b	B	7.01	a
	C	7.84	b	D	6.76	a
	A	7.48	b	A	5.86	b
	Lime					
	with	8.00	a	with	7.86	a
	without	7.85	a	without	5.52	b

*, **, *** - significant at 5, 1 and 0.1%, respectively; n.s. - non-significant; mv. - mean values followed by the same letter are not significantly different.

IC is a relative measure for the volume of water entering and filling up the system at the beginning (0-100 s) of percolation. This measure is controlled by a) the proportion of the interaggregate pores within the sand on the top of the aggregates as well as within the aggregates themselves, b) by the initial sorption of water by dry aggregates, and c) by the slaking velocity of the uppermost aggregates which controls further infiltration into the aggregate column. a) and b) increase the volume whereas c) decreases the volume of water and therefore IC. Water-stable aggregates which settle little during the filling process preserve a high proportion of interaggregate pores. Thus, a significantly higher IC for limed plots indicates a stabilizing effect of liming. The CR characterizes the extent and temporal change of the slaking and disturbance of aggregates during the percolation process. Therefore, CR is a measure of the tendency for the surface soil sealing. The higher CR, the more water can percolate through the aggregate column as the aggregates slake slower. In most cases, the limed plots show significantly higher CRs. This means that the limed plots have a smaller tendency for sealing even under ploughed conditions as the summary in Fig. 3 demonstrated. This finding is consistent with the observations.

Settlement

The courses of relative settlement (initial height = 100 %) demonstrated variability between replicate samples (Fig. 4). In total, however, the differences between samples were smaller than in the percolation test. The settlement on repeated loading simulated by the number of knocks (see Materials and Methods), was best-fitted by the non-linear Eq. (2) (Becher and Vogl, 1983).

$$y = \mathrm{a} - \mathrm{b}\sqrt{x} + \mathrm{c} \cdot x\,. \tag{2}$$

Due to relatively high variability of settling among the replicates and due to small differences between properties of the soil samples, no significant effect of depth or plot (with some exceptions) on the coefficients **a** and **b** were found. The three-way analysis of variance (ANOVA) excludes any effect of liming on settling (Table 4). Therefore no further statistical analysis was done.

No meaning can be given for the intercept **a** of Eq. (2); whereas a great absolute value of the coefficient of regression **b** (always negative) indicated a strong initial settling and a relatively large value of the coefficient of regression **c** (always positve) indicated a low final settling within the range of loading represented by 100 knocks. The latter part of this statement is in contrast with the statement given by Becher and Vogl (1983), but is correct since the positive **c**-values counteract the negative **b**-values and thus

T a b l e 3. Percolation: Mean values ± standard deviations, and significance at 5% for **a** and **b** of the equation $y = \mathrm{a} + \mathrm{b}\sqrt{x}$ for all soil samples

Depth (cm)	Plot			
	A	B	C	D
	Intercept **a** Unlimed			
0- 4	7.04±1.17cd CD	6.27±0.70d D	7.39±0.18d BC	8.03±0.35d AC
4-10	6.66±0.91d D	8.75±1.61abcd BCD	7.40±1.10cd CD	**9.14**±0.18ab ABC
10-20	7.59±0.70bcd CD	7.32±0.57cd D	8.26±0.56abcd ABCD	8.24±0.78bcd BCD
20-30	8.87±1.05abc ABCD	8.43±0.35b BCD	8.21±0.95bcd CD	8.04±0.23cd D
	Limed			
0- 4	7.56±0.86cd D	**8.03**±0.81bcd BCD	7.63±1.69d CD	**9.26**±0.51bc ABC
4-10	7.04±0.57d D	7.82±0.31cd CD	8.05±0.31bcd ABCD	7.98±0.70cd BCD
10-20	7.77±0.46abcd CD	**8.70**±0.18ab AB	8.07±0.85abcd BCD	7.59±0.61d D
20-30	7.74±0.46bcd CD	7.76±0.35d BCD	7.70±0.61cd D	**9.61**±0.21ab A
	Coefficient of regression **b** Unlimed			
0- 4	5.01±0.86abc D	6.29±0.42abc CD	8.19±0.41a A	7.04±0.49bc BC
4-10	3.97±0.38bc D	6.24±0.32bc B	5.31±0.42cd C	**8.41**±1.13abc A
10-20	4.59±0.86b D	4.92±1.00cd CD	6.18±0.39bcd BC	6.73±0.49c AB
20-30	2.48±0.51d D	4.04±0.31d BC	5.09±0.94d ABC	3.79±0.11d C
	Limed			
0- 4	**7.58**±0.77bcd D	**13.49**±1.55a A	9.06±1.08bc BCD	7.80±0.16abc CD
4-10	**8.64**±0.42abc C	**8.94**±0.66bc BC	**9.87**±0.55abc AB	5.96±0.84d D
10-20	**7.49**±0.85cd CD	**7.85**±0.46c BCD	**8.60**±1.40c ABCD	7.33±0.38bcd D
20-30	**6.73**±0.26d B	4.31±0.33d D	4.73±0.30d CD	**7.05**±0.81cd AB

Same lower case letter within a column and treatment = non-significant (influence of depth); same upper case letter within a line = non-significant (influence of plot); mean value in **bold** letters for a pair of values = significant greater value (effect of liming).

diminish the final settling. This corresponds to the general settling behaviour of soils (Hartge and Horn, 1999). If $|\mathbf{c}| > 0.05 \times |\mathbf{b}|$ then settling increases towards the end of the loading process. But such a settling is normally not possible under the given conditions. At $|\mathbf{c}| = 0.05 \times |\mathbf{b}|$ that part of the fitted settling curves for a number of knocks ≥90 is more or less parallel to the abscissa that means the soil has reached its densest packing due to the compacting force generated. If $|\mathbf{c}| < 0.05 \times |\mathbf{b}|$, then settling will continue even if loading is higher than represented by 100 knocks.

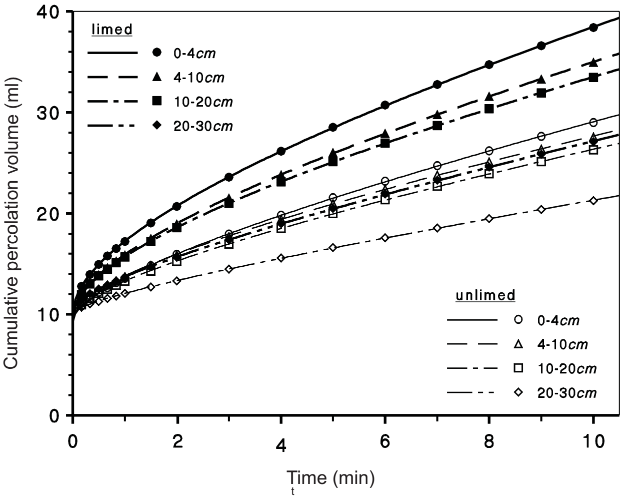

Fig. 3. Averaged cumulative percolation volumes for the 4 sampling depths of limed and unlimed plots.

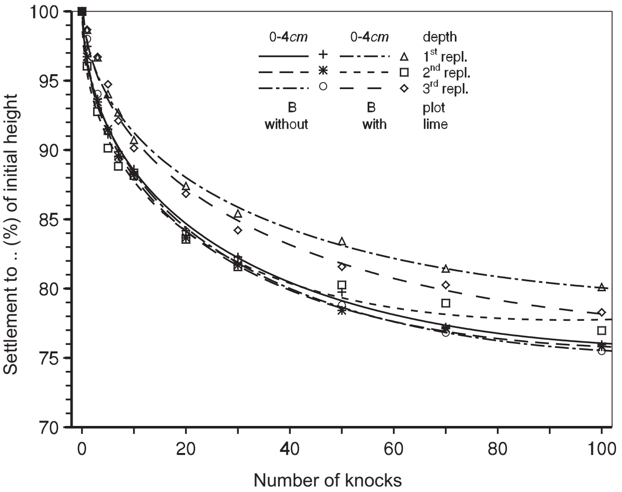

Fig. 4. Variability of the tendency to settle for 2 different soil samples.

Table 4. Tendency to settling: Significance and ranking due to three-way analysis of variance (ANOVA) with all variants for **b** and **c** of the equation $y = a - b\sqrt{x} + c \cdot x$ and for the absolute initial height (of the subsample in the tube)

Variant	Coefficient of regression **b**		Coefficient of regression **c**		Initial height	
	Significance					
Depth (D)	***		***		***	
Plot (P)	**		*		*	
Lime (L)	n.s.		n.s.		n.s.	
D x P	n.s.		*		**	
D x L	n.s.		n.s.		n.s.	
P x L	n.s.		n.s.		n.s.	
D x P x L	***		***		***	
	Ranking					
		mv. sign.		mv. sign.		mv. sign.
	Depth					
	0-4	4.35 a	0-4	0.20 a	0-4	7.67 a
	20-30	3.84 b	4-10	0.16 b	4-10	7.36 b
	4-10	3.74 b	20-30	0.16 b	10-20	7.32 b
	10-20	3.43 c	10-20	0.13 c	20-30	7.26 b
	Plot					
	A	3.97 a	D	0.18 a	C	7.48 a
	B	3.95 a	A	0.17 ab	D	7.41 ab
	C	3.83 a	C	0.16 ab	A	7.38 ab
	B	3.62 b	B	0.15 b	B	7.34 b
	Lime					
	without	3.88 a	without	0.17 a	without	7.40 a
	with	3.81 a	with	0.16 a	with	7.40 a

*, **, *** - significant at 5, 1 and 0.1%, respectively; n.s. - non-significant; mv. - mean values followed by the same letter are non-significant different.

DISCUSSION AND CONCLUSION

Different results obtained when using the two methods, are confirmed by the findings of Roth and Eggert (1994) who reported a stabilizing effect of increased Ca cation contents (or liming) only for the aggregates of <2 mm, but not for the aggregates of 2-10 mm. From those results and the results presented here, it may be concluded that the effects of liming on the structural properties can only be demonstrated by the carefully selected methods, as also stated by Bohne (1991). Concurrently, the soil (horizon) under study must be sufficiently homogeneous regarding its original properties or must be homogenized by soil tillage. Homogenizing by tillage includes a uniform incorporation of the lime (Baeumer, 1978). In the case of bigger structural elements like aggregates of 5-8 mm ∅, soils must be sampled at several dates during the year for at least some years to demonstrate the effects of liming. However, in the case of small aggregates (≤1-2 mm), it seems possible to demonstrate that liming affects, or at least its tendency to seal (reduced slaking; Fig. 3) applying one soil sampling and using sensitive methods. However, the present methods do not allow to predict thickness of the sealing crust, its strength at different water contents, its permeability to air and water or consequences for emerging seedlings.

ACKNOWLEDGMENTS

Mrs. Aumann from the Institute of Plant Nutrition is thanked for her very careful measurements of soil stability.

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