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Relieving the calcium deficiency of field soils by means of liming

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Abstract. Over 22% of Estonian field soils are calcium-deficient and acidificated, and are also among the poorest soils in Estonia in terms of humus; their average humus content remains below 2%. Low humus content in calcium-deficient soils results from either, a lesser generation of organic matter on acid soil, or its decomposition speed as affected by the micro fungi, which are dominant in calcium-deficient (*Haplic Podzoluvisols*) soils. The dissolved organic matter succumbs easily to leaching and transport caused by wind and water (erosion), whereby the fertility of the soil will decline. Thus, calcium plays an important role in ensuring the fertility and sustainability of soil; liming is used to relieve its deficiency. To eliminate calcium-deficiency in field soils, the quick-acting fine dusty limes with 5-year interval 5 t ha^{-1} are mainly used in Estonia. Paying attention to the dynamics of available calcium content in the soil limed with fine dusty lime fertilisers, it appeared that the calcium content remained at the optimum level in the ploughed layer for only 2–3 years, a considerably shorter period of time than expected. Since the level of fineness determines its ability to dissolve and the effect of lime on the available calcium content in soil, then to improve the effectiveness of liming and, from the aspect of an economical use of resources, it is advisable to use dusty limes with a shorter than 5-year interval and, respectively, in smaller quantities, which would guarantee a more stable calcium content in the soil with a better use of resources. For longer effect, limestone should sufficiently contain a coarser fraction, dissolving only in the 3rd–4th year.

Key words: available calcium, liming, cement kiln dust, limestone, time of effect

INTRODUCTION

Climate-wise, Estonia's average annual precipitation is 750 mm per year. Compared with rainfall, evapotranspiration is less by ca 290 mm as an annual average (Kask, 1996). Consequently, calcium and magnesium carbonates are leached out from the surface levels of soil by the percolating water, that is, the leaching of carbonates occurs. As a result of the leaching of carbonates, soil becomes deprived of calcium and magnesium. After the leaching of carbonates, the hydrogen of humic acids will replace the metal cations in the absorbing complex of soil, and the soil will acidificate. But calcium deficiency in soil may lead to degradation of soil qualities.

The acid soils are predominantly frequent in southwestern and southeastern Estonia, located on non-carbonate matrix. According to the data of the ARC soil survey in 2000–2006, more than 22% of all Estonian field soils consist of deficient calcium carbonates, and are also among the most humus-deficient soils in Estonia: average humus content remains below 2%. The content and resources of organic matter in soil develops on the basis of the difference in sediment and losses of organic matter.

The organic matter accumulating in soil decomposes, leading to its full mineralization. The main agents that decompose organic matter are microorganisms: soil bacteria, micro fungi, actinomyzetic fungi, etc. The intensity and particularities of microbial decomposition of the organic matter of soil as well as the count of micro organisms in soil have been studied in Estonia (Lasting V. et al., 1966, 1988); it was established that in the ploughed stratum of the *Haplic Podzoluvisols* (A_1-horizon), the decomposition of organic matter takes place more rapidly than in *Calcaric Cambisols* due to a greater number of micro organisms. In *Haplic Podzoluvisols*, the abundance of micro fungi was noticeable. While the number of soil bacteria in the organic matter of *Haplic Podzoluvisols* exceeded that in *Calcaric Cambisols* by a mere 5% and the number of actinomyzetic fungi by 13%, the number of micro fungi exceeded that by 50% (Kask, 1996). The higher number of micro fungi in the calcium-deprived *Haplic Podzoluvisols* can be accounted for their ability to live in an environment which has a pH of 1.4–12; however, the majority prefers pH between 5–6 (Konsa, 2006). Hence, in the calcium-deprived acid soils, the micro organisms decomposing the organic matter can be found in abundance, and their activity decomposes the organic matter quickly. The dissolved organic matter is easily subject to leaching and transport by wind and water (erosion). According to the data by R. Kask (1996), leaching humus deeper in loamy carbonate soils is insignificant, whereas it is significant in acid sandy soils that also frequent southwestern and southeastern Estonia. Thus, humus deficiency in these soils may have been caused, firstly, by the lower plant production due to acid growing environment, and secondly, by the great number of degrading actors that cause a rapid decomposition of organic matter and its leaching from the soil as a result of the percolating water.

With humus decreasing, the ability of the soil to hold nutrients and water will decrease, and in more loamy soils, the water percolation ability will decrease, as well. The resistance of the soil particles of calcium-deficient soils to external agents is weak, the particles will fall apart and soil will grow denser. These are only some of the factors that will degrade the quality and sustainability of soil in the case of calcium deficiency.

Limestone is commonly used throughout the world to remove soil acidity and is being used increasingly in Estonia. For many years, for economic reasons, oil shale ash dust and cement kiln dust were used for liming soils. Cement kiln dust is still the most widely used lime, due to its better effect (calcium carbonates, nutrients).

Cement kiln dust (also oil shale ash) is a material of fine dust that dissolves rapidly in soil. In addition, the cement kiln dust typically has high potassium content in the form of potassium sulphate. Since soil does not compound with sulphur and the sulphate ions absorb in soil negatively in terms of physics, it encourages the leaching of anions with cations, especially in the form of calcium- and magnesium cations (Lauk & Turbas, 1988; Turbas, 1996). Therefore, due to the impact of sulphur,, calcium and other elements which have been supplied to the soil with cement kiln dust, are easily leached from the soil. In order to reduce the losses and increase the effectiveness of fine dusty limes, i.e., cement kiln dust and limestone dust, on the stability of the available calcium content in soil, the given study looked into the effect and duration of limes used in practice on the available calcium content in a ploughed soil layer.

MATERIALS AND METHODS

The field trial was established in 2005–08 on *Gleyic Podzoluvisol*, sandy loam, at the Kuusiku trial centre. Geographic coordinates: longitude $58^0 58'57.91''$, latitude $24^0 42'19.55''$, altitude 55 m. The agrochemical indicators of soil upon establishing the trial (0–22 cm): humus content 2.7%, pH_{KCl} 4.4–4.8; from the extraction solution Mehlich 3 available P 80–130 mg kg^{-1} – content high; available K 125-130 mg kg^{-1}, – content average; available ch Ca 400–1000 mg kg^{-1} – content low; available Mg 50–65 mg kg^{-1} – content low.

The estimated $CaCO_3$-requirement of the trial soil was 8.7 t ha^{-1}. Cement kiln dust and limestone were used for lime. Cement kiln dust includes 25–30% of oil shale ash and 70–75% of partly decarbonized raw mix composed of ~94% limestone and ~6% clay. Cement kiln dust is a fine-grained material (residue on sieve 0,15 mm < 5%). The indicators of limestone dust fineness are provided in Table 1.

The neutralisation capacity ($CaCO_3$) of the limes used in the trials was 76% and content CaO 43.2% for cement kiln dust and 92% and content CaO 50.2% for limestone. Of the important plant nutritive elements, cement kiln dust contained K 6.5%; S 3.1%, and Mg 2.0%. Limestone contained Mg 0.3%, the nutritive elements even less. Lime fertilisers were spread manually prior to cultivation. In the cement kiln dust version, the lime was inserted into the soil in the amount 5 t ha^{-1} in the spring of 2005 and its influence was observed during the next four years. In the case of the limestone variant, liming was used in the total amount of 10 t ha^{-1}, out of which the first dose of 5 t ha^{-1} was inserted in the spring of 2005 and the other half in 2006 with autumn ploughing.

Table 1. Fractions of limestone used in trial.

Fraction, mm	4–3	3–2	2–1	1–0.5	0.5–0.16	0.16–0.1	0.1–0.05	< 0.05
Content, %	5.7	11.4	19.4	18.9	22.2	4.9	4.1	13.9

The soil preparation in autumn varied with year: autumn ploughing was performed in 2005 and 2006, whereas in 2007 and 2008 the soil was cultivated only on the surface. Soil samples (0–22, 0–10, 10–20, 20–30, 30–40 cm) were taken annually after harvest. Chemical analyses of soil were made at the Agricultural Research Centre.

Soil analysis data of the field trails was processed mathematically using dispersion and regression analysis.

RESULTS AND DISCUSSION

As the trial results (Fig. 1) revealed, the content of available calcium was at its highest due to the influence of the cement kiln dust supplied in soil in the spring and on the optimum level during the first year of effect of the liming; afterwards, it began to decrease and, by the autumn of the third year, dropped to the pre-liming level. Thus, upon using cement kiln dust, the calcium content maintained its optimal level only during the first year of application. To neutralise soil acidity and to optimise calcium content, the second half of the lime requirement dose should be supplied in the soil in the second year, however, it is not expedient in the case of cement kiln dust, since the excessive proportion of plant nutrients in the soil will not be used by plants during the first year and are largely subject to leaching, especially sulphur and magnesium. Although the plants receive part of the potassium supplied in the soil for a longer period of time, even part of that will be lost in the course of time. Therefore, when there is a major need for lime, limestone is more expedient; hence, limestone was used for the second lime dose in the trial.

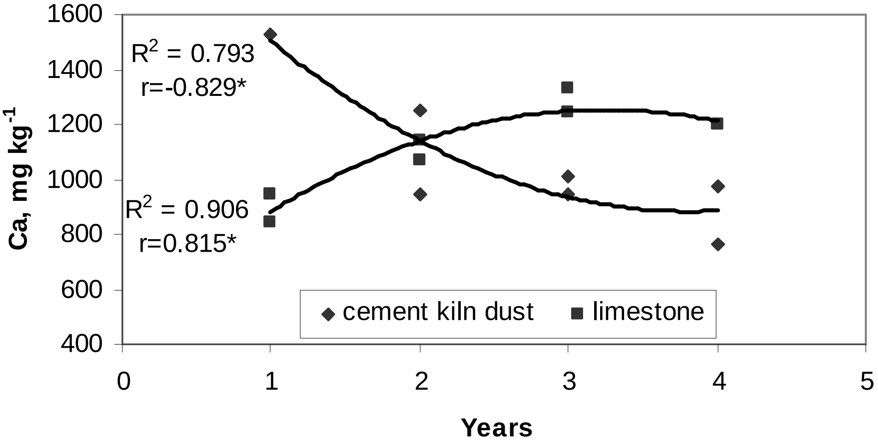

Figure 1. Variations in available calcium content related to liming cement kiln dust – 5 t ha^{-1}, limestone – 5+5 t ha^{-1}

As the limestone variant results show, the impact of limestone on the calcium content of soil was somewhat weaker than that of the cement kiln dust. By autumn of the second year, the calcium content remained below the optimal level (< 1500 mg kg^{-1}), so the second half of the lime requirement dose was inserted in soil with the expectation that one part of the lime would fall into subsoil and the other part of the lime into topsoil, thereby evening up the calcium content in the topsoil. By the third year of the trial, the content of available calcium in the topsoil was slightly over 1200 mg kg^{-1} and remained roughly on the same level in the fourth year. The trial is being continued and further results will indicate the dynamics and stability of the calcium content in soil.

Observing (Fig. 2) also the dynamics of the available calcium content in the topsoil (0–10 cm and 10–20 cm) in the turned topsoil and in subsoil (20–30 cm and 30–40 cm), the following aspects became apparent: Beginning in the third year, in the liming variant with cement kiln dust, both topsoil and subsoil were equally deprived of calcium and acidic like an unlimed soil. Results of the limestone variant indicated that ploughing lime deeper into the soil has no significant effect on calcium content in subsoil; turning over the topsoil with liming helped to homogenize the calcium content only in the topsoil. Calcium content in the topsoil of the limestone variant remained at 10 t ha^{-1}, still below the optimal level due to the impact of limestone by the end of observation period, i.e., by the end of the fourth year.

The abovementioned aspects allow the inference that the lime fertilisers used for optimisation and stabilisation of the calcium content in soil, cement kiln dust in particular, have little effect. As the trial has continued, limestone has not proved to be notably more effective. The dissolving speed of lime determines the time span of its effect. The speed of dissololution of the lime fertilisers depends on the parameters of its particles – the finer they are, the more rapidly it will decompose (Kalkitusopas, 1999). The very fine structure of cement kiln dust is one of the reasons why it exerts a short-term effect on the calcium content in soil. The effect of limestone can be equally short if it consists of an excessive proportion of fine fraction.

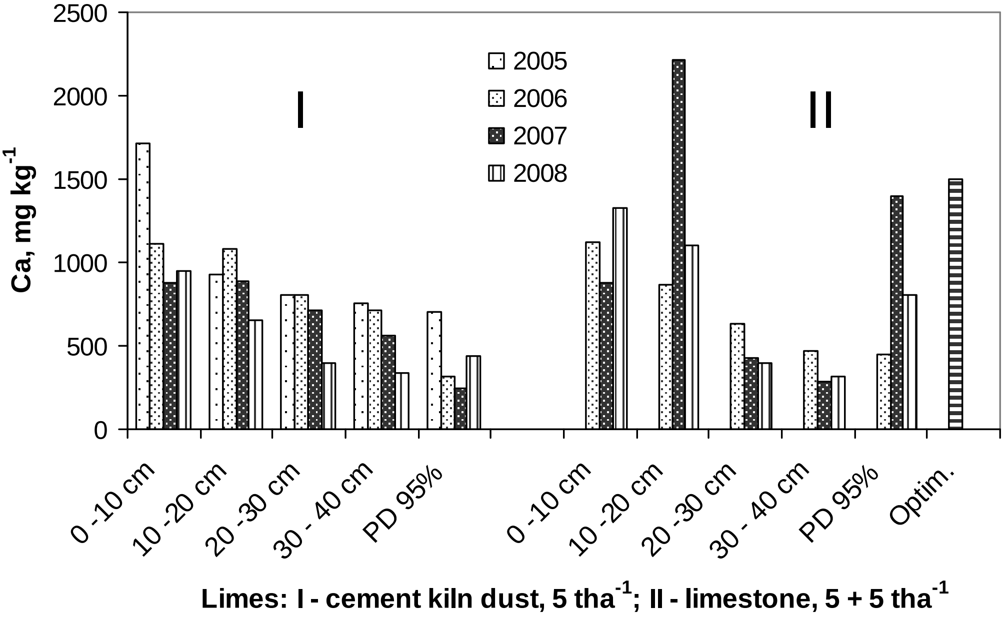

Figure 2. The influence of different agricultural limes on the available calcium content dynamics in different soil depths.

In accordance with the Fertiliser Act (and followed in this limestone trial), 8% of the limestone dust must pass through a 2 mm square-sized sieve, 90%, a 1 mm sieve and at least 50% through a 0.15 mm sieve. The effective period of lime with 90% of the particle size being up to 1 mm will not exceed 600 days. When a field is limed every 5th year at 5 t ha^{-1}, a trivial amount of lime is left for the last three years. Thus, in the case of finely structured lime fertilisers, it may become necessary to use liming within shorter intervals and in smaller doses in Estonia. A shorter, three-year period of liming application has been recommended also in other countries (Havlin *et al.*, 2005; Rahmenempfehlungen …, 2000). It is especially expedient to use cement kiln dust in smaller quantities in order to take greater advantage of its potential. But upon stabilising the calcium content, better results can also be achieved by lime supplies with a longer dissolution period (coarser structure). Although the research on liming has been plentiful, it is necessary to continue the studies towards the improvement of liming efficiency and a more sustainable use of resources.

CONCLUSIONS

The study results allow the following conclusions: Since replacing the calcium leached from the ploughed layer is a crucial factor for maintaining and improving the soil fertility, the stability of optimal calcium content plays an important role in ensuring the sustainability of soil. The stability of calcium content also depends on the qualities of the lime supplied in soil.

The trial results indicated that in order to improve the calcium condition of soils requiring liming, it is advisable to use limestone as the main lime; in that case, more attention should be paid to its structure, affecting the speed of decomposition. The duration of the effect of finely structured cement kiln dust and limestone had a short-term effect on the calcium content (2–3 years), which needs to be considered upon liming. Since the degree of fineness of lime determines its dissolving ablity and its effect on the available Calcium content in soil, then, to improve the efficiency of liming and for a better use of resourcess, it is recommended to use dusty lime fertilisers with a shorter than 5-year interval and, respectively, in smaller quantitities, which would ensure a more stable calcium content in soil. For longer effect, limestone should sufficiently contain a coarser fraction, dissolving only in 3rd –4th year.

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