

daudzums bija tieši atkarīgs no fosfora ($r=0.97^{**}$) un slāpekļa ($r=0.86^*$) saturs, kas iekļauts ar organisko un minerālmēslojumu.

THE SOIL ACIDITY PARAMETERS OF SOILS WITH STOPPED LIMING

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Abstract

The present problem is mass soil acidification in the whole of Lithuania, especially in the eastern and western regions and soil variability in the acidification stages. The results of the last stage (2002-2006) of the long-term experimental work carried out at the LIA Voke branch since 1972, demonstrate that the effect of primary soil liming is statistically significant only for mobile Al. Changes in the periodically limed soil pH, hydrolytic acidity and mobile Al were more intense and their restoration to previous levels is slower compare to primary limed. In such soils even after 14-23 years since last the lime application the productivity of crop rotation is still higher than in unlimed soils.

Our conclusions clarified questions about the use of agricultural soils with stopped liming – what soil parameters can identify soil acidity and what is the lime requirement of previously limed soils? It suggest further investigations into the effects of stopping liming on soil profile chemical properties changes, especially the dynamic of mobile Al restoring. The selection of new criteria for lime requirements and the optimal lime rate determination concerning ecological and economical efficiency are the most important questions for maintaining the productivity of these acidifying soils. Only the further monitoring of the soils will enable a more detailed evaluation of the liming effect on the environment and make accurate predictions about the restoration of soil acidity possible.

Key words: acidifying soils, primary liming, mobile Al

Introduction

The territory of Lithuania is located in the transitional climatic zone between maritime West European and continental East European and Asian. According to the hydrothermal conditions, Lithuania is located in the zone of excessive precipitation and moderate organic matter decomposition. (Buzas *et al.*, 1966). The mean annual air temperature is $+6.2^{\circ}\text{C}$, and the mean annual atmospheric precipitation constitutes 661 mm.

Areas with acid soils are mainly distributed in the eastern and western parts of Lithuania (Eidukevičienė, 1993; Eidukeviciene, Vasiliauskienė, 2001). Agricultural soils with a pH value below 5.5 have been regularly limed for several decades (1965-1990), resulting in a decrease in the total area of acid soils from 40.7 to 18.6 percent (Mazvila *et al.*, 2004).

With the period of economical changes, since 1991 the practice of soil liming significantly declined and has practically stopped at the present time. This led to the secondary acidification of limed soils and resulted in a negative effect upon crop production and the economics of Lithuania. The dynamics of agrochemical soil properties have changed in the 35 y. period passed since the primary liming analyzed in the current work. The restoration of soil acidity after regular liming and the stopping of naturally acid soils and the methods of evaluation of limed soil acidity are discussed.

Materials and Methods

Experiments were conducted at the Lithuanian Institute of Agriculture's Vokė Branch (located in latitude $54^{\circ}37'$ North and longitude $25^{\circ}08'$ East.) during 1972-2006. The experimental plots were established in sandy loam on carbonaceous fluvial-glacial gravel soil, *Haplic Luvisols* (LVh) according to the FAO-UNESCO classification. The depth of carbonate effervescence was 60–80 cm. It was a typical arable soil in the eastern part of Lithuania characterized by low organic matter

content (1.6-2.0 % of humus), very acid soil reaction ($\text{pH}_{\text{KCl}} < 4, 5$) and a low content of available plant phosphorus and potassium ($100\text{-}150 \text{ mg kg}^{-1}$). Dust limestone was used as liming agent, with 95-98% of CaCO_3 . Lime requirements were calculated according to the soils hydrolytic acidity (H). Primary soil liming was executed in 1972. Primary lime rates were 1,0 r from H ($7,18 \text{ t ha}^{-1} \text{ CaCO}_3$). Regular liming was repeated in 5-10 year cycles, with various dust limestone rates in various treatments. In this paper we discuss the efficiency of moderate intensity liming when during 4 cycles (20 years) 1,0-3,5 rates of CaCO_3 according H have been applied (table 1). Liming efficiency was tested in a crop rotation that was composed of 50% cereals. The average rates of mineral fertilizers were: $\text{N}_{30-60} \text{ P}_{30-60} \text{ K}_{60} \text{ kg ha}^{-1}$ active matter.

Table 1 The intensity of liming in experiment of periodical liming

Treatment	Date of liming and lime rates									
	1973		1978		1983		1988		total	
	rate	t ha ⁻¹	rate	t ha ⁻¹	rate	t ha ⁻¹	rate	t ha ⁻¹	rate	t ha ⁻¹
Regularly limed 1,0 r CaCO_3 every 10 year	1,0	7,86	0	0	1,0	7,86	0	0	2,0	15,72
Regularly limed every 5 year : 0,5r-0,5r+1,5r+1,5r CaCO_3	0,25	1,96	0,25	1,96	1,5	11,78	1,5	11,78	3,5	27,48

Methods of analyses. Soil samples from the arable layer (0-20 cm) for the determination of agrochemical properties were collected at the beginning of the experiment and after every rotation (1972, 1977, 1982, 1987, 1992, 1996, 2002, and 2006). After 24 years since the beginning of regular liming (in 1996), soil samples from individual profiles (to 1m depth, every 20cm) were collected, for the evaluation of dust limestone effect on subsoil layer properties.

Agrochemical analyses of the soil samples were performed applying the following methods: soil pH_{KCl} by the method of potentiometry (1 M KCl suspension), hydrolytic acidity (H) – by Kapen, exchangeable acidity and mobile aluminum (mob. Al) – by Sokolov, the amount of absorbed bases (S) – by Kapen–Hilkovic methods.

For the statistical analysis, the ANOVA procedure was used. The data of the plant and soil agrochemical analyses were processed applying the analysis of variance and the LSD test (Little, T.M., Hills, F.J., 1978).

Results and Discussion

The analysis of the changes in soil acidity characterizing properties (pH , hydrolytic acidity, absorbed bases, mobile Al) during the 34 year period show that natural soil acidity is determined by such abiotic factors as the pH of precipitation, the soil moisture regime, the development of the root system of crops and the errors of laboratory analyses. Altogether these factors led to variations in pH and mobile Al in unlimed soil during the experimental period (Figure 1).

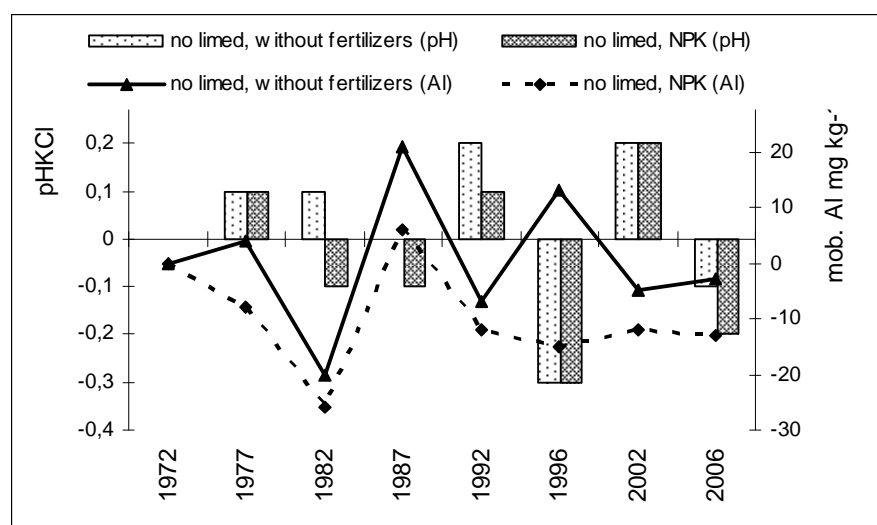


Figure 1. Changes of pH_{KCl} and mobile aluminum in unlimed soil (Voke, 1972-2006)

The total experimental period variation of pH was from -0.4 to +0.2 counted from the primary level (4.4 pH), the variation of the mobile Al from -20 to +19 mg kg⁻¹, (counted from primary 63 mg kg⁻¹ Al). The application of average mineral fertilizers 30-60 kg ha⁻¹ N, 30-60 kg ha⁻¹ P and 60 kg ha⁻¹

K didn't stimulate soil acidification. Soil pH and mobile Al levels did not differ significantly between unlimed unfertilized soils and unlimed fertilized soil. At the 4.4 pH level the removing of Ca with the yield was negligible (7-8 kg ha⁻¹ Ca per year) and didn't decline the soil pH. Because higher yield from fertilized plots respectively increased the removal of Ca (10-12 kg ha⁻¹ Ca), but it was partly compensated by the input of Ca with superphosphate. During the experimental period about 18 kg ha⁻¹ P was applied.

Primary liming with an optimal dust limestone rate (1,0 r CaCO₃ according H) decreased soil acidity from pH 4,4 to 5,2 (Fig. 2). After five years liming efficiency started to decline and during the tenth year after liming the pH was just 0.2 of a unit higher compare to the unlimed plots. pH change was still significant after 15 year, but after 20 year the soil return to its primary acidity level. Intensive regular liming for 20 years (in total 2,0 to 3,5 rates according H) had a more significant effect for pH changes and led to different dynamic changes. Every new cycle of liming compared to the primary was more effectively increasing soil pH. Application of 2 rates of limestone in total allow one to achieve a 5.7 pH level (in 1992), application of 3.5 rates – 6.4 pH. With stopped regular soil liming acidification started. The speed of the acidification was similar to acidification in the primary limed soil. The speed of the acidification is expressed by the logarithmic equation - $y_1(\text{pH}_{\text{KCl}}) = -0,413\text{Ln}(x)+1,466$. The correlation of pH changes with time passed after liming is very strong (R 0.95). Respectively acidification after regular liming is described in $y_2(\text{regular, 2,0 rates}) = -0,612\text{Ln}+3,12$ (R 0,24) and $y_3(\text{regular, 3,5 rates}) = -0,779\text{Ln}+4,40$ (R 0.45).

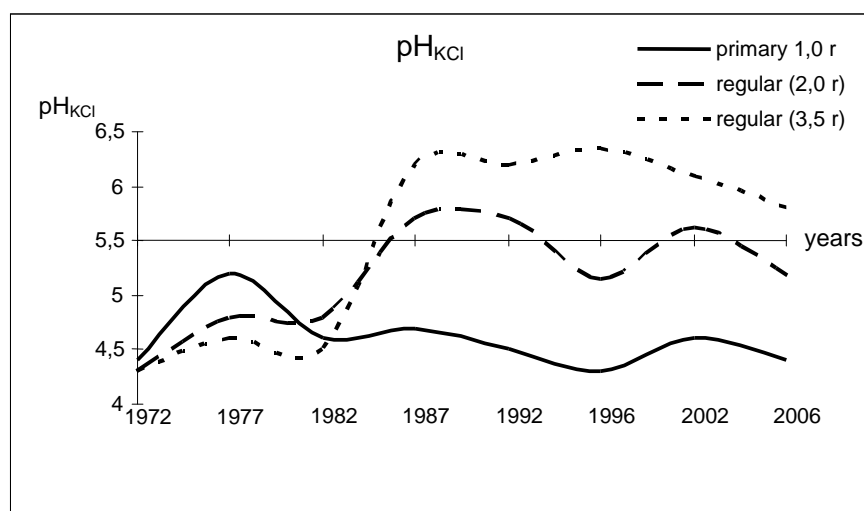


Figure 2 The effect of primary and periodical liming on soil pH_{KCl} in Luvisol

Primary liming declined hydrolytic acidity by 200 cmol kg⁻¹, regular more – 290 cmol kg⁻¹ if 2.0 rates were applied, and by 430 cmol kg⁻¹ if 3,5 rates were applied (Fig. 3.). In the case of primary liming hydrolytic acidity returns to its initial levels slightly latter then pH, and after 20 year was similar to unlimed soil. The effect of regular liming on hydrolytic acidity was more intense. Five year since liming stopped hydrolytic acidity continuing to decrease and later signs of restoration appeared.

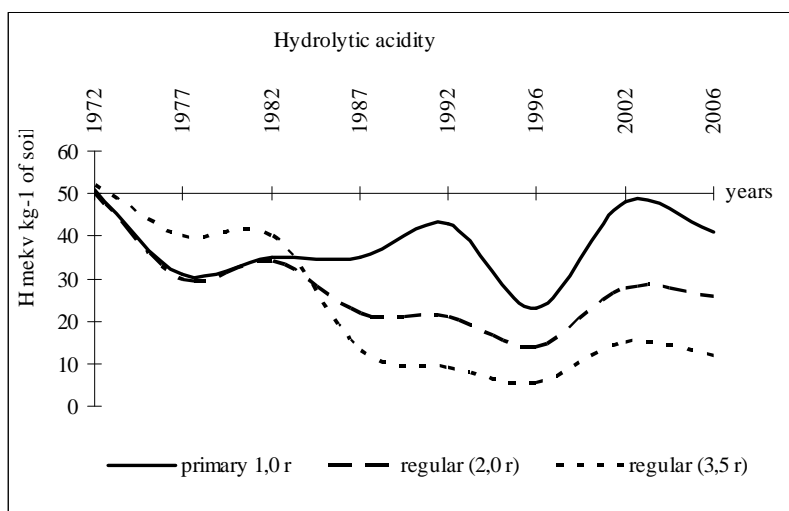


Figure 3 The effect of primary and periodical liming on hydrolytic acidity in Luvisol

The 20 year period after liming shows an increase in hydrolytic acidity 120-70 cmol kg^{-1} depending on the limestone rate, but stays 2-4 times lower than the primary level. The third and one of the main soil acidity characterizing parameters is mobile aluminum. Before liming the mobile Al level was 70 mg kg^{-1} . To apply 1 rate of limestone was enough to bind mobile Al to the immobile compounds. Primary liming kept Al immobilized for the 5 years - at the level 4 mg kg^{-1} (Fig 4). A significant increase was registered after 15 years and continued to increase slightly with time. But even after 34 years the mobile Al concentration in soil was twice as low (34 mg kg^{-1}) compared to the primary status (66 mg kg^{-1}). Regular liming also immobilized almost all of the mobile Al, but not after a first single application of 0.25 rates CaCO_3 . Minimal mobile Al levels in the soil after the whole regular liming cycle were similar to those of primary liming - 2-4 mg kg^{-1} . The restoration of that parameter after liming had stopped and was slow compared to others. The amount of mobile Al was negligible - 1-3 mg kg^{-1} even 20 years after the last liming.

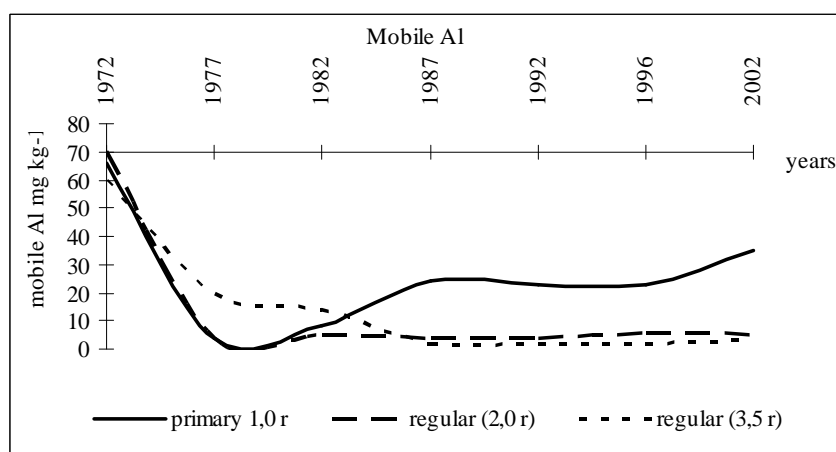


Figure 4 The effect of primary and periodical liming on mobile aluminium concentration in Luvisol

Another important soil chemical property is the amount of absorbed bases. At the beginning of the experiment the background level was as low as 200-300 cmol kg^{-1} (Fig. 5). Primary liming increased the amount to 480 cmol kg^{-1} , but because of decalcification processes and continuing decline after 20 years, the amount was similar to the primary state. Regular liming increased the amount of absorbed bases to higher levels - by 560 cmol kg^{-1} if 2.0 rates CaCO_3 were applied, and by 690 cmol kg^{-1} if 3.5 of CaCO_3 were applied. A significant decline in regularly limed soil was registered 10 years after the last liming, but even after 20 years it was 2,5-3,4 times higher then before the first liming.

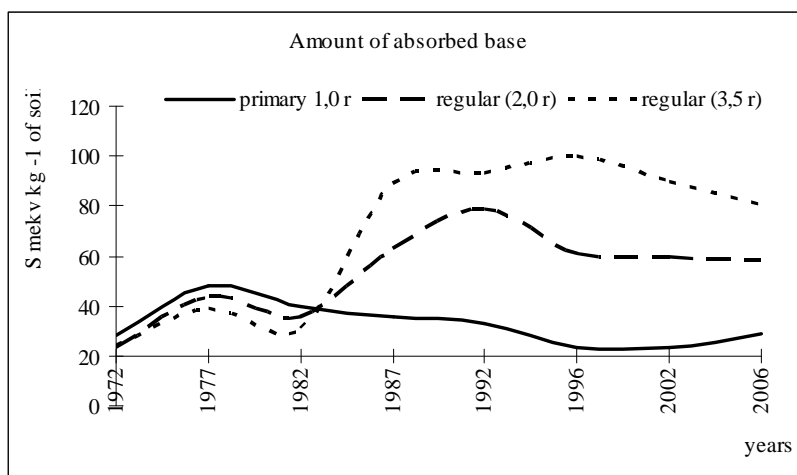


Figure 5 The effect of primary and periodical liming on amount of absorbed base in Luvisol

Productivity evaluation of the last crop rotation (2002-2006) shows that the primary liming effect continued to stimulate yield 30-34 years after (1.0 rate) liming – the total productivity of crop rotation compared to the unlimed soil was 8% higher. The regular liming affected productivity even more, because after the last liming a shorter period passed (20 years) and more limestone was used in total. From the plant production point of view, most effective was soil liming every 10 year with 1 rate of limestone, which resulted in pH changes from 4.4 to 5.7 and the immobilizing of mobile Al. More intensive neutralizing – up to pH_{KCl} 6.4, didn't stimulate plant production and even had a negative effect compared to pH 5.7 soil. Nevertheless, the productivity of crop rotation compare to unlimed soil was still 18% higher in the 20th year.

The results of long-term experiments shown that primary liming efficiency in various Lithuanian regions and foreign countries relate to the liming rate, lime material (type and particle size) as well as on soil properties (genesis, initial chemical, hydrothermal) (Ahern, Weinand, 1995; Motowicka-Terelak, 1985). Regular liming compared to primary is characterized by a lower economic effect, but stabilize soil acidification processes, improve soil physical properties and the microbiologic background (Plesevičius, 1995; Tripolskaja, Marcinkonis, 2005; Bernotas *et al.*, 2005).

The results of the experiment proved that in Lithuanian climate conditions for light textured soils formed on calcareous parent materials liming is having a long-term effect. The liming effect on very acid soils ($\text{pH} \leq 4.5$) with 1.0 rate CaCO_3 according H persist for 34 years. The fastest restoration (after 17-20 y) to previous levels is shown by pH, slower (20-25 y) for hydrolytic acidity and absorbed bases. The mobile Al restoring dynamic is slowest. 34 years after limestone (1.0 rate accord. H, or 7.18 t ha^{-1}) application, the mobile Al concentration in soil was half that before liming. Analogical results of liming publicized by Shilnikov *et al.* (2002) summarizing long-term experimental results in Russia: the dynamic of soil acidity characterizing parameter changes are similar to our soils dynamics. A lower concentration of mobile Al after primary liming had a positive effect on plant production. After 30-34 years because of the primary liming effect crop production was still 8% higher compared to unlimed soil, even pH, hydrolytic acidity and absorbed bases were restored to primary levels. According to Pleseviciene (2000) data, the effect of primary liming depends on the lime rates and persists up to 50 years for light loam acidity properties. It should be noticed that pH level restoration to the primary state during the shortest period (20 y.) where slaked lime was applied, but persisted for 50 years where tufa had been applied. Similar to other experiments the slowest was mobile Al restoring.

Periodical soil liming changed soil the reaction from pH 4.4-4.5 to pH 5.7 or 6.4 depending on the lime rates. Crop production evaluation concludes that neutralizing to pH 6.0 or higher is not productive because it does not stimulate production increase. A similar opinion was published by Russian scientists, who registered that during a 14 year period highest crop production was from soil limed with 0.5 or 1 rates (ШИЛЬНИКОВ *et al.*, 2002).

Our research on soil acidification in regularly limed soil was conducted for a shorter time than the primary limed one – just 20 years. During this period the soil pH in soils above 5.5 declined by 0.5 unit and the downgrade was close to those in primary limed soil. But the amount of absorbed bases and mobile Al increased much slower. Practically, after 20 years since the last liming which led to the decline of mobile Al to 2 mg kg^{-1} it was stabilized. Nevertheless after primary liming the mobile Al started to increase after 10 years, and increased significantly after 15 years (32 mg kg^{-1}). There is a substantial difference between the slower restoration of mobile Al. Regular liming is a more intensively changing structure of exchangeable acidity, consisting of hydrogen and aluminum ions concentration in the soil liquid phase. For instance in 34th year of the experiment at same pH level ($\text{pH}_{\text{KCl}} 4.5$) in unlimed and 1.0 rate limed the soil proportions between H^+ and Al^{3+} ions was different - 4,10 and 3,39 respectively. This proportion becomes less with the increase in the number of liming cycles. After 20 years since the last liming H^+ and Al^{3+} ratio was 2,09 in 2,0 limed soil and 0,85 – in 3,5 rates limed soil. Significant changes of acidity structure in the periodically limed soil limit options to evaluate the real soil acidity of me pH value.

Studies of soil acidity characterizing properties in the soil profile of the 25th year of the experiment suggest that long-term liming acidity declined not only in the arable layer but also in the subsoil (Eidukeviciene *et.al.*, 2001). In relation to liming rates, the duration and soil texture neutralizing effect can cover up to 100 cm of the soil profile. If the calcareous layer is laying at 80-100 cm depth the liming effect getting in touch with the calcareous layer has a neutralizing effect. It means that the parent material relieve the soil acidity optimization in the whole profile. Other researchers had to similar evaluations (Ivanov, 2000; Bernotas *et.al.*, 2005).

Field studies of soil acidity changes in 1998-2002 proved the conclusions of the experimental studies. With stopped liming since 1991 acidification is slower than the prognosis predicted. The comparison of results from 1995-2000 and 1986-1990 assumes an increase in the area of acid soils (≤ 5.5) only by 1.7 % (Mazvila *et al.*, 2004). The most intensive acidification was registered in Western Lithuania soils where soils are naturally very high in acidity and the depth of the calcareous layer is quite deep ($\sim 300 \text{ cm}$). During the period of the study the acid soils in western Lithuania increased by 3.6%, in Eastern Lithuania – 1.3%, in Central Lithuania – 0.8%. Soil acidification is a natural cross border phenomenon and can be regulated by agrochemical means.

Conclusions

Modern environmental protection requirements and soil protection among them also as economic factors stimulate investigations into new criteria for the determination of ecologically and economically based lime rates. Changes in the agrochemical properties listed above in regularly limed soils (structure of exchangeable acidity, mobile Al, absorbed bases, subsoil acidity) warning from use of same principles of lime requirement determination as in unlimed soils – pH and hydrolytic acidity. To answer the question – what is the optimal liming strategy of regularly limed soils, further investigation is required. At the Voke branch of LIA studies of various lime requirement determination methods (to immobilize Al, neutralizing a part of the hydrolytic acidity suggested by Nebolsin, according to base saturation or modified Adam-Evans method) have started since 2000. The first phases do not have a clear advantage over any other method, but proved that the increasing of pH in sandy soils above 6.0 is not needed because in earlier regularly limed soils at pH above 5.0 mobile Al is almost completely immobilized and the negative effect on crop production is minimal.

The experience of Western Europe countries, where long-term liming practice and soil acidity optimization suggest that in Lithuanian conditions in soils with mobile Al below 10 mg kg^{-1} , for the stabilizing of the acidification processes a balance method can be applied. It means lime requirement calculation to cover Ca leaching and removal with crops. The calculated amount can be corrected according to the soil texture which determines sorption capacity and the depth of the calcareous layer.

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AUGSNES SKĀBUMA PAKĀPES RĀDĪTĀJI AUGSNĒM AR PĀRTRAUKTU KAĻĶOŠANU

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Lielākās daļas augšņu paskābināšanās un augsnes paskābināšanās pakāpes dažādība ir mūsdienu problēma visā Lietuvas teritorijā, īpaši austrumu un rietumu reģionos. Kopš 1972. gada Lietuvas Zemkopības institūta Voķe nodaļā veikto ilglaicīgo izmēģinājumu pēdējā posma (no 2002.-2006. gadam) rezultāti parādīja, ka augsnes sākotnējās kaļķošanas ietekme statistiski nozīmīga tikai kustīgajam Al. Salīdzinot ar sākotnēji kaļķotām augsnēm, periodiski kaļķotu augšņu pH, hidrolītiskā skābuma un kustīgā Al izmaiņas bija intensīvākas un to atjaunošanās iepriekšējā līmenī lēnāka. Šādās augsnēs pat pēc 14-23 gadiem kopš pēdējās kaļķošanas augu sekas produktivitātē joprojām ir augstāka nekā nekaļķotās augsnēs.

Pētījumā iegūtajos secinājumos tika noskaidroti šobrīd aktuālie jautājumi lauksaimniecības augšņu ar pārtrauktu kaļķošanu izmantošanai – kādi augsnes rādītāji raksturo augsnes skābumu un kāda ir kaļķošanas nepieciešamība agrāk kaļķotām augsnēm? Nepieciešama tālāka kaļķošanas pārtraukšanas ietekmes uz augsnes profila ķīmisko īpašību izmaiņām, it īpaši kustīgā Al dinamikas atjaunošanos, izpēte. Jaunu kritēriju izvēle kaļķošanas nepieciešamības un optimālās kaļķu normas noteikšanai attiecībā uz ekoloģisko un ekonomisko efektivitāti ir visnozīmīgākais jautājums, lai saglabātu šo skābo augšņu auglīgumu. Tikai tālāks augšņu monitorings dos iespēju detalizēti novērtēt kaļķošanas ietekmes uz vidi un precīzāk prognozēt augsnes optimālā skābuma līmeņa atjaunošanos.