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Agrochemical properties of Lithuanian soils and their changes after regaining independence

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Since 1992, when the volume of liming in the country has greatly decreased and since 1997 the liming of fields has practically ceased, soil acidification has been in progress. Comparing the data of 1995–2006 and 1985–1993, the area of conditionally acid (pH 5.5 and <) soils in the country has increased on an average by 2.1%. The most intensive acidification is observed in previously strongly and moderately acid soils of West Lithuania where it increased by 8.7%, while in Plungė, Tauragė and Šilalė districts by 12.3–29.9%. Acidification of soils in East Lithuania, as compared to West Lithuania, is less. At present, the decreasing pH is far less harmful to plants as they contain a still unrecovered content of exchangeable Al. Besides, the content of exchangeable cations is still relatively high at a depth of 1 m. In the soils of Šilalė, Tauragė, Kretinga, Klaipėda districts (pH 4.6–5.0), the content of exchangeable aluminium (Al) after intensive liming comprised only 0.42–1.76 mekv kg^{-1}, while that of exchangeable cations (Ca, Mg) in the humus layer (pH 4.1–5.0) comprised 30.8–42.0 mekv kg^{-1}.

According to data of 1995–2006, 11.2% of Lithuanian soils have a very low, 33.4% low, 26.6% moderate, 13.7% a bit too high and 15.1% a high or very high content of available phosphorus. Most available P_2O_5 is found in soils of Central Lithuania where the average P_2O_5 content comprises 138.1 mg kg^{-1}. A considerably lower content of available P_2O_5 is found in West Lithuania (average 99.4 mg kg^{-1}). Its changes are insignificant. The content of available phosphorus in East Lithuanian soils, as compared to Central Lithuania, is lower (117.4 mg kg^{-1}).

Lithuanian soils contain more of available K_2O than of available P_2O_5. Soils with a very low content of potassium comprise 2.1%, low 14.7%, moderate 38.6%, high 26.3%, high and very high 18.3%, while soils with a sufficient content of K_2O (> 150 mg kg^{-1}) comprise 44.6%.

The content of available P_2O_5 and K_2O and their balance in the soil were mostly dependent on the rate of phosphorus (R = 0.95) and potassium (R = 0.92) fertilizers and their ratio with nitrogen.

Obtaining average yields of agricultural crops and seeking to ensure positive changes in the content of available P_2O_5 and K_2O, agricultural crops should be fertilized applying 40–60 kg ha^{-1} P_2O_5 and 90–120 kg ha^{-1} K_2O rates.

Key words: soils, fertilizers, pH, exchangeable cations, available P_2O_5 and K_2O

INTRODUCTION

Lithuanian soils were formed on Quaternary deposits, the layer of which at different depths covers the whole territory of the country. It is thought that the Lithuanian territory was affected by no less than three different glaciacions and two periods between them, which have shaped the current relief, while the remaining rocks were affected by water, wind, climatic variations, woody and herbaceous vegetation which in the post-glacial period was changing very fast and at the same time made an impact on the ground cover and its properties. It was to a large extent influenced also by the purposeful anthropogenic activity. Agrotechnical and reclamation measures applied by man affected not only the direction of soil formation, but also soil properties, increased their productivity (Basalykas, 1965; Jankauskas, 1996; Kudaba, 1983; Narbutas, Linčius, Marcinkevičius, 2001). Soil productivity was highly affected by soil agrochemical characteristics. Soil reaction (pH) influenced the regime of nutrients, soil physical properties, the biological activity of microorganisms, the development of plants (Eidukevičienė, Mineikienė, 1995; Mažvila ir kt., 2000; Mažvila ir kt., 2004). Phosphorus and potassium are the main nutrients of plants, and their content in soil depends on the abundance of these elements in soil-forming rocks as well as on fertilization (Bogdevitch et al., 2003; Krištaponytė, 2003; Vaišvila, 1996). Plants contain less phosphorus than nitrogen, potassium and calcium, however, as a yield-limiting factor, it is more important than calcium and potassium (Astover, Roostalu, 2003; Thompson, Troeh, 1982). Phosphorus in the soil is less available than nitrogen, however, its changeability in the soil is sufficiently distinct (Bar-Yosef, 2003; Jaakkola, Hartikainen, Lemola, 1997; Lietuvos dirvožemiai..., 2001; Vaišvila, 1996).

Potassium is a factor of a normal and healthy plant and cannot be substituted by any other element. Some plants may take from the soil more than 300 kg K ha^{-1} annually. European soils usually contain about 40 000 kg K ha^{-1}, however, only about 40 kg ha^{-1} of it is readily available to plants. The remaining potassium is a constituent of soil minerals and is hardly available to plants. The deficient amount of potassium plants should receive with fertilizers (Cook, 1986; Karpinets, Greenwood, 2003).

In the period 1963–1991, soil agrochemical properties were studied in more detail 4–5 times. However, after regaining Independence, due to the lack of means, agrochemical studies of soils slowed down and in some cases even ceased. Therefore, in different soils on 1 / 5 of Lithuanian territory, based on the data renewal program of 1995–2006, some areas were specially selected for observation (since 2005 using GPS) to carry out a detailed investigation of pH and available P_2O_5 and K_2O. Having studied the areas, it became possible to compare the data obtained after regaining Independence with data of earlier investigations.

In 2001–2003, owing to a support from Lithuanian State Science and Studies Fund, 131 soil profile samples taken from 204 plots in agricultural fields, forest outskirt areas and forest soils, were used to ascertain exchangeable cations, total base, hydrolysis and exchangeable acidity, and in some areas available aluminium (Mažvila ir kt., 2006). To ascertain changing tendencies of the content of available P_2O_5 and K_2O, data of experiments with NPK application rates in rotation, conducted since 1971 in Skėmiai, Radviliškis region, were used in this article.

The study aimed at assessing the change of soil pH, plant-available P_2O_5 and K_2O content in soil since the restoration of independence, highlighting the impact of long-term liming activities conducted in the past on the content of exchangeable cations (Ca, Mg) and exchangeable aluminium, assessing the change of plant-available P_2O_5 and K_2O content in soil caused by a long-term (36 years) fertilization with different NPK fertilizer rates, determining the correlation between the agrochemical indicators (P_2O_5 and K_2O) and NPK fertilizer rates and (based on the available research results) the PK fertilizer rates necessary for achieving the optimum crop yields.

METHODS AND CONDITIONS

After regaining Independence, having no possibility to study pH, available P_2O_5 and K_2O in all farmland soils of the country, these studies in 1995–2006 (since 2005 are conducted by GPS devices), based on the data renewal program by monitoring principle, were carried out in all soil regions of the country – in the areas of agricultural companies and private farms of different administrative regions (in 1 / 5 of the territory). Selecting study areas in former farms of individual administrative regions, not only soil genesis, granulometric composition, but also soil pH, its condition following intensive liming, the amounts of available P_2O_5 and K_2O as well as their changes were taken into account. Data obtained during the studies were compared with data of earlier investigations (1985–1993) of the same areas. However, monitoring data after the regaining of Independence are more detailed. If earlier sampling from 15–20 places was done on an average area of 4–8 ha, the last sampling was done on 2–4 ha areas.

The data of earlier studies were summarized using the first computers – electronic calculators (ESM). ESM could also ascertain prevailing groups of provision with available phosphorus and potassium in similarly fertilized fields. No more than two prevailing groups were distinguished for a similarly fertilized field, distributing the areas of the groups at 50%.

During the last agrochemical study, farms of different sizes were being established, thus no large rotation fields were left, they became much smaller and their fertilization differed. Well-doing farms used to fertilize all crops, those that were lacking means applied lower doses, quite often only nitrogen, and some of them applied complete fertilization only to the main crops.

During the last investigation, taking into account soil genesis, granulometric composition, pH, crops and their boundaries in recent years, highly differing amounts of available P_2O_5 and K_2O of earlier studies, even very small areas were distinguished and individual samples were taken from them. Fields with similar soil properties, distinguished during chamber studies, were not combined into similarly fertilized fields as earlier. Therefore, soils of some areas, as compared to the data of earlier studies, contain a slightly higher content of P_2O_5 and K_2O not only due to a more intensive fertilization, but also due to a more detailed study and more accurate data estimation.

Data of the analysis of pH, available P_2O_5 and K_2O are stored in computers. Based on the data, digital maps of soil acidity (pH) and similar soil properties have been compiled, where the groups of available phosphorus and potasium are pointed out. The material of crop declaration in control land sites (blocks) serves as the background.

Available P_2O_5 and K_2O by the Egner–Riehm–Doming method (A-L) have been analysed since 1968 up to now, and pH was analysed by the electrometric method in KCl solution. Besides, changes in the amounts of available P_2O_5 and K_2O in this article are analysed based on study results of a long-term experiment conducted in 1971–2006 in Skėmiai sandy loam *Cambisols* of Radviliškis region (conditions of the experiment are provided in the Journal of Agriculture. 2007. N 3. P. 4–5).

Data on exchangeable cations, total base, exchangeable aluminium and acidity are analysed based on the data of 131 soil profiles from 204 plots studied in 2001–2003.

Exchangeable cations were ascertained in the ammonium acetate solution (Manual..., 1998), while total sum base was established by the Hilkovic method, and exchangeable aluminium was determined using KCl solution.

The statistical validity of the study data was estimated applying the methods of dispersion and correlation-regression analysis, as well as square deviations of the data were calculated (Tarakanovas, Raudonius, 2003).

RESULTS AND DISCUSSION

Soil pH. Lithuanian soils develop in the conditions of leaching regime. Under the effect of precipitation, not only soluble chemical elements, but also fine dispersion particles are leached from the upper soil layers. In the soils of West, East and Southeast

Lithuania, due to higher amounts of precipitation (700–800 mm), leaching is most intensive. Therefore, these soils under the humus layer contain elluvic podzolic E, El horizons from which not only calcium, magnesium, iron oxides, but also fine organic and mineral particles may be leached out; soils become acid and the concentration of hydrogen ions starts prevailing in the base complex.

Earlier, before regaining Independence, liming was applied only in soils with pH 5.5 and lower. The most intensive liming started since 1965. Prior to intensive liming, there were 40.7% of conditionally acid (pH 5.5 and lower) soils in the country, of them 11.9% very acid (pH 4.5 and <), 15.8% moderately acid (pH 4.6–5.0) and 13.0% slightly acid (pH 5.1–5.5). The total amount of conditionally acid soils in West Lithuania comprised about 2 / 3, while very acid and moderately acid soils comprised almost one half. At that time, conditionally acid soils in the farms of Šalčininkai district comprised even 92.8%, in Šilalė, Plungė districts 85–87%, and in Skuodas, Širvintos, Kretinga, Klaipėda districts more than 70%. The yield of crops sensitive to soil reaction was rather low. Owing to intensive (at 160–200 thousand ha annually) and long-term (1965–1990) liming, the area of conditionally acid soils (study data of 1985–1993) was reduced to 18.6%, from them the area of strongly acid soils to 1.5% and of moderately acid to 10.1% (Lietuvos dirvožemių..., 1998; Lietuvos dirvožemiai..., 2001; Mažvila ir kt., 2003).

Since 1991–1992, the volume of liming decreased to 70–40 thous. ha. In 1993–1996 liming was still applied on 5 and 40 thousand ha, while since 1997 the liming of soil has practically ceased. Without liming, soils suffer from acidification. The most intensive acidification has been recorded in the soils of West Lithuania (Table 1).

According to the study data of 1995–2006, the area of conditionally acid soils here increased on average by 8.7%, that of acidulous soils (pH 5.6–6.0) by 2.9%, while the area of close to neutral soils (pH 6.1–6.5) decreased by 14.8%. In individual districts of the zone, soils have become even more acid: in Plungė district by 29.9%, in Tauragė, by 13%, Šilalė district by 12.3%. Changes of soil pH in Plungė and Šilalė districts, which prior to intensive liming had the largest area of acid soils, are presented in Table 2.

Soils of cadastral areas of some of the mentioned regions have been undergoing an even more intensive acidification. The amount of conditionally acidic soils in the Karklėnai cadastral location of Plungė district has increased by even by 44.1%, in Labardžiai by 41.6%, Daugėdai by 40.9%; in Šilalė district: Pajūralis by 34.9%, Žadeikiai by 21.5%. In West Lithuanian soils, the calcareous layer is deeper than in other soils of the country (at a depth of 1.5–3 m), while the subsoil, due to intensive leaching prior to liming, was strongly, sometimes moderately acid.

Acidification in the soils of East Lithuania, as compared to West Lithuania, is less because the calcareous layer here is higher (at a depth of 0.8–1.4 m) and the subsoil is less acid. Thus, the area of conditionally acidic soils in the recently studied Širvintos, Vilnius and Švenčioniai districts has increased by 6.7–8.2%.

Soil liming in Central Lithuania, as a means of soil improvement, has never been actual. In some soils of the zone, although the humus layer is acid, carbonates are skin-deep (mostly at a depth of 0.6–0.8, seldom at 1 m), the subsoil is low-acid. However,

Table 1. **Soil acidity (pH_{KCl}) and its change (1985–1994 and 1995–2006)**

Region	Years of investigation	Area of investigation, ha	Soil pH_{KCl}						
			4.5 & <	4.6–5.0	5.1–5.5	5.6–6.0	6.1–6.5	6.6 & >	Conditionally acid soils (5.5 & <)
			%						
East Lithuania	1985–1994	269,451	2.2	9.8	14.4	17.6	49.2	6.8	26.4
	1996–2006		2.5	8.1	15.5	21.8	42.9	9.2	26.1
Central Lithuania	1985–1991	230,231	0.2	2.0	3.8	5.7	29.1	59.2	6.1
	1997–2006		0.5	1.8	4.0	6.1	23.9	63.7	6.3
West Lithuania	1986–1990	167,827	1.7	8.8	13.4	18.8	49.9	7.4	23.9
	1995–2005		2.3	10.0	20.3	21.7	35.1	10.6	32.6
Lithuania	1985–1991	667,509	1.4	6.9	10.5	13.7	42.5	25.0	18.8
	1995–2006		1.7	6.4	12.8	16.4	34.4	28.3	20.9

Table 2. **Changes of pH_{KCl} in soils of Plungė and Šilalė districts (%)**

Years of investigations	Soil pH_{KCl}										Conditionally acid soils (5.5 & <)	
	4.5 & <		4.6–5.0		5.1–5.5		5.6–6.0		6.1 & >			
	1	2	1	2	1	2	1	2	1	2	1	2
1964–1966	43.6	46.8	28.2	27.2	13.1	12.7	–	–	–	–	84.9	86.7
1968–1970	30.0	37.5	24.1	26.1	17.0	14.9	13.0	10.6	15.9	10.9	71.1	78.5
1976–1978	17.7	20.9	26.2	27.8	28.5	25.2	17.3	17.3	10.3	8.8	72.4	73.9
1982–1983	5.3	8.2	20.5	24.8	25.4	21.5	35.5	31.6	13.3	13,9	51.2	54.5
1988	3.3	5.8	11.8	15.2	16.1	14.3	19.9	18.8	48.9	25.8	31.2	35.3
2005–2006	4.2	1.7	17.9	11.6	33.7	32.0	28.5	30.6	15.6	24.1	55.8	45.3

1 – Plungė district.

2 – Šilalė district.

quite on a large portion of the studied areas (in 9 regions out of 16), the area of conditionally acid soils has increased.

Comparing study data of 1995–2006 and 1985–1993, it was found that the area of conditionally acid (pH 5.5 and <) soils in the country has increased only by 2.1%. This was influenced also by the fact that in some regions, following earlier studies, liming was still applied, which led to a reduction of conditionally acid soils.

However, the decreased pH after an intensive liming now should be regarded slightly differently than prior to intensive liming. Prior to intensive liming, crops sensitive to soil reaction, namely mangel and sugar-beet, red clover, wheat, corn, barley, growing on soils having pH 5.0 and lower, produced very low yields (Knašys, 1985; Lenkšaitė, 1995). At present, its harmful effect on crop yield in acidifying soils and soils of a similar pH (after 30 years, 4–5 times of liming) is not yet felt, and such soils (having applied NPK fertilizers) still produce tolerable yields.

Exchangeable aluminium. Tolerable yields today are influenced also by the former liming applying comparatively high (in West Lithuania even 6–15 t ha^{-1}) $CaCO_3$ rates. First of all, such liming not only increased pH, but also extremely reduced and in some places completely depleted available aluminium; over several decades it has extremely altered not only subsoil pH, but also other agrochemical indices. Recent studies of exchangeable aluminium (Al) in the soils of Šilalė, Tauragė, Kretinga, Klaipėda districts where soil pH is 4.6–5.0 have shown that its content following an earlier intensive liming comprised only 0.42–1.76 mekv kg^{-1} (Table 3).

Exchangeable cations. Besides, it is very important that, being limed for several times and now acidified, soils still contain a large content of exchangeable cations, especially Ca and Mg. Having studied exchangeable cations (Ca, Mg) in field soils which over 1965–1991 were limed 4–5 times, their sum at pH 4.1–4.5 was found to be 30.8 mekv kg^{-1}, at pH 4.6–5.0–42.0 mekv kg^{-1}, in soils of forest outskirts which were limed 1–2 times 14.1 and 27 mekv kg^{-1}, and in unlimed forest soils 10.7 and 16.7 ekv kg^{-1}, respectively. An intensive, long-term liming had a great influence on the accumulation of exchangeable cations also in deeper layers – up to 1 m deep (Tables 4, 5).

However, the uptake of exchangeable cations by growing crops, their leaching by precipitation, application of physiologically acid fertilizers, their amounts along with pH will be constantly decreasing. Thus, to stop soil acidification and a decrease of exchangeable cations, it is necessary to apply soil liming, although at lower rates (2–4 t ha^{-1}).

Available phosphorus. Phosphorus is one of the main nutrients required by all living organisms. According to study data of 1995–2006, soils with a very low content of phosphorus (<50 mg kg^{-1}) comprise 11.2%, low (50–100) – 33.4%, moderate (100–150) – 26.6%, a bit too high (150–200) – 13.7%, high and very high (>200 mg kg^{-1}) – 15.1% (Table 6).

Soils of Central Lithuania are best supplied with available phosphorus (P_2O_5). Soils with a very low content of phosphorus there comprise only 2.9%, while those with a high and very high

Table 3. **Content of exchangeable aluminium in acid Lithuanian soils**

Settlement, district	Soil	pH_{KCl}	Exchangeable Al_{KCl} (mekv kg^{-1})
	West Lithuania		
Girininkai, Tauragė	ID p/p_1	4.6	1.78
	IDg p/p	4.8	1.56
	ID p/p_1	4.9	1.11
	ID ps/p/p_1	4.9	0.89
Laukuva, Šilalė	JI p/p_2	4.8	0.53
	ID s_1 (ps)/p_1	4.9	0.42
Darbėnai, Kretinga	SDg ps/s	5.8	0.56
Venta, Kelmė	JI ps/p	5.2	0.29
Gargždai, Klaipėda	JI ps/p_1	5.9	0.05
	East Lithuania		
Mera, Švenčionys	PL ps/s/p	5.0	1.44
Dysna, Ignalina	GL p/m	4.9	1.22
Mostiškės, Vilnius	JI ps/p_1	4.9	1.20
Geisiškės, Vilnius	SD ps/s	5.0	0.93
Paliūniškis, Panevėžys	SDg ps/s	5.3	0.11
Kalnėnai, Jonava	SDg ps/s	5.8	0.11
Grybėnai, Ignalina	ID ps/ps/ž	5.8	0.09
	ID p/p_2 + m	5.4	0.13

Table 4. **Ca, Mg and total exchangeable cations in humus horizons of Lithuanian soils 2001–2003**

pH_{KCl}	Ca^{2+}			Mg^{2+}			Total exchangeable cations		
	fields	outskirts	forests	fields	outskirts	forests	fields	outskirts	forests
	mekv kg^{-1}								
≤4	–	*6.1 ± 1.5 (6)	9.5 ± 7.4 (32)	–	2.3 ± 0.2 (6)	2.1 ± 1.2 (32)	–	9.4 ± 1.9 (6)	13.1 ± 9.0 (32)
4.1–4.5	25.0 ± 12.9 (13)	10.1 ± 4.8 (34)	7.4 ± 7.0 (20)	3.2 ± 1.5 (13)	2.7 ± 0.9 (34)	1.9 ± 1.5 (20)	30.8 ± 13.3 (13)	14.1 ± 6.1 (34)	10.7 ± 9.0 (20)
4.6–5.0	34.0 ± 19.0 (36)	20.9 ± 11.9 (3)	12.4 ± 11.6 (6)	5.5 ± 5.8 (36)	5.1 ± 3.9 (3)	2.9 ± 2.4 (6)	42.0 ± 24.3 (36)	27.0 ± 16.4 (3)	16.7 ± 14.6 (6)
5.1–5.5	39.5 ± 14.9 (27)	–	27.7 ± 23.4 (2)	7.0 ± 4.8 (27)	–	6.2 ± 7.7 (2)	49.3 ± 18.2 (27)	–	35.2 ± 31.4 (2)
average	34.4 ± 17.1 (76)	10.3 ± 6.0 (43)	9.7 ± 8.9 (60)	5.7 ± 5.1 (76)	2.8 ± 1.3 (43)	2.3 ± 1.9 (60)	42.7 ± 21.4 (76)	14.4 ± 7.6 (43)	13.4 ± 11.1 (60)

* Numerator – average ± standard error.
(Denominator) – number of samples.

Table 5. **Exchangeable cations and total sum base in different groups of pH in Lithuanian soils (2001–2003)**

pH_{KCl}	Sampling depth, cm	Number of samples	Total sum base	Exchangeable cations				
				Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Sum of exchangeable cations
			mekv kg^{-1}					
≤4.0	0–20	38	15.06 ± 8.78	9.05 ± 6.99	2.21 ± 1.18	0.77 ± 0.5	0.55 ± 0.22	12.59 ± 8.38
	30–40	2	30.91 ± 18.61	19.63 ± 3.01	4.11 ± 3.95	2.05 ± 2.61	0.73 ± 0.06	26.52 ± 9.63
	45–60	6	96.56 ± 18.42	53.19 ± 8.64	20.89 ± 11.62	2.68 ± 0.81	0.78 ± 0.12	77.54 ± 19.75
	60–90	2	70.64 ± 18.31	32.04 ± 2.96	9.91 ± 2.26	3.09 ± 0.04	0.52 ± 0.25	45.56 ± 5.44
4.1–4.5	0–20	68	19.21 ± 14.8	12.2 ± 9.7	2.61 ± 1.31	1.15 ± 0.96	0.42 ± 0.26	16.38 ± 11.32
	30–45	51	41.88 ± 34.49	25.1 ± 22.38	5.82 ± 5.84	1.46 ± 1.12	0.62 ± 0.3	33 ± 28.72
	45–60	40	71.07 ± 45.55	43.52 ± 29.4	11.06 ± 8.52	2.08 ± 1.36	0.69 ± 0.31	57.35 ± 38.02
	60–90	13	79.12 ± 47.51	52.37 ± 37.01	12.24 ± 8.01	2.23 ± 1.03	0.78 ± 0.32	67.62 ± 45.27
4.6–5.0	0–20	47	47.6 ± 39.76	30.26 ± 19.26	5.2 ± 5.4	1.57 ± 1.31	0.66 ± 0.27	37.69 ± 24.32
	30–45	62	29.21 ± 32.57	19.36 ± 21.15	4.67 ± 6.19	1.15 ± 0.96	0.55 ± 0.24	25.72 ± 27.5
	45–60	49	32.86 ± 38.43	20.47 ± 25.09	5.61 ± 8.05	1.04 ± 1.16	0.68 ± 0.67	27.79 ± 33.56
	60–90	14	49.28 ± 36.2	29.72 ± 21.73	8.01 ± 6.31	1.09 ± 0.83	0.58 ± 0.22	39.39 ± 27.64
5.1–5.5	0–20	30	61.28 ± 29.81	38.71 ± 15.37	7 ± 4.87	1.93 ± 1.15	0.69 ± 0.35	48.33 ± 18.94
	30–45	38	42.32 ± 31.22	29.95 ± 23.26	5.99 ± 6.01	1.12 ± 0.83	0.67 ± 0.35	37.73 ± 29.29
	45–60	34	42.86 ± 36.56	27.42 ± 23.08	6.98 ± 6.63	1.19 ± 0.93	0.68 ± 0.65	36.27 ± 29.53
	60–90	12	88.91 ± 109.01	39.16 ± 45.0	9.73 ± 11.56	0.94 ± 0.94	0.67 ± 0.4	50.5 ± 57.29
>5.5	0–20	69	103.77 ± 77.99	66.56 ± 40.24	10.45 ± 7.32	2.03 ± 1.45	0.65 ± 0.35	79.69 ± 46.82
	30–45	51	104.51 ± 101.41	50.46 ± 33.01	13.73 ± 13.87	1.66 ± 1.1	0.67 ± 0.31	66.52 ± 47.38
	45–60	51	158.59 ± 153.35	83.71 ± 82.03	20.04 ± 18.05	2.69 ± 7.58	0.72 ± 0.33	107.18 ± 101.6
	60–90	17	162.69 ± 239.76	66.54 ± 83.66	11.68 ± 12.84	1.16 ± 0.85	0.72 ± 0.41	80.1 ± 89.76

Table 6. **Available phosphorus and its change in Lithuanian soils**

Region	Years of investigation	Area of investigation, ha	P_2O_5, mg kg^{-1}				
			< 50	51–100	101–150	151–200	> 200
			%				
East Lithuania	1985–1994	269,451	17.6	36.7	23.2	12.4	10.1
	1996–2006		10.2	32.9	26.2	14.6	16.1
Central Lithuania	1985–1991	230,231	8.5	41.3	28.2	12.6	9.4
	1997–2006		2.9	28.2	33.2	17.1	18.6
West Lithuania	1986–1990	167,827	26.4	44.4	17.3	7.4	4.5
	1995–2005		24.2	41.2	18.2	7.6	8.8
Lithuania	1985–1991	667,509	16.7	40.2	23.4	11.2	8.5
	1995–2006		11.2	33.4	26.6	13.7	15.1

(>200 mg kg^{-1}) content of phosphorus were found in almost 1/5 (18.6%) of the study area. The average content of P_2O_5 in all studied areas of the zone comprises 138.1 mg kg^{-1}. Comparing to the data of earlier studies, the content of soils with a very high content of phosphorus in Central Lithuania has increased by 9.2%, with a high content by 4.5%, moderate by 5.0%, while soils with a very low content of phosphorus decreased by 5.6% and those with a low content by 13.1%.

The situation is considerably worse in West Lithuania where soils with a very low content of phosphorus comprise 24.2%, low 41.2%, moderate 18.2%, while soils with a sufficient content of phosphorus (>150 mg kg^{-1}) comprise only 16.4% in all the areas studied in this zone. Here, the average content of P_2O_5 comprises 99.4 mg kg^{-1}. Obviously, this is to a large extent influenced by soil reaction which is gradually recovering to its former condition, because in acid soils phosphorus fertilizers faster form hardly assimilable compounds, and because in this zone many areas are occupied by pasturelands which are less fertilized with phosphorus fertilizers and quite often only nitrogen fertilizers are applied. Thus, comparing to the data of earlier studies, its changes here are insignificant.

The content of phosphorus in East Lithuanian soils, as compared to Central Lithuania, is lower, however, it is higher than in West Lithuania. Here, soils with a very low content of phosphorus comprise only 10.2%, low 32.9%, moderate 26.2%, and rather rich in phosphorus even 30.7%. The average content of P_2O_5 in all the areas studied in this zone was 117.4 mg kg^{-1}. Comparing with the data of earlier studies, changes in the content of available P_2O_5 in the soils of this zone are significantly more pronounced: soils with a very low content of phosphorus have decreased by 7.4%, with a low by 3.8%, while the area of soils with a medium content increased by 3.0% and rather rich in phosphorus by 8.2%.

In the Skėmiai experiment where fertilization at different rates of NPK was applied (up to 180 kg ha^{-1}) in rotation for 36 years, the content of available P_2O_5 in soil was closely (R = 0.95) dependent on the rates of phosphorus fertilizers and their ratio with nitrogen and potassium (Tables 7 and 8). The parameters of the regression equation show a great positive effect of phosphorus fertilizers on the content of available phosphorus in soil. However, due to the interaction with other fertilizers, under a higher assimilation by plants, the content of phosphorus in soils had a tendency to increase less. If in plots not fertilized with phosphorus the content of available P_2O_5 comprised 63–117 mg kg^{-1}, in plots fertilized with phosphorus (P_2O_5) at average rates of 60–90 kg ha^{-1} it reached 257–317 mg kg^{-1}, at the rate of 120 kg ha^{-1} 306–425 mg kg^{-1}, and at the rate of 180 kg ha^{-1} 413–564 kg ha^{-1}. Applying fertilization over the mentioned period in rotation at a rate of 30 kg ha^{-1} NPK and obtaining low yields of individual crops, the increase of available P_2O_5 (to 204 mg kg^{-1}) in the soil was reliable.

Available potassium. The soils of administrative regions studied in Lithuania in 1994–2006 are better supplied with available K_2O, as compared to available P_2O_5. A very low (<50 mg kg^{-1}) content of potassium in them comprises 2.1%, low (50–100) – 14.7%, moderate (100–150) – 38.6%, a bit too high (150–200) – 26.3%, high and very high (>200 mg kg^{-1}) – 18.3% of the study area (Table 9).

Most soils with a very low and low content of potassium are found in West (17.3%) and East Lithuania (17.8%), slightly less in Central Lithuania (15.4%). Among the administrative districts, the greatest areas of potassium-poor soils were found in the districts of ilutė, Varėna, Šalčininkai (respectively 41%; 39.7%; 38.8%). Soils with a sufficient content of potassium (>150 mg kg^{-1}) were found in 44.6% of the studied area.

Having compared data on soil investigation in former farms of all 44 studied administrative districts over the periods 1984–1994 and 1994–2006, it was found that the area with a very low (4.1%) and low (17.4%) content of potassium in soils has decreased, while the area with a moderate (4.9%), a bit too high (8.3%), high and very high (8.3%) content of potassium has increased. A very low content of potassium in East and West Lithuanian soils has decreased almost evenly (3.4% and 3.7%) and slightly more in Central Lithuania (5.0%). The area of low

Table 7. The effect of long-term fertilization on the content of available phosphorus and potassium in soil Skėmiai, 2006

Ferilization rate kg ha^{-1}								
Nitrogen	Phosphorus	Potassium						
		0	30	60	90	120	150	180
		Available P_2O_5 / K_2O, mg kg^{-1}						
0	0	83/90			102/149			110/185
	90	285/109			263/121			310/199
	180	471/90			457/153			503/194
30	30		204/100				192/204	
	150		529/116				605/188	
60	60			257/106		307/150		
	120			306/115		404/171		
90	0	63/108			96/140			98/190
	90	317/95			295/131			249/184
	180	564/106			499/126			413/200
120	60			249/105		288/139		
	120			382/119		425/137		
150	30		205/99				181/147	
	150		504/105				449/178	
180	0	117/96			86/129			78/179
	90	282/103			286/131			274/171
	180	436/102			501/109			458/158
R_{05}		66.4/25.8						

Table 8. Dependence of available phosphorus and potassium (y) on fertilizer rate and ratio (NPK)

Equation $y = a_0 + a_1 N + a_2 P + a_3 K + a_4 N^2 + a_5 P^2 + a_6 K^2 + a_7 NP + a_8 NK + a_9 PK$ coefficients										R
a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	
Content of available phosphorus in soil, mg kg^{-1}										
66.2	0.45	2.73	0.71	–0.0018	–0.0013	0.0028	0.0015	0.0018	–0.0012	0.95
Content of available potassium in soil, mg kg^{-1}										
94.5	0.15	0.0033	0.30	–0.00067	0.00016	0.0016	0.0003	0.0010	0.00003	0.92

Table 9. **Available potassium and their change in Lithuanian soils**

Region	Years of investigation	Area of investigation, ha	K_2O, mg kg^{-1}				
			< 50	51–100	101–150	151–200	>200
			%				
East Lithuania	1985–1994	269,451	7.0	27.9	33.0	19.5	12.6
	1996–2006		3.6	14.2	36.5	26.7	19.0
Central Lithuania	1985–1991	230,231	6.1	36.5	33.4	16.3	7.7
	1997–2006		1.1	14.3	39.3	25.6	19.7
West Lithuania	1986–1990	167,827	4.9	33.0	35.1	18.2	8.8
	1995–2005		1.2	16.1	40.7	26.8	15.2
Lithuania	1985–1991	667,509	6.2	32.1	33.7	18.0	10.0
	1995–2006		2.1	14.7	38.6	26.3	18.3

potassium soils has connsiderably decreased in all zone studied, while the area of rather rich in potassium soils has increased. However, regularities of changes are similar in all groups of potassium. A slightly less decrease in soils with a low content of potassium and an increase of sufficiently potassium-rich soils was recorded in East Lithuania (at 13.7% and 13.6%) and West (16.9% and 15.0%) and a slightly greater in Central Lithuania (22.2% and 21.3%).

Having estimated the dependence of potassium content in soil on the rate of NPK fertilizers and their interaction in the Skėmiai experiment, a close (R = 0.92) correlation was ascertained (Tables 7, 8). The parameters of regression equation show that the content of available potassium in the soil was mostly dependent on the rates of potassium fertilizers, however, application of nitrogen and phosphorus fertilizers was highly influential as well. If plots free from potassium fertilizers contained only 90–108 mg kg^{-1} of available potassium in soil, application of K_2O for 36 years at a rate of 30 kg ha^{-1} failed to alter its content in the soil (100 mg kg^{-1}). Small changes were observed in rotation applying $N_{60}P_{60}K_{60}$ (106 mg kg^{-1}). Only applying no less than 90 kg ha^{-1} of available potassium annually, its amount after 36 years increased to 126–140 mg kg^{-1}, applying 120 kg ha^{-1} – to 137–171 mg kg^{-1}, applying 150 kg ha^{-1} – to 147–178 mg kg^{-1}, applying 180 kg ha^{-1} – to 126–140 mg kg^{-1}, and, due to interaction with other fertilizers, the content of available potassium increased to 158–179 mg kg^{-1}.

Summarizing the study data, it can be stated that changes in the content of available phosphorus and potassium balance in the soil depend of the rate of these fertilizers and their ratio with nitrogen. Similar results were obtained by other authors (Astover, Roostalu, 2003; Bogdevitch et al., 2003; Krištaponytė, 2003). Obtaining average crop yields and seeking for a positive balance, according to our studies, crops should be fertilized applying 40–60 kg ha^{-1} P_2O_5 and 90–120 kg ha^{-1} K_2O rates.

CONCLUSIONS

1. Since 1992 when the volume of liming in the country has considerably decreased, and since 1997 when liming has practically ceased, acidification of soils is progressing. Comparing the data of 1995–2006 and 1985–1993, it was found that the area of conditionally acid (pH 5.5 and <) soils has on an average increased by 2.1%.

2. The most intensive acidification is observed in previously strongly acid (pH 4.5 and <) and moderately acid (pH 4.6–5.0) soils of West Lithuania. Conditionally acid soils here have increased on an average by 8.7%, while in Plungė, Tauragė and Šilalė districts by 12.3–29.9%.

3. In East Lithuania where liming has been stopped several years ago, former acid soils due to a higher located (at a depth of 0.8–1.4 m) carbonate layer, less acid subsoil, experience acidification again, however, less intensively (0.3%) than in West Lithuania.

4. Soil liming in Central Lithuania is not very actual, however, in 9 out of 16 districts the area of relatively acid soils has increased.

5. At present, the decreasing pH is less harmful to plants because the content of exchangeable Al, reduced to its minimum by intensive liming, has not recovered yet, and exchangeable cations at a depth of 1 m are still relatively abundant. In the soils of Šilalė, Tauragė, Kretinga, Klaipėda districts (pH 4.6–5.0), the amount of exchangeable aluminium (Al) after intensive liming comprised only 0.42–1.76 mekv kg^{-1}, while that of exchangeable cations (Ca, Mg) in the humus layer (pH 4.1–5.0) comprised 30.8–42.0 mekv kg^{-1}.

6. Based on the studies in Lithuania in 1995–2006, soils with a very low content of phosphorus comprised 11.2%, low 33.4%, moderate 26.6%, bit to high 13.7%, high and very high 15.1%. The highest amount of P_2O_5 is found in soils of Central Lithuania. There, soils with a very low content of phosphorus comprise 2.9%, high and very high 18.6%, and the average content of available P_2O_5 comprises 138.1 mg kg^{-1}.

7. A significantly lower amount of available P_2O_5 is found in West Lithuania where soils with a very low content of phosphorus comprise 24.2%, low 41.2%, moderate 18.2%, while sufficiently rich in phosphorus (>150 mg kg^{-1}) soils comprise only 16.4%, and the average content of P_2O_5 reaches 99.4 mg kg^{-1}.

8. The content of available phosphorus in East Lithuanian soils, as compared to Central Lithuania, is lower, however, it is higher than in West Lithuania. Here, soils with a very low content of phosphorus comprise only 10.2%, low 32.9%, moderate 26.2%, sufficiently rich in phosphorus even 30.7%, and the average P_2O_5 content comprises 117.4 mg kg^{-1}. Comparing with the data of earlier studies, changes in the content of available P_2O_5 in soils of this zone are significantly more distinct: soils with a very

low content of phosphorus have decreased by 7.4%, with a low by 3.8%, while soils with a moderate content increased by 3.0% and sufficiently rich in phosphorus by 8.2%.

9. Lithuanian soils contain more of available K_2O than of available P_2O_5. Soils with a very low content of potassium comprise 2.1%, low 14.7%, moderate 38.6%, bit too high 26.3%, high and very high 18.3%.

10. Most soils with a very low and low content of potassium are found in West (17.3%) and East Lithuania (17.8%), but slightly less in Central Lithuania (15.4%).

11. Soils with a sufficient (> 150 mg kg^{-1}) content of potassium in the country comprise 44.6%. Their area in East and Central Lithuania is similar (45.7% and 45.3%), and it is slightly less in West Lithuania (42.0%).

12. The area with a very low content of potassium has decreased by 4.1%, low by 17.4%, but the area with a moderate content of potassium has increased by 4.9%, a bit too high 8.3%, and high and very high by 8.3%.

13. The content of available P_2O_5 and K_2O and their balance in soil were mostly dependent on the rate of phosphorus (R = 0.95) and potassium (R = 0.92) fertilizers and their ratio with nitrogen.

14. Obtaining average crop yields and seeking to ensure positive changes of available P_2O_5 and K_2O in the soil, agricultural crops should be fertilized applying no lower than 40–60 kg ha^{-1} P_2O_5 and 90–120 kg ha^{-1} K_2O rates.

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LIETUVOS DIRVOŽEMIŲ AGROCHEMINĖS SAVYBĖS IR JŲ KAITA PO NEPRIKLAUSOMYBĖS ATKŪRIMO

Santrauka

Lietuvoje nuo 1992 m. kalkinimo darbų apimtims labai sumažėjus, o nuo 1997 m. praktiškai dirvų nebekalkinant, jos rūgštėja. Palyginus 1995–2006 ir 1985–1993 m. tyrimo duomenis nustatyta, kad šalyje sąlygiškai rūgščių (pH 5,5 ir <) dirvų padaugėjo vidutiniškai 2,1%. Labiausiai rūgštėja anksčiau buvę labai ir vidutiniškai rūgštūs Vakarų Lietuvos dirvožemiai (padidėjo 8.7%), o Plungės – Tauragės ir Šilalės rajonuose – 12,3–29,9%.

Rytų Lietuvoje kelerius metus nekalkinant, buvusios rūgščios dirvos rūgštėja mažiau. Šiuo metu mažėjantis pH gerokai mažiau žalingas augalams, nes juose dar neatsistatęs intensyviu dirvų kalkinimu iki minimumo sumažintas mainų Al kiekis, palyginti, dar daug yra mainų katijonų iki 1 m gylio. Šilalės, Tauragės, Kretingos, Klaipėdos rajonų dirvožemiuose, kurių pH 4,6–5,0, mainų aliuminio (Al) po intensyvaus kalkinimo nustatyta tik 0,42–1,76 mekv kg^{-1}, o mainų katijonų (Ca, Mg) humusingajame sluoksnyje, esant pH 4,1–5,0, – 30,8–42,0 mekv kg^{-1}.

Lietuvoje, 1995–2006 m. tyrimo duomenimis, labai mažo fosforingumo dirvožemių nustatyta 11,2, mažo – 33,4, vidutinio – 26,6, didoko – 13,7 ir didelio– 15,1%. Daugiausia judriojo P_2O_5 yra Vidurio Lietuvos dirvožemiuose. Juose labai mažo fosforingumo dirvų tėra 2,9, didelio (>200 mg kg^{-1}) – 18,6%, o judriojo P_2O_5 vidurkis yra 138,1 mg kg^{-1}. Kur kas mažiau judriojo P_2O_5 yra Vakarų Lietuvoje: labai mažo fosforingumo dirvų – 24,2, mažo – 41,2, vidutinio –18,2%, pakankamai fosforingų (>150 mg kg^{-1}) dirvožemių tėra 16,4%, o P_2O_5 vidurkis – 99,4 mg kg^{-1}. Jo pokyčiai nežymūs. Rytų Lietuvos dirvožemių fosforingumas, palyginti su Vidurio Lietuva, yra mažesnis, tačiau didesnis negu Vakarų Lietuvoje. Čia P_2O_5 vidurkis – 117,4 mg kg^{-1}, tačiau gerokai ryškesni jo pokyčiai.

Judriojo K_2O Lietuvos dirvožemiuose, palyginti su judriuoju P_2O_5, yra daugiau. Juose labai mažo kalingumo dirvožemių yra 2,1, mažo – 14,7, vidutinio – 38,6, didoko – 26,3, didelio ir labai didelio – 18,3, pakankamo kalingumo (>150 mg kg^{-1}) – 44,6%. Daugiausia labai mažo kalingumo ir mažo kalingumo dirvožemių yra Vakarų (17,3%) ir Rytų Lietuvoje (17,8%) bei kiek mažiau – Vidurio Lietuvoje (15,4%).

Ilgą laiką (36 m.) įvairiai tręšiant augalus sėjomainoje NPK trąšomis (iki 180 kg ha^{-1}) nustatytas glaudus judriųjų P_2O_5 (R = 0,95) ir K_2O (R = 0,92) kiekių dirvožemyje, taip pat fosforo bei kalio trąšų normų ir jų derinių ryšys.

Gaunant optimalius žemės ūkio augalų derlius ir siekiant teigiamo maisto medžiagų balanso žemės ūkio augalus reikėtų tręšti ne mažiau kaip 40–60 kg ha^{-1} P_2O_5 ir 90–120 kg ha^{-1} K_2O.

Raktažodžiai: dirvožemis, trąšos, pH, mainų katijonai, judrieji P_2O_5 ir K_2O