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Change of soil pH in the territory of Lithuania: spatial and temporal analysis

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The paper offers an analysis of the processes of soil acidity neutralization and soil acidification, their interaction and practical consequences. The study object is acid Lithuanian soils. The study was carried out in Lithuania on national and local levels. Material collected in a fifty-year period of agrochemical studies of agricultural land and long-term investigation of soil liming has been used and summarized. The aim of the work was to verify the competence level of the scientific conception and the practical value of scientific recommendations using GIS statistical methods. Systemic spatial and temporal analysis was the main method used in the study. Geoinformation methods were employed to establish the spatial gradation regularities of acid soil areas. The statistical analysis of the upper horizon pH and soil granulometric composition diversity involved the method of statistical grid (2×2 km = 4 km^2).

It was revealed that localization of acid soil areas as natural bodies in its essence is a regular natural phenomenon predetermined by soil genesis. The change of acid soil plots (decrease and increase) takes place in the same areas. Regular liming of acid soils according to scientific recommendations at recommended intensity and cycles, equally as omitting one cycle of liming, exert the greatest changes in the areas of the same acidity, i. e. in very acid and medium acid soils. Soil acidification in the whole territory of Lithuania, if no liming is applied, confirms the necessity of regular uninterrupted liming. The spatial gradation (decrease and increase) of acid soil areas corroborates the adequacy of the scientific conception and of practical scientific recommendations.

Key words: acid soils, soil pH, GIS statistic analysis

INTRODUCTION

Soil pH reflects changes in soil acidity. Soil acidification takes place in both natural and anthropogenized environments. At present, the acidification of cultured soils is understood as cation leaching and removal with plant production in the theoretical sense [22], while practically it is regarded as soil degradation, i. e. the process of deterioration of its chemical, physical and biological properties [2, 21]. Acidity neutralization and soil acidification are the different process that proceed simultaneously , and the degree of intensity of both depends on soil bufferness [19, 22]. This is the explanation of the dependence of both processes on carbonate content in the parent rocks or bedrocks [22].

In Europe, over the last 150 years studies of liming as the most efficient and irreplaceable preventive means of soil degradation have been exhaustive and encompassed the object of liming (soil genesis), duration of the effect of liming substances (chemical meliorator, fertilizers) and their impact on soil and yield. In the sense of knowledge, the core problem has always been and still remains the lack of systemic analysis. Experimental results have revealed the variegated effects of liming – agrochemical, agrophysical, biological, agronomical, environmental [5, 6, 21, 22] – both those widely known positive and potentially negative [5, 6].

Soil acidification as a process has been studied far less comprehensively because since the mid 1960s it has been most often analysed only in the context of liming as a result of the chemical activity of lime fertilizers.

With the conception of the nature-friendly anthropogenized environment gaining an ever increasing importance since the ninth decade of the 20th century, and with the present-day concepts of the profitable market economy, of particular significance has become elucidation of soil acidification processes.

The concept of a correlation between soil as the object of liming and soil acidification as a process in the 20th century underwent changes because of different approaches to soil and to the need of liming: the scientific approach to an individual soil profile and the resulting conception of differentiated liming depending on the depth to carbonate (Lithuania, the sixth decade), the overestimation of the upper soil horizon and the concept of liming in dependence on the upper horizon properties (Eastern Europe, seventh–eighth decades), the scientific spatial approach to soil, dependence of activity of natural and anthropogenic factors of soil acidification on the carbonate content of parent rocks, the depth of parent rocks and bedrocks, the recognition of the significance of the geological and hydrological state of the soil cover, profile pH (Bulgaria, Denmark, the United Kingdom, Poland, Lithuania, the Netherlands, Russia, Hungary, Germany – the ninth decade) and the revival of the concept of differentiated liming effects on the properties of soil profile horizons or parient rocks (Poland, Lithuania, Russia – the ninth decade) [22].

In East-European countries, nowadays the problem of soil acidification is especially urgent. In Lithuania, both for economic reasons and because of the underestimation of scientific knowledge, 15 years ago soil liming intensity was reduced, and the cessation of liming in 1997 because of the lack of financing already shows its first results: acidification of soil has been recognised [11]. This applies to both heavy- and light-textured soils [11].

In Belarus, even a temporary (three-year) reduction of liming by 50–60% evoked sings of soil acidification [16]. In Russia, where the volume of liming was drastically reduced after 1990, soil acidification is expected to increase [20].

The turn of the centuries did not manifest any leap of the scientific thought; on the contrary, a strengthening of the former ideas is evident [11, 19, 20]. When interpreting the results of the most recent investigations it has been recognized that under real conditions of farming on light loam moraine soils, only intensive liming gives fast results as it allows a rapid optimization of the acidity / basicity indices [6, 20]. The state of soil acidity / basicity is related to the chemical composition of parient rocks, therefore even in well culturized soils the influence of genetic differences remains preserved [11, 20]. It has been acknowledged that soil acidification differences in the territory of Lithuania, in the absence of liming, are essentially dependent on the genetic diversity of soil acidity in a profile, therefore, in the face of soil liming renewal, the concept of differentiated liming is proposed. The concept prioritizes the so-called originally acid soil areas that were present before intensive liming [11].

The search of a correlation between the above-mentioned conceptions and the practical solution of the problem gave the following results: the spatial differences in soil acidity neutralization were elucidated and substantiated; the prognostication of differentiated liming depending on the depth to carbonate was proposed [22]; spatial differences in soil acidification in the territory of Lithuania were established [11], the methods of investigation – GIS statistical analysis [7, 15] – were improved and provided a scientific background for developing the theory of soil acidification prognosis.

The aim of the present work was to verify the conformity between the scientific conception and practical scientific recommendations using GIS statistical methods.

The tasks were as follows:

1. A retrospective analysis of acid soil gradation on the national level.

2. A retrospective analysis of soil acidification rates on a local level (field trial).

3. Assessment of soil acidification conformity between the national and local levels.

The novelty of the work consists in the substantiation of a correlation between the upper soil horizon pH and the spatial diversity of soil granulometric composition using the statistical grid method and elucidation of the spatial localization of decreasing and increasing acid soil areas using the GIS method.

METHODS

The object of the study was acid soils of Lithuania. Systemic spatial and temporal analysis was the main method used in the study. The methods were literature analysis, cartographical analysis, GIS, GIS statistical analysis, laboratory analysis and field trial. The research was carried out on the national and local levels (Fig. 1). Materials collected in the course of 50 years were used and summarized.

The national level:

• Data of agrochemical investigations of agricultural lands for a period of 40 years (1964–2004) were summarized. They represent the spatial and temporal distribution of conditionally acid ($pH < 5.5$) soil areas.

The local level:

• Data of long-term stacionary investigations of liming for the period 1949–2006 (stacionary trials at the Vėžaičiai and Vokė branches of the Lithuanian Institute of Agriculture, Fig. 2). They represent cadastre localities in which the areas of acid soils are increasing.

Data of the investigations represent Albeluvisols on moraine deposits in West Lithuania and Luvisols on fluvioglacial sediments in East Lithuania.

The investigations were carried out in three stages:

1. A retrospective analysis of change of acid soil areas on the national level.

2. A retrospective analysis of soil acidification rate on the local level.

3. The processes of soil acidification and their conformity on the local and national levels.

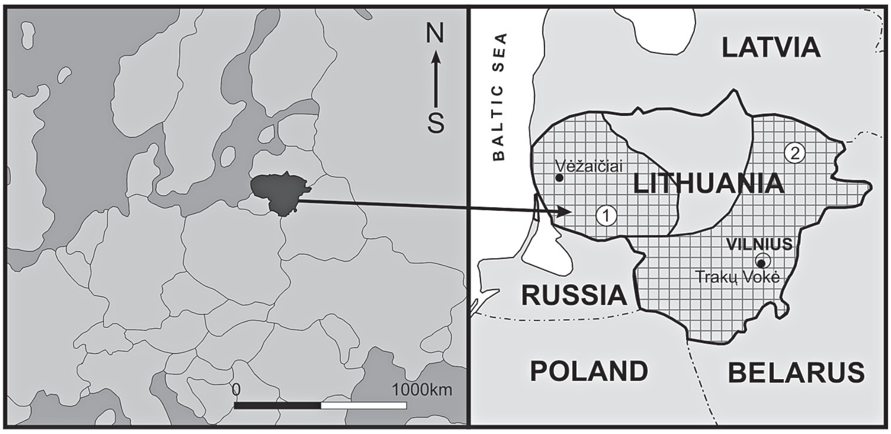

Fig. 1. The study site. 1 – systemic analysis template in Fig. 3, 2 – systemic analysis template in Fig. 4

1. Retrospective analysis of the change of acid soil areas on the national level

Systemic analysis was used to investigate the spatial distribution regularities of acid soils on the territory of Lithuania (Fig. 2), employing the literature analysis and geoinformative methods. To perform a spatial multilayered correlation with the application of GIS (geographical information system), the geographical information (the spatial information provided by maps) was transformed and co-ordinated with regard to the LKS-94 system of co-ordinates. This method was used to compare the maps of acid soil areas (Figs. 2–4) and agricultural land soil pH [18].

The statistical analysis of soil pH spatial distribution was based on a modified map of agricultural land soil pH (Fig. 2). The method of statistical grid (2×2 km = 4 km^2) was employed for the statistical analysis of pH diversity. Soil pH diversity was expressed in points, and the spatial structure diversity was differentiated into five categories: very uniform, uniform, rather diverse, diverse and very diverse. The choice of the intervals was predetermined by the structure of a data set (binomial distribution of the values). The soil pH diversity map was compiled according to the deviation of the diversity point value from the mean value (Figs. 3, 4). The methods of soil pH diversity statistical analysis and map compilation have been presented in detail elsewhere [7] as a study accomplished by J. Volungevicius.

The map of soil pH shows the distribution of pH values in the upper (0–20 cm) soil horizon on the territory of Lithuania. The pH values were determined in KCl extract.

The map of the soil granulometric composition was compiled on the basis of data of the digital map of Lithuanian soils at a scale 1 : 300000 compiled in 1998 by the Land Research and Assessment Department of the National Land Management Institute. The soil granulometric composition types were differentiated according to both the numerator and denominator of the first member in the soil combination contour (Fig. 2). This means that the contour of the map reflects only the predominant soil granulometric composition. The map shows the granulometric composition of the upper 1 m layer of surface deposits (soil particles less than 1 mm). The method of the map compilation has been presented in detail elsewhere [15]. The method of statistical grid (2×2 km = 4 km^2) was employed for the statistical analysis of granulometric composition diversity. Granulometric composition diversity was expressed in points and the spatial structure diversity was differentiated into five categories: very uniform, uniform, rather diverse, diverse and very diverse. The soil granulometric composition diversity map was compiled according to the deviation of the diversity point value from the mean value (Figs. 3, 4).

2. Retrospective analysis of soil acidification rate on the local level

Data of long-term investigations were used to assess soil pH changes in the upper layer under the effect of soil liming.

Laboratory analysis of soil pH was performed by the method of potentiometry (1 n KCl suspension). Soil pH_{KCl} indices in long-term studies were assessed by the method of correlation–regression analysis employing STATISTICA software.

RESULTS

Retrospective analysis of acid soil spatial change on the national level

A systemic analysis of acid soil plot change over a period of 40 years (1964–2004) [11, 22] has confirmed that the spatial (territorial) distribution of acid soils is predetermined by natural reguliarities. The localization of acid soil areas in a profile is a stabile natural phenomenon. Liming of the upper horizon of soil (0–20 cm) according to scientific recommendations has no effect on acid soil spatial distribution, because systemic liming at a standard 1.0 rate exerts no essential residual effect on the whole soil profile over a period of 50 years [4–6].

In West Lithuania, acidification of Albeluvisols on moraine loams, according to pH level in Ap and EB horizons was slowed down to the depth of 0.5 m only under intensive application of powder lime – 2.0 rates every 3–4 years or 2.5 rates every 7 years over a period of 50 years. In East Lithuania, systemic liming (3.5 rates of powder lime) after 25 years reduced soil acidity to the depth of 0.8 m.

Liming of the upper soil horizon according to scientific recommendations influences only the spatial and temporal distribution of pH level (the plot of acid soils in %, calculated for the pH level <5.5). The pH level of the upper horizon in cultured soils changes with time – it either increases (neutralizes as a result of liming) or decreases (as a result of acidification). As a consequence, the area of acid soils in time and space (plot in %) also changes – it either increases or decreases, respectively. The methodic aspects of explaining changes in acid soil plots (specific features of liming and methods of pH investigation), which were given much attention earlier and are mentioned also at

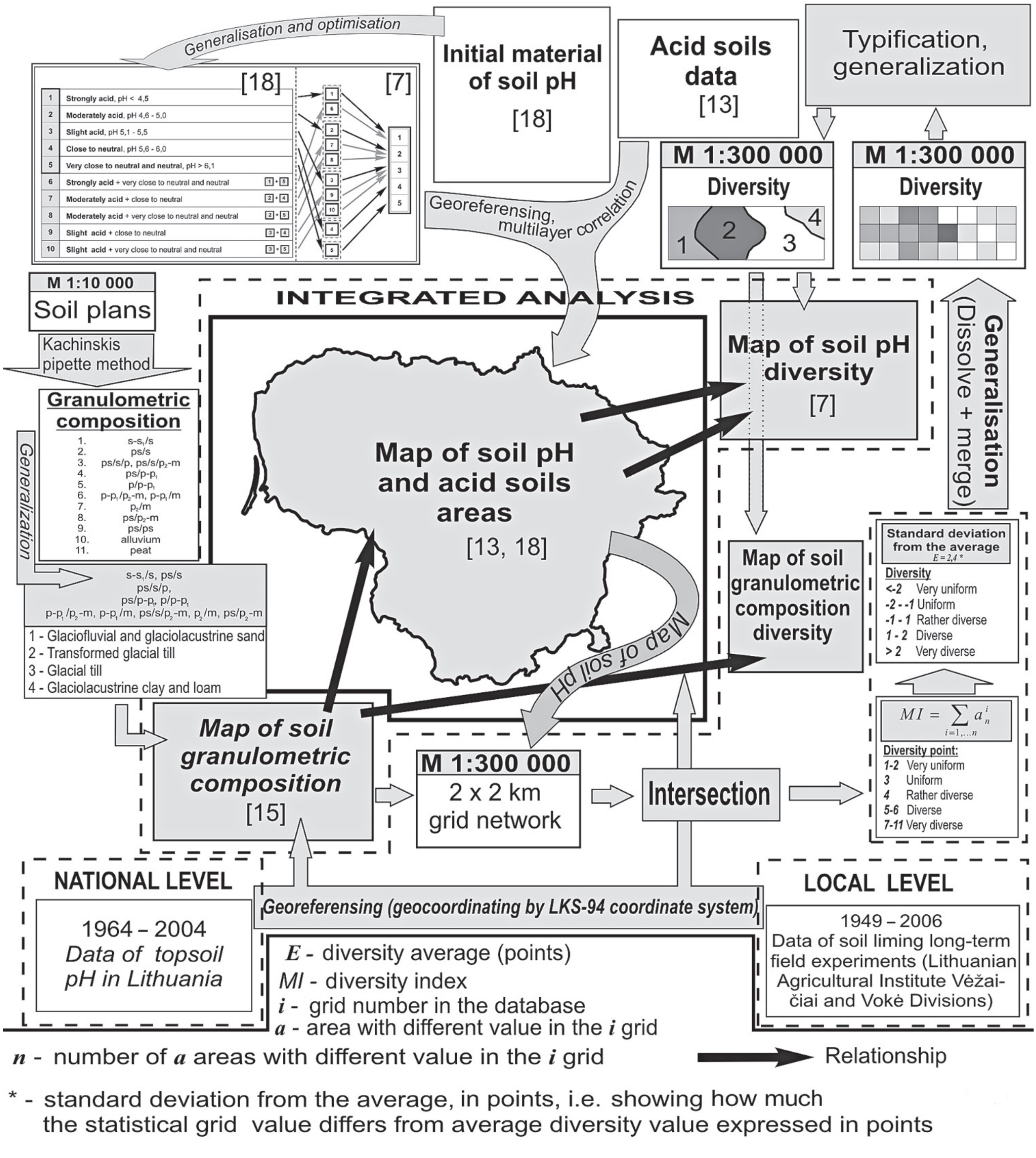

Fig. 2. Methodological scheme of the investigations.
Compiled by J. Volungevičius

present [11], are of secondary importance. In the present work, attention is focused on the most significant regularities:

– systemic liming according to scientific recommendations (intensity and periodicity [22]), as well as omiting one cycle of liming [11] induce most significant changes in soil groups of the same acidity – those very acid and medium-acid, which decrease under the effect of liming and increase as a result of acidification;

– after ten years of intensive liming (1–2 cycles) [18], in 1978 a very acid and medium-acid soil pH of the upper soil horizons was found in the Žemaičiai Highland (West Lithuania) where acid soils comprised more than 70% (Fig. 3) before intensive liming and 50% to 60% [10, 13, 18, 22] after four cycles of liming. It is exactly in this region that omitting one cycle leads to an increase of acid soil plots;

– both a decrease and an increase of acid soils plots depend on a particular geochemical environment in soil – its relief, moisture regime and the genetic properties of the soil profile [11, 22]. The regularities have been proven for both the cadastre localities and the whole territory of Lithuania [11, 22].

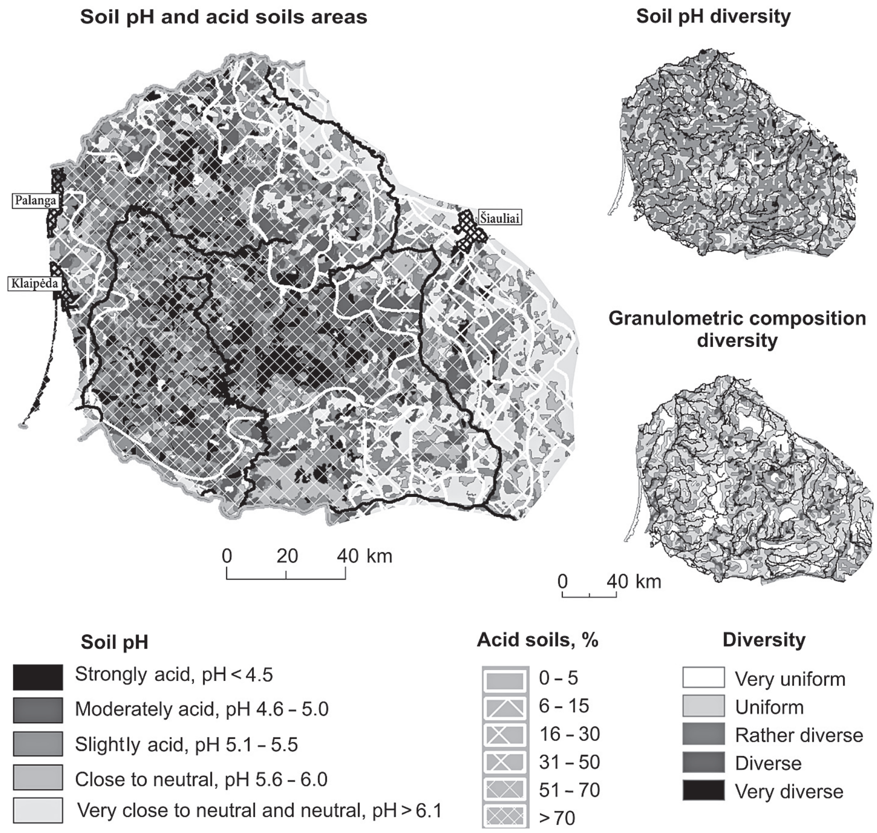

Fig. 3. Spatial structure characteristic of acid soils (Fig. 1, template 1) .
Compiled by J. Volungevičius

In the light of these regularities which became pronounced in the course of 40 years, logical seems the structure of the upper soil horizon pH determined before [22]. After ten years of intensive liming, the spatial structure of the upper soil horizon pH diversity actually repeats the macrostructure of the relief – the contours of highlands and lowlands – and reflects their internal spatial structure: in the Žemaičiai Highland, the spatial structure is concentric (Fig. 3), whereas in the Baltic Highlands it is radial (Fig. 4). Very acid and medium-acid areas are situated mostly on the hilly relief of the Albeluvosol contours in West Lithuania and on Albeluvisol and Planosol contours in East Lithuania [4]. The interaction of various factors (soil depth / depth to carbonate, soil granulometric composition and carbonate content of parent rocks, surface relief, the age of the relief) predetermines a low or a high diversity of soil pH. Low pH diversity is characteristic of granulometric composition of homogeneous, relatively younger parent rocks with a higher carbonate content (Central Lithuanian Lowland) and older (Lyda Plateau) territories with a more levelled surface. High pH diversity is characteristic of territories of various granulometric composition and medium age, such as parts of the Baltic Highlands and the Žemaičiai Highland. A correlation between soil granulometric composition and upper horizon pH is obvious: low soil granulometric composition diversity areas show also a poor diversity of the pH index (Figs. 3, 4).

Retrospective analysis of soil acidification rates on a local level

Moraine loam Albeluvisols. With regard to soil neutralization, liming is a long-standing means. As regards mobile aluminium, its effect survives for up to 53 years [12]. However, as regards soil pH, the effect of liming is essentially shorter.

In very acid soils limed with 1.0 rate of coarse lime fertilizers (tufa or carbonaceous loam), the soil acidity level pH_{KCl} 5.5 is achieved within 13 years, while the application of chemically active lime fertilizers (slaked lime and powder lime) reduces this period to 7 years [12].

Very acid soils after liming with 1.0 rate of powder lime preserve the economically and ecologically optimal level of pH_{KCl} 5.8–6.0 for a period of five years. The above-mentioned distribution of very acid and medium-acid soils on the territory of Lithuania after ten years of intensive liming (Figs. 3 and 4) may be a consequence of the scheduled first liming, because within this period very acid soils after the initial liming with powder lime (the standard 1.0 rate) acidify by 0.8 pH unit [3].

As a result of systematic periodical liming with 1.0 rate of powder lime every seven years, the pH of very acid and medium-acid soils does not attain the level $pH_{KCl} < 5.5$ and this rate of liming applied for 14 years changes soil acidity to the level of pH 6.0–6.2, which is optimum for most plants. This level is justifiable also ecologically. With liming intensified to 1.0 rate every 3–4 years, an analogous pH_{KCl} 5.9–6.1 is attained within 7 years, and it increases to pH_{KCl} 6.5 within 14 years (Table 1). This mode of liming leads to soil degradation.

Fluvioglacial sandy Luvisols. In very acid soils, initial liming with the standard 1.0 rate of limestone dust fails to ensure the recommended pH_{KCl} limit of 5.0. Repeated liming at the same rate after 10 years increases soil pH to the level exceeding 5.5, and soil acidification stabilizes (Table 2).

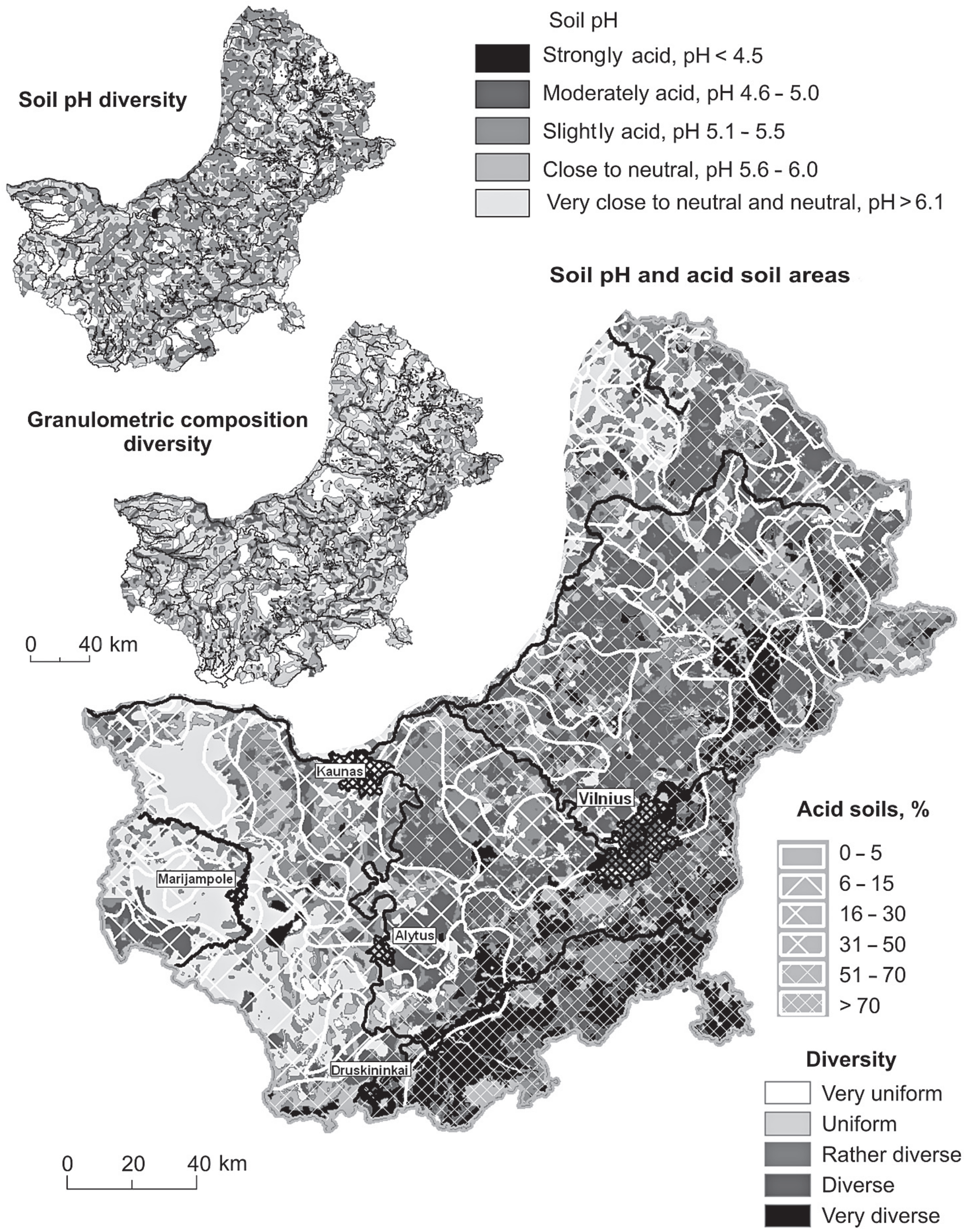

Fig. 4. Spatial structure characteristic of acid soils (Fig. 1, template 2)
Compiled by J. Volungevičius

Table 1. **Soil pH dynamics under the effect of periodic liming in West Lithuania.**
Vėžaičiai, 1985–2005, trial in honour of J. Kalvaitis

Period	No lime added	Limed	
		1.0 rate every 7 years	1.0 rate every 3–4 years
pH_{KCl} changes after one / two cycles of periodic liming			
1985–1988	4.2 ± 0.07	–	5.5 ± 0.14
1985–1991	4.3 ± 0.05	5.6 ± 0.07	6.0 ± 0.06
Average per 7 years	4.3 ± 0.05		5.7 ± 0.13
pH_{KCl} changes after two / four cycles of periodic liming			
1992–1995	4.3 ± 0.05	–	6.4 ± 0.17
1992–1998	4.2 ± 0.06	5.8 ± 0.06	6.5 ± 0.09
Average per 7 years	4.2 ± 0.06		6.5 ± 0.09
pH_{KCl} changes after three / six cycles of periodic liming			
1999–2002	4.2 ± 0.04	–	6.7 ± 0.05
1999–2005	4.2 ± 0.04	6.4 ± 0.07	6.8 ± 0.12
Average per 7 years	4.3 ± 0.04		6.8 ± 0.06

Table 2. **Soil pH_{KCl} changes after periodic liming in East Lithuania**
Vokė, 1973–1992

Liming intensity	pH_{KCl} before liming (1973)	pH_{KCl} after primary liming (1983)	pH_{KCl} after periodical liming (1992)
0.5 rate every 10 years	4.3	4.5	5.1
1.0 rate every 10 years	4.3	4.8	5.7
R_{05}	0.08	0.08	0.10

Conformity of soil acidification processes on the local and national levels

Data of long-term studies confirm the change of acid soil plots in the territory of Lithuania. Moraine loam Albeluvisols and fluvioglacial sandy loam Luvisols limed keeping to scientific recommendations should not acidify. Under intensive liming, acid soil areas were decreasing. The present-day increase of acid soil areas is a result of the interrupted liming.

SUMMARY OF RESULTS

Acid soil plots in Lithuania over 50 years have changed under the combined effect of various lime fertilizers and as a result of the interrupted liming.

Systemic analysis of the previous and most recent studies shows that in moraine loam Albeluvisols the rate of both neutralization and acidification processes depends on the initial soil acidity level and on the type of lime fertilizers applied. In both cases, pH changes in the upper soil horizon modify the properties of the whole soil profile as an indivisible natural body resulting from the genesis of the parent rocks.

The correlation between the spatial structure of pH of the upper soil horizon (0–20 cm) of agricultural lands limed one or two times and the regularities of an increase or decrease of acid soil plots over a period of 40 years is an evident proof of the spatial localization of acid soil areas and indicative of potentially acid territories.

All the above facts confirm an agreement between the scientific conception under review and the scientific recommendations, and thus the discussion of the uneven spatial efficiency of liming on the territory of Lithuania is hopefully closed.

CONCLUSIONS

1. The localization of acid soil areas as a natural body is an essentially regular natural phenomenon predetermined by soil genesis. Changes of acid soil plots (decrease and increase) are evident in the same areas.

2. Under systematic liming according to scientific recommendations at a certain intensity and periodicity, as well as with one cycle omitted, most pronounced changes occur in the plots of the same acidity groups, i. e. in very acid and medium-acid soils.

3. Soil acidification, presently observed on the whole territory of Lithuania as a result of the interrupted liming, confirms the data of long-term field trials and the necessity of regular uninterrupted liming.

4. The spatial dynamics of acid soil plots (decrease and increase) corroborates the conformity between the scientific conception and the related scientific recommendations.

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DIRVOŽEMIO pH KAITA LIETUVOJE: ANALIZĖ ERDVĖJE IR LAIKE

Santrauka

Analizuojama dirvožemio rūgštumo neutralizacijos bei dirvožemio rūgštėjimo procesų vyksmo sąveika ir pasekmės žemės ūkio praktikos požiūriu. Tyrimo objektas – rūgštūs Lietuvos dirvožemiai. Tyrimai atlikti Lietuvoje nacionaliniame ir lokaliniame lygmenyse. Panaudota ir apibendrinta pusės amžiaus laikotarpio tyrimų medžiaga (žemės ūkio naudmenų dirvožemio agrocheminių tyrimų ir dirvožemių kalkinimo ilgalaikių tyrimų duomenys). Šio darbo tikslas – patikrinti gamtos mokslų koncepcijos ir mokslinių rekomendacijų praktikai suderinamumą GIS statistiniais metodais. Tyrimai atlikti erdvėje ir laike sisteminės analizės metodu. Taikyti literatūrinės analizės, kartografinis, GIS, GIS statistinės analizės, laboratorinių tyrimų ir lauko metodai. Rūgščių dirvožemių plotų kaitos erdviniai dėsningumai Lietuvos teritorijoje nustatyti geoinformaciniais tyrimo metodais. Dirvožemio viršutinio horizonto pH ir dirvožemio granuliometrinės sudėties įvairumo statistinė analizė atlikta statistinės gardelės metodu (2×2 km = 4 km^2).

Nustatyta, kad rūgščių dirvožemių kaip gamtinio kūno arealų lokalizacija iš esmės yra dėsningas gamtos reiškinys, nulemtas dirvožemio genezės. Rūgščių dirvožemių plotai kinta (mažėjimas ir didėjimas) iš esmės tuose pačiuose arealuose. Rūgščius dirvožemius kalkinant sistemingai pagal mokslines rekomendacijas nustatytu intensyvumu ir ciklais, o lygiai taip pat ir vieną ciklą nekalkinant labiausiai keičiasi tų pačių rūgštumo grupių – labai rūgščių ir vidutinio rūgštumo dirvožemių plotų dydis. Dirvožemių rūgštėjimas visoje Lietuvos teritorijoje, jų nekalkinant, pagrindžia sistemingo nepertraukiamo kalkinimo būtinumą. Rūgščių dirvožemių plotų kaitos (mažėjimo ir didėjimo) erdvinė lokalizacija patvirtina gamtos mokslų koncepcijos ir mokslinių rekomendacijų suderinamumą.

Raktažodžiai: rūgštūs dirvožemiai, dirvožemio pH, GIS statistinė analizė

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ИЗМЕНЕНИЕ pH ПОЧВЫ В ЛИТВЕ: АНАЛИЗ ВО ВРЕМЕНИ И В ПРОСТРАНСТВЕ

Резюме

В статье анализируются взаимодействие процессов нейтрализации и подкисления почв и их практические последствия. Объект исследований – кислые почвы Литвы. Исследования выполнены в Литве на национальном и локальном уровне. Использованы и обобщены материалы исследований за полувековой период (данные агрохимических исследований сельскохозяйственных угодий и длительных стационарных опытов по известкованию). Цель данной работы – проверить компетенцию естественнонаучной концепции и научных рекомендаций по известкованию почв. Исследования выполнены во времени и в пространстве методом системного анализа. Применены методы литературного анализа, картографический, ГИС, статистический анализ ГИС, лабораторные и полевые методы. Закономерности пространственного изменения площадей кислых почв на территории государства установлены геоинформационными методами исследований. Статистическая обработка данных разнообразия pH верхнего горизонта сельскохозяйственных угодий и гранулометрического состава почвы выполнена методом статистической решетки (2×2 км = 4 км^2).

Установлено, что локализация кислых почв как ареала природного тела, по сути, есть закономерное природное явление, обусловленное генезисом почвы. Изменение площадей кислых почв (уменьшение и увеличение) происходит практически в одних и тех же ареалах. При основном на научных рекомендациях систематическом известковании (с определенной периодичностью и конкретными нормами), а также не известкуя почвы один цикл, изменяется величина площадей одних и тех же самых групп почв – очень кислых и среднекислых. Процесс окисления известкованных почв на всей территории Литвы после прекращения известкования обосновывает необходимость непрерывного систематического известкования сельскохозяйственных угодий. Пространственная локализация изменения (уменьшения и увеличения) площадей кислых почв подтверждает согласованность естественнонаучной концепции и научных рекомендаций.

Ключевые слова: кислые почвы, pH почвы, статистический анализ ГИС