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DREDGING OF LAKE AND APPLICATION OF SAPROPEL FOR IMPROVEMENT OF LIGHT SOIL PROPERTIES

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Abstract. Approx. 1.5 billion m^3 of sapropel are accumulated in silty Lithuanian lakes. Sapropel is a valuable organic and limy matter, which can be used for fertilisation and soil improvement. Silted lakes usually require mechanical cleaning, i.e. removal of lake sapropel. Such cleaning was carried out in one of the lakes of Lithuanian – Lake Ilgutis: using a dredge, sapropel was extracted, dried in sediment bowls to 80–85% of humidity, carried to a field and insert into the soil. Summarised results of the long-term experiment showed that calcareous sapropel can reduce soil acidity and increase the amount of exchangeable bases (Ca+Mg). Under the influence of sapropel, the contents of organic carbon and total nitrogen increased as well. The results of investigations demonstrated that by the end of the second (after 12 years), third (after 18 years) and fourth (after 24 years) rotation, the effect of sapropel on soil chemical properties was positive. Compared with limestone, calcareous sapropel improved physical characteristics of the soil to a greater extent.

Keywords: dredge, sapropel, transportation, soil, chemical properties, physical properties.

1. Introduction

Lakes are a special natural resource of the surface freshwater. This wealth of freshwater sustains abundant and diverse populations of plants and animals as well as many recreational activities; besides, they are a readily available waterway system for economic activity and fisheries. Human activities led to destruction of water resources. Due to natural eutrophication of lakes and nearby human activity, many lakes around the world are silty; they are decaying and turning into marsh (Adriaens *et al*. 2002; Alkan *et al*. 2009; Andresini *et al.* 2003). However, the problem of silted lakes is usually solved by mechanical cleaning, i.e. removal of lake sapropel. Used properly, sapropel could cover some dredging costs. Application of lake sediments as fertilisers looks most appropriate (Ciūnys 1997; Katkevičius *et al.* 1998; Hidenori *et al.* 2003). Sapropel is one of lake restoration by-products. Approx 1.5 billion m^3 of sapropel are accumulated in silty lakes of Lithuania. Expansion of its utilisation possibilities could greatly intensify the restoration of decaying lakes in Lithuania (Žvironaitė *et al.* 2002).

Despite of being clean from technogenic pollution, many lakes have problems related to eutrophication: coastal overgrowth with deciduous trees and shrubs, dense aquatic vegetation, and surface runoff from agricultural areas lead to worse water quality, high nutrient content, algal blooms, overgrowth by macrophytes, and etc. These conditions promote even greater accumulation of mud, thus water depth decreases from year to year. Lakes, with an average water depth less than 3.0 m are referred to as “endangered” (Katkevičius *et al.* 1998).

As in general Lithuanian lakes are not polluted by municipal and industrial sewage, they contain rather clean water and mud (sapropel). Thus, sapropel from Lithuanian lakes can be used as a high quality organic fertiliser. Detailed studies have demonstrated that not even the mud from lakes situated in big industrial towns (e.g. Lake Talkša in Šiauliai and Lake Mastis in Telšiai) is highly contaminated, with contamination localised around the points of former pre-treated industrial sewage discharges. Therefore, the majority of lake mud (sapropel) could be used for other purposes than agriculture, including curative and wellness procedures (Katkevičius *et al.* 1998).

Sapropel is a mixture of organic and inorganic material washed into lakes from the catchment and generated within the lake. Research on the effects of lake sapropels – which was carried out in a number of countries – suggests that its efficacy depends on the chemical composition. Sapropels are subdivided into types: organic (50–90% of organic matter), calcareous (30–60% of calcium carbonate), siliceous (25–45% of silicon dioxide) and mixed. They contain all macro-elements and line microelements necessary for plants, as well as biologically active substances, such as vitamins, enzymes and antibiotics (Troels-Smith 1955; Daux *et al.* 2006; Thomson *et al.* 2006). Besides in Lithuania, the region of the main lake sapropel resources coincides with the region of poor and erosive soil. Thus, organic sapropel is available where it is needed the most. The sapropel extracted from lakes can be used for land amelioration. Its mineralisation is slow, so it improves the properties of light textured soils for a long time (Encke, Körschens 1988; Gruner, Belau 1990; Liepins 1993; Orlov, Sadovnikova 1996; Bakšienė, Janušienė 2005). All kinds of sapropels are used to fertilise unproductive soils. They not only improve the agrochemical and physical properties of soil as well as increase the productivity of plants (Tsekhanovich *et al.* 1993), but also decrease the migration of radionuclides from soil to plant products by 1.5–2 times (Prister *et al.* 1996; Zhishkevich *et al.* 1996).

Experiments with the purpose to study the possibilities to clean lakes and use sapropel for improvement of infertile soil have been carried out in the Voke Branch of the Lithuanian Research Centre for Agriculture and Forestry since 1984.

2. Materials and methods

Lake cleaning experiments were conducted in Lake Ilgutis (Vilnius district, 54° 34' N, 25° 04' E). To clean a shallow lake, a dredge MZ-8 was used. The system consisted of sedimentation lagoons, a mounted dredge and pulp pipelines, some of which were floating and others – onshore. The number and capacity of sedimentation lagoons – i.e. 50×120 m and 40×80 m – corresponded to the amount of sapropel that could be dredged from the lake in one season.

Before starting to dredge, the lake was partitioned to sectors and to routes (a sector is a district of a lake, which is dredged in one season; a route – the strip within a sector to be cleaned in one movement of a dredge). The depth of the lake and the water table were fixed to 3.5–4.0 m.

Dredging started according to the routes, with the dredge moving from water to the shore. Moving from one side of the route to another, the submersible pump (sucking pipe) sucked the upper layer of lake mud or sapropel. Once this movement was completed and the upper layer of sediments was dredged, the pump was submersed into the deeper layer of sediments and the same process was repeated. Once the necessary depth was reached, the submersible pump was lifted to the surface of the sediment layer and the dredge moved forward to start the same procedure again. When the necessary depth was reached in one route, the dredge went to the next route and continued working till the sector or the entire lake was dredged.

Field experiments. Due to different meteorological conditions, two identical experiments were conducted in 1984 and 1985, () to study the efficacy of calcareous sapropel in sandy loam Haplic Luvisols (54° 37^1 N, 25° 07^1 E). Agrochemical parameters of the soil before the experiment were as follow: pH_{KCl} – 6.1, mobile P – 101–115, K – 132–161 mg kg^{-1}, organic carbon – 1.05–1.13%. Treatment experiments: 1) Control – only mineral fertilisers (NPK); 2) 50 t ha^{-1} of dry sapropel (S); 3) 100 t ha^{-1} dry sapropel (S); 4) 150 t ha^{-1} of dry sapropel (S); 5) 200 t ha^{-1} of dry sapropel (S) and 6) 30 t ha^{-1} of dry manure (M) (to compare its effect with sapropel). On the background of mineral fertilisers, sapropel and manure were applied in the crop rotation. Sapropel was applied only once during three crop rotations (1984 and 1985) to the first crop (*Zea mays* L.). Since its decomposition in the soil is very slow, we wanted to study the length of its effect. As manure decomposition period is much shorter than that of sapropel, manure was applied in every crop rotation in 1984–1985, 1990–1991 and 1995–1996. Calcareous sapropel from Lake Ilgutis contained: N – 1.20, P – 0.041, K – 0.005, Mg – 7.89, Ca – 13.2, organic carbon – 14.8% of the dry matter. Manure contained: N – 2.10–2.32; P – 0.26–0.33; K – 1.08–1.63; Ca – 1.12–1.26; and organic carbon – 30.0–33.0% of dry matter.

Soil sampling. Soil samples were taken from the 0–25 cm depth in six treatments and four replications before the experiments (in 1984–1985), subsequent to completion of the first (in 1989–1990), second (in 1995–1996), third (in 2001–2002) and fourth crop rotations (in 2007–2008). During the period of 1994–2004, soil moisture, bulk density and total porosity were measured annually after sowing in spring (S) and harvesting in autumn (A).

Analytical methods. Basic soil properties were determined using the following methods: pH_{KCl} – potentiometricaly (LST ISO 10390:1994); exchangeable bases – 0.1 M $BaCl_2$ (1: 10) extract (LST ISO 11260:1994); mobile P and K – using Egner–Riem–Domingo method (AL method) (GOST 26208-91:1993); and total nitrogen – using Kjeldahl apparatus (LST ISO 11261:1995).

The content of organic carbon in the soil and that in different extracts was measured spectrophotometrically after sulfochromic oxidation (LST ISO 14235:1998). The insoluble residue was calculated by subtracting the soluble fractions from the total content of organic carbon in the soil.

Soil moisture, bulk density and total porosity were estimated using the weighing method.

Statistics. The data of soil chemical and physical properties were processed using the computer programme ANOVA for $EXCEL_{2000}$ version 2.2. All data were evaluated according to Fisher criteria (F) and LSD_{05} (Clewer, Scarisbrick 2001; Tarakanovas, Raudonius 2003).

3. Results and discussion

3.1. Production of sapropel

The pulp, which consists of sapropel with water, is transported to sedimentation lagoons by pipelines (Fig. 1).

Our experience showed that it is better to discharge sapropel to sedimentation lagoons by layers: placing 0.2–0.3 m of sapropel into each sedimentation lagoon in sequence, until all of sedimentation lagoons contain the first layer of sapropel. It usually takes 10–20 days for all lagoons to be filled with one layer.

During this period, sapropel dries and its volume decreases by 3–4 times (Table 1). Then, the second layer of sapropel can be distributed in the same sequence. At the time, the first layer of sapropel is resistant to newly added water, thus its humidity remains almost the same.

Table 1. Technical indicators of sedimentation lagoons

Depth of lagoons m	Capacity of sapropel $m^3\ ha^{-1}$	Area of lagoons ha 100 t m^{-3}	Top of evaporation $m^2\ m^{-3}$	Turnover of lagoons in summer	Required area of lagoons 100 t m^3 according turnover
0.5	4787	20.9	2.01	4	5.2
1.0	9428	10.6	1.01	2	5.3
1.5	13945	7.2	0.68	–	7.8
2.0	18279	5.2	0.51	–	5.5

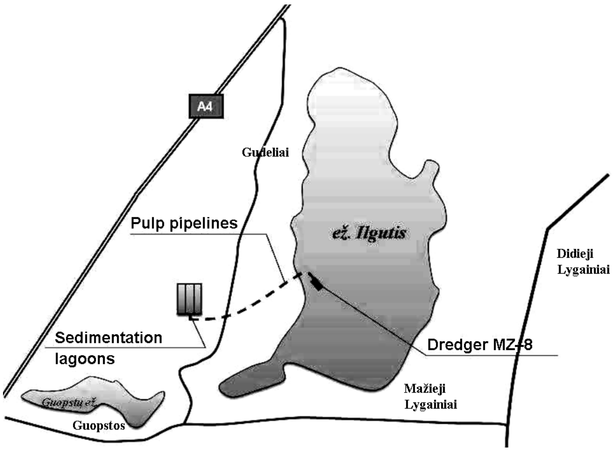

Fig. 1. Plan for sapropel extraction from Lake Ilgutis

Once filled with 3–4 layers of sapropel, the overall thickness on the layer in a lagoon usually reaches approx. 0.8 m. Then, sedimentation lagoons are left for winter (Fig. 2). The data of the investigations showed that water slide was much faster when the pulp consistency was lower, which also improves the formation of sapropel layer. When the pulp consistency was up to 2.7%, particles of sapropel were deposited in 2 hours. With greater consistency, particles seated much lower and the texture was close to or greater than 3.5% sedimentation of sapropel matter (curves 6 and 8).

As sapropel was of average consistency, it deposited in at least few hours.

Deposition of sapropel in the first layer was not uniform. Sapropel surface average slope in the lagoon was 0.0108, and near the pulp of release – 0.064.

While drying, sapropel becomes very hard and resistant to mechanical impact. Sapropel clumps are resistant to water and almost inactive biologically. Thus, to make a valuable substance that could be used as a fertiliser or for other purposes, sapropel must be frozen. As

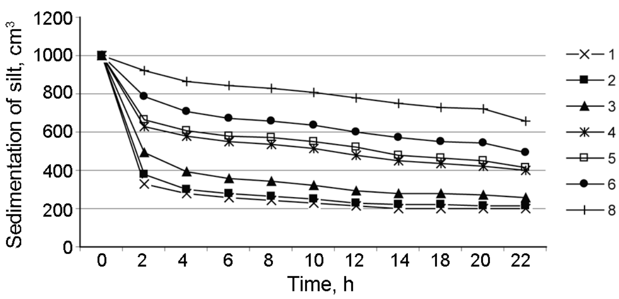

Fig. 2. Sedimentation of sapropel fractions of Lake Ilgutis. Consistency of the pulp: 1 – 1.2%, 2 – 1.9%, 3 – 2.7%, 4 – 3.4%, 5 – 3.6%, 6 – 3.8%, 8 – 4.7%

frost breaks-up the clumpy structure, sapropel becomes light and odourless as well as gains different physical properties, such as lower density, porous structure, and the filtration coefficient increased by hundreds of times just as well as water release. Absorption of sapropel also increases markedly (Katkevičius *et al.* 1998).

In recent years, freeze-over of sapropel become difficult due to mild winters: only 0.32–0.36 m of sapropel froze to the necessary level. Sometimes, in order to freeze all of the sapropel, the frozen surface layer can be removed from sedimentation lagoons to expose deeper layers to frost.

In spring, frozen sapropel melts, dries and becomes light and crumby. Such sapropel has good product view, could be packed and/or stored for almost an unlimited time, and used for a great variety of fertilisation needs alone or together with additives.

3.2. Soil agrochemical properties

The experiments revealed that the use of calcareous sapropel for fertilisation has a positive influence on agrochemical properties of sandy loamy cambisol post 24 years of sapropel action.

Fertilisation with sapropel of various rates decreased the soil acidity (Fig. 3) and increased the pH by 1.0–1.3. With the increasing rates of sapropel, the total amount of absorbed bases increased proportionally by 159–380 m-equiv/kg^{-1} of soil. Application of fertilisers increased the content of the total nitrogen by 0.003–0.036% units, humus – by 0.56–1.19% units and available phosphorus by 44–90 mg·kg^{-1} of soil. Meanwhile, the amount of available potassium decreased by 7–43 mg·kg^{-1} of soil, as sapropel contains a very low amount of the element.

By the end of the second crop rotation, the influence of sapropel to agrochemical characteristics of sandy loamy cambisols remained positive. In comparison with the first crop rotation, the soil acidity did not decrease and pH was 7.2–7.4. At that time, the control pH was 6.3. The changes of total amount of absorbed bases also remained increased (in treatments with sapropel – 101–258, and in treatment with manure – 34 m-equiv/kg^{-1} of soil). The amount of humus was 0.15–0.30, and 0.40%; and the amount of mobile phosphorus was – 12–50 and 26 mg·kg^{-1} of soil. The amount of mobile potassium was smaller (33–61 mg·kg^{-1} of soil) in treatments with sapropel than in the treatment with manure (83 mg·kg^{-1} soil).

Comparing the data of agrochemical indices after the third and the fourth crop rotation with the data of agrochemical indices after the second crop rotation, we can notice that long-term efficiency of different rates of calcareous sapropel decreases, but does not reach the initial data collected before the experiments. Soil pH did not change. In comparison to values found at the beginning, amounts of absorbed bases remained greater, i.e. 74–167 m-equiv/kg^{-1} of soil. Also, there were major indices of the total nitrogen (0.007–0.021% units) and humus (0.06–0.30% units). Consequently, humus substances incorporated into the soil with calcareous sapropel were stable in terms of decomposition. Humus substances in the soil get gradually hydrolysed, and the regenerated humic acids are analogous to the acids present in the soil, which take part in organic matter metabolism (Stepanova, Orlov 1996). The data have demonstrated that on light-textured soils, humus readily mineralises and more than half of its composition goes for hydrolysed part (Cherkinsky, Brovkin 1993).

Results show that efficiency of manure ends much faster, than that of sapropel.

Comparing data of mobile phosphorus and potassium with the data of the previous rotation, it became clear that amounts of these elements increased in all treatments with fertilising with sapropel of all rates and manure (by 47–125 mg·kg^{-1} soil phosphorus and 19–100 mg·kg^{-1} soil potassium).

3.3. Physical properties of the soil

The application of lake sapropel had a positive impact on the quality of physical properties of sandy loam soil (Fig. 4).

While analysing the impact of sapropels on soil moisture, it was found to be lower in spring and higher in autumn. In this experiment, a stronger effect was observed when fertilising with sapropels and sapropel-manure mixtures.

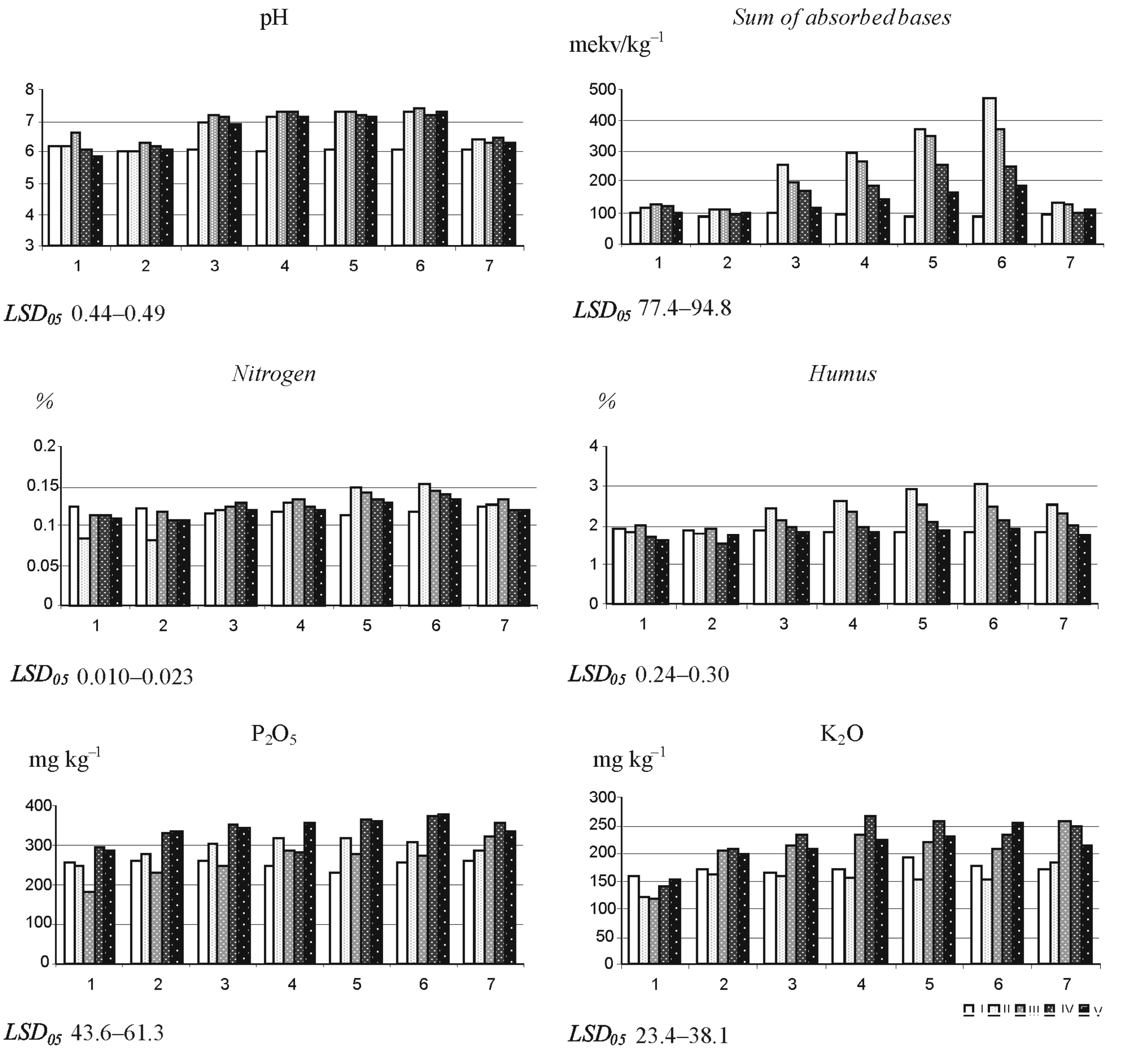

Fig. 3. Changes of agrochemical indices after fertilisation of sandy loam Haplic Luvisols with various rates of calcareous sapropel: 1–7 – treatments of trials: 1) without fertiliser, 2) NPK (B-background, 3) B + 50 t ha^{-1} sapropel (S), 4) B + 100 t ha^{-1} sapropel (S), 5) B + 150 t ha^{-1} sapropel (S), 6) B + 200 t ha^{-1} sapropel (S), 7) 100 t ha^{-1} manure (M). O-IV – agrochemical indices before experiments and after separate crops rotations

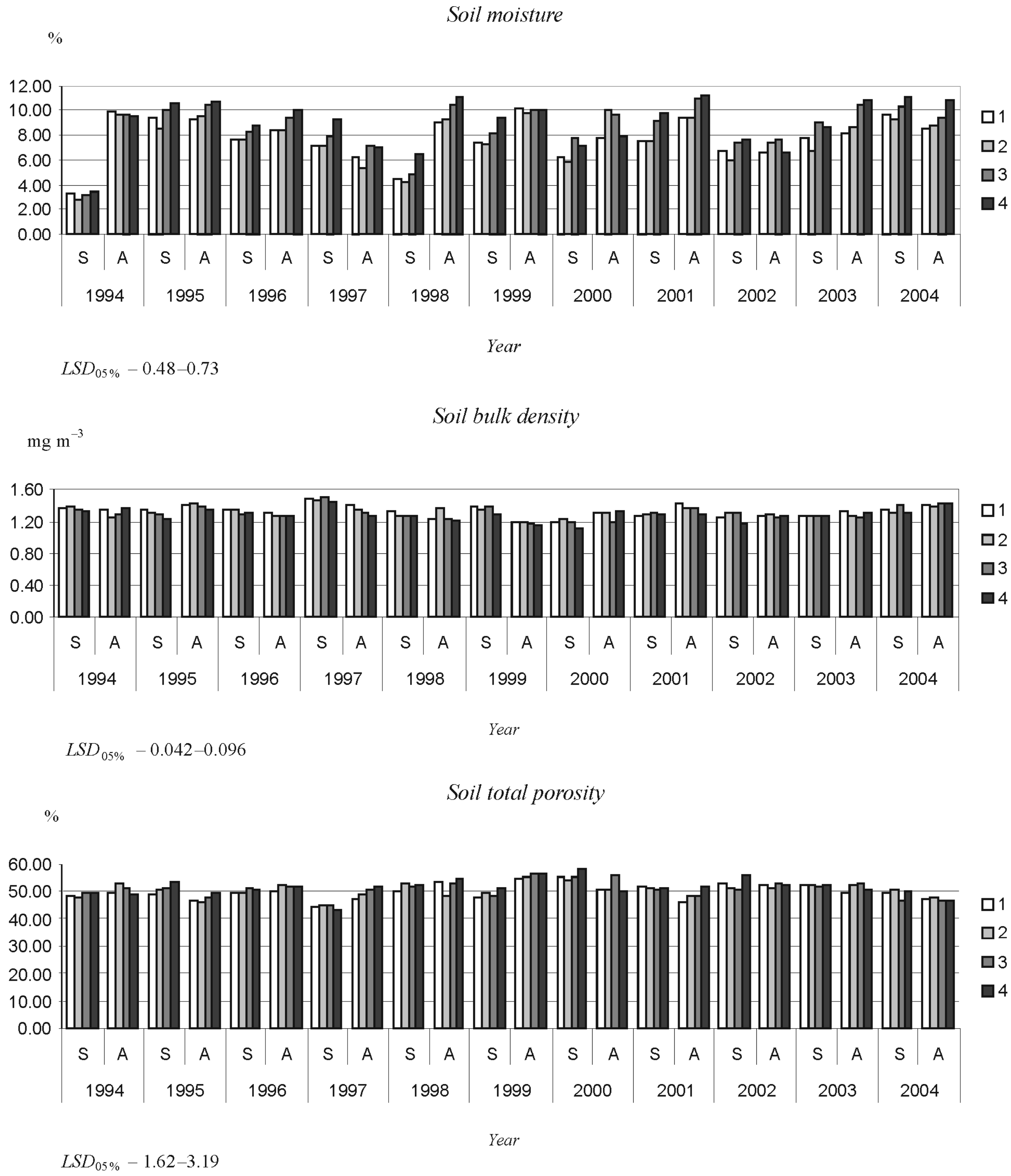

Fig. 4. The effect of calcareous sapropel on moisture, density and total porosity of sandy loam cambisol: S – spring, after sowing; A – autumn, after harvesting; 1–4 – treatments of trials: 1) control; 2) 10 t·ha^{-1} limestone ($CaCO_3$); 3) 25 t·ha^{-1} calcareous sapropel; 4) 25 t·ha^{-1} calcareous sapropel + 25 t·ha^{-1} manure

Soil bulk density did not depend on moisture. The data indicate the tendency towards the decrease of this parameter only after application of 25 t·ha^{-1} of calcareous sapropels and sapropel-manure mixture. Soil bulk density varied from 1.24 to 1.38 mg·m^{-3} only in certain periods, and only in autumn it was slightly lower.

The total soil porosity directly depended on the soil bulk density. With the decrease in density, the porosity increased. It was evidenced by the research results. The total soil porosity was higher in spring and decreased in autumn. Almost during the entire experimental period, the highest (52.57–53.03%) total porosity was identified in the soil applied with 25 t·ha^{-1} of sapropels and their mixtures with manure.

Summarised results of long-term experiments demonstrate that lake sapropel can improve the soil. Sapropels increase soil moisture and porosity, and decrease bulk density. In comparison to limestone, calcareous sapropel improves the aforementioned physical indicators of the soil.

Norwegian and Canadian scientists (Sveistrup *et al*. 1995; Zebarth *et. al*. 1999) have reported about the positive effects of lake sapropels on physical properties of the soil. Application of sapropels increased soil porosity and moisture retention capacity as well as improved soil texture and quality.

Summarised results of the long-term experiments demonstrated that fertilising with sapropel can efficiently improve the soil. Improvement of the chemical and physical condition of the soil is very important to protect freshwater bodies from infiltration of soil nutrients.

4. Conclusion

1. Productivity of the dredge depends on the distance of pulp transportation and geometrical platform between the level of water and the height of sedimentation lagoons. The consistency of pulp was 0.8–2.4%.

The formation of sapropel layer was better when the pulp consistency was lower. The sedimentation lagoons should be left for winter as frozen sapropel becomes light and odourless as well as gains better physical properties as a soil fertiliser.

2. The use of calcareous sapropel for fertilisation on sandy loam Haplic Luvisols has demonstrated that after 24 years of sapropel action, the acidity of sandy loamy soil reduced, while the amounts of absorbed bases, humus, total nitrogen, and mobile phosphorus increased. The amount of available potassium decreased. By the end of the second and third crop rotation, the influence of sapropel on agrochemical properties of sandy loamy cambisols was positive.

3. The application of lake sapropel produced a positive effect on the physical properties of sandy loam soil. The lake sapropel increased soil moisture and porosity, and reduced its bulk density. In comparison to limestone, calcareous lake sapropel improved physical characteristics of the soil.

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EŽERO VALYMAS IR SAPROPELIO NAUDOJIMAS DIRVOŽEMIO SAVYBĖMS GERINTI

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Santrauka

Uždumblėjusiuose Lietuvos ežeruose susikaupę apie 1,5 mlrd. m^3 sapropelio. Sapropelis, vertinga biogeninė organinė ar kalkinė medžiaga, gali būti plačiai naudojamas dirvoms tręšti ir gerinti. Ežerai, kasant sapropelį iš jų, būtų išvalomi ir pagilinami. Tai padėtų atkurti jų būklę, funkcinę paskirtį. Žemsiurbe *MZ*-8 buvo kasamas sapropelis iš Ilgučio ežero ir sėsdintuvuose džiovinamas, tada išvežamas į laukus, ir tręšiama dirva.
Nustatyta, kad dirvožemio agrocheminės savybės kas rotacija prastėjo, tačiau nepasiekė rodiklių, buvusių prieš bandymų rengimą. Teigiamas sapropelio veikimas pastebėta po antrosios (12 metų), trečiosios (18 metų) ir ketvirtosios (24 metų) sėjomainų rotacijų. Sapropelis laukams tręšti turėjo teigiamos įtakos dirvožemio fizikinėms savybėms. Kalkinis sapropepelis veikė geriau nei klintmilčiai.

Reikšminiai žodžiai: žemsiurbė, sapropelis, transportavimas, dirvožemis, cheminės savybės, fizikinės savybės.

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