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IMPROVEMENT OF LAKE SAPROPEL QUALITY: A NEW METHOD

Rapolas Liužinas, Karolis Jankevičius, Mudis Šalkauskas
Public Agency "Soil remediation technologies", Antakalnio str. 42, LT-10304, Vilnius
E-mail: gvt@takas.lt

Mykolas Mikalajūnas
Vilnius Pedagogical University, Studentų str. 39, LT-08106, Vilnius
E-mail: mykolas@biblijosdraugija.lt

Introduction

Seeking to satisfy its needs, modern society is developing different kinds of industrial production. The intensive economic activity in the past and present is responsible for the ever-increasing environmental pollution. Not only human activities but nature itself affects ecosystems. Lakes may serve as an example of ecosystems affected by natural factors. Mud formation processes are taking place in them. The shores of lakes overgrow with higher plants-macrophytes. As the lakes grow shallow, macrophytes tend to penetrate into their deeper parts occupying new areas. Slowly such lakes convert into fens and, later, into high moors. Lakes are aging and declining. These processes are especially typical in case of small lakes. In Lithuania there is about 1 billion m^3 of pure sapropel which lays mostly in 1 to 2 m thick layers but in some places layers are up to 5 m, and there is about 6 billion m^3 of sapropel in mixture with other sediments (Tarybų…, 1987). About 4.5 bill m^3 of sapropel underlie the peat layer of lacustrine swamps. The now cleaned silted up lakes (a few hundred) have accumulated 1.5 billion m^3 of sapropel.

Formation of organic sediments in lakes depends on many factors, one of them being changes of the climate in the past. Thick layers of sapropel are linked with longer spells of dry climate (Basalykas et al., 1958).

Lakes are a great national treasure. They are important from the natural and economic point of view. First, lakes are a source of fresh water. They are also used for modern fish-culture, development of hunting economy, hydroenergetical, water sports, recreational and tourism purposes. Therefore, recovery of silted lakes is very important. On the other hand, sapropel is a valuable lake product. In agriculture it is suitable for soil fertilization and as addition to food for animals, and is a good raw material for chemical and even building industry or a remedy in health cure (for mud baths).

An ecosystem is regarded as recovered when it has sufficient biotic and abiotic resources for further independent functioning without human interference. The remediated ecosystem – lake – must be identical to a standard undisturbed ecosystem. It must have the same combinations of species and structure of communities. The remediated lake ecosystem must be integrated into a wider ecological environment – landscape – through biotic and abiotic flows and exchange. It must be as resistant to environmental factors as a natural one. The dynamics of its components under changing environmental conditions must be analogous to the dynamics of components in a standard ecosystem.

Based on the mentioned principles of ecological recovery, the article discusses the issues of lake remediation related with elimination of sapropel from silted lakes and improvement of sapropel quality. There is a double advantage of ecological recovery: a renovated lake and a valuable product sapropel which can be used for different purposes.

1. Methods

The content of nitrogen in sapropel was determined by photometric method using sodium salicilate and hypochlorite solution in alkaline medium. The content of phosphorus was determined photometrically using ammonium molybdate solution in acid medium. The method of potassium bichromate in a medium of sulphuric acid was applied for determining the content of organic carbon. Soluble hydrocarbons were determined photometrically using anthron reagent. The summary fraction of lipids was determined by mass analysis. The extraction was performed with the aid of ethyl alcohol and diethyl alcohol mixture followed by petrol ether. Trace elements were determined by the method of emission spectroscopy. Vitamins of B and other groups were evaluated using microbiological methods. Chromatographic methods (Потапова, Куприн, Фролова, 1980; Топачевский, 1975; Жукова, Одинцова, 1967; Звягинцев, 1991; Standard…, 1992; Флора..., 1993–2003) were employed for determining the concentration of free amino acids in sapropel. All data are attributed to the weight of dry sample.

2. Results

Lithuania is a country of the Baltic basin. Its area is 65 200 km^2. It has 4000 lakes and is called “a country of lakes”. One of the European lake-abundant zones coinciding with the glacier margin of the last Ice Age runs across Lithuania.

Peat, silt and sapropel are valuable lake products. Sapropel is composed of sediments (Liužinas, Jankevičius, 2005). Sediments are of double origin: autochthonous and allochthonous. The autochthonous sediments are composed of dead phyto- and zooplankton and, at the end of the vegetation period, of macrophytes (Liužinas et al., 2004). This category of sediments also includes the material of coastal erosion. Allochthonous sediments are composed of drift from external drained basins and material transported by streams, rivers and airflows. Pollution of the territories of farmlands, animal-breeding farms, settlements and industrial objects increases the load of allochthonous material on lakes.

Sedimentation rates in lakes with different nutrient income are varying from a few to a few tens of centimetres.

Mineral, organic or intermediate types of sediments prevail in different lakes. Organic sediments tend to accumulate in lakes with high nutrient income. They form an unstructured mud composed of remains of plankton and benthic organisms with some mineral components. The term sapropel is applied to this kind of mud.

2.1. Chemical composition of sapropel

According to its chemical composition, sapropel can be organic, calcareous, siliceous, and mixed (organic–calcareous and organic–siliceous).

The quantitative chemical composition of sapropel varies within a wide range depending on maturity, lying depth and formation conditions. The data on chemical composition of examined sapropel are given in Table 1.

Table 1. Chemical indices of sapropel samples.

Nitrogen (N), %	Phosphorus (P_2O_5), %	Organic carbon, %	Soluble hydrocarbons, %	Summary fraction of lipids, %
0.2–2	0.1–0.2	9–35	0.4–4	0.3–2

The highest concentrations of nitrogen occur in the organic sapropel. High concentrations of phosphorus occur in organic and organic–calcareous sapropel.

Humic acids in sapropel account for about 11–38%, fulvic acids for 2–23% and unhydrolized remains for 5–22% (Бракш, 1971; Лопотко, Евдокимова, 1986). The composition of trace elements in sapropel is demonstrated in Table 2.

Table 2. Concentrations of trace elements in sapropel, mg/kg.

Li	B	Mn	Ti	V	Cr	Co	Ni	Cu	Zn	Pb	Mo	Sr	Cd
6–15	24–53	280–660	1000–2400	11–35	9–25	3–5	9–27	12–63	29–120	7–31	1–3	48–130	2–4

Trace elements are very important for biological effects. They (30 of them) are indispensable for normal vital activity of plant and animal organisms. For example, copper (Cu) is included in the composition of important respiratory enzymes, zinc (Zn) is a constituent of many enzymes (carboanhydrase, carboxypeptidase, different dehydrogenases) and molybdenum (Mo) is included in the active centre of nitratreductase. The concentrations of trace elements determined in sapropel do not exceed the permissible general hygienic values and limit values for phytotoxines. The value of sapropel depends on the content of physiologically active substances – vitamins and amino acids. We examined the content of these substances in different kinds of sapropel (Tables 3 and 4).

Table 3. Concentrations of some vitamins in sapropel, μg/kg.

Inosite	Biotin (H)	Thiamine (B_1)	Pantothene acid (B_3)	Pyridoxine (B_6)	Nicotinic acid (PP)	Para-amine benzoic acid	Vitamin B_{12}
7500–45000	0.6–26	3.3–136	1200–16000	3.1–54	700–11000	1.7–66	3.5–73

Vitamins play an important role in metabolism and other vital functions. The content of vitamins in sapropel considerably exceeds the values found in the soils of medium fertility: inosite, thiamine (B_1) and pantothenic acid (B_3) by 14 times, biotin (H) by 12 times, pyridoxine (B_6) and nicotinic acid (PP) by 4 times, and para-amine benzoic acid and vitamin B_{12} even by 25 times.

Amino acids are characterized by high physiological activity. They participate in protein synthesis and as a starting material in the synthesis of hormones, coenzymes and pigments. Especially important are essential amino acids lysin, hystidin, arginine, threonine, valine, methionine, leucyne, isoleucyne, phenylalanine, and tryptophan. Animal organism is unable to synthesize them. It must receive them with food. It is a virtue of sapropel that it contains high concentrations of essential amino acids (48–60% of the total amount of aminoacids).

Table 4. Free amino acids and their content in sapropel, mg/100g.

Cystine	Lysin	Hystidin	Arginine	Aspartic acid	Serine	Threonine
0.001–0.7	0.1–0.5	0.1–0.4	0.2–0.7	1.1–1.6	1.0–1.1	traces

Glutamic acid	Alanine	Tyrosine +Tryptophan	Methionine	Valine +Phenylalanine	Leucyne +Isoleucyne
0.7–0.8	1.4–1.7	1.3–1.8	0.9–1.1	0.9–1.9	1.6–2.3

2.2. Practical use of sapropel

The results of ecogeochemical evaluation of sapropel and physiological active substances detected in it, revealed a possibility to use it for improvement of agrochemical and physical properties of soils. A positive influence of sapropel on yields of various cultures has been reported in many research papers (Bakšienė, 1996; Christensen, 1985; Korschens et al., 1984).

Latvian, Polish, Belarusian, Russian, and German researchers investigate various possible methods of soil fertilization with sapropel and its optimal amounts for different cultural plants. The effect of sapropel on yields of plants depends on its chemical composition, the methods of its processing for fertilization, type of fertilized soil, soil productivity, and culture.

Taking into consideration that sapropel abounds in physiologically active substances (vitamins, amino acids, etc.), it is investigated for suitability as fodder supplement. Investigations of this kind are carried out in Lithuania (Малашкайте, 1962) and Belarus (Лопотко, Евдокимова, Кузмицкий, 1992). Fodder supplements made of sapropel are produced as granules, briquettes or powder. It is experimentally proved that sapropel granules increase the value of combined fodder enriching it in mineral macro- and microelements.

It is known that sapropel can be used for mud therapy (Виръясов, Иванова et al., 1997). Organic sapropel is rich in bioactive substances and is highly colloidal. These properties account for its hydrophilic capacity, high thermal recipience and ability to retain heat for a long time. The use of sapropel as curative mud mixed with peat or combined with aromatic officinal plant extracts is rather promising.

Detailed examination of sapropel lipids revealed that they resemble wax in their chemical composition. They contain compound ethers, hydrocarbons, cyclic and aliphatic alcohols, acids, į- and ā- unsaturated carbonylic and other compounds. The content of lipids in sapropel is rather high and their extraction could be profitable. The sapropel lipids can be used in cosmetic and pharmaceutical industries.

Technologists of production of new materials are also interested in sapropel. It was tested as an additive facilitating formation of pores in the raw material used for production of poriferous stone wear. Sapropel containing low content of ash (when ash do not exceed 30% of its dry weight) is tested as an adhesive able to replace combinations of glues. Algal-zoogenic sapropels are best fit for this purpose. Peat sapropels do not have adhesive properties.

A possibility to use a combination of sapropel with perlite in the production of insulation materials has been worked out (Виръясов, Иванова et al., 1997).

The spectrum of sapropel utilization is rather wide. Sapropel is a valuable raw material. At present, sapropel is used as a fertilizer for improvement physical and chemical properties of soils and for increase of yields. Therefore, it is expedient to investigate its specific properties.

Sapropel is a colloidal formation. Organic colloids are able to absorb much water; 90% and more. It hardly vaporizes water and becomes very solid after drying. Due to its structure, sapropel is distinguished by low filtration capacity.

Sapropel contains much iron and aluminium oxides. Ash of different types of sapropel contains 2.3–8.3% of iron (Fe_2O_3), 1.1–3.9% aluminium (Al_2O) and 6.8–36 % of silicon (SiO_2) (Katkevičius, Ciūnys, Bakšienė, 1998). Iron and aluminium oxides form gels in sapropel. They are colloids in a more solid form than a solution. Gels are friable and elastic. Friable gels do not swell. They (iron gel, aluminium gel and silica gel) retain their form and volume when drying. These properties are characteristic of some kinds of sapropel containing greater amounts of Fe, Al and Si.

Phosphorus (P) is an important element for plant growing. A plant assimilates phosphorus in the form of phosphates (PO_4^{2-}). Phosphorus participates in many essential reactions of metabolism and energy exchange. Iron ions combine phosphates of sapropel and fertilized soil into poorly soluble or insoluble salts. $FePO_4$ is a product of this reaction.

When using sapropel as a fertilizer we must bear in mind that chemical sorption can occur (combining of cations and anions into poorly soluble salts). These processes inhibit the access of ions to plants and are unwanted.

Seeking to increase the value of sapropel as a fertilizer, we tested the efficiency of sapropel blends with various organic and mineral substances (7 variants). The following blends were prepared: 1. Sapropel + peat (1:1, 1:2, 1:3); 2. Sapropel + soil (1:5, 1:10, 1:15); 3. Sapropel + rye straw (10:1); 4. Sapropel + NPK mineral fertilizers (40 mg of each element per one kg of sapropel); 5. Sapropel + soil (1:10) + straw (10% of the sapropel mass); 6. Sapropel + soil (1:10) + straw (10% of the sapropel mass) + NPK mineral fertilizers (40 mg of each element per one kg of sapropel) and 7. Sapropel + soil (1:10) + peat (10% of the mass of blend) + straw (10% of the mass of blend) + NPK (40 mg of each element per one kg of sapropel). The efficiency of the blends was determined according to their influence on viability of cucumber ("Alfa" variety) seeds and their germination energy and on growth of test-microorganism *Escherichia coli* (in the latter case, water extracts of substrata were used).

Preliminary results showed that NPK increased the efficiency of sapropel fertilizer by 7%, NPK + straw 16% and NPK + straw + peat 20%. This is related with microorganism activity what is proved by higher reproduction rates of *Escherichia coli*. Components activating microorganism activity in sapropel increase its biological value. The obtained results encouraged us to search for simple methods of enrichment of sapropel with easily degrading organics and activation of microbiological activity facilitating the disintegration of organic material to simple mineral compounds easily accessible to cultural plants.

3. Methods of Lake Recovery (Renovation)

Lake renovation is a complicated task. A scheme of the main stages of regeneration is given in Fig.

Cleaning of silted lakes can be started after topographic, hydrogeological, hydrochemical, and comprehensive hydrobiological survey of a locality. Evaluation of environmental effects is indispensable prior to elaboration of limno-technological plan of sapropel extraction.

Sapropel extraction and lake recovery were assumed in Lithuania in 1960 (Ciūnys, Lazauskienė, Katkevičius, 1994; Linčius, 1997). At approximately the same time (a project for recovery of Trumen Lake in Sweden by elimination of sediments in 1970–1971), lakes were renovated in Sweden, Finland and other countries (Björk, 1972, 1985; Ripl, 1976; Edmondson, Lehman, 1981; Forsberg, 1985).

In Lithuania, 13 lakes were deepened by excavation of sapropel. Twenty-eight Lithuanian lakes have been so far limnologically investigated. Their limnological–technological plans were compiled. The lakes are due to be cleaned.

Lithuania has gained certain experience in sapropel excavation and lake remediation. The hydraulic sapropel excavation method is most widespread. The sapropel pulp is transported through pulp pipes to reservoirs. The reservoirs are built in impermeable rocks. They represent 120–150 m long, 60–120 m wide and up to 2.5 m deep areas encircled by dikes. The reservoirs are filled with sapropel pulp to the depth of 1.2 m.

A new method was suggested for sapropel extraction and improvement of its quality. Sapropel pulp is transported to reservoirs by pulp pipes until it forms a 30–40 cm thick layer. It is given some time for thickening. After sedimentation of pulp particles, the layer is planted with common reed (*Phragmites australis*) rhizomes (4 seedlings/m^2). Rhizomes are accommodated to high organic and mineral loads. They immediately strike roots and sprouts and act as biological absorbers. The clarified water is regularly drained away into the lake, and the reservoir is filled with a new portion of sapropel. When reeds are growing in the reservoir, the pulp layer may be 100–120 cm thick.

Advantages. Reeds speed up the evaporation of water from the reservoir (evaporation is backed up by transpiration) and drying of sapropel. The root system of reeds and rhizomes

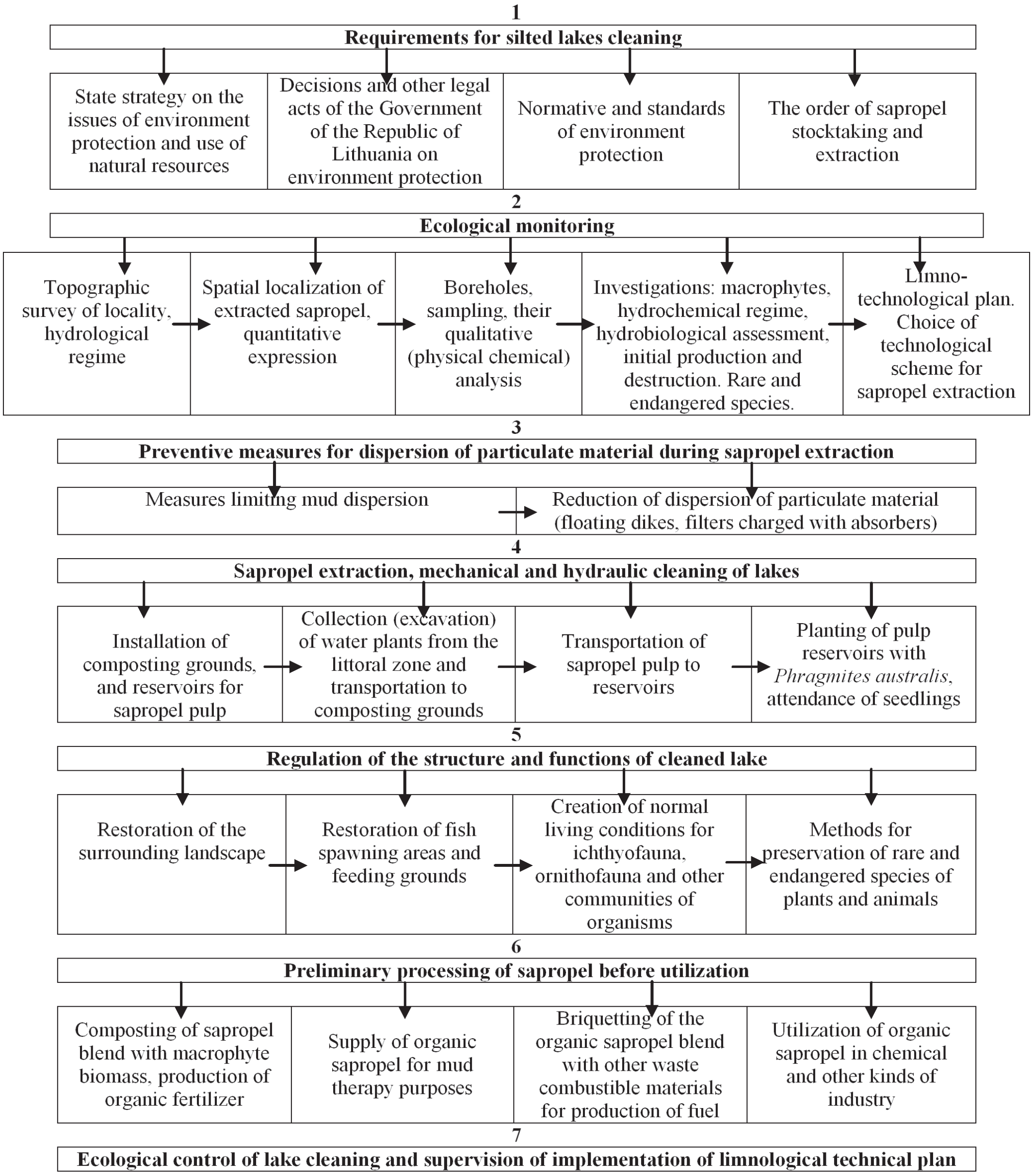

Fig. Scheme of sapropel extraction and utilization.

emit H^+ ions and organic acids. They release the cations strongly consolidated with humus (NH_4^+, Mg^+, K^+, Ca^+, etc.) and anions (NO_3^-, PO_4^{3-}, HPO_4^{2-}, SO_4^{2-}, etc.) making them easily available to plants. After blending with reed roots, rhizomes and plant biomass, sapropel is composted and converted into a high quality marketable (in the country and abroad) organic–mineral fertilizer.

Conclusions

Lakes are a great national treasure (fresh water source can be used for hydroenergy production, recreation, fishery, etc.). Yet lakes tend to age, bog up and disappear. Therefore, they have to be renovated (remediated) by elimination of mud (sapropel). Sapropel is a valuable natural raw material. It abounds in biogenic elements, physiologically active substances (vitamins and amino acids) and lipids. The spectrum of sapropel utilization is wide. It is especially fit for soil fertilization. In order to optimize utilization of sapropel as a fertilizer, we sought for measures facilitating the concentration of free cations and anions in it. We showed that the water plant *Phragmites australis*, which is planted on the thickened sapropel pulp, emit H^+ ions and organic acids by rhizomes and roots releasing the elements necessary for growth of cultural plants. Moreover, transpiration by leaves and stems of *Phragmites australis* facilitates rapid desiccation of sapropel.

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Rapolas Liužinas, Karolis Jankevičius, Mudis Šalkauskas
Public Agency "Soil remediation technologies", Vilnius

Mykolas Mikalajūnas
Vilnius Pedagogical University

Ežerų sapropelio kokybės gerinimas: naujas metodas

Santrauka

Poveikį bei žalą ekosistemoms sukelia ne tik žmogaus veikla, bet ir gamtinės priežastys. Tokios ekosistemos, patiriančios gamtos poveikį, pavyzdžiu yra ežeras. Jame vyksta dumblodaros procesai. Dumblas (sapropelis) yra struktūra, kuri susiformuoja iš autochtoninių ir alochtoninių organinių ir mineralinių medžiagų, vykstant jų biodestrukcijai, humifikacijai ir struktūrizacijai. Renovuojant – atgaivinant ežerus, sapropelis yra išsiurbiamas arba iškasamas. Sapropelis tinka ne tik dirvožemiams tręšti, bet yra vertinga žaliava chemijos pramonei. Tačiau sapropeliui kaip trąšai nepageidautini joje esantys geležies (Fe_2O_3 sapropelyje yra 2,3–8,3%), aliuminio (Al_2O – 1,1–3,9%), silicio (SiO_2 – 6,8–36,2%) oksidai. Jie sudaro gelius – koloidinius tirpalus. Dėl to sapropelius sunku išdžiovinti. Juose esantys katijonai ir anijonai jungiasi į nelabai tirpias druskas, todėl jų nedaug patenka į augalus. Bandymais nustatyta, kad sapropelio kokybė yra pagerinama, kai į sutankėjusią sapropelio pulpą, transportuotą į sėsdintuvus, pasodinama paprastoji nendrė (*Phragmites australis*). Sodinama šakniastiebiais (4 sodm./m^2). Nendrių šakniastiebiai ir šaknys išskiria H^+ jonus bei organines rūgštis, kurios atpalaiduoja tvirtai su humusinėmis medžiagomis susijungusius katijonus ir anijonus, pagerina jų prieinamumą žemės ūkio kultūroms, kurios tręšiamos sapropeliu. Dar geriau, kai tręšimo reikalams gaminamas sapropelio ir nendrės biomasės kompostas. Yra dar kitas nendrių privalumas. Jos, augdamos sapropelio pulpoje, dėl transpiracijos keleriopai paspartina sapropelio džiovinimą.