The effects of calcareous sapropel application on the changes of Haplic Luvisols chemical properties and crop yield

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ABSTRACT

The possibilities to use sapropel for fertilisation have been investigated at the Voke Branch of the Lithuanian Institute of Agriculture since 1984. The experiments were carried out on sandy loam Haplic Luvisols in the crop rotation (maize, barley, clover, winter rye, potatoes, oats) with the application of 50, 100, 150, 200 t/ha rates of dry calcareous sapropel and 30 t/ha of dry manure on the background of mineral fertilisers. Sapropel was applied only to the first crop (maize) in the rotation (in 1984). Manure was applied to the first crop in each crop rotation (in 1984, 1990 and 1996). Summarised results of a long-term experiment showed that by the end of the second (after 12 years) and third (after 18 years) rotation the effect of sapropel on soil chemical properties was positive. Calcareous sapropel reduced soil acidity, increased the amount of exchangeable bases (Ca + Mg). Under the influence of sapropel the contents of organic carbon and total nitrogen increased as well. The amount of mobile phosphorus increased, and mobile potassium decreased. Sapropel improved the composition of humus (C_{HA}:C_{FA} = 0.74–0.77; in control = 0.71). The results of investigations have shown that after 18 years of application the higher rates (150, 200 t/ha) of dry sapropel increased the productivity of crops. The highest rate of sapropel (200 t/ha) was almost of the same effectiveness as manure applied in every rotation.

Keywords: sapropel; soil; chemical properties; humus composition; yield

The 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 and there is a readily available waterway system for economic activity and fisheries. Because of natural eutrophication lakes and anthropological activity of people in the areas of lakes, many lakes around the world are silty and decaying and turning into marsh (Adriaens et al. 2002, Andresini et al. 2003).

As lakes are silting the concentration of phytoplankton increases. Such lakes are suitable neither for recreation nor for pisciculture; they can even become the source of infectious diseases. There are plenty of ways to reduce lake silting (Kavaliauskiene 2000). Dealing with the already silted lakes most attention is given to mechanical cleaning – removal of lake sapropel (from the Greek language: sapro – decay, pelos – silt). There is however a problem of utilization of sapropel of lakes, even though if it is used properly some costs involved in the cleaning could return. Application of lake sapropels as fertilisers looks as the most appropriate. Moreover, the highest numbers of silted lakes are in the zone with unfertile, fine textured soils where requirements for fertilisation are highest. Also in Lithuania the region of the main lake sapropel resources is also the region of poor and erosive soil.

The lake sapropels contain 15–90% of organic matter. Their chemical composition consists of all macroelements and microelements necessary for plants, biologically active substances – vitamins, enzymes, antibiotics (Kershaw 1997). The amount of bacteria decomposing cellulose is not high in sapropels; its functioning is therefore more prolonged compared to other organic fertilisers. The sapropel is then of high importance in cultivated soils. It can be used for land amelioration. Its mineralization is slow, so it improves the properties of light textured soils for a long time (Orlov and Sadovnikova 1996).

Since sapropel accumulates in lakes under anaerobic conditions, toxins can be identified only in extracted sapropel. In order to remove the toxins it is recommended to keep sapropel in sediment bowls for some time prior to use. However, nitrogen content tends to decline in stored and dewatered sapropel (James et al. 2003).

All kinds of sapropel are used to fertilise soils. The application improves the agrochemical and physical properties of soils and increases the productivity of plants (Orlov and Sadovnikova 1996), but also decreases the migration of radionuclides from soil to plant products 1.5–2 times (Prister et al. 1996).

The application of sapropel for soil fertilisation is the objective of our study.

The experiments with the purpose to study the possibilities to use calcareous sapropel for fertilisation have been carried out at the Voke Branch of the Lithuanian Institute of Agriculture since 1984–1985.

MATERIAL AND METHODS

Field experiments

Two identical experiments were conducted in 1984 and 1985 (due to different meteorological conditions) to study the efficacy of calcareous sapropel in sandy loam Haplic Luvisols (54°37′N, 25°07′E). Soil agrochemical parameters before the experiment were as follows: pH_{KCl} = 6.1, mobile P = 101–115, K = 132–161 mg/kg, organic carbon = 1.05–1.13%. The treatments of experiments: (1) Control – only mineral fertilisers (NPK); (2) 50 t/ha dry sapropel (S); (3) 100 t/ha dry sapropel (S); (4) 150 t/ha dry sapropel (S); (5) 200 t/ha dry sapropel (S); (6) 30 t/ha of dry manure (M) (in order to compare its effect with sapropel). Sapropel and manure on the background of mineral fertilisers were applied in the crop rotation: maize (*Zea mays* L.), undersown barley (*Hordeum* L.), clover (*Trifolium pratense* L.), winter rye (*Secale cereale* L.), potatoes (*Solanum tuberosum* L.), oat (*Avena sativa* L.). Sapropel rates were applied only (1984 and 1985) to the first crop (maize) in the rotation (sapropel was applied only once during three crop rotations). Since its decomposition in the soil is very slow, we wanted to study how long its effect will last. Manure was applied in every crop rotation (because manure decomposition period is much shorter than that of sapropel) in 1984–1985, 1990–1991, 1995–1996. Mineral fertilisers were spread on the soil before sowing each crop of the rotation every year (in order to ensure a higher crop yield: maize – $N_{120}P_{26}K_{100}$, barley – $N_{30}P_{26}K_{50}$, clover – $P_{26}K_{50}$, winter rye – $N_{60}P_{26}K_{50}$, oats – $N_{60}P_{26}K_{50}$, potatoes – $N_{90}P_{26}K_{100}$). Size of experimental plots – 40 m^2, replications – 4.

Calcareous sapropel from Lake Ilgutis (54°34′N, 25°04′E) 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, 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), after completion of the first (in 1989–1990), second (in 1995–1996) and third (in 2001–2002) crop rotation.

Analytical methods

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

Separate humus substances were dissolved in different solvents: in 0.1M NaOH, in 0.05M H_2SO_4 (soil decalcification), in 0.1M NaOH after soil decalcification and after that in 0.02M NaOH. In all the mentioned extracts humic acids were separated from fulvic acids by precipitation of humic acids with 0.5M H_2SO_4. Deposits of humic acids were filtered and, after washing with 0.05M H_2SO_4, they were dissolved in 0.1M NaOH. Three fractions of humic acids (accordingly: HA-1 – mobile, HA-2 – bound with calcium, HA-3 – bound with clay minerals) and four fractions of fulvic acids (accordingly: FA-1a – 0.05M H_2SO_4 extract, FA-1 bound with HA-1, FA-2 bound with HA-2, FA-3 bound with HA-3) were determined according to this method (Orlov and Grishina 1981). The contents of organic carbon in soil and in different extracts were measured spectrophotometrically after sulfochromic oxidation (ISO 14235, 1998). The insoluble residue was calculated by subtracting the soluble fractions from the total content of organic carbon in soil.

Statistics

The cumulative curve was calculated by adding up yearly yield increase to the yield increase of previous year.

Relative feed value (RFV) is calculated from predicted values for both dry matter intake (DMI) and digestible dry matter (DDM) based on laboratory analyses for neutral-detergent fibre (NDF) and acid-detergent fibre (ADF), respectively. The current equations used by National Norage Testing Association (NFTA) are: DMI, % of BW = 120/(NDF, of DM); DDM, % of DM = 88.9–0.779 × (ADF, % of DM); RFV = DMI × DDM/1.29. The divisor, 1.29, was chosen so that the RFV of full bloom alfalfa has a value of 100 (Moore and Undersander 2002).

The data of soil chemical properties and crop yield 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 and Scarisbrick 2001).

RESULTS AND DISCUSSION

The experiments revealed that the use of calcareous sapropel for fertilisation has a positive effect on chemical properties of sandy loam Haplic Luvisols.

Fertilising with various rates of sapropel declined soil acidity (Figure 1), pH increased by 1.0–1.3 units. With the increasing rates of sapropel the amount of exchangeable bases (Ca + Mg) increased in soil proportionally by 2044–7144 mg/kg. Application of sapropel increased the content of total nitrogen by 0.003–0.036% units, organic C by 0.32–0.69% units and mobile phosphorus by 19–40 mg/kg

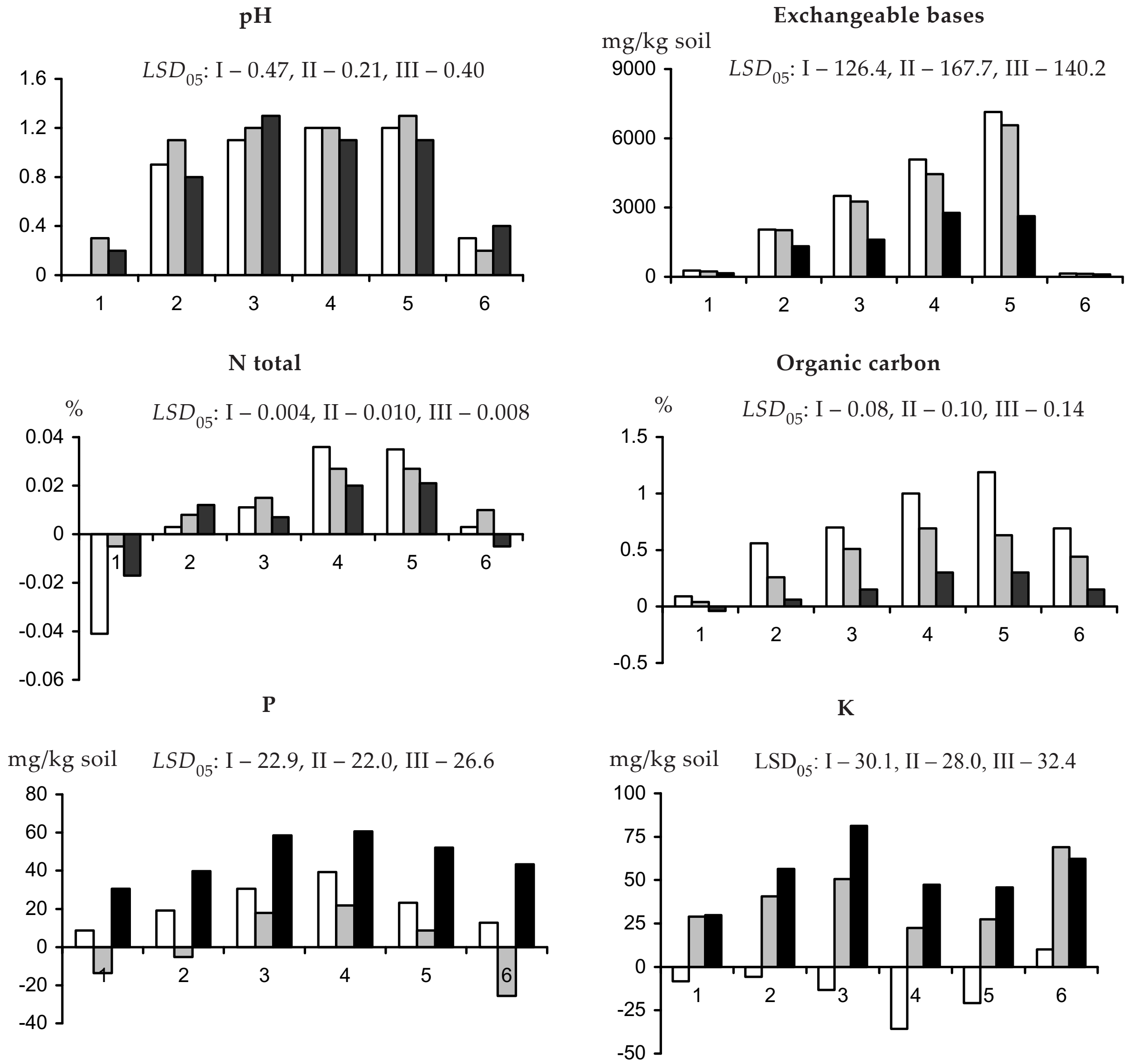

Figure 1. Changes of agrochemical indices after fertilisation of sandy loam Haplic Luvisols with calcareous sapropel; I – agrochemical indices after the first crop rotation; II – agrochemical indices after the second crop rotation; III – agrochemical indices after the third crop rotation; 1 – NPK (control); 2 – S 50 t/ha; 3 – S 100 t/ha; 4 – S 150 t/ha; 5 – S 200 t/ha; 6 – M 30 t/ha; S – dry sapropel, M – dry manure

of soil, while the amount of mobile potassium decreased by 6–36 mg/kg of soil, because there is a little amount of it in the sapropel and high removal with crop yield.

By the end of the second crop rotation the influence of sapropel on chemical characteristics of sandy loam soils remained positive. In comparison with the first crop rotation, the soil acidity did not decrease, pH was 7.2–7.4, whereas the control pH was 6.3.

Amount of exchangeable bases (Ca + Mg) also remained high (in soils treated with sapropel increased by 101–258, and in the treatment with manure – 548 mg/kg). Amount of organic C increased by 0.09–0.17, and by 0.40% units and total nitrogen respectively by 0.008–0.027 and by 0.017. Amount of mobile phosphorus in the treatments with sapropel increased by 5–22 and in the treatment with manure by 21 mg/kg. The amount of mobile potassium was smaller (27–51 mg/kg) in the treatments with sapropel than in the treatment with manure (69 mg/kg).

Comparing the data of agrochemical indices after the third crop rotation with the data of agrochemical indices after the second crop rotation, we can notice that a long-term efficacy of different rates of calcareous sapropel decreased, but has not reached the initial data from the period before the conduct of the experiment. Acidity of soil did not change. Exchangeable bases remained by 1190–2693 mg/kg, total nitrogen by 0.007–0.021% units and organic C by 0.03–0.17% units higher than at the beginning of the experiment. Results show that the efficacy of manure expired much faster, than that of sapropel. Comparison of the data of mobile phosphorus and potassium with the data of the previous rotation suggests that their amount increased in soil of all treatments with fertilising of all rates of sapropel and manure (phosphorus by 20–55 mg/kg soil and potassium by 16–83 mg/kg soil).

Organic carbon content accounted for 14.8 ± 0.10% in the composition of calcareous sapropel used in our tests. The larger part of total organic carbon of sapropel was accumulated in insoluble residue (75.6 ± 0.61% from C_{org}), less – in humic acids (9.6 ± 0.3% from C_{org}) and fulvic acids (14.8 ± 0.20% from C_{org}). Humic acids composition was dominated by humic acids strongly bound with clay minerals (63.5% from total HA), less humic acids bound with calcium (27.1% from total HA) and still less mobile humic acids (9.4% from total HA). Consequently, humus substances incorporated into the soil with calcareous sapropel were stable in terms of decomposition. Humus substances in the soil are gradually hydrolysed, and the regenerated humic acids are analogous to the acids present in the soil and take part in organic matter metabolism (Stepanova and Orlov 1996). Tests done by radio carbonic method have shown that on light-textured soils humus readily mineralises and more than

Table 1. Changes in composition of humus substances under the influence of calcareous sapropel and manure

Indices of humus composition	Before experiment	Treatments (after 18 year)						LSD_{05}
		NPK (control)	S 50 (t/ha)	S 100 (t/ha)	S 150 (t/ha)	S 200 (t/ha)	M 30 (t/ha)	
Organic C (% in soil)	1.13	1.29	1.46	1.52	1.50	1.53	1.52	0.12
C % from organic carbon in the soil								
HA-1	10.6	12.4	8.2	7.9	8.0	7.8	10.5	1.4
HA-2	7.1	6.2	8.9	8.6	8.7	8.5	8.0	1.5
HA-3	10.6	9.3	11.6	11.2	11.3	11.1	11.8	1.6
Sum of humic acids	28.3	27.9	28.7	27.7	28.0	27.4	30.3	1.9
FA-1a	8.0	7.0	5.5	5.3	5.3	5.3	5.9	0.7
FA-1	9.7	7.0	6.2	5.9	6.0	5.9	5.3	1.1
FA-2	7.1	11.6	10.9	10.5	10.7	9.8	11.8	1.6
FA-3	15.0	13.9	16.4	15.8	14.7	14.4	15.1	1.6
Sum of fulvic acids	39.8	39.5	39.0	37.5	36.7	35.4	38.1	1.7
Insoluble residue	31.0	32.5	32.3	34.8	35.3	37.2	31.6	1.8
C_{HA}:C_{FA}	0.71	0.71	0.74	0.74	0.76	0.77	0.80	0.02

S – dry sapropel, M – dry manure

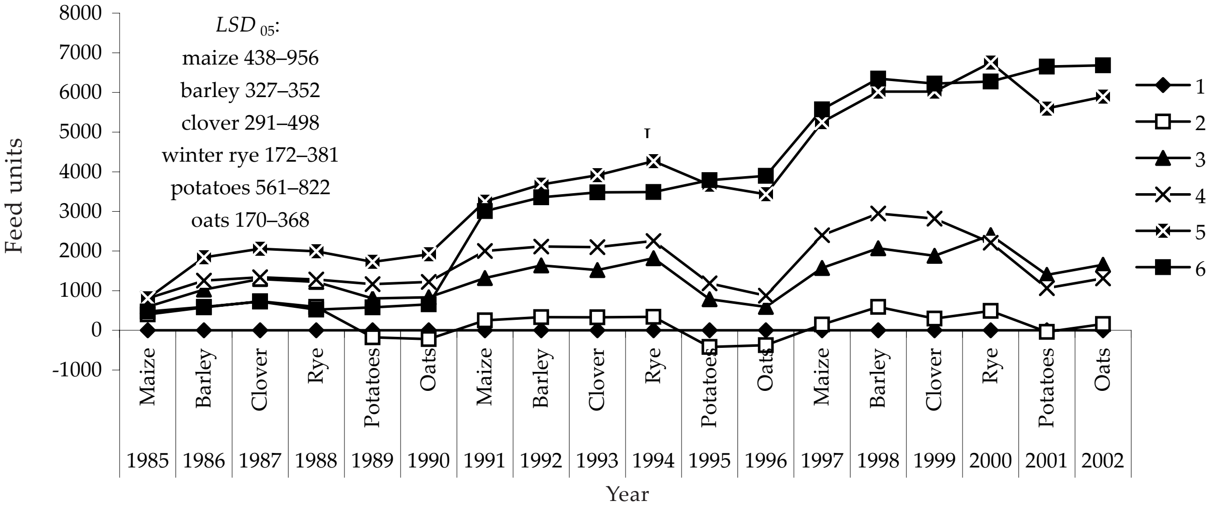

Figure 2. The cumulative curve of yield increase from the different rates of calcareous sapropel; 1 – NPK (control); 2 – S 50 t/ha; 3 – S 100 t/ha; 4 – S 150 t/ha; 5 – S 200 t/ha; 6 – M 30 t/ha; S – dry sapropel, M – dry manure

a half of its composition goes for hydrolysed part (Cherkinsky and Brovkin 1993).

All rates of sapropel after 18 years of application had some effect on the composition of humus substances, but more significant effect was produced by the higher (150, 200 t/ha) rates of sapropel (Table 1). Calcareous sapropel increased the content of humic acids bound with calcium (HA-2) and declined the content of mobile humic acids (HA-1). In this case this regrouping of humic acids fractions was related with the increased amount of calcium incorporated in the soil with calcareous sapropel. The content of total humic acids changed insignificantly. The higher (100–200 t/ha) rates of sapropel reduced the content of fulvic acids significantly. The ratio of humic acids to fulvic acids increased (C_{HA}:C_{FA} = 0.74–0.77; in control = 0.71). The increased content of insoluble residue was caused by higher rates of sapropel. Manure application in every crop rotation improved humus composition, as well (C_{HA}:C_{FA} = 0.80).

Comparison of the data of humus composition in the treatments applied with calcareous sapropel with the data in the treatments applied with manure suggests that the content of mobile humus substances reduced in the treatments with the higher rates (100–200 t/ha) of sapropel. Calcareous sapropel applied in the soil increased the amount of stable humus substances.

Experimental evidence suggests that calcareous sapropel as the lime-containing material not only reduces soil acidity but also improves and stabilizes soil properties necessary for plant growth.

The introduction of different rates of dry sapropel in a sandy loam soil had influence on the increase of crop productivity in three crop rotations.

The cumulative curve of the increase of plant productivity (Figure 2) showed that during the first four years of crop rotation the efficacy of the smallest rate (50 t/ha) of sapropel was equal to that of manure. Higher rates (100–200 t/ha) of sapropel proportionally increased the productivity of crop rotation. However, during the years when potatoes and oats were cultivated in the crop rotation, all rates of sapropel reduced the productivity of these crops. In the second crop rotation the productivity increased from the repeated introduction of manure and further effect of the largest rate (200 t/ha) of sapropel was even more efficient. However, at repeated cultivation of potatoes and oats, the negative effect of sapropel (50 t/ha) on the productivity reappeared, like in the first crop rotation. The data show that from the beginning of the third crop rotation (1997) the cumulative curve began to raise but in 2001 and 2002 when potato and oats were cultivated, the productivity decreased, as in previous crop rotations. These crops are more tolerant to acid soils. Large amounts of Ca^{2+} ions were introduced into the soil with the high rates of calcareous sapropel. They might have blocked up available potassium and other elements necessary for the development of potato and oats yield.

It is established that organic and siliceous sapropel influences agricultural crops much more effectively (Orlov and Sadovnikova 1996). However, the data of the experiments provided in this article show that in the majority of cases calcareous sapropel causes an increase in crop production, too.

Summarised results of the long-term experiment (18 years) suggest that the influence of calcareous sapropel on agrochemical properties of sandy loam Haplic Luvisols was positive. Sapropel applied in the soil improved humus composition, increased the amount of stable humus substances. The highest rates (150, 200 t/ha) of dry calcareous sapropel increased the productivity of crop rotation. The highest rate (200 t/ha) of sapropel was almost of the same effectiveness as manure applied in every crop rotation.

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ABSTRAKT

Vliv aplikace vápenatých sapropelů na chemické vlastnosti luvizemí a výnos pěstovaných rostlin

Využití sapropelů pro hnojení bylo sledováno v Litevském zemědělském ústavu od roku 1984. Sapropel byl testován na písčité luvizemi v rotaci plodin (kukuřice, ječmen, jetel, ozimé žito, brambory a oves) v dávkách 50, 100, 150 a 200 t/ha sušiny sapropelu a 30 t/ha sušiny hnoje, podle něhož byla dodána minerální hnojiva. Sapropel byl aplikován pouze před první plodinou (kukuřice) v první rotaci (1984). Hnůj byl použit k první plodině v každé rotaci (1984, 1990 a 1996). Výsledky dlouhodobých pokusů ukázaly, že na konci druhé (po 12 letech) a třetí (po 18 letech) rotace byl vliv sapropelu na chemické vlastnosti půdy pozitivní. Vápenatý sapropel omezil půdní kyselost a zvýšil podíl výměnných bází (Ca a Mg) v půdě. Sapropel příznivě ovlivnil obsah organického uhlíku a celkového dusíku v půdě, stejně jako složení humusu, přičemž na variantách se sapropelem byl poměr $C_{HA} : C_{FA}$ 0,74–0,77, zatímco v kontrolní variantě 0,71. Vyšší dávky sapropelu (150–200 t/ha) ukázaly vyšší produktivitu plodin po 18 letech pokusu. Nejvyšší dávka sapropelu (200 t/ha) dosahovala téměř stejné produktivity jako hnůj aplikovaný v každé rotaci.

Klíčová slova: sapropel; půda; chemické vlastnosti; složení humusu; výnos

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