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Assessment of a single application of sewage sludge on the biomass yield of *Silphium perfoliatum* and changes in naturally acid soil properties

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Abstract

In order to estimate the effect of granulated sewage sludge on the productivity of the cup plant (*Silphium perfoliatum* L.), soil physical and microbial properties, a field experiment was carried out in Western Lithuania, on a naturally acid moraine loam *Bathygleyic Dystric Glossic Retisol* with a pH of 4.3–4.9. The dry matter yield of the cup plant consistently increased over the experimental years from 2.83 t ha^{-1} (in 2013) to 12.86 t ha^{-1} (in 2016). Each year, the optimum sewage sludge rate for dry matter yield of cup plant was 45 t ha^{-1}. The use of both sewage sludge rates 45 and 90 t ha^{-1} had a similar and positive impact on soil chemical composition, water-stable aggregate formation, topsoil bulk density, soil penetration resistance and moisture content. Each experimental year, the application of sewage sludge at a rate of 90 t ha^{-1} had the strongest impact on the increase in soil microbial biomass carbon at the 0–30 cm depth.

Experimental results suggest that when growing cup plant as an energy crop on a moraine loam *Retisol*, it is expedient to use granulated sewage sludge at a rate of 45 t ha^{-1}.

Key words: cup plant, fertilization, productivity, soil aggregates, soil chemical parameters, soil microbial biomass.

Introduction

Sewage sludge as a cheap organic product of water treatment may substitute mineral fertilizers, because it contains high amounts of organic matter, nitrogen and phosphorus (Annabi et al., 2011; Chen et al., 2012). For energy and other non-food crops sewage sludge might be a suitable fertilizer. The application of sewage sludge improves soil physical properties, such as bulk density, aggregate stability, water holding capacity, total porosity and saturated hydraulic conductivity (Ojeda et al., 2008; Annabi et al., 2011). Addition of sewage sludge deposit may cause undesirable changes, such as decreasing soil acidity (pH) and increasing heavy metal contents.

Since sewage sludge contains high amounts of heavy metals and pathogenic bacteria, its further application as an organic fertilizer for food crops is restricted in all European Uunion countries and its extensive use as organic fertilizer is still problematic (Kelessidis, Stasinakis, 2012; Latare et al., 2014). Mondal et al. (2015) have reported that short-term application of sewage sludge has effect on different soil properties, particularly on soil fertility improvement. Soil microbial activity, microbial diversity and fertility are closely related, as during the process of sewage sludge mineralization the released mineral nutrients become available and readily absorbed by soil microorganisms and plants (Ros et al., 2003). Therefore, the applied sewage sludge contributes to an increase in the organic carbon and macronutrient contents in the soil (Kołodziej et al., 2016). According to Usman et al. (2012), low rates of sewage sludge had beneficial effects on microbial activity, while excessive soil application with sewage sludge caused an increase in the bioavailability of heavy metals and negative effect on soil ecosystem.

The impact of sewage sludge on soil environment is closely related to the cation exchange capacity, organic matter content and soil acidity (Singh et al., 2012). It is very important to evaluate the possibilities of sewage sludge application on acid soils, where heavy metals are easily accessible to plants (Losada et al., 2017). Naturally acid and less productive soils – *Retisol* and *Fluvisol* – are prevalent in Western Lithuania. Intensive agricultural practices in these soils have significant effects on soil degradation through loss of soil organic matter, decline of soil structure, resulting in soil compaction and root growth retardation (Karcauskiene et al., 2018). As an alternative, some of these acid soils might be designated for non-food crop species cultivation, while paying special attention to the species, which tolerate high soil acidity. In general, energy crops and other non-food crops should be grown in the regions, where growing of traditional agricultural crops is less profitable (Nilsson et al., 2015).

In the light of increasing importance of perennial energy crops, several coarse stem herbaceous species originating from North America and belonging to *Silphium* genus: *S. perfoliatum* L., *S. integrifolium* Michx.

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and *S. laciniatum* L., might be promising as energy crops due to high annual biomass yield (Voigt et al., 2012; Assefa et al., 2015). Perennial energy crops usually have a well-developed root system, which together with fungal hyphae are important factors in the formation of stable soil aggregates (de Vries, Bardgett, 2012). Cup plant is among those energy crops that could be grow on acid soils; however, the effect of sewage sludge on the productivity of cup plant and soil has not been studied before.

The aim of this study was to carry out a complex evaluation of sewage sludge impact on the biomass yield of cup plant and on the properties of acid moraine loam soil.

Materials and methods

Experimental site and design. A field experiments with an energy crop – cup plant (*Silphium perfoliatum* L.) – was started in 2013 at Vėžaičiai Branch of the Lithuanian Research Centre for Agriculture and Forestry in Western Lithuania (55°43′ N, 21°27′ E). The soil of the experimental site is naturally acid moraine loam *Bathygleyic Dystric Glossic Retisol* (WRB, 2014), with a clay (<0.002 mm) content of 15.0% and acidity (pH_{KCl}) of 4.30–4.93. Sprouts of cup plant were planted at the end of May in 2013. One factorial experiment was composed of the following treatments: 1) not fertilized (control treatment), 2) fertilized $N_{60}P_{60}K_{60}$, 3) 45 t ha^{-1} and 4) 90 t ha^{-1} of granulated sewage sludge. All the treatments with three replications were randomly allocated. The granulated sewage sludge was incorporated into the soil during the third ten-day period of May in 2014. NPK fertilization was carried out each year before the beginning of the growing season.

Granulated sewage sludge. The material was obtained from the water treatment plant JSC "Šilutės vandenys". The composition of the treated sewage sludge was as follows: pH – 5.56, total nitrogen – 33.4 g kg^{-1}, total phosphorus – 5.02 g kg^{-1}, organic matter – 64.97%. The concentrations of heavy metals were as follows: lead (Pb) – 14.47 mg kg^{-1}, cadmium (Cd) – 0.44mgkg^{-1}, chromium (Cr) – 11.51 mg kg^{-1}, copper (Cu) – 47.8mgkg^{-1}, nickel (Ni) – 8.22 mg kg^{-1}, zinc (Zn) – 287mgkg^{-1} and mercury (Hg) – 0.96 mg kg^{-1}. According to contamination with heavy metals, the sewage sludge met the requirements laid down for the 1st category.

Sampling and analytical methods employed. The assessments of cup plant productivity (dry matter (DM) yield) were started in 2014. Each year, at the end of September, the stems of cup plant were cut by a rotary reaper. The cup plant productivity was recalculated into the air-dry matter yield.

Soil chemical analyses (in 0–30 cm topsoil layer) were done twice in October 2013 (before the experiment) and in October 2016. Soil samples for the analyses were taken from three treatments (except $N_{60}P_{60}K_{60}$) and three replications. Soil analyses were done using the following techniques: pH_{KCl} – potentiometrically, organic carbon (C_{org}) – by Turin method, total nitrogen (N_{tot}) – by Kjeldahl method, plant available phosphorus (P_2O_5) and potassium (K_2O) – by the Egner-Riehm-Domingo (A-L) method.

Microbial biomass carbon (μg g^{-1} C) was determined by the chloroform-fumigation extraction (CFE) method, according to the modified Vance et al. (1987) methodology at Vytautas Magnus University Agriculture Academy. Soil sampling for soil microbial biomass analysis was done in all treatments in three replications in the spring and autumn ($N_{60}P_{60}K_{60}$ treatment impact was evaluated only in the autumn).

Soil samples for bulk density, moisture and structure analysis were collected in the topsoil in triplicate after harvesting in 2015 and 2017. The composition of soil aggregates (dry sieving) and water stability of soil aggregates (wet sieving) were estimated according to Savinov method, soil bulk density (100 cm^3) was estimated according to Kachinsky method, and soil moisture content was established by weight (Вадюнина, Корчагина, 1986). Soil bulk density was determined using the Kachinsky method, and the soil penetration resistance in the profile to the 40 cm depth was estimated using soil penetration tester software *PenetroViewer*, version 6.03 ("Eijkelkamp", The Netherlands). The soil penetration resistance was measured in 2016 at the end of plant vegetation by doing five tests in each treatment.

Meteorological conditions. In 2014, cool and relatively dry weather prevailed until the end of June. Since early July, dry and warm weather settled. There was a lack of soil moisture. Heavy rain occurred in the 2nd and 3rd ten-day periods of August. The amount of rainfall was 320 mm (annual average 424 mm); the sum of active temperatures (above 10°C) was 2379°C. In 2015, in the first half of the vegetation season, the weather was relatively cool and rainy. Warmer and drier weather settled in August. The amount of rainfall was 418 mm; the sum of active temperatures was 2118°C. In 2016, the rainfall distributed relatively evenly throughout the vegetation period. Monthly temperatures were close to the perennial values. The amount of rainfall was 526 mm; the sum of active temperatures was 2336°C. In the growing season of 2017, the weather was changeable, dry with low soil moisture periods alternated by rainy weather. The amount of rainfall was 458 mm; the sum of active temperatures was 2186°C.

Statistical analysis. The data of the studied parameters and their interactions were statistically processed using the analysis of variance (*ANOVA*) to determine significant differences at 95% and 99% probability levels (LSD_{05} and LSD_{01}) (Raudonius, 2017).

Results and discussion

Dry matter (DM) yield. The effect of fertilization type (mineral and sewage sludge application) on the DM yield of cup plant is presented in Table 1. Since the cup plant formed approximately 12–14 leaves in a rosette and did not produce stems during the first year of growing, the biomass yield was not observed. During the first harvest year, the DM yield of cup plant averaged 2.83 t ha^{-1}. Typically, the yield of the second growing season is not high. A significant DM increase was observed during the second and third harvest years (in 2015 and 2016). Accordingly, the dry matter yield increased up to 5.49 and 12.86 t ha^{-1} (or by 190% and 440% compared to the first growing season). The average DM yield of cup plant was slightly lower in 2017 – 11.95 t ha^{-1}. Generally, during the first growing season, the aboveground biomass yield of cup plant was relatively low. However, it substantially increases in the subsequent growing years (Gansberger et al., 2015; Šiaudinis et al., 2015).

The cup plant produced relatively high DM yield in the control treatment (without fertilization) during each experimental year, which suggests that the amount of mineral nutrients in the experimental site's soil was sufficient. Thus, the cup plant was able to accumulate enough nutrients from the soil upper layer in order to maintain normal physiological metabolism and produce the annual DM yield from 2.20 t ha^{-1} (in 2014) to 8.78 t ha^{-1} (in 2016).

The annual application of mineral fertilizers ($N_{60}P_{60}K_{60}$) increased DM yield from 2.93 t ha^{-1} (in 2013) to 10.41 t ha^{-1} (in 2016), i.e. from 18.56% to 43.58% compared to the control treatment. However, the increase of DM was not statistically significant. Given that mineral fertilization is an expensive investment, mineral fertilizer use for energy crops is economically inexpedient.

Overall, the application of 45 t ha^{-1} of granulated sewage sludge was most effective in terms of dry matter accumulation in cup plant biomass. Compared to the control treatment the dry matter yield increased by 50–210%, depending on the growing year. Sewage sludge

Table 1. The effect of fertilization type on the dry matter yield (t ha^{-1}) of cup plant during the 2014–2017 experimental years

Treatment	2014	2015	2016	2017
Control	2.20 a	3.74 a	8.78 a	8.68 a
$N_{60}P_{60}K_{60}$	2.93 a	5.37 a	10.41 a	10.30 a
45 t ha^{-1} sewage sludge	3.31 a	6.83 a	17.58 b	14.05 b
90 t ha^{-1} sewage sludge	2.87 a	6.02 a	14.68 b	13.49 b
On average	2.83	5.49	12.86	11.63
$LSD_{05/01}$	*1.93/2.92*	*2.67/4.05*	*3.34/5.06*	*3.30/5.00*

Note. The differences between values marked by different letters are significant.

contains high amounts of organic matter, nitrogen and phosphorus. Altogether, it increases humus content and enhances soil microbial activity. As for the experiment, the positive effect of sewage sludge was visible already during the year of application (2014). Contrarily, the application of the higher rate (90 t ha^{-1}) of sewage sludge tended to decrease the productivity of cup plant; thus, it was economically inexpedient.

The roots of cup plant grow deep up to 150 cm depth (Stanford, 1990). This makes the species less susceptible to water shortage in dry periods. The results from another field experiment indicate that depending on the meteorological conditions, annual dry matter productivity of cup plant may vary from 8.22 to 13.48 t ha^{-1} (Šiaudinis et al., 2015). The field studies with the same seeding material conducted in Central Lithuania (soil – *Eutri-Cambic Arenosol*) revealed that with the annual application of N_{60}, the average cup plant yield was 7.29 t ha^{-1} DM (Slepetys et al., 2012). The dry matter yield of cup plant in its native United States regions is relatively low – 2.00–6.80 t ha^{-1} (Voigt et al., 2012). Contrarily, the data obtained in Chile shows that under different plant density and fertilization levels, the dry matter yield of cup plant may vary from 15.0 to 20.0 t ha^{-1} (Pichard, 2012). It is important to note that the seed material of cup plant is not homogeneous. Its productivity depends not only on climate and soil conditions, but also on the available seed material (Assefa et al., 2015; Gansberger et al., 2015).

Soil chemical properties. At the beginning of the field trial, soil pH value (in the 0–30 cm topsoil layer) at the experimental site was 4.50, on average (irrespective of the treatment) (Table 2).

Table 2. Soil acidity (pH_{KCl}), organic carbon (C_{org}), total nitrogen (N_{tot}), mobile phosphorus (P_2O_5) and potassium (K_2O) content in the growing site of cup plant at the 0–30 cm topsoil layer in 2013 and 2016

Treatment	pH_{KCl}	C_{org} %	N_{tot} %	$C_{org}:N_{tot}$	P_2O_5 mg kg^{-1}	K_2O mg kg^{-1}
2013 (before the experiment)						
	4.50 ± 0.37	1.26 ± 0.1	0.78 ± 0.0	16.27 ± 1.22	83.73	270
2016						
Control	4.45 a	1.25 a	0.08 a	15.36 a	80.6 a	245 a
45 t ha^{-1} sewage sludge	4.27 a	1.75 b	0.13 b	13.64 b	933 b	245 a
90 t ha^{-1} sewage sludge	4.59 a	1.79 b	0.13 b	13.15 b	984 b	246 a
$LSD_{05/01}$	*0.30/0.46*	*0.16/0.25*	*0.017/0.026*	*1.64/2.48*	*186/282*	*63.1/95.61*

Note. The differences between values marked by different letters are significant.

In the following three years, the soil analyses revealed that sewage sludge application had no significant impact on soil acidity. On the contrary, other authors argue that the application of sewage sludge tends to reduce soil acidity (Neilsen et al., 1998; Eitminavičiūtė et al., 2009). The average soil C_{org} content at the trial site was 1.26 % (in 2013). Meanwhile other authors state that sewage sludge tends to decrease soil acidity (Latare et al., 2014). In 2016, after three growing seasons, the application of 45 t ha^{-1} sewage sludge significantly increased C_{org} content by up to 1.75%. However, the use of double rate (90 t ha^{-1}) of sewage sludge had similar impact on the increasing of soil C_{org} content – 1.69%.

At the beginning of the experiment, the average N_{tot} content was 0.78%. The application of both sewage sludge rates had a similar and significantly positive impact on soil nitrogen content; thus three years after sewage sludge application, N_{tot} content was 0.13%. By increasing both C_{org} and N_{tot}, content in the upper soil layer, the $C_{org}:N_{tot}$ ratio tended to decrease from 15.36 (in unfertilized soil) to 13.15–13.64 (in the soil applied with sewage sludge). According to the results of other authors, the application of sewage sludge increases soil organic content, improves soil C_{org} and N_{tot} mineralization processes (Roig et al., 2012).

It is noteworthy that after three experimental years, there were no significant differences between both sewage sludge rates for all the studied soil chemical parameters. Accordingly, the data of other authors reveal that under the sewage sludge application, the content of soil nutrients highly varies throughout the entire year. Altogether, the use of different composted rates (50 and 100 t ha^{-1}) of sewage sludge had a similar impact on the following soil parameters: organic matter, total C and N contents and C:N ratio (Larchevêque et al., 2006). Other researchers indicate that the use of the highest sewage sludge rates significantly improved soil chemical parameters already in the first year of growth. However, in the subsequent years, the beneficial effect of high sewage sludge rates on soil chemical composition becomes less evident (Alvarenga et al., 2017).

Large amounts of phosphorus were introduced into the soil with sewage sludge. Before the experiment, the average amount of mobile P_2O_5 in the topsoil layer was low – 83.73 mg kg^{-1}. After three years of growth, the amount of mobile P_2O_5 in the topsoil layer increased approximately 12 times to 933–984 mg kg^{-1}. Usually, different sewage sludge materials contain high amounts of phosphorus (Alvarenga et al., 2017). It is a good alternative for traditional mineral phosphorus fertilization, particularly for energy crops, since inorganic phosphorus resources on the Earth are quite limited (Linderholm et al., 2012). Before the experiment, the average amount of mobile K_2O was 270 mg kg^{-1}. After three years of vegetation (in 2016) and irrespective of the fertilization type, the amount of mobile K_2O in the 0–30 cm topsoil layer remained essentially unchanged.

Water-stable aggregates are single-particles formed by different materials – plant roots, adhesives of bacteria and fungi, polysaccharides, and fungi hyphae. The application of organic material is a simple and effective way to restore disrupted soil structure. Particularly, sewage sludge can be an effective means to solve this problem (Angin, Yaganoglu, 2011; Annabi et al., 2011). Composted, fresh and heat-treated sewage sludge improves the physical state of soil and increases the resistance of aggregates to raindrops (Ojeda et al., 2008).

Recent studies showed that the application of sewage sludge in the growing site of cup plant had a positive effect on the formation of water-stable aggregates, especially macro-aggregates (>1.0 mm) (Table 3).

In 2015 (one year after the application of sewage sludge), the highest amount (14.3%) of macro-aggregates was estimated in the soil applied with 90 t ha^{-1} sewage sludge. Meanwhile in 2017 (three years after sewage sludge application), the highest amount of macro-aggregates was found in the soil with the application of the lower rate (45 t ha^{-1}) of sewage sludge. In the third experimental year (in 2017), cup plants already had a deep and dense root system; thus, the roots also contributed significantly to the formation of macro-aggregates. According to Angers (1992), vegetation affects soil structural form and stability at different scales and through various direct and indirect mechanisms.

Table 3. The effect of sewage sludge on the amount (%) of water-stable aggregates in the topsoil of the growing site of cup plant

Treatment	2015		2017	
	>1.0 mm	>0.25 mm	>1.0 mm	>0.25 mm
Control	10.1 a	50.3 a	12.0 a	47.9 a
$N_{60}P_{60}K_{60}$	10.6 a	45.7 a	–	–
45 t ha^{-1} sewage sludge	13.5 a	50.6 a	20.0 b	62.6 b
90 t ha^{-1} sewage sludge	14.3 b	59.3 a	16.9 a	59.6 a
LSD_{05}	4.17	13.02	8.00	12.46

Note. The differences between values marked by different letters are significant.

In the third experimental year, compared with the control treatment, the use of sewage sludge increased the amount of ecologically and agronomically valuable aggregates (>0.25 mm) by 24–31%. It might be explained by the fact that sewage sludge application increased soil C_{org} content by 35–40% compared with the untreated soil (Table 2). Different authors emphasized that with the application of sewage sludge, the amount of water-stable soil aggregates is increasing due to the increase in soil organic matter content and its distribution among soil aggregates of various sizes (Sort, Alcañiz, 1999; Annabi et al., 2011). Soils with a higher content of stable aggregates are less susceptible to soil compaction. Soil penetration resistance as well as soil bulk density tests also confirmed this statement.

Soil bulk density and penetration resistance are the major soil properties regulating plant root elongation, water accessibility and plant productivity (Colombi et al., 2018). Optimum topsoil conditions for plant root growth in a sandy clay loam and clay loam are <1.40 Mg m^{-3} and penetration resistance – <1.5 MPa.

The study data showed that moraine loam soil bulk density and penetration resistance depended on the fertilization type (Table 4). In the growing site of cup plant, compared with unfertilized soil, the application of lower rate (45 t ha^{-1}) of sewage sludge significantly (by 6.5%) decreased soil bulk density. The application of both sewage sludge rates had no impact on soil moisture content.

Table 4. The effect of sewage sludge on topsoil bulk density and moisture content in the growing site of cup plant

Treatment	2015		2017	
	bulk density Mg m^{-3}	moisture %	bulk density Mg m^{-3}	moisture %
Control	1.39 a	23.2 a	1.33 a	21.3 a
$N_{60}P_{60}K_{60}$	1.32 a	23.5 a	–	–
45 t ha^{-1} sewage sludge	1.30 b	22.2 a	1.19 b	20.3 a
90 t ha^{-1} sewage sludge	1.33 a	22.2 a	1.12 b	21.0 a
LSD_{05}	*0.074*	*2.933*	*0.121*	*1.737*

Note. The differences between values by different letters are significant.

According to the results obtained in late autumn of 2017, soil penetration resistance in all treatments in deeper layers was higher than in the upper layers, which was determined by the morphogenetic peculiarities of the soil profile (Fig.). The least penetration resistance was in the 0–40 cm soil layer, where 45 t ha^{-1} of sewage sludge had been applied. In other words, soil penetration resistance was by 16% lower compared with the control (without fertilization) and conventional $N_{60}P_{60}K_{60}$ fertilization.

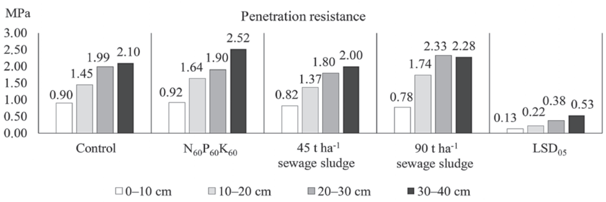

Figure. The effect of sewage sludge on the soil penetration resistance in the growing site of cup plant in 2017

Summarizing the data, it can be concluded that the application of sewage sludge (particularly 45 t ha^{-1}) in the acid moraine loam soil increased the aggregate stability, decreased the bulk density and penetration resistance in the upper soil layer.

Microbial biomass carbon in the soil is expressed as biomass of microorganisms in the soil (µg g^{-1} C). The effect of sewage sludge on soil microbial activity is presented in Table 5.

Microbial biomass carbon content changed during all experimental years. It was found that the variation of microbial biomass carbon between spring and autumn periods in the humus horizon in the cup plant site at the 0–30 cm depth was rather negligible.

Since the first evaluation of soil microorganisms was done before sewage sludge application, there were no differences between treatments in the spring period of 2014. Later on, sewage sludge application (both 45 and 90 kg ha^{-1}) had a significant impact on the increase in soil microbial biomass. The positive and significant effect of sewage sludge application on microbial biomass carbon had already been observed in the autumn period of 2014 and gradually increased during the experimental years. The microbial biomass was mostly increasing in the 2016 season, compared with the first harvest year: microbial biomass carbon increased 2.5 times, on average. The application of 90 t ha^{-1} sewage sludge had the most significant and positive impact on soil microbial biomass expansion. However, the conventional $N_{60}P_{60}K_{60}$ fertilization had a similar impact on soil microbial

Table 5. The changes of soil microbial biomass carbon (μg g^{-1} C) in the humus horizon (0–30 cm depth) in the growing site of cup plant during the 2014–2016 experimental years

Treatment	2014		2015		2016	
	spring	autumn	spring	autumn	spring	autumn
Control	217 ± 23.9 a	211 ± 18.2 a	187 ± 10.4 a	191 ± 10.3 a	183 ± 12.1 a	200 ± 8.2 a
$N_{60}P_{60}K_{60}$	–	208 ± 12.5 a	–	151 ± 21.0 a	–	188 ± 10.8 a
45 t ha^{-1} sewage sludge	226 ± 11.8 a	229 ± 12.4 ab	243 ± 11.3 b	282 ± 20.1 b	455 ± 38.0 b	472 ± 45.8 b
90 t ha^{-1} sewage sludge	241 ± 14.3 a	247 ± 13.7 b	287 ± 14.3 c	368 ± 18.0 c	724 ± 15.0 b	724 ± 19.2 c
On average	*234 ± 13.1*	*228 ± 13.9*	*265 ± 12.8*	*267 ± 19.7*	*590 ± 38.2*	*590 ± 26.5*

Note. Mean values ± standard deviation; the differences between values marked by different letters are significant.

biomass as the control. It could be predicted, that conventional fertilization was slightly improving nutrient availability for cup plants but not as effective contributor to soil microbial biomass.

It is likely that not only the application of sewage sludge but also a strong rooting system of energy crops (cup plant, in our case) actively promote the growth of soil microbial biomass, and, at the same time, the immobilization of nutrients (Kallenbach, Grandy, 2010; Annabi et al., 2011; de Vries, Bardgett, 2012).

According to the obtained experimental results, cup plant as an energy crop might be successfully grown in less fertile and high acidity moraine loam *Retisol*. Based on the four years' experimental data, it can be concluded that the usage of sewage sludge as organic matter at a rate of 45 t ha^{-1} is sufficient for maintaining high annual biomass productivity of cup plant. Besides, organic sewage sludge application was far more superior to annual NPK fertilization. In a broad sense, sewage sludge is not only a source of organic matter with high amount of nutrients, but also the improver of soil physical and microbial properties and plant growth conditions in naturally acid *Retisol*. Besides, the annual use of mineral fertilization is costly and energetically inexpedient for perennial energy crops (particularly cup plant) cultivation; thus, sewage sludge as a cheap organic matter might be an appropriate substitution. In this way, the growing expenses would be significantly reduced.

Besides the positive impact on biomass yield, sewage sludge significantly improved soil quality. The addition of sewage sludge in the soil increased the amount of water-stable aggregates and microbial activity. As a result, the soil became less compact.

It can be hypothesized that the positive effect of sewage sludge application on both biomass and soil productivity will remain in the next few years. In order to determine the long-term impact of sewage sludge on soil qualitative parameters, the intensity of soil decontamination process, dynamics of above-ground biomass productivity and its suitability as feedstock for bioenergy purposes, the experiment is going to be continued until 2022.

Conclusions

1. The studies conducted on a *Retisol* indicate that the dry matter (DM) yield of cup plant (*Silphium perfoliatum* L.) increased significantly in the first three consecutive experimental years. A single sewage sludge application at a rate of 45 t ha^{-1} had the highest impact on DM yield increment. The effect of annual conventional mineral fertilization on DM yield was less substantial.

2. Both rates (45 and 90 t ha^{-1}) of sewage sludge had no significant effect on soil acidity (pH) and mobile potassium (K_2O) amount in the topsoil layer. Herewith, the amounts of organic carbon (C_{org}), total nitrogen (N_{tot}) and mobile phosphorus (P_2O_5) increased significantly.

3. A single sewage sludge application (particularly 45 t ha^{-1}) in an acid moraine loam soil increased the aggregate stability, decreased the bulk density and penetration resistance in the upper soil layer.

4. Microbial biomass carbon content increased already in the first year as a result of sewage sludge application (especially 90 t ha^{-1}) and consistently increased in subsequent experimental years.

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References

1. Alvarenga P., Palma P., Mourinha C., Farto M., Dôres J., Patanita M., Cunha-Queda C., Natal-da-Luz T., Renaud M., Sousa J. P. 2017. Recycling organic wastes to agricultural land as a way to improve its quality: a field study to evaluate benefits and risks. Waste Management, 61: 582–592. https://doi.org/10.1016/j.wasman.2017.01.004
2. Angers D. A. 1992. Changes in soil aggregation and organic carbon under corn and alfalfa. Soil Science Society of American Journal, 56: 1244–1249. https://doi.org/10.2136/sssaj1992.03615995005600040039x
3. Angin I., Yaganoglu A. V. 2011. Effect of sewage sludge application on some physical and chemical properties of soil affected by wind erosion. Journal of Agriculture Sciences and Technology, 13 (5): 757–768. https://doi.org/10.1007/s10341-016-0303-9
4. Annabi M., Le Bissonnais Y., Le Villio-Poitrenaud M., Houot S. 2011. Improvement of soil aggregate stability by repeated applications of organic amendments to a cultivated silty loam soil. Agriculture, Ecosystems and Environment, 144 (1): 382–389. https://doi.org/10.1016/j.agee.2011.07.005
5. Assefa T., Wu J., Albrecht K. A., Johnson P. J., Boe A. 2015. Genetic variation for biomass and related morphological traits in cup plant (*Silphium perfoliatum* L.). American Journal of Plant Sciences, 6: 1098. https://doi.org/10.4236/ajps.2015.68114
6. Chen H., Yan S. H., Ye Z. L., Meng H. J., Zhu Y. G. 2012. Utilization of urban sewage sludge: Chinese perspectives. Environmental Science and Pollution Research, 19 (5): 1454–1463. https://doi.org/10.1007/s11356-012-0760-0
7. Colombi T., Torres L. C., Walter A., Keller T. 2018. Feedbacks between soil penetration resistance, root architecture and water uptake limit, water accessibility and crop growth – a vicious circle. Science of the Total Environment, 626: 1026–1035. https://doi.org/10.1016/j.scitotenv.2018.01.129
8. de Vries F. T., Bardgett R. D. 2012. Plant–microbial linkages and ecosystem nitrogen retention: lessons for sustainable agriculture. Frontiers in Ecology and the Environment, 10: 425–432. https://doi.org/10.1890/110162
9. Eitminavičiūtė I., Matusevičiūtė A., Gasiūnas V., Radžiūtė M., Grendienė N. 2009. Ecotoxicological assessment of arable field soils fertilized with sewage sludge. Ekologija, 55 (2): 142–152. https://doi.org/10.2478/v10055-009-0018-4
10. Gansberger M., Montgomery L. F., Liebhard P. 2015. Botanical characteristics, crop management and potential of *Silphium perfoliatum* L. as a renewable resource for biogas production: a review. Industrial Crops and Products, 63: 362–372. https://doi.org/10.1016/j.indcrop.2014.09.047
11. Kallenbach C., Grandy A. S. 2010. Controls over soil microbial biomass responses to carbon amendments in agricultural systems: a meta-analysis. Agriculture, Ecosystems and Environment, 144: 241–252. https://doi.org/10.1016/j.agee.2011.08.020
12. Karcauskiene D., Repsiene R., Ambrazaitiene D., Skuodiene R., Jokubauskaite I. 2018. Soil pH control, ecological and agronomic assessment in agroecosystem. Soil pH for nutrient availability and crop performance. IntechOpen, p. 47–71. https://doi.org/10.5772/intechopen.75764

13. Kelessidis A., Stasinakis A. S. 2012. Comparative study of the methods used for treatment and final disposal of sewage sludge in European countries. Waste Management, 32: 1186–1195. https://doi.org/10.1016/j.wasman.2012.01.012
14. Kołodziej B., Antonkiewicz J., Sugier D. 2016. *Miscanthus × giganteus* as a biomass feedstock grown on municipal sewage sludge. Industrial Crops and Products, 81: 72–82. https://doi.org/10.1016/j.indcrop.2015.11.052
15. Larchevêque M., Baldy V., Montes N., Fernandez C., Bonin G., Ballini C. 2006. Short-term effects of sewage-sludge compost on a degraded Mediterranean soil. Soil Science Society of America Journal, 70 (4): 1178–1188. https://doi.org/10.2136/sssaj2005.0115
16. Latare A. M., Kumar O., Singh S. K., Gupta A. 2014. Direct and residual effect of sewage sludge on yield, heavy metals content and soil fertility under rice–wheat system. Ecological Engineering, 69: 17–24. https://doi.org/10.1016/j.ecoleng.2014.03.066
17. Linderholm K., Tillman A. M., Mattsson J. E. 2012. Life cycle assessment of phosphorus alternatives for Swedish agriculture. Resources. Conservation and Recycling, 66: 27–39. https://doi.org/10.1016/j.resconrec.2012.04.006
18. Losada R. M., Garcia A. A., Fereiro M. M., Santiag-Freijanes J. J., Dominguez M. F., Franco R. R., Rodriguez A. A. 2017. Sustainable use of sewage sludge in acid soils within a circular economy perspective. Catena, 194 (1): 341–348. https://doi.org/10.1016/j.catena.2016.10.007
19. Mondal S., Singh R. D., Patra A. K., Dwivedi B. S. 2015. Changes in soil quality in response to short-term application of municipal sewage sludge in a typic haplustept under cowpea-wheat cropping system. Environmental Nanotechnology, Monitoring and Management, 4: 37–41. https://doi.org/10.1016/j.enmm.2014.12.001
20. Neilsen G. H., Hogue E. J., Neilsen D., Zebarth B. J. 1998. Evaluation of organic wastes as soil amendments for cultivation of carrot and chard on irrigated sandy soils. Canadian Journal of Soil Science, 78 (1): 217–225. https://doi.org/10.4141/S97-037
21. Nilsson D., Rosenqvist H., Bernesson S. 2015. Profitability of the production of energy grasses on marginal agricultural land in Sweden. Biomass and Bioenergy, 83: 159–168. https://doi.org/10.1016/j.biombioe.2015.09.007
22. Ojeda G., Alcanĩz J. M., Le Bissonnais I. 2008. Differences in aggregates stability due to various sewage sludge treatments on a Mediterranean calcareous soils. Agriculture, Ecosystems and Environment, 125: 48–56. https://doi.org/10.1016/j.agee.2007.11.005
23. Pichard G. 2012. Management, production, and nutritional characteristics of cup-plant (*Silphium perfoliatum*) in temperate climates of southern Chile. Ciencia e Investigación Agraria, 39: 61–77. https://doi.org/10.4067/S0718-16202012000100005
24. Raudonius S. 2017. Application of statistics in plant and crop research: important issues. Zemdirbyste-Agriculture, 104 (4): 377–382. https://doi.org/10.13080/z-a.2017.104.048
25. Roig N., Sierra J., Martí E., Nadal M., Schuhmacher M., Domingo J. L. 2012. Long-term amendment of Spanish soils with sewage sludge: effects on soil functioning. Agriculture, Ecosystems and Environment, 158: 41–48. https://doi.org/10.1016/j.agee.2012.05.016
26. Ros M., Hernández M. T., García C. 2003. Soil microbial activity after restoration of a semiarid soil by organic amendments. Soil Biology and Biochemistry, 35: 463–469. https://doi.org/10.1016/S0038-0717(02)00298-5
27. Singh R. P., Singh P., Ibrahim M. H., Hashim R. 2012. Land application of sewage sludge: physicochemical and microbial response. Reviews of environmental contamination and toxicology. Springer, p. 41–61. https://doi.org/10.1007/978-1-4614-0668-6_3
28. Slepetys J., Kadziuliene Z., Sarunaite L., Tilvikiene V., Kryzeviciene A. 2012. Biomass potential of plants grown for bioenergy production. International scientific conference Renewable Energy and Energy Efficiency. Jelgava, Latvia, p. 66–72.
29. Sort X., Alcañiz J. M. 1999. Effect of sewage sludge amendment on soil aggregation. Land Degradation and Development, 10 (1): 3–12. https://doi.org/10.1002/(SICI)1099-145X(199901/02)10:1<3::AID-LDR305>3.3.CO;2-S
30. Stanford G. 1990. *Silphium perfoliatum* (cup-plant) as a new forage. Proceedings of the 12th North American Prairie Conference. Cedar Falls, USA, p. 33–37.
31. Šiaudinis G., Jasinskas A., Šarauskis E., Steponavičius D., Karčauskienė D., Liaudanskienė I. 2015. The assessment of Virginia mallow (*Sida hermaphrodita* Rusby) and cup plant (*Silphium perfoliatum* L.) productivity, physico-mechanical properties and energy expenses. Energy, 93: 606–612. https://doi.org/10.1016/j.energy.2015.09.065
32. Usman K., Khan S., Ghulam S., Khan M. U., Khan M. A., Khalil S. K. 2012. Sewage sludge: an important biological resource for sustainable agriculture and its environmental implications. American Journal of Plant Science, 3: 1708–1721. https://doi.org/10.4236/ajps.2012.312209
33. Vance E. D., Brookes P. C., Jenkinson D. S. 1987. An extraction method for measuring soil microbial biomass C. Soil Biology and Biochemistry, 19: 703–707. https://doi.org/10.1016/0038-0717(87)90052-6
34. Voigt T. B., Lee D. K., Kling G. J. 2012. Perennial herbaceous crops with potential for biofuel production in the temperate regions of the USA. CAB Reviews, 7: 1–13. https://doi.org/10.1079/PAVSNNR20127015
35. WRB. 2014. World reference base for soil resources. World Soil Resources Reports No. 106. FAO, p. 187–189.
36. Вадюнина А. Ф., Корчагина З. А. 1986. Методы исследования физических свойств почвы. Москва, Россия, 416 с. (in Russian).

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Nuotekų dumblo vienkartinio panaudojimo įtaka geltonžiedžių legėstų biomasės derliui ir natūraliai rūgštaus dirvožemio savybių kaitai

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Santrauka

Siekiant įvertinti granuliuoto nuotekų dumblo įtaką geltonžiedžio legėsto (*Silphium perfoliatum* L.) produktyvumui, dirvožemio fizikinėms ir mikrobiologinėms savybėms, lauko eksperimentas buvo atliktas Vakarų Lietuvoje natūraliai rūgščiame balkšvažemio moreniniame priemolyje (Jlj6-b), kurio pH_{KCl} 4,3–4,9. Geltonžiedžių legėstų sausųjų medžiagų derlius nuosekliai didėjo nuo 2,96 (2013 m.) iki 13,0 (2016 m.) t ha^{-1}. Kiekvienais metais geltonžiedžių legėstų sausųjų medžiagų derliui optimalu buvo tręšimas 45 t ha^{-1} nuotekų dumblo. Ir 45, ir 90tha^{-1} nuotekų dumblo turėjo panašų teigiamą poveikį dirvožemio cheminės sudėties kaitai, vandeniui atsparių trupinėlių susidarymui, dirvožemio tankiui bei kietumui ir drėgmės kiekiui. Kiekvienais tyrimo metais dirvožemio mikroorganizmų biomasės anglies padidėjimui 0–30 cm gylyje didžiausią įtaką turėjo tręšimas 90 t ha^{-1} nuotekų dumblo.
Tyrimo rezultatai leidžia teigti, kad energinius augalus geltonžiedžius legėstus auginant balkšvažemio moreniniame priemolyje, juos tikslingiausia tręšti 45 t ha^{-1} granuliuoto nuotekų dumblo.

Reikšminiai žodžiai: dirvožemio cheminė sudėtis, dirvožemio mikroorganizmų biomasė, dirvožemio trupinėliai, produktyvumas, *Silphium perfoliatum*, tręšimas.