

Changes in soil carbon, nitrogen and sulphur content as influenced by liming and nitrogen fertilization of three energy crops

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ABSTRACT

An experiment with three perennial energy crops – common mugwort (*Artemisia vulgaris* L.), cup plant (*Silphium perfoliatum* L.) and virginia mallow (*Sida hermaphrodita* Rusby) has been carried out in Lithuania (55°43'N, 21°28'E) in order to evaluate the effect of liming and nitrogen fertilization on soil total carbon (C_{tot}), nitrogen (N_{tot}) and sulphur (S_{tot}) contents. The soil of the experimental site is a naturally acid moraine loam Bathyglyeic Dystric Glossic Retisol. Soil composition was analysed in two consequent years 2010 and 2011. The application of the highest rate (6 t ha⁻¹) of the lime material increased C_{tot} , N_{tot} and S_{tot} concentration in the top 0–30 cm soil layer. The soil under cup plant and virginia mallow accumulated a higher concentration of N_{tot} and S_{tot} compared to that under common mugwort. N fertilization significantly increased C_{tot} content, but had no significant impact on soil N_{tot} and S_{tot} changes.

Keywords: carbon, common mugwort, cup plant, nitrogen, soil sulphur, virginia mallow

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Tilraun með þrjár orkuplöntur; malurt (*Artemisia vulgaris* L.), bollafil (*Silphium perfoliatum* L.) og moskusrós (*Sida hermaphrodita* Rusby) var gerð í Litháen (55°43'N, 21°28'E) til að meta áhrif kölkunar og köfnunarefnisáburðargjafar á heildar kolefni (C_{tot}), köfnunarefni (N_{tot}) og brennistein (S_{tot}) í jarðvegi. Jarðvegur tilraunasvæðisins var á finkorna jökulruðningi sem er súr að eðlisfari (Bathyglyeic Dystric Glossic Retisol). Jarðvegur var greindur tvö ár í röð, 2010 og 2011. Hæsti skammtur af kalki (6 t ha⁻¹) leiddi til þess að C_{tot} , N_{tot} og S_{tot} jukust í efstu 30 cm jarðvegsins. Ræktun á bollafil og moskusrós leiddi til hækkunar á N_{tot} og S_{tot} í efri lögum jarðvegs miðað við þar sem malurt var ræktuð. Köfnunarefnisáburður leiddi til marktækrar aukningar á C_{tot} í jarðvegi en hafði engin áhrif á N_{tot} og S_{tot} í jarðvegnum.

INTRODUCTION

The main objective of the Kyoto protocol (1992) and the subsequent Doha conference (2012) was to reach an agreement to reduce global greenhouse gas (GHG) emissions. In this context, the European renewable energy directive 2009/28/EC (Directive 2009/28/EC, 2009) provides a legislative framework

for reducing GHG emissions by 20%, while achieving a 20% share of energy from renewable sources by 2020. One way to achieve this is to replace fossil fuel by renewable bioenergy fuel sources and energy crops (Clifton-Brown et al. 2007, Sarkhot et al. 2012). Energy crops are characterised by rapid growth and a large

amount of an annual low-moisture biomass compared to trees, and consequently a very large amount of residues left in the field (Borzecka-Walker et al. 2011). Many researchers state that perennial crops allow carbon accumulation and sequestration in the soil (Sladen et al. 1991, Bransby et al. 1998, Anderson-Teixeira et al. 2009). A highly important factor for carbon sequestration in the soil is that energy crops are grown for a long time in the same field. The ability of perennial grasses to effect change in soil properties is well documented (Blanco-Canqui 2010, Follett et al. 2012), but the information about soil changes specific to crops managed for bioenergy production in Lithuanian soil and climate conditions is limited. Perennial energy crops like *Panicum virgatum* L., *Miscanthus giganteus*, *Artemisia vulgaris* L., *Silphium perfoliatum* L., *Sida hermaphrodita* Rusby are projected to reduce reliance on fossil fuels, reduce GHG emission and enhance the rural economy. Further, most of the land dedicated to perennial bioenergy crops should be marginal cropland in order to avoid competition with food crops, decrease water pollution and reduce wind and water erosion (Schmer et al. 2011). Perennial grasses used for energy purposes are characterized by a high yield potential, deep root systems, require low fertilization input and conservative agricultural practices (Lewandowski et al. 2003), which determine the low soil organic matter mineralization (Lemus & Lal 2005). As a result, perennial energy grasses have the potential to accumulate C in the soil and diminish GHG emissions. Nitrogen fertilization stimulates root development, which in turn results in carbon accumulation (Schuman et al. 2002). Although the effects of liming on carbon sequestration are insufficiently studied, long-term experiments with perennial grasses show that lime application enhances the possibility of soil organic carbon (C_{org}) sequestration (Fornara et al. 2011). Soil productivity improves with increasing soil C_{org} content, which in turn retards the loss of N from fertilizer and agricultural waste (Bransby et al. 1998).

The above-ground biomass productivity, morphological and technological characteristics

of the energy crops investigated in our study were explored by Jasinskas et al. (2014). We chose to evaluate the content of C_{tot} , N_{tot} and S_{tot} due to their direct contribution to soil basic characteristics, such as aggregation and aggregate stability, soil buffering capacity, water holding capacity, fertility and soil biological quality.

The objective of this study was to ascertain the effect of unconventional agricultural crops – common mugwort, cup plant and virginia mallow — on soil quality in Western Lithuania's *Bathygleyic Dystric Glossic Retisol*.

MATERIALS AND METHODS

A field experiment has been conducted in the Vėžaičiai Branch (LAMMC) (55°43'N, 21°28'E) since 2008. The soil of the experimental site is a naturally acid moraine loam *Bathygleyic Dystric Glossic Retisol* (WRB 2014). Before the experiment, topsoil pH (1M KCl, w/v 1:2.5) ranged between 4.25 and 4.85, and the content of available phosphorus (P) and potassium (K) determined by Egner-Riehm-Domingo AL-method (Egner et al. 1960) was 15–52 mg kg⁻¹ and 116–173 mg kg⁻¹, respectively; hydrolytic acidity values determined according to *Kappen* method (Kappen, 1929) were 35.1–62.1 cmol kg⁻¹; the content of exchangeable aluminium (Al), determined according to the Sokolov method (Barnhisel & Bertsch, 1982) using 1 M KCl for displacing Al ions, ranged between 10.7 and 50.9 mg kg⁻¹.

The experiment was laid out in a two-factor design, including 3 levels of liming: without liming, 3 t ha⁻¹ and 6 t ha⁻¹ of liming material, and two levels of nitrogen (N) fertilization: 0 and 120 kg ha⁻¹. The experimental plots were limed with Opokos (powdered limestone), which contains up to 30% of CaCO₃ on the 20th of April, 2008. The seedlings of common mugwort were planted on the 27th of May, and seedlings of cup plant were planted at a 2–3 leaf stage on the 3rd of June, 2008.

The experimental site was divided into three strips with different soil pH levels. All nitrogen treatments were arranged randomly with three replications for each pH (different liming)

background. Since 2009, mineral fertilization has been applied each year before the beginning of the test crops' growth in mid-April. Ammonium nitrate was applied as N fertilizer. Single superphosphate and potassium chloride were used as P and K fertilizers. The 120 kg ha⁻¹ N rate was split and applied twice (60+60 kg ha⁻¹), in the middle of April and in the beginning of July. The annual rate of phosphorus and potassium fertilization was 26 kg P ha⁻¹ and 50 kg K ha⁻¹ respectively.

Eight sub-samples per plot were taken randomly with a steel auger from 0–30 cm depth and a composite sample was formed for each plot. The samples were collected in 2010 and 2011 at the end of plant vegetation (beginning of October) from two limed strips in the 0 and 120 kg ha⁻¹ N fertilization treatments from three field replicates. All samples were air-dried, and visible roots and plant residues were manually removed. Then the samples were crushed, sieved through a 2-mm sieve and homogeneously mixed. For the analysis of soil C_{tot}, N_{tot} and S_{tot} an aliquot of the soil samples was passed through a 0.25-mm sieve. The soil C_{tot}, N_{tot} and S_{tot} contents were determined by a dry combustion (Dumas) method using a fully automatic CNS analyser Vario EL IIII (Elementar, Germany). All data were expressed on an oven-dry basis.

The experimental data for all three soil parameters were statistically processed using analysis of variance (*Anova*) as a three factorial randomized block variant to determine significant differences between means (*P<0.05 and **P<0.01) and *LSD*₀₅ and at a 0.05 probability level (Tarakanovas & Raudonius 2003).

RESULTS

Analysis of variance was used to evaluate the effect of crop species (Cr), liming rate (L) and nitrogen rate (N) and their interactions. The data are presented in Table 1. According to Fisher's criterion, crop and liming rates were determining factors affecting the contents of C_{tot}, N_{tot}, and S_{tot} in a naturally acid *Bathygleyic Dystric Glossic Retisol* (P<0.01 and P<0.05). The analysis

Table 1. Fisher criterion's mean squares for organic carbon (C_{tot}), total nitrogen (N_{tot}) and total sulphur (S_{tot}) as affected by crop species (Cr), liming (L) and nitrogen rate (N)

Variable	Total carbon (C _{tot})	Total nitrogen (N _{tot})	Total sulphur (S _{tot})
Crop (Cr)	5.99*	815*	17.5*
Liming rate (L)	4.49*	16.9*	6.69*
Nitrogen rate (N)	0.99	0.94	0.80
Cr x L	3.97*	13.6*	2.34
Cr x N	0.93	0.62	0.36
L x N	4.69	0.24	0.13
Cr x L x N	1.43	0.24	0.13

* - significant at P<0.05 level

also indicated that different crops and different liming rates had an unequal impact on the soil's chemical content. Thus, the interaction between crop species and liming rate (Cr x L) positively influenced soil carbon (C_{tot}) and total nitrogen (N_{tot}) content (P<0.01 and P<0.05). On the other hand, the effect of the nitrogen rate (N) on the studied parameters was insignificant. The interactions of other parameters (Cr x N, L x N and Cr x L x N) were also statistically insignificant.

The results shown in Figure 1 suggest that liming at a 6 t ha⁻¹ rate had a positive impact on the accumulation of C_{tot} irrespective of energy plant species tested (P<0.01). After 2 years of energy crop cultivation, soil C_{tot} significantly increased in the 0–30 cm soil layer, compared with the unlimed treatment. The C_{tot} content increased from 8.25 to 14.16 g kg⁻¹ under cup plant, and from 9.85 to 13.61 g kg⁻¹ under virginia mallow. Meanwhile the effect of liming on soil C_{tot} content under common mugwort was insignificant. N fertilization significantly increased the C_{tot} content in the upper soil layer for all three plants.

The data from our study suggest that liming with 6 t ha⁻¹ of liming material had a substantial impact on the soil N_{tot} increase under cup plant only (Figure 2). Conversely, the N_{tot} content

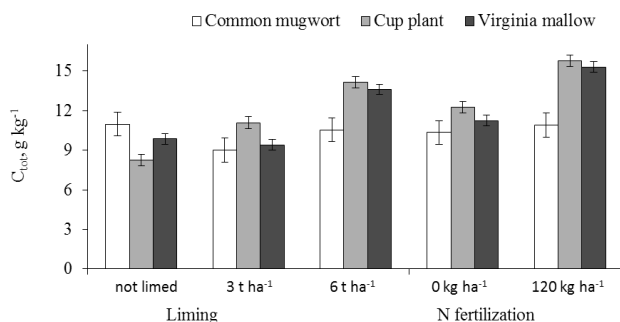


Figure 1. The content of C_{tot} in the soil (0–30 cm) under common mugwort, cup plant and virginia mallow as affected by liming and fertilization. Average of 2010–2011.

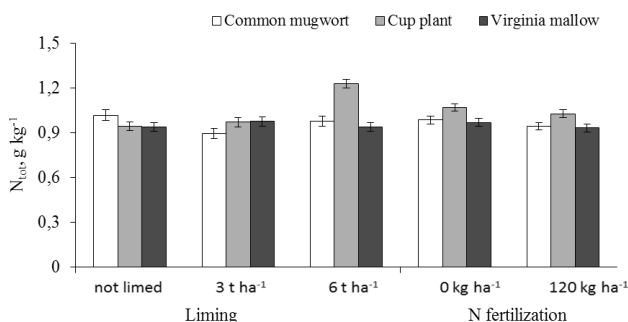


Figure 2. The content of N_{tot} in the soil (0–30 cm) under common mugwort, cup plant and virginia mallow as affected by liming and fertilization. Average of 2010–2011.

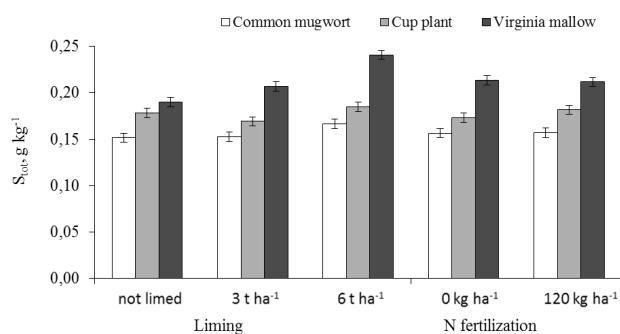


Figure 3. The content of S_{tot} in the soil (0–30 cm) under common mugwort, cup plant and virginia mallow as affected by liming and fertilization. Average of 2010–2011.

decreased from 1.02 (without liming) to 0.898 (liming with 6 t ha⁻¹) under common mugwort. The N_{tot} content under virginia mallow remained stable. The highest N_{tot} content was observed under cup plant. However, no significant changes in soil N_{tot} resulting from the N fertilization were established, possibly due to the ability of plants to utilise soil nutrients.

No S fertilizer was applied prior to or during the experimental period. The concentration of S_{tot} was substantially higher under virginia mallow compared with common mugwort and cup plant (Figure 3). The highest S_{tot} content was found in the soil applied with 6 t ha⁻¹ liming rate – from 0.17 g kg⁻¹ under common mugwort to 0.24 g kg⁻¹ under virginia mallow. N fertilization had no significant effect on S_{tot} content.

The experimental results indicated that liming improves the rooting system (particularly of cup plant and virginia mallow), which in turn enhances the uptake of mobile nutrients (including N and S) from deeper soil layers. In the soil under cup plant, soil liming tended to decrease $C_{\text{tot}}:N_{\text{tot}}$ ratio from 15.7 to 10.4; meanwhile 120 kg ha⁻¹ N application had the opposite tendency. It seems that neither liming nor N application had significant impact on $C_{\text{tot}}:N_{\text{tot}}$ ratio under the other two crops tested – common mugwort and virginia mallow (Table 2). The data of the current study (Table 2) showed that the $C_{\text{tot}}:S_{\text{tot}}$ ratio also varied in response to liming, N fertilization, as well as cultivated plant species. In all the cases, the application of 3 t ha⁻¹ liming and 120 kg ha⁻¹ N fertilization caused a significant decrease in the $C_{\text{tot}}:S_{\text{tot}}$ ratio. Although statistically significant, the influence of liming and 120 kg ha⁻¹ N application on $N_{\text{tot}}:S_{\text{tot}}$ ratio was less obvious. Soil C_{tot} content positively correlated with $C_{\text{tot}}:N_{\text{tot}}$ ratio (+0.92

Table 2. The ratios of $C_{tot} : N_{tot}$, $C_{tot} : S_{tot}$ and $N_{tot} : S_{tot}$ in the soil (0–30 cm) under common mugwort, cup plant and virginia mallow as affected by liming and fertilization. Average of 2010–2011. Different letters indicate significant differences ($P < 0.05$).

Factor	Common mugwort	Cup plant	Virginia mallow	Common mugwort	Cup plant	Virginia mallow	Common mugwort	Cup plant	Virginia mallow
	$C_{tot} : N_{tot}$			$C_{tot} : S_{tot}$			$N_{tot} : S_{tot}$		
<i>Liming t ha⁻¹ CaCO₃</i>									
Not limed	10.5 a	15.7 a	10.3 a	106.7 a	110.8 a	67.1 a	9.60 a	7.08 a	6.43 a
3 t ha ⁻¹	10.0 a	11.5 b	9.83 b	79.0 b	95.5 b	52.4 c	7.93 b	7.95 a	5.34 b
6 t ha ⁻¹	10.4 a	10.4 b	11.5 c	76.9 b	93.5 b	60.8 b	7.72 b	9.89 b	5.27 b
<i>LSD</i> ₀₅	0.52	2.47	0.25	13.5	9.47	7.54	0.98	1.16	0.46
<i>Nitrogen fertilization kg ha⁻¹</i>									
0 kg ha ⁻¹	10.3 a	11.7 a	10.7 a	93.3 a	95.5 a	63.3 a	8.89 a	8.97 a	5.91 a
120 kg ha ⁻¹	10.4 a	13.4 a	10.4 b	81.8 b	81.7 b	56.9 b	7.94 b	7.64 b	5.46 a
<i>LSD</i> ₀₅	0.36	1.75	0.18	9.53	6.63	5.33	0.69	0.82	0.65

for common mugwort, and +0.87 for virginia mallow). In all cases, S_{tot} content in the soil negatively correlated with $C_{tot} : S_{tot}$ ratio (-0.85 for common mugwort, -0.85 for cup plant and -0.88 for virginia mallow), and with $N_{tot} : S_{tot}$ ratio (-0.91 for common mugwort, -0.91 for cup plant, and -0.93 for virginia mallow).

DISCUSSION

The potential of herbaceous energy crops to contribute carbon to the soil has been demonstrated by numerous authors (Lemus & Lal 2005, Clifton-Brown et al. 2007, Anderson-Teixeira et al. 2009, Blanco-Canqui 2010, Schmer et al. 2011, Borzecka-Walker et al. 2011, Follett et al. 2012, Sarkhot et al. 2012). The soil cations influenced the accumulation and sequestration of C_{tot} because high concentration of cations protected C_{tot} against decomposition (Manna et al. 2007, Morris et al. 2007). The calcium cations were especially important because their high concentration was introduced into the soil with liming. Soil C_{tot} tended to decline due to N fertilizer use.

Higher C_{tot} contents were recorded in cup plant and virginia mallow treatments, compared with common mugwort treatment; however, the differences were statistically insignificant. Cup plant and virginia mallow form a larger root system in the upper soil layer, which enhances C_{tot} accumulation and improves soil fertility. Thus, both means had a significant impact on the transformation of plant residues in the soil, and thus on C_{tot} accumulation.

Our data agree with the findings of other researchers suggesting that the application of lime and N fertilization has a positive impact on soil C_{tot} . It has been reported that soil pH and C content increase in the rhizosphere zone in response to liming (Repšienė 2003). Besides liming, other factors may have indirect influence on soil carbon accumulation: abundant root mass of energy crops, organic residues, leaf debris, root secretions are transformed into soil organic matter, humus and other soil-related elements. The increase of soil carbon levels over longer periods occurs due to the perenniality of crops and a large amount of unharvested roots. Yet, it

may take several years before any increases are detectable (Ma et al. 2000).

Subsequently, both liming and N fertilization had a substantial positive effect on the above-ground biomass content (Šiaudinis et al. 2012, Jasinskas et al. 2014).

Our results corresponds to the data of many researchers, that N fertilization can increase C_{tot} because of the enhanced above-ground and below-ground biomass production (Lemus & Lal 2005, Clifford-Braun et al. 2007, Schmer et al. 2011, Follett et al. 2012).

Sulphur (S) is also an important nutrient. However, the available of S in the soils of Lithuania as well as in other European countries is insufficient. Liming not only neutralizes soil acidity and improves soil chemically, but also influences S regime in the soil and can reduce the amount of mobile S in the soil by up to 7–8 times (Guryš & Aksomaitiene 2005). An adequate S availability for plants depends on several factors, including moisture, temperature regimes, pH as well as C_{tot} : S_{tot} and N_{tot} : S_{tot} ratios in the soil (Sachs & Luff 2002). A strong relationship among C_{tot} , N_{tot} and S_{tot} in the non-calcareous soils has been proven by Williams et al. (1960). The soil C: N ratio is considered to be an important indicator which characterizes the degree of organic matter decomposition in the soil (Tejada et al. 2008, Govaerts et al. 2009). However, in our trials, longer time observations are need to evaluate the changes of C: N ratio as well as their dependence on crop species or agrotechnical means. Yet in our study, a strong relationship was established between the N_{tot} and S_{tot} ; however, the N_{tot} : S_{tot} ratio was rather moderate.

By cultivating such energy crop species as miscanthus and switchgrass, which have a deep root system, the content of carbon and nitrogen has a tendency to increase in the upper soil layer (Fisher et al. 1994, Kahle et al. 2001). The use of 6 t ha⁻¹ lime material had a positive impact to increase soil mineral nutrients concentrations. Overall, substantially higher concentration of N_{tot} and S_{tot} accumulated in the soil under cup plant and virginia mallow compared with that under common mugwort. In all the treatments,

the effect of nitrogen fertilization had a positive impact on soil C_{tot} content only. The current study is ongoing.

CONCLUSIONS

According to the results of the soil analyses in the current study, irrespective of energy crops species, the application of lime material had a positive impact on increasing C_{tot} , N_{tot} and S_{tot} concentrations in the top soil layer. By setting the target to reduce CO₂ emissions into the atmosphere, the higher importance has C sequestration in soil organic matter. We expect that these long-term experiments will help to comprehensively highlight and validate the dynamics of different soil nutrients (in particular, soil carbon) in response to energy crop species grown, liming and fertilization applied.

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