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Liming effect on soil organic matter quality in grassland

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Abstract

Global carbon storage in soils is widely discussed today because of climate uncertainty and maintaining sustainable agricultural production. Human intervention in agricultural or energy production poses many changes in soil management, which highly affects soil quality/health. Permanent grasslands fulfil a wide range of ecosystem functions and have a high potential for increasing arable land. Today, grasslands are becoming more and more intensively used, fertilized and disturbed. Optimizing their management is essential to maintain a resilient and stable ecosystem. The produced biomass is used as a forage or for energy production. We aimed at the impact of long-term grassland liming on the total content of soil organic carbon (SOC), humic substances (C_{HS}), and microbial biomass (C_{mic}). Furthermore, soil reaction and available nutrient content were evaluated. Soil samples were collected from a split-plot field experiment at Mendel University in Brno (locality Kameničky). The soil was classified as Dystric Planosol Siltic, medium textured, strongly acidic, with high soil organic carbon content. The yearly liming rate was 1.4 t/ha CaO. The linkage between the soil pH, SOC, C_{mic}, and available nutrient content was evaluated by the multivariate exploratory techniques and regression models. Results showed that long-term liming affects both soil biota and carbon storage.

1. Introduction

The atmosphere-climate system is closely connected with microbial activity and it is supposed that soil respiration is the main process by which carbon dioxide is emitted from the terrestrial ecosystem into the atmosphere (Deng et al., 2016). Managed temperate grasslands play a very important role in this process and may affect global climate change. Among the other crucial functions of grassland is the ability to create, accumulate, and transform organic material and water. Carbon stock level in grasslands significantly follows the management practice and increases with the conversion from arable soil to grasslands (Deng et al., 2016). The global carbon budget is widely discussed today not only because of climate change but also because of the importance of maintaining the forage yields with no negative consequences for animals, humans, soil and the environment. However, human intervention and reclamation may significantly affect or alter soil properties (Song et al., 2014; Bordonal et al., 2017). Various factors (e.g. habitat specifics, plant groups, climatic conditions, water regime, soil properties, etc.) need to be considered. Grassland management, in particular the cutting system, fertilisation, and restoration of native and semi-natural grasslands should be taken into account in the context of expected climate change and temperature increases (Sollenberger, 2019; Mayel, 2020).

In the Czech Republic, grasslands are usually used extensively without any nutrient application. Some grassland areas are also left unused as fallow lands. Today, there are no common instructions regarding agricultural practices such as mowing, fertilizing, liming, and water regime regulation. The absence of grassland management practices may cause many environmental problems (e.g. erosion, acidification, soil depletion, water contamination etc.). Soil acidification is one of the serious soil degradation processes and there are approximately 45% of acidic soils in the Czech Republic. These less favourable conditions generate changes in soil chemical and biological properties. Being mostly established by people grasslands mainly provide forage for animals, which accelerate by incorrect practices. Increasing management intensity may also generate negative changes in the soil-vegetation-live stock-food chain system (Duffkova et al., 2005; Hejcman et al., 2010; Beneš, 2013).

Grassland liming and fertilizing are recommended for maintaining the better current status of the soil environment. This is a common management technique used not only on arable land but also on pastures, meadows, and forest stands (Upjohn et al., 2005). On one hand, there is food security and on the other the soil degradation due to the additional application of acidic fertilizers (Holland et al., 2018; Frank et al., 2019). Therefore, fertilizing must be decided primarily according to the soil type, culture, and land management (e.g. arable land, orchards, vineyards, grasslands). Unfortunately, the soil type is not frequently considered despite the duration of nutrients and liming's effect depending on soil type, texture, and soil reaction. The ameliorative liming modifies soil reactivity in the shortest time horizon. Usually, crushed limestone, dolomitic limestone, calcium oxide, calcium hydroxide, and lime mud are used as the most frequent calcium ameliorants (Filep and Szili-Kovacs, 2010; Mosley et al., 2015). Lately, also ash and biochar are applied to the soil to affect soil porosity, water holding capacity, soil pH, cation exchange capacity, and nutrient content Lehman et al. (2020). Contrary, Zhang et al. (2016) showed that biochar had even a negative effect on plant growth. Plants and soil biota are very sensitive indicators of the effect of amended materials on the soil Blanchet et al. (2016). As the soil biota is maintaining ecological services it enhances the sustainability of the whole ecosystem. Biota's metabolic activity is regarded as a sensitive indicator of soil quality/health. Any disturbance of soil biota causes changes in the intensity of mineralization and humification processes. Besides, the high microbial activity may indicate also the stress of the microbial community, and as a result, the humic substances (HS) are decomposed before they can be humified (Condron et al., 2010; Zhao et al., 2014; Zornoza et al., 2015). However, extreme negative impacts on ecosystems and the services they provide have been reported following the long-term application of inorganic fertilizers; such impacts have included increased nitrate and soil acidification (Zhao et al., 2020), reduced soil microbial diversity and richness (Dai et al., 2018).

To clarify these issues, we aimed to: (1) examine the effects of liming on soil chemical properties; (2) understand the effect of liming on microbial community richness; and (3) assess the relevance between soil microbial communities and soil organic matter quality.

Understanding and predicting changes in soil biological and chemical properties could help to predict and improve carbon balance and management of grassland soils.

The objective aims at the relationship between the soil organic matter content and quality and the amount of microbial biomass after liming.

2. Material and methods

The experimental area is located in the Czech-Moravian Highland. The altitude is 650 m a.s.l., the mean annual air temperature is 5.8°C, and the mean annual precipitations are 758 mm. The natural meadow ecosystem of the *Polygalo-Nardetum strictae* type is widely distributed in submontane and montane areas of the Czech Republic. The forage production is poor and fodder has low quality, and is not usually harvested. As a result, degeneration, waterlogging and natural afforestation occurred in this area. The experimental plots were designed in 2014 and have been carried out till now. The experiment was arranged as a split-plot design with four replicates and the rectangle area is approximately 5 m^2. Grassland is managed with a two-cut system and the ameliorative liming dose is 1.4 t·ha^{-1} of CaO. Characterization of the liming material is as follows: natural limestone, standard quality, 54 (equivalent CaO). Granulometry by dry sieving: 90% by mass passing through a sieve 1 mm. The instruction of the Central Institute for Supervising and Testing in Agriculture for liming was used (Decree No. 275/1998 Coll.). Applied manually, uniformly, and incorporated in the soil. The first application was in the spring of 2014. Subsequently, liming followed always in the autumn during 2015–2022 in the stated dosage. The recommended dosage therein for medium-textured, extremely acid soils is 0.7 t·ha^{-1} of CaO and the maximum single dose is 3 t·ha^{-1} (guidelines valid for the Czech Republic). Soil type was classified according to IUSS WRB (2022) as Dystric Planosol Siltic, on a gneiss diluvium. Horizons signature and sequence were done according to Němeček et al (2011). Textural classes within the soil profile were: Adn (0.5–0.15 m): sand = 33.5%, silt = 38.15%, clay = 28.35% (Loam); En (0.20–0.30 m): sand = 25.60%, silt = 43.30%, clay = 31.10% (Clay Loam); Bm (0.40–0.65 m): sand = 43.60%, silt = 26.40%, clay = 30.00% (Clay loam); Cg (> 0.65 m): sand = 50.60%, silt = 25.40%, clay = 24.00% (Sandy Clay Loam).

Soil samples were collected from the topsoil (5–15 cm) every year, always in spring and autumn during 2014–2022. Basic soil chemical properties were determined by standard analytical methods (Zbíral et al., 2016). Air-dried soil samples were screened through a 2 mm sieve. Then, soil particle size analysis was performed by the pipette method. Soil reaction was measured in 1:2.5 suspension in water and 1M KCl using a Hanna pH meter (HI 98120, Hanna Instruments, USA, 2015). Total organic carbon (SOC) was determined by the oxidimetric titration method (Nelson and Sommers, 1996; Sparks, 2003). Humic substances (HS) fractional composition was evaluated by the short fractionation method (Kononova, 1963; Horáková, 2020). Total nitrogen (Nt) was determined according to ISO 13878:1998. The Mehlich-III method was used for the available nutrients' determination (Mehlich, 1984).

Biological properties were determined from the samples collected in plastic bags and incubated for one month at 5°C in a refrigerator. The amount of microbial biomass was measured using the fumigation-extraction method according to Vance et al. (1987). C/N and Cmic and SOC ratios were determined as widely accepted indicators of microbial activity (Horáková et al., 2020).

Statistical analysis was displayed by STATISTICA (data analysis software system, version 14, TIBCO Software Inc., Palo Alto, USA, 2022) and QC Expert 3.3 Pro (TriloByte Statistical Software Ltd., Pardubice, Czech Republic). For the statistical evaluation Exploratory Data Analysis (EDA), analysis of variance (ANOVA), Tukey test (HSD test), Fisher's LSD test (LSD test) and linear regression models by regression triplet were used according to Meloun and Militký (2011). Linear regression modelling used the regression triplet Meloun and Militký (2011) and consisted of the following steps: (1) model design, (2) preliminary data analysis (multicollinearity, heteroskedasticity, autocorrelation and influence points), (3) estimation of parameters using the classical least squares method (LSM) and subsequent testing of the significance of parameters using the Student's t-test, mean square error of prediction, and Akaike information criterion (AIC), (4) regression diagnostics–identification of influence points and verification of the LSM assumptions, and (5) construction of the refined model. Statistical significance was assessed at a significance level of 0.05.

3. Results and discussion

The texture of Dystric Planosol Siltic within soil profile: horizon Adn (0.5–0.15 m): sand = 33.5%, silt = 38.15%, clay = 28.35%, horizon En (0.20–0.30 m): sand = 25.60%, silt = 43.30%, clay = 31.10%, horizon Bm (0.40–0.65 m): sand = 43.60%, silt = 26.40%, clay = 30.00%, and horizon Cg > 0.65 m: sand = 50.60%, silt = 25.40%, clay = 24.00%. Soil reaction before liming (active = pH/H2O and exchangeable = pH/KCl) was extremely acidic (pH/H2O < 5.0; pH/KCl < 4.5). The extremely acidic soil reaction remained stable (pH/KCl = 4.2–4.3) on the control site during the whole experiment. After liming the acidity decreased and the pH/KCl values increased up to 4.9. The average exchangeable soil reaction on the liming site was 4.65. The differences between the control and liming sites were statistically significant – see Fig. 1. Documented results in Fig. 1 represent differences between the data obtained in spring and autumn during the period 2014–2022.

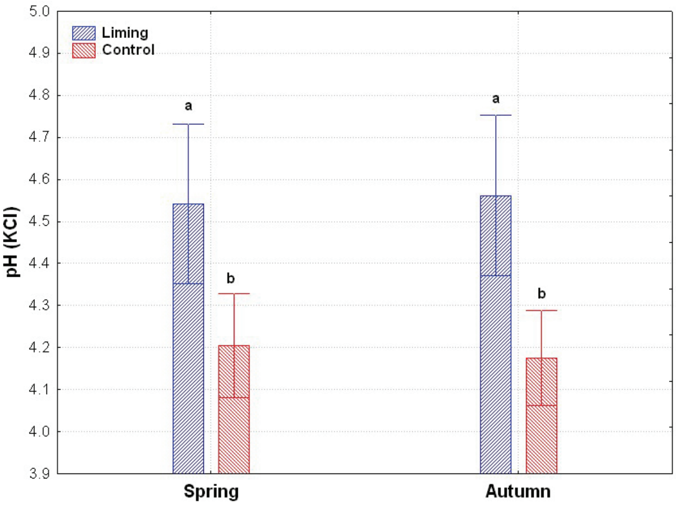

Fig. 1. Average values of exchangeable soil reaction (pH/KCl) obtained in spring and autumn during the period 2014–2022 (where: blue-liming site; red-control site).

The SOC content decreased by 0.4–0.5% on the liming site (Fig. 2). The statistically significant differences between control and liming sites were found. There is a close relationship between the HS and the SOC contents. In Fig. 3, it is documented decrease of the HS is approximately 1.5–2.0 g kg^{-1} on liming site. But the differences between control and liming sites were not statistically significant. Similarly, the HA content fell slightly after liming but the differences were not statistically significant. The average values of the HA/FA ratio stood at 0.77–0.82, and no statistically significant differences were found. Documented results in Fig. 2 and 3 represent differences between the data obtained in spring and autumn during the period 2014–2022.

Literature data showed that liming can have a positive or negative effect on permanent grassland soils. Furthermore, Paradelo et al. (2015) and Sapek and Burzynska (1996) did not find any changes in soil organic carbon content after liming. Fornara et al. (2011) evaluated data from 129 year's long-term experiments in Rothamsted and concluded that organic carbon increased in arable soils after liming. Our research showed that natural vegetation was adapted to the current soil reaction. Therefore after liming biomass production was lower and maybe this was the reason why soil carbon content decreased. It may be also caused by poor quality vegetation, specific soil condition and water regime, and low biomass. It was suggested to combine the soil liming with the change of vegetation and improve the soil water regime. More biomass – aboveground and belowground, resp. increasing grass yields is a benefit for SOC stock increase.

Measured values of C/N ratios are shown in Fig. 4. Differences between variants were statistically significantly higher after lim-

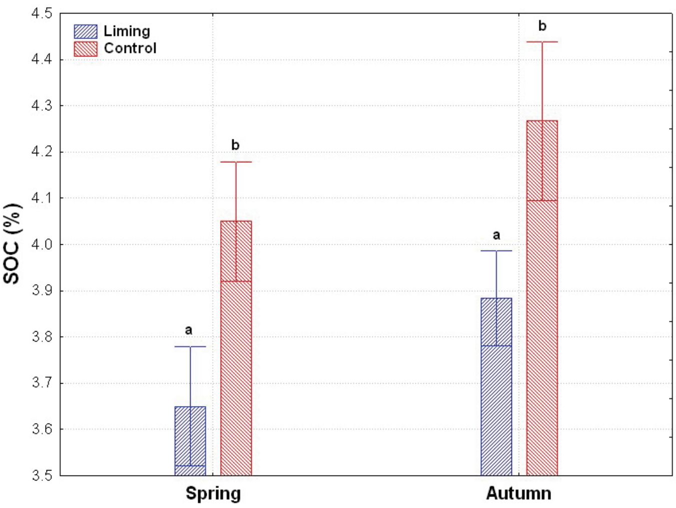

Fig. 2. Average values of total organic carbon (SOC) obtained in spring and autumn during the period 2014–2022 (where: blue-liming site; red-control site).

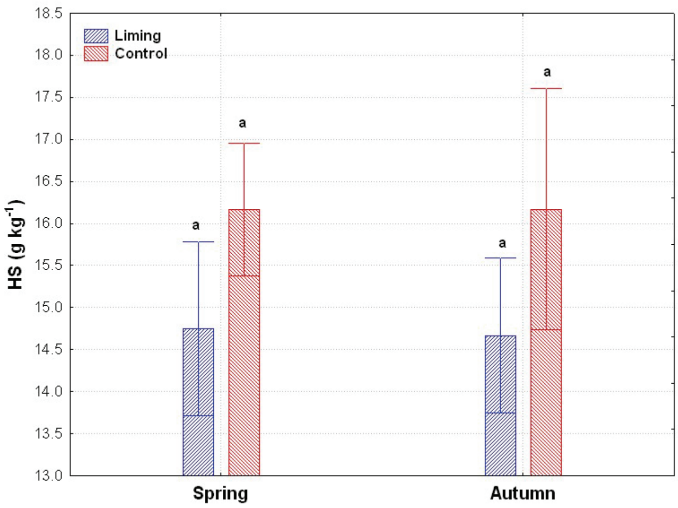

Fig. 3. Average values of humic substances (HS) content obtained in spring and autumn during the period 2014–2022 (where: blue-liming site; red-control site).

ing. Total nitrogen content varied between 0.24–0.45% and total organic carbon content varied between 3.6–4.4%. As a result, the C/N ratio was higher on the control site and lower after liming. Because of the narrower C/N ratio (less than 10), there are more favourable conditions for soil biota on liming site – see Fig. 4. Documented results in Fig. 4 represent differences between the data obtained in spring and autumn during the period 2014–2022.

Obtained values of available nutrients such as P, K, Mg, and Ca are given in Fig. 5–8. Results showed that on liming site the amount of available phosphorus increased up to 60 mg kg^{-1}. The average content available phosphorus was higher after liming but the differences were not statistically significant. Similarly, potassium and calcium contents were higher on liming site but the differences were not statistically significant. The opposite situation showed magnesium. The average content of magnesium was significantly lower after liming. Documented results in Fig. 5–8 represent differences between the data obtained in spring and autumn during the period 2014–2022.

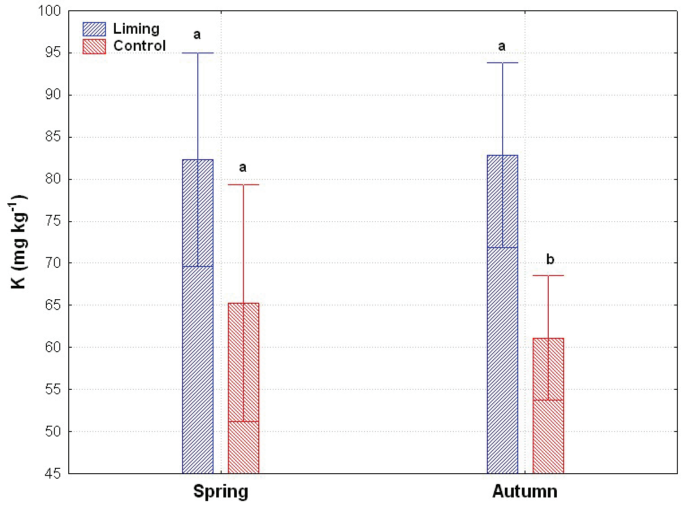

Fig. 6. Average values of available potassium obtained in spring and autumn during the period 2014–2022 (where: blue-liming site; red-control site).

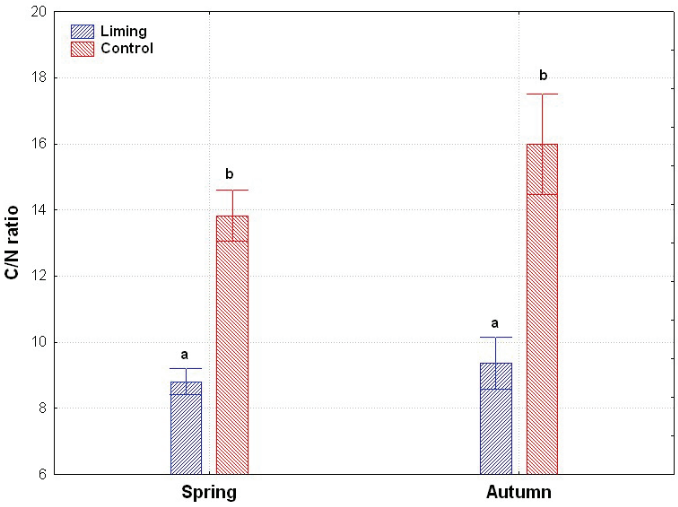

Fig. 4. Average values of C/N ratio obtained in spring and autumn during the period 2014–2022 (where: blue-liming site; red-control site).

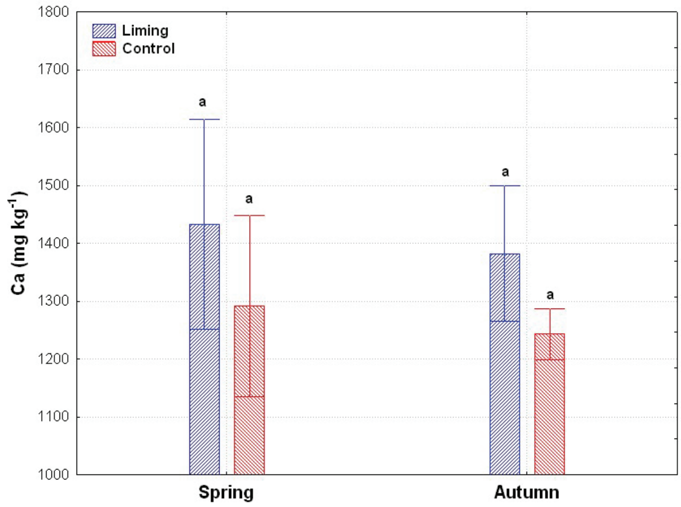

Fig. 7. Average values of available calcium obtained in spring and autumn during the period 2014–2022 (where: blue-liming site; red-control site).

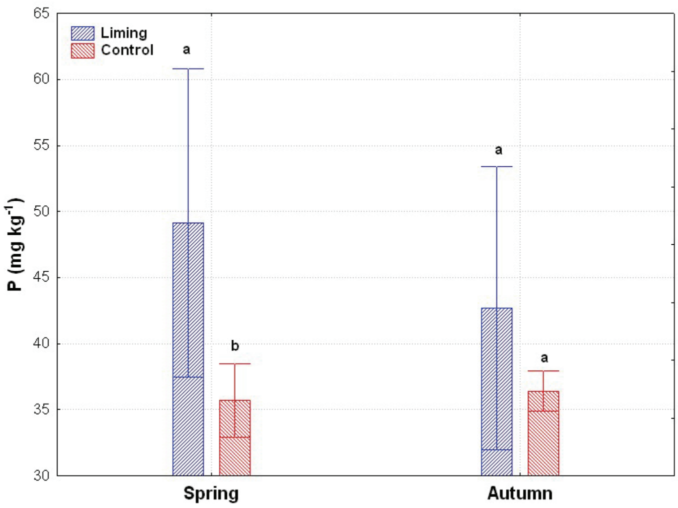

Fig. 5. Average values of available phosphorus obtained in spring and autumn during the period 2014–2022 (where: blue-liming site; red-control site).

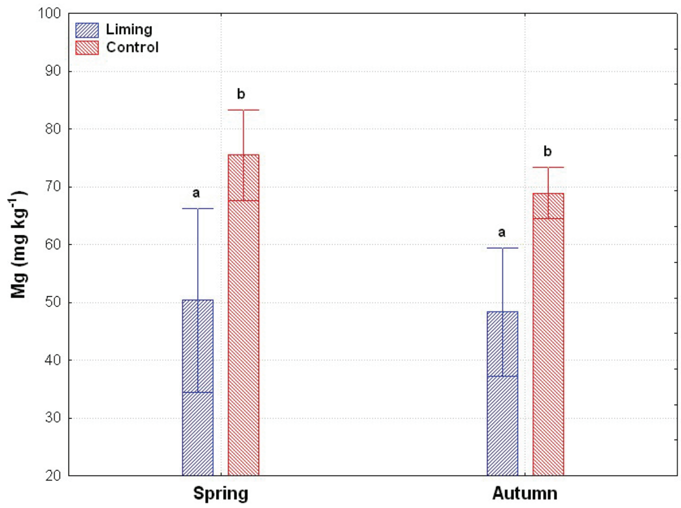

Fig. 8. Average values of available magnesium obtained in spring and autumn during the period 2014–2022 (where: blue-liming site; red-control site).

In general, the amount of microbial biomass (Cmic) was a very dynamic and changeable parameter. The average C mic content was statistically significantly higher after liming. Based on regression modelling (Fig. 9 and 10) the correlation between the pH and Cmic, and Cmic and SOC was confirmed. The correlation between pH/KCl and Cmic was 0.6465, and between Cmic and SOC, it was –0.7843. The models were significant according to the Fisher-Snedecor model significance test (pH and Cmic: F = 11.4908, quantile F = 4.4908, p = 0.0037; Cmic and SOC: F = 23.1756, quantile F = 4.4513, p = 0.0001). The models were correct according to Scott's criterion of multicollinearity (SC = 0.1908 and –0.4586). Residues in both models have a normal distribution (Jarque-Berr normality test) and autocorrelation was insignificant (Wald's autocorrelation test).

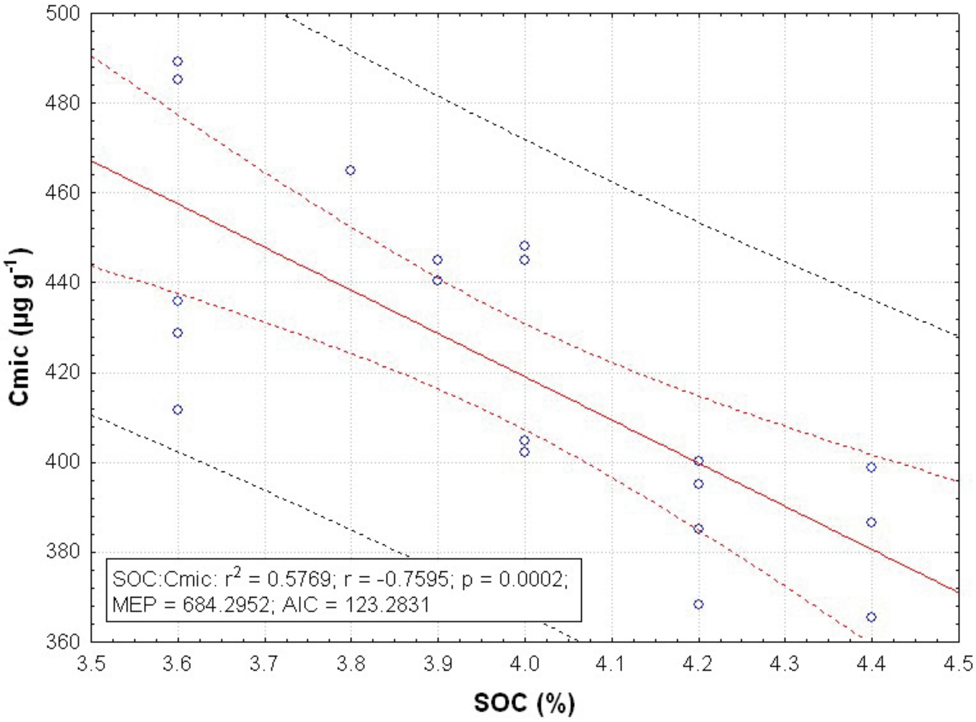

Fig. 9. Correlation between exchangeable soil reaction (pH/KCl) and amount of soil organic carbon (SOC).

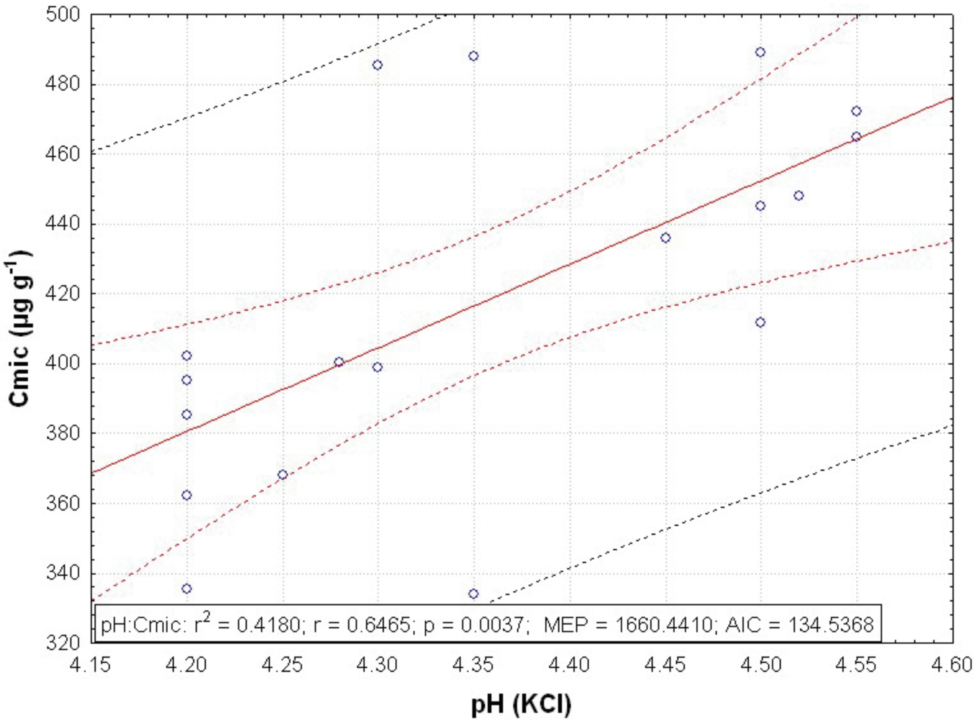

Fig. 10. Correlation between exchangeable soil reaction (pH/KCl) and amount of microbial biomass (Cmic).

The metabolic efficiency of soil biota was also studied by Hobley et al. (2016). They showed significant variations in the SOC stock levels in different land-use and managed areas with the same soil type. They evaluated the amount of microbial biomass and Cmic/SOC ratio and concluded that a higher Cmic/SOC ratio gave greater nutrient immobilization for plants. Such changes may have a strong effect on plants. It is supposed that human activities and geographic characteristics are key factors affecting the SOC spatial distribution. Li et al. (2019) and Ondrasek et al. (2019) studied the organic carbon sequestration and humic substance fractions as affected by nitrogen application. They stressed the coupling relationship between carbon and nitrogen content in the soil and similarly to us concluded that the narrower C/N ratio means more favourable conditions for soil biota. Lehman et al. (2020) and Kallenbach et al. (2016) showed that soils have a high potential to sequestrate organic carbon and draw down atmospheric carbon dioxide. Achieving this requires better knowledge and modelling of coupling organic carbon input and biological soil parameters. The stability and decomposition rate of organic materials depends on the microbial spectrum, diversity and activity. Therefore, the complexity of soil biological and chemical parameters is important for the proper modelling of soil organic carbon stock. Functional complexity is also important to generate soil management recommendations in agricultural practices. Therefore, there is a need to focus on ongoing care to manipulate the organic carbon balance (inputs and losses), rather than rely on locking away carbon in the soil for the long term. Chen et al. (2020), Tang et al. (2015) and Lange et al. (2015) evaluated soil microbial activity and soil carbon storage as affected by plant diversity. They quoted that a mixture of organic inputs and a diversity of plant species stimulated the activity of soil biota. It was shown the soil biota´s importance in carbon sequestration and the humification rate. They concluded that quantifying soil biological properties and their modelling for global applications will not be easy because of high variability and heterogeneity. In the near term, this challenge may be resolved by measuring carbon-relevant responses to a change in land cover or use, soil properties or climate etc. All these findings are important for protecting grasslands, and improving their quality and management system as they have a huge potential as future arable land sources.

4. Conslusions

Dystric Planosol after ameliorative liming showed a statistically significant increase in exchangeable soil reaction. Total soil organic carbon content statistically significantly decreased by 0.4–0.5%. The decrease in the content of the humic substance after liming was not statistically significant. The correlation between pH and microbial biomass, and between total organic carbon content and microbial biomass was documented based on linear regression modelling. Further research is necessary to improve the knowledge about the relationship between carbon sequestration and soil microbial activity, the intensity of mineralization and nutrient release, and humification processes.

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