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ORIGINAL PAPER

CHANGES IN THE SOIL CONTENT OF ORGANIC CARBON NITROGEN AND SULPHUR IN A LONG-TERM FERTILISATION EXPERIMENT IN CZARNY POTOK (POLAND)*

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Abstract

The paper discusses fluctuations, including the underlying causes, in the organic carbon, nitrogen and sulphur content of meadow sward from a fertiliser experiment set up on a mountain meadow in 1968. The experiment included 7 fertilising objects with full NPK fertilisation and with control treatment. The area of the experimental plots was 42 m^2 (6 m x 7 m). The experimental treatments involved the following fertilisation regimes: nitrogen alone, phosphorus alone, phosphorus and potassium, nitrogen (at two doses of application, and until 2004 in two forms: ammonium nitrate and urea), phosphorus and potassium. Since 1985, the experiment has been conducted in two series: unlimed and limed. Botanical composition and plant yield formed under experimental conditions strongly affected the soil properties. The following were determined in the soil: pH, hydrolytic acidity and total forms of carbon, nitrogen, and sulphur. Soil properties are important for sustainable agriculture and conservative livestock rearing. Changes in acidification were primarily caused by fertilisation with nitrogen, while liming conducted every 10 years significantly counterbalanced this negative effect. Mineralisation of organic matter caused by liming increased the total nitrogen content, hence a significantly narrower C:N ratio was observed. The C:N and C:S ratios cannot be treated as valid indicators of grassland management practice. The reason is the high dynamic of sulphur, nitrogen and carbon cycles caused not only by liming, but also by diversity in plant yield.

Keywords: acidification, macronutrient ratios, meadow sward yield.

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INTRODUCTION

Soils under permanent pasture, especially peat ones, are usually characterised by acidic pH, shortage of available forms of phosphorus and potassium (Hejcman et al. 2014, Sochorová et al. 2016). An ecological approach to agriculture has resulted in reducing the productivity of grassland in response to a smaller number of livestock for which the biomass harvested from meadows and pastures was the primary source of feed. On the other hand, there are examples of the intensification of production on animal farms as well as cases of the deterioration of agricultural production on farms with low productivity soils. Meadow and pasture sward supplies farm animals with good, species-rich and inexpensive feed, while protecting the soil profile from erosive processes. Restoring the production potential of permanent pastures is more difficult than maintaining it at the optimum level (Berninger et al. 2015).

Farmers typically delay the liming of grassland or, even worse, abandon this treatment altogether. The motivation is the lack of spectacular, visible production effects. Although liming improves and optimises physical and chemical properties of soil, thereby having a positive effect on the development of most meadow species, the yields remain unchanged and the potential impact of liming is associated with the botanical and chemical composition of sward (Čop 2015, Sochorová et al. 2016). Availability of elements is the main factor in grassland productivity and the composition and species diversity of grass communities (Soons et al. 2017, DeMalach 2018). In modern nutrition, concentrations of elements should be given primary consideration, especially in farming based on conservative system of livestock rearing.

Maintaining proper soil pH is important for agricultural production and soil fertility because it conditions many chemical biochemical and biological processes in soil (Pavlů et al. 2016, Riesch et al. 2018). Liming is essential for sustaining soil resources and saving the valuable soil potential for future generations (Honsova 2007, Čop 2015). It is especially important in conditions difficult for agricultural production, for example in mountains. However, the relationship between elements of an ecosystem and pH can be very complex (Zarzycki, Kopeć 2020). Significant dependence between soil pH and biological life (e.g. the size of earthworm populations) affecting bird populations was found by McCallum et al. (McCallum et al. 2016). The authors concluded that lower pH values of soil, caused by reduced use of lime on the grassland, probably led to a lower number of earthworms and poorer quality of the habitat for birds. This relationship was especially evident when the soil had low buffering capacity, and heavy rainfall fostered the leaching of Ca and Mg cations from the soil. In a certain long-term agricultural trial, an attempt was made to analyse agronomic factors by comparing relationships between macronutrients (Khan et al. 2016). According to the authors, some of the relationships between elements are an important indicator which reliably reflects the soil conditions. These relationships indicate tendencies occurring in the soil and are more stable than the absolute macronutrient content. In addition to studying the impact of factors on yielding in various farming systems, another important issue to explore is how to maintain soil fertility. A possible contributing factor is building a sorption complex that promotes the buffering of negative factors. The sorption complex can be improved by increasing the carbon content and attaining a correct relationship between carbon and nitrogen. This promotes the accumulation of humus in the soil, which is formed as a result of microbiological changes. In addition to carbon, nitrogen and sulphur are other elements necessary in these processes.

The aim of the study is to propose a rational grassland fertilisation system by evaluating the content of carbon, nitrogen, and sulphur in soil against the changes in pH caused by fertilisation and liming.

MATERIALS AND METHODS

Study site and experimental design

The experimental field is situated in Czarny Potok near Krynica, Poland (20°54′53″ E; 49°24′35″ N), about 720 m a.s.l., at the foot of Jaworzyna Krynicka in the south-eastern Beskid Sądecki mountains, Poland. The field lies on a 7° slope along the NNE aspect. The experiment was set up in 1968 on a natural mountain meadow of moor mat-grass (*Nardus stricta* L.) and red fescue (*Festuca rubra* L.) type with a large share of dicotyledonous plants. Prior to the experiment, the area was covered with matgrass (*Nardus stricta*) and red fescue (*Festuca rubra*), with a considerable share of dicotyledonous plants, mainly *Leontodon hispidus, Thymus pulegioides,* and *Plantago lanceolata* (Zarzycki, Kopeć 2020).

Soil was classified as an Endoskeletic Dystric Cambisol (WRB 2014) with sandy loam composition consisting of 60% sand, 38% silt and 2% clay. Details of the experiment are shown in a previous study (Kopeć 2000) and Figure 1.

Experimental design

It is hypothesized that some fertiliser experiments are difficult to maintain for a long period, which is due to the simplification of experimental factors and changes in methodology. In such experiments, soil degradation occurs over time, offset by introducing additional treatments, which does not diminish the importance of the experiment. In the present experiment, the treatments introduced in order to maintain satisfactory productivity of soil, together with the constant fertilisation, provide the basis for scientific research concerning the management of a mountain meadow. Since the autumn of 1985, the experiment has been conducted in two series: unlimed

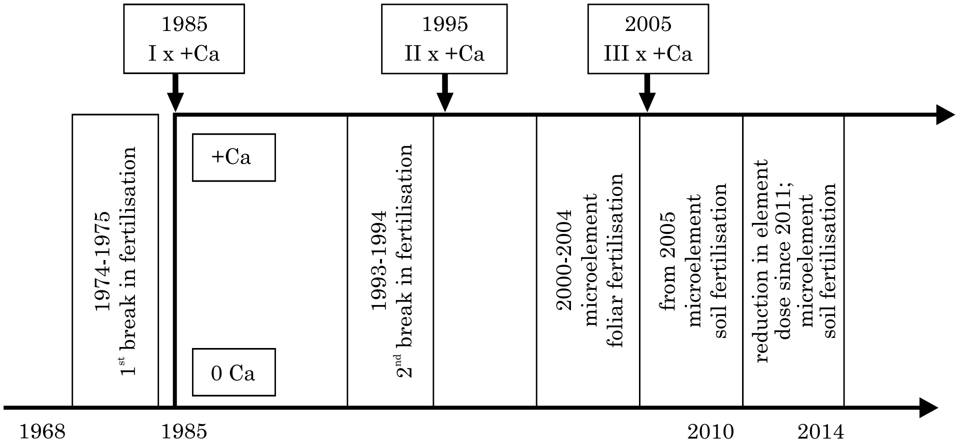

Fig. 1. The diagram illustrating modifications of fertilisation in the experiment

and limed, both with the same level of fertilisation. In 1995 and 2005, the liming treatment was repeated. The first and third liming treatments were carried out by calculating the dose of lime based on 0.5 value of (Hh) (HRIVŇÁKOVÁ et al. 2011); in the second treatment, the dose of lime was based on the total hydrolytic acidity of soil determined in the previous year. In the years 1974-1975 and 1993-1994, there were breaks in mineral fertilisation, and the research was limited to determination of the sward yield and its chemical composition.

The experiment, carried out in 5 replicates, includes 7 fertilising objects and a control object (Table 1) with nitrogen or phosphorus fertilisation. The area of the experimental plots was 42 m^2 (6 m x 7 m). The experimental treatments involved the following fertilisation regimes: nitrogen alone, phosphorus alone, phosphorus and potassium, nitrogen (at two doses of application, and until 2004 in two forms: ammonium nitrate and urea), phosphorus and potassium. As plants responded similarly to the different forms of nitrogen, the treatments with the same application dose but different forms of nitrogen were ultimately pooled together, and five treatments were analysed. In 2011, the fertilisation was reduced and the number of cuts was increased from two to three. The purpose of these changes was to unify variations in botanic composition within objects.

At the beginning of the experiment, in the 1968-1980 period, phosphorus and potassium fertilisers were applied in the autumn. Since 1981, these fertilisers have been applied in the spring, but potassium (1/2 dose) was supplemented in the summer, after the 1st cut. In the 1968-1973 period, thermophosphate was applied; from 1976 to 2005, triple superphosphate (46% P_2O_5) was applied, and enriched superphosphate (40% P_2O_5) has been since 2005. During the entire experiment, nitrogen fertilisers were applied twice a year: 2/3 of the annual dose in the spring, at the beginning of vegetative growth; and 1/3 dose a few days after the 1st cut. In 1994, 10 kg Cu and 8 kg Mg ha^{-1}

Table 1

The design of fertilisation in the long-term, controlled experiment in Czarny Potok

Fertilising objects factor I	Annual element dose in series of 0 Ca and + Ca (factor II) 1985, 1995, 2005 (kg ha^{-1})			Nitrogen fertiliser	Microelements (2008 and 2011)
	P	K	N		
PK	39.24/19.62*	124.5/62.25	–		B, Cu, Zn, Mn, Co, Mo
PK+N1	39.24/19.62	124.5/62.25	90/60	ammonium nitrate	B, Cu, Zn, Mn, Co, Mo
PK+N2	39.24/19.62	124.5/62.25	180/120	ammonium nitrate	B, Cu, Zn, Mn, Co, Mo
PK+N1-0M	39.24/19.62	124.5/62.25	90/60	urea to 2004/ /ammonium nitrate from 2005	0 microel.**
PK+N2-0M	39.24/19.62	124.5/62.25	180/120	urea to 2004/ /ammonium nitrate from 2005	0 microel.
N1	–	–	90/60	ammonium nitrate	B, Cu, Zn, Mn, Co, Mo
P	39.24/19.62	–	–		B, Cu, Zn, Mn, Co, Mo
„0”	–	–	–		B, Cu, Zn, Mn, Co, Mo

* – dose reduction in 2011; ** – 0 microel. – without microelements (–0M); series of 0 Ca without liming; series of + Ca limed.

were applied as one-time regenerative fertilisation. In 2000–2004, foliar fertilisation (2 times with 2 dm^3 ha^{-1} year^{-1}) with Mikrovit-1 microelement fertiliser was applied. The applied microelement fertiliser contained in 1 dm^{-3}: 23.3 g Mg, 2.3 g Fe, 2.5 g Cu, 2.7 g Mn, 1.8 g Zn, 0.15 g B and 0.1 g Mo. In the years 2005-2007, 0.5 kg B per ha was applied each year, and – in the spring of 2008 and 2011 – 5 kg Cu, Zn and Mn and 0.5 kg Co and Mo were supplied per ha.

Yields of sward were harvested twice a year: in June/July and in September. Since 2011, yields have been harvested three times a year – at the beginning of June, at the end of July, and in September. After the last cut, soil for analyses was sampled from the 0-10 cm soil layer. The highest dynamics of element cycling and changes in physical properties in grassland soil occur in the 0-10 cm soil layer (Głąb et al. 2009, Liaudanskienė et al. 2013, Mueller et al. 2013, Fornara et al. 2016). The following were determined in the soil: pH (with the potentiometric method) in the suspensions of soil and distilled water (1 : 5), and soil and 1 mol dm^{-3} solution of KCl; and hydrolytic acidity (Hh), after extraction of a sample in 1 mol CH_3COONa

dm^{-3} according to the Kappen method (Hrivňáková et al. 2011). Total forms of carbon, nitrogen, and sulphur were determined in the soil using a Vario Max Cube thermal conductivity detector. Some properties of soil before the experiment are given in Table 2 (Kopeć 2000).

Table 2

Selected properties of soil in the 0-10 cm layer before setting up the experiment in Czarny Potok

pH H_2O	pH KCl	Hh	Hw	P_2O_5*	K_2O*	Ca**	Mg**	Na**	K**
		(cmol (+) kg^{-1} soil)		(mg kg^{-1} soil)					
5.20	4.38	4.42	0.46	11.0	135.0	680	38.0	20.0	69.0

* – available forms according to the Egner-Riehma metod, ** – exchangeable cations

Meteorological conditions

The plant growing season in the experimental area stretches from April to September (150-190 days). Meteorological conditions (Table 3) in the experimental area show extensive variability of precipitations.

Table 3

Statistical precipitation and temperature parameters in the period 1968-2014

Parameter	Precipitation (mm)		Temperature (°C)	
	01-12*	04-09	01-12	04-09
Arithmetic mean	882	576	6.0	12.3
Standard deviation	198	152	0.9	0.8
Range of 25–75% cases	736-997	458-666	5.6-6.4	11.8-12.9

* – months of the year

Statistical analysis

Statistical parameters that confirm the results, including the arithmetic mean, standard deviation and range of 25-75% cases, were used in the work. Statistical analysis based on two-factor (I – level of fertilisation, II – series of liming) variance analysis (ANOVA) was performed and homogeneous groups ($p<0.05$) were determined. *Post-hoc* comparisons were performed with the Tukey's test to identify differences between individual treatments.

RESULTS AND DISCUSSION

Figure 2 shows yields from the three selected periods of the experiment between 2005 and 2014 in individual objects. The period presented in the graph begins after the third liming and included microelement soil fertili-

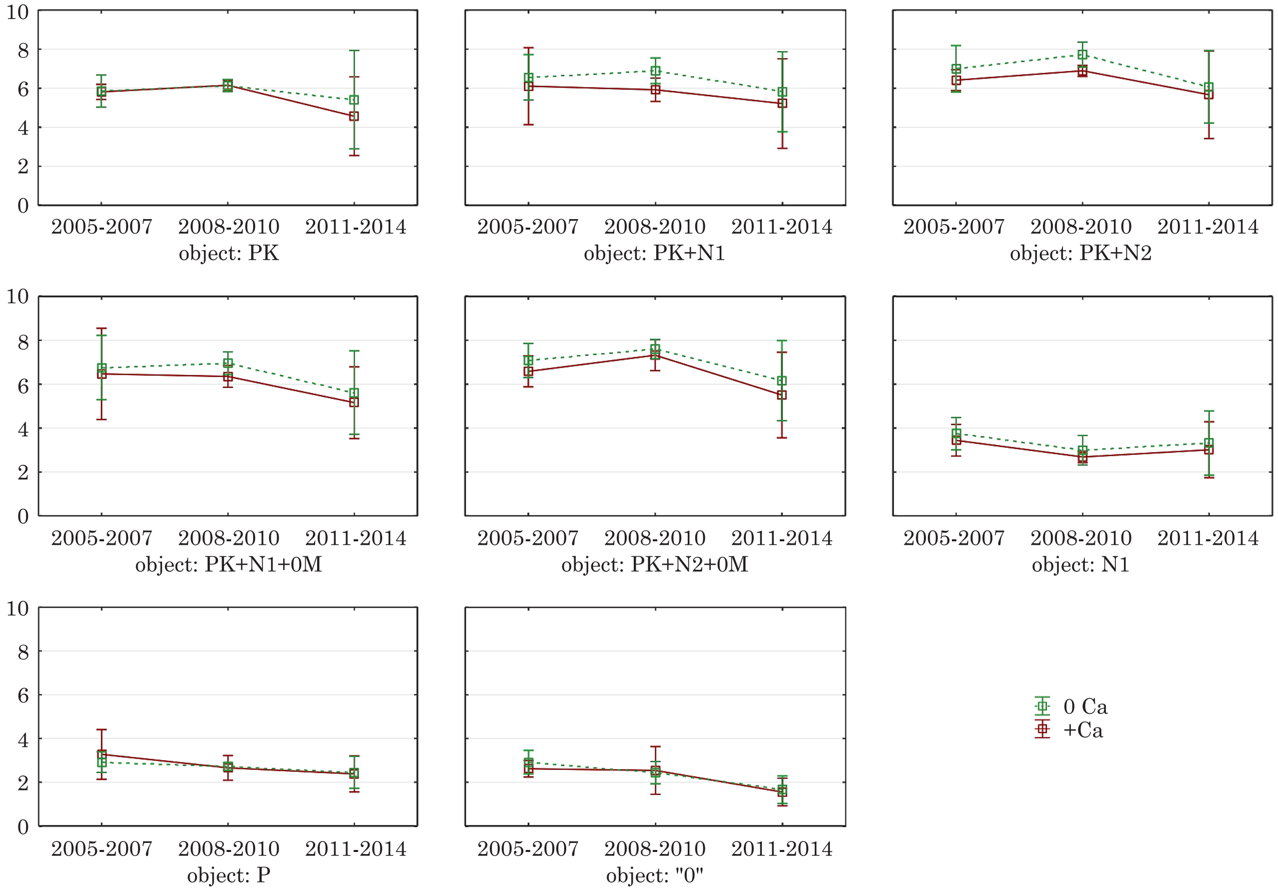

Fig. 2. Dry matter yields (t ha^{-1}; ±SD) of various fertilising objects in three periods: 2005-2007, 2008-2010 and 2011-2014

sation and reduced doses of components (Table 1). No significant differences in yields from the objects were found between the limed and unlimed series. However, there were small differences in yields in favour of limed objects with full fertilisation. Reduced component doses, except for the reduced dose of nitrogen fertilisation, caused insignificant reduction in yields. Lack of significance results from high variability within objects, since the response measured based on means from objects is in some cases significant. This large variation within objects deepens with time of the experiment and concerns multidirectional relationship between the botanical composition of sward and soil properties.

Compared with the data on soil acidification in the year when the experiment was set up (Table 2), a significant increase in hydrolytic acidity in the control object (Table 4) was observed. The lowest increase in hydrolytic acidity was observed in the soil under the object with superphosphate fertilisation, which is due to the presence of calcium phosphates in the fertiliser. Potassium fertilisation led to an increase in hydrolytic acidity of the soil; however, differences between the P and PK objects were of no significance. The effect of nitrogen fertilisation on acidification was fully confirmed, in particular regarding the dose of nitrogen or exclusive application of fertiliser. The analysis of variance indicates significantly higher accumulation of hydrogen ions in soil after the application of a double dose of nitrogen compared to the reference dose (90/60 kg ha^{-1} N) – Table 1.

Table 4

The pH and hydrolytic acidity values in the 0-10 cm soil layer in series with and without liming in 2014

Fertilising objects	pH H_2O		pH KCl		Hh (cmol kg^{-1})	
	0Ca	+Ca	0Ca	+Ca	0Ca	+Ca
PK	5.19*ab**	5.61*e*	4.23*abc*	4.83*gh*	8.10*cde*	5.85*ab*
PK + N1	5.24*bcd*	5.62*e*	4.31*bcd*	4.83*gh*	9.00*f*	6.30*ab*
PK + N2	5.00*a*	5.41*cd*	3.92*a*	4.50*cde*	10.50*g*	7.20*abcd*
PK + N1-0M	5.20*abc*	5.58*e*	4.26*abcd*	4.80*fgh*	8.70*de*	6.30*ab*
PK + N2-0M	5.05*ab*	5.43*de*	4.00*a*	4.53*def*	10.65*g*	7.35*bcd*
N1	5.18*ab*	5.46*e*	4.16*ab*	4.64*efg*	10.90*g*	8.85*e*
P	5.49*e*	5.68*e*	4.64*efg*	5.00*h*	6.60*abc*	5.72*a*
“0”	5.48*e*	5.77*e*	4.55*defg*	5.11*h*	7.45*bcde*	5.28*a*
Effect of factor II	5.23*a*	5.57*b*	4.25*a*	4.75*b*	8.98*b*	6.61*a*

* – homogeneous groups of two-factor variance analysis (I – level of fertilisation, II – series of liming)

In the series with liming, differences between the maximum values of hydrolytic acidity of soils from the objects were significantly lower than in the series without liming. Its value in the control object was higher than determined in 1968, when the experiment was set up. This is due to several factors, particularly the removal of base cations with yield and their leaching. In the course of the research, 10 years after the last liming, the value of hydrolytic acidity of soil from individual objects in the limed series corresponded to 69-86% of hydrolytic acidity in the unlimed series objects.

Ten years after the third liming, the soil pH in the suspensions of soil and H_2O, and soil and KCl also demonstrated significant differences between the limed and unlimed series. The scope of changes and variation in soil acidification in the objects are consistent with the literature data pertaining to similar areas and objects. According to Chmolowska et al. (2015), the level of acidification of mountain soils is unfavourable for plant growth, but stable. However, acidification reduces biodiversity, and this can be mitigated by liming, whose versatile impact persists over a long period of time (Hejcman et al. 2014, Čop 2015, Vigovskis 2016).

Table 5 shows the content of total C, N and S forms in soil. These concentrations were slightly different between the objects and series. Minor differences in the content of C, N, and S may have been caused by changes in the pattern of fertilisation, particularly the reduction of fertilisation doses (in 2011). A significant difference between the limed and unlimed series was observed only for the nitrogen content. Higher nitrogen content was determined in the series with liming, although only the unfertilised object was found to be significantly different from the others. Higher content of nitrogen in soil after liming may be reflected in a higher content of this element in the sward, which was confirmed by Fornara et al. (2013).

In the analysed 0-10 cm soil layer, differences in the carbon content are ambiguous. The objects with a lower dose of nitrogen against PK had a higher carbon content in the limed series, contrary to the objects with a higher

Table 5

The content of carbon, nitrogen and sulphur in the 0-10 cm soil layer in the series with and without liming

Fertilising objects	(g C kg^{-1})		(g N kg^{-1})		(g S kg^{-1})	
	0Ca	+Ca	0Ca	+Ca	0Ca	+Ca
PK	29.8_abc_*	27.7_a_	2.80_abc_	2.82_abc_	0.150_a_	0.152_ab_
PK + N1	28.8_ab_	29.6_abc_	2.77_ab_	3.03_bcd_	0.150_a_	0.162_abc_
PK + N2	30.0_abc_	28.2_ab_	2.91_ab_	2.98_abc_	0.170_bc_	0.172_bc_
PK + N1-0M	29.3_ab_	29.8_abc_	2.88_ab_	2.99_abc_	0.158_ab_	0.168_abc_
PK + N2-0M	28.7_ab_	28.3_ab_	2.97_abc_	2.99_abc_	0.174_c_	0.160_abc_
N1	30.7_bc_	30.3_abc_	3.17_cd_	3.27_d_	0.176_c_	0.162_abc_
P	29.5_abc_	30.4_bc_	2.75_a_	2.94_abc_	0.160_abc_	0156_ab_
“0”	31.4_bc_	32.9_c_	3.06_bcd_	3.26_cd_	0.170_bc_	0.160_abc_
Effect of factor II	29.7_a_	29.4_a_	2.90_a_	3.02_b_	0.162_a_	0.163_a_

* – homogeneous groups of two-factor variance analysis (I – level of fertilisation, II – series of liming)

nitrogen dose, where a reverse dependence was confirmed; however, the differences were greater in the objects were fertilised only with ammonium nitrate which from the onset of the experiment. No significant effect of fertilisation on the content of carbon in the 0-10 cm soil layer was observed.

Same as the soil carbon content, the sulphur content was not significantly diversified. Nevertheless, attention should be paid to a higher sulphur content in the soil of objects from the unlimed series which were more intensively fertilised with nitrogen, and in the soil without fertilisation (Mathot et al. 2008). Large seasonal variations in the content of sulphate sulphur, but also in the total sulphur content, in grassland soils suggest that there may be a deficit of sulphur over a substantial area of the mineral land occupied by grasslands. This is confirmed by the results of the research. In the course of the experiment with microelement fertilisation, in 2011, 12 kg ha^{-1} of S was introduced, and no accumulation of sulphur in the soil was identified in the objects fertilised with microelements compared to objects without microelement fertilisation (0M). The sulphur content in soil depends on the water-air conditions, rainfall and the organic matter content of soil (Luo et al. 2016). This demonstrates the high dynamics of the element cycling, which depends on the carbon content and quality of organic matter as well as on the soil phosphorus content (Kopeć et al. 2013, Siwik-Ziomek, Lemanowicz 2014, Khan et al. 2016). In the case of relative dependences, measured by ratios of studied elements in soil, significant differences between the fertilisation effect (factor I) and liming series (factor II) were found (Table 6).

Higher content of nitrogen in soil of the limed series as well as smaller variations in the soil sulphur content resulted in significant differences in the N:S ratio.

Table 6

Relationship between carbon, nitrogen and sulphur in the 0-10 cm soil layer in series with and without liming

Fertilising objects	C:N ratio		N:S ratio		C:S ratio	
	0Ca	+Ca	0Ca	+Ca	0Ca	+Ca
PK	10.64hi*	9.85cde	18.88abc	19.64bc	200c	195bc
PK+N1	10.42ghi	9.77bcde	18.68abc	18.69abc	195bc	183abc
PK+N2	10.33fghi	9.45ab	17.21a	17.37ab	178abc	164a
PK+N1-0M	10.17efg	9.98def	18.37abc	17.83acb	187abc	178abc
PK+N2-0M	9.70bcd	9.48abc	17.07ab	18.70abc	166a	179abc
N1	9.67abcd	9.27a	18.06abc	20.22c	175ab	177abc
P	10.74i	10.34fghi	17.18a	18.82abc	185abc	195bc
“0”	10.26efgh	10.07defg	18.03abc	20.41c	185abc	206c
Effect of factor II	10.24b	9.76a	17.93a	18.84b	184a	184a

* – homogeneous groups of two-factor variance analysis (I – level of fertilisation, II – series of liming)

The ratio of carbon to nitrogen was significantly lower in the limed series. Substantial differences were observed in objects with constant fertilisation with ammonium nitrate against PK and in the PK object soil. The highest value of the C:N ratio was determined in the soil under the object with exclusive phosphorus fertilisation, while the lowest values were identified in the soil of the limed series fertilised with a double dose of nitrogen or exclusively fertilised with nitrogen. Values of the C:N ratio can be used to predict dry matter yield (Fornara et al. 2013, Mueller et al. 2013, Cenini et al. 2015). Pavlů et al. (2016) demonstrated the dependence of smaller grassland yield in the case of a narrower C:N ratio in soil. The processes of mineralization and humification of biomass on and below the soil surface cause changes in the carbon content in the soil. The dynamics and direction of these changes depend on the intensity of abiotic factors (Volk et al. 2016). On the other hand, Chmolowska et al. (2015) believe that the C:N ratio is indicative of the way in which land has been previously managed. By comparing fallow land and grassland, the authors found that the ratio is wider for grassland, which they maintain can be attributed to more intense exhaustion of nitrogen. This can occur at low production intensification (extensification process). As emerges from our research, liming can distort this dependence. The mutual ratio of carbon and nitrogen in soil is not an appropriate indicator for assessing the preservation of mineral fertilisation, especially when it is fairly stable. The absolute values of carbon and nitrogen in soil become more important in assessing the conservative nature of a land management system. Their level is shaped for many years (Fornara et al. 2016, Triberti et al. 2016).

The results corroborate the observations of Čop (2015), who claims that the resistance of mountain ecosystems may be particularly low in response to perturbations that significantly change the soil pH or other key determinants of the soil environment. Limited production intensification, e.g. through the reduction of a component dose, unifies some of the properties of soil with different fertilisation regimes applied. However, the outcome can depend on the level of previous soil fatigue. Liming increases the sorption capacity of soils. A similar effect of raising the pH and sorption capacity of soils in mountain meadows can be achieved by using spent filter materials used in household wastewater treatment (Cucarella et al. 2009). The effect of liming on soil biological activity was proved in a previous study (Kopeć et al. 2013). Similar findings regarding the increase in earthworm populations and biopores in mountain soils as a result biological activity have been reported (Glab et al. 2009). Both these properties are of utmost importance for a conservative system of livestock rearing. In theory, greater abundance of components in limed soils should favour higher yields, but biological sorption may limit the availability of nitrogen to plants, for example. Restoration of the plant cover can be achieved relatively fast, while the recovery of its botanical composition is much slower and requires extensification. Fertilisation causes significant differences in yield, but the yield of aerial parts does not reflect, for example, variation in the soil content of carbon. Relationships between carbon, nitrogen and sulphur in soil are of no significance for the assessment of conservatism of mineral fertilisation, especially under conditions of low diversity. In this context, better results can be obtained by using organic materials such as compost (not investigated in this study) – Reynolds et al. (2015). This factor completely distorts relationships of C:N:S and of other elements in soils, refuting the interpretation of indicators based on mutual relationships between these elements in the short term, or even within several decades. This conclusion does not undermine the importance of relationships between some macronutrients in soil for soil-forming processes in the absence of human pressure. Monitoring levels of C, N and S in soil, due to the complexity and variability of soil conditions, requires verification in long-term experiments (Wang et al. 2016).

CONCLUSIONS

1. Repeated liming (0.5; 1.0 and 0.5 Hh) did not diversify the meadow sward yielding; however, fertilisation reduced by 1/3 resulted in poorer yields.

2. Protective liming (three times every 10 years) significantly reduced soil acidification.

3. Higher nitrogen doses decreased the C/N and C/S ratios.

4. Higher total nitrogen content was determined in soil in which liming was applied.

5. In the studied period, the NPK fertilisation used in the experiment did not affect the carbon and total nitrogen content in the soil.

Conflicts of interest

The authors declare no conflict of interest.

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