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Losses of Soluble Forms of Organic Carbon in Relation to Different Agro-Technical Treatment of Meadows

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Abstract

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Studies were performed to determine the loss of soluble forms of organic carbon in differently used meadows on mineral soil. In a long-term experiment two variants were distinguished: a productive meadow (N120-AN and N120-CN) and a non-productive one (Kp-AN, Kp-CN, Kz-AN, Kz-CN). Productive meadows were fertilized with 120 kg N/ha/year, 34.9 kg P/ha/year, and 149.4 kg K/ha/year and mown three times a year. Nitrogen fertilization was applied in a form of ammonium nitrate (AN) and calcium nitrate (CN). The only agro-technical measure applied to non-productive meadows was the regular cutting of vegetation and leaving it on the plots (variants: Kp-AN and Kp-CN) or taking it away from the plots (variants: Kz-AN, Kz-CN). Significant positive Pearson's linear correlations were found between pH (in $CaCl_2$) of mineral soil and total organic carbon (TOC) content in the following variants: Kz-AN (r = 0.457**), N120-AN (r = 0.491**), and N120-CN (r = 0.424**) and in all meadows fertilized with AN (r = 0.243**). The obtained linear correlation coefficients between pH and TOC indicate that soil organic carbon may be lost as a result of progressive acidification of the soil. Dissolved organic carbon in the mineral meadow soil increased in the following order: Kp-CN > N120-CN > Kz-CN > N120-AN > Kp-AN > Kz-AN.

Keywords: dissolved organic carbon; meadow experiment; mineral soil; total organic carbon

The content and quality of soil organic matter is determined by physical, chemical, biological, and environmental soil properties. Soil organic carbon (SOC) is one of the most important sources of carbon in nature and participates in the transport of mineral components such as N, P, and K. For these reasons it is very important from the environmental point of view (Grupta & Germida 1988; Kalbitz *et al.* 2000; Jimenez & Lal 2006).

The SOC is an important factor considered in the climate change and environmental policy in the EU (Schilis 2008, Lugato *et al.* 2014; Weismeier *et al.* 2015). According to some studies (Goulding *et al.* 2000; Haynes 2005; Clark *et al.* 2010; Ritson *et al.* 2014) SOC is considered one of the most important indicators of soil quality (Zsolany 1996). Studies (Fenner & Freeman 2011; Larssen *et al.* 2011) suggest that climate change will contribute to the leaching of soluble forms of carbon from soils.

Dissolved organic carbon (DOC) is defined as organic particles of varying structure and pore sizes with a diameter of 0.20–0.45 μm, and can be classified into three types of DOM I–III (Neef & Aster 2001). SOC is highly reactive, it accumulates in the surface soil layer and remains in a dynamic equilibrium with the environment (Haynes & Bare 1996; Lal 2000). Soil utilization may influence the content of soil organic matter. Changes in the land use and deforestation combined with the climate change may reduce organic carbon accumulation in top soil layers (Schlesinger 1990; Veldkamp 1994; Breja 1997; Bashkin & Bionkley 1998).

It has been estimated that grassland soils show a considerable storage capacity of organic carbon, similar or even higher than the forest soils. Long-term meadow use contributed to the increase of labile fractions of organic matter and to stabilization of soil aggregates, compared with arable land use (Lugo *et al.* 1986; Haynes 2005). DOC is a fraction of labile

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organic matter easily soluble in water and in solutions of neutral salts, and is easily washed into ground water (Dębska & Gonet 2002; Burzyńska 2004, 2013) The aim of this study was to evaluate the effect of different utilization of meadows growing on mineral soil on the losses of soluble organic carbon.

MATERIAL AND METHODS

Studies were carried out in a long-term meadow experiment conducted in Laszczki, Masovian Province, Poland. The experiment was set up in 1981 on Gleyic Phaeozems. The content of grains < 0.02 mm was 18.4%, pH in 1 mol/l KCl soil extract was 5.2, and TOC was 29.3 g/kg in dry matter (DM).

In the years 1981–2003 the experimental meadow was used productively. Two levels of nitrogen fertilization were applied: 120 and 240 kg N/ha in form of ammonium nitrate (AN) or calcium nitrate (CN). In the years 2004–2008 fertilization with 34.9 kg P/ha and 149.4 kg K/ha was applied, while harvesting was given up in the experiment. The only agro-technical measure was the regular cutting of the meadow vegetation and leaving it on the plots. In the year 2009, three variants with varied use were selected: two meadows without fertilization – Kp (meadow vegetation was systematically cut and left on the plots) and Kz (meadow vegetation was cut and taken away from the plots); one meadow fertilized with mineral fertilizers, such as: 120 kg N/ha, 34.9 kg P/ha and 149.4 kg K/ha per the year. Nitrogen fertilizers were AN and CN. In the years 2009–2012 the experiment was continued as in 2009.

Meadow sward was composed in 87.8% of grasses (*Poa pratenese*, *Dactilis glomerata* L., *Lolium multiflorum* Lam., *Lolium parenne* L., *Festusa arundinacea* Schleb., *Aloperus pratensis* (L.), in about 11% of dicotyledons (*Taraxacum officinale* FH Wigg. and *Rumem acetosa* L.), and in 1.2% of legumes (*Trifolium repens*, *Medicago lupulina*).

Soil samples were taken from 10-cm deep soil layers in early spring of the years 2009–2012. Samples were extracted with 0.01 mol/l $CaCl_2$ according to Houba *et al.* (1990). The content of DOC in soil extracts was determined by means of colorimetric method using a segmented flow analysis (SFA) system (Skalar Methods 2001). The soil pH in 0.01 mol/l $CaCl_2$ soil extract was measured potentiometrically. The content of TOC was determined according to the modified Orlov's method (Sapek & Sapek 1997) and also by means of colorimetric method. The study was carried out in the Laboratory of Environmental Chemistry, Institute of Technology and Life Sciences, Falenty, Poland.

Statistical analysis. Results of chemical analysis of soil samples from the meadow experiment were statistically processed using STATISTICA Ver. 7.0 software. One-way ANOVA was used to assess the significance of differences in pH, TOC, and DOC contents in mineral soils between differently treated meadows. The significance of differences between the means was tested with Tukey's HSD test at $P = 0.05$. Linear Pearson's correlation was applied to evaluate the effect of pH on TOC and DOC and the TOC–DOC relationships in the three variants of meadow utilization in the years 2009–2012. These correlations were determined at $P = 0.001$, $P = 0.01$, and $P = 0.05$.

RESULTS AND DISCUSSION

Soil pH measured in 0.01 mol/l $CaCl_2$ soil extract from experimental meadows varied because long-term N fertilization with AN and CN had affected soil pH (Table 1). Long-term use of AN contributed to progressive acidification of mineral meadow soil, while the opposite effect (reduction of acidity) was observed

Table 1. Values of pH, total organic carbon (TOC), and dissolved organic carbon (DOC) measured in a 10-cm meadow top soil layer (2009–2012, $n = 128$)

Variant	pH (0.01 $CaCl_2$ mol/l)			TOC (g/kg DM)			DOC (mg/kg DM)		
	mean	min–max	SD	mean	min–max	SD	mean	min–max	SD
Kp-AN	5.40	4.15–6.33	0.49	28.75	15.70–48.40	7.16	166.20	15.50–288.20	45.89
Kp-CN	6.07	4.95–6.67	0.30	30.83	18.62–48.40	8.02	177.83	93.00–352.64	50.13
Kz-AN	5.78	4.34–6.76	0.47	25.70	14.00–38.00	5.55	154.22	75.21–274.70	40.30
Kz-CN	6.42	5.30–7.02	0.34	28.49	17.10–38.00	5.13	167.99	19.40–300.62	48.38
N120-AN	4.84	3.76–6.49	0.60	26.20	14.30–47.30	8.42	180.60	84.98–327.70	48.23
N120-CN	5.89	5.03–6.77	0.36	28.79	16.20–47.30	9.70	176.35	87.90–321.87	51.07

AN – ammonium nitrate; CN – calcium nitrate

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in variants with CN fertilization. The soil was most acidic (pH 4.84) in productive variant N120-AN and least acidic (pH 6.42) in Kz-CN variant.

Negative skewness of soil pH indicates the left-tailed asymmetry of pH distribution towards more acidic regions (Figure 1). Meadow soils showed a very wide range of acidity from very strong (pH 3.76) to weakly acidic (pH 6.76), according to the classification by Scheffer & Schachtschabel (1984).

Total organic carbon. The total organic carbon (TOC) content in a 0–10-cm top layer of meadow soils varied between the experimental variants (Table 1). The lowest TOC content (25.70 g/kg DM) was detected in the meadow soil of the non-productive object Kz-AN. The highest TOC content (30.83 g per kg DM) was found in the soil of the object Kp-CN. Except the variants Kz (AN and CN), soil TOC showed a right-tailed asymmetry of distribution evidenced by positive skewness of results (Figure 1).

Regardless of the nitrogen form (AN or CN), the largest number of samples from our experiment fell within the range of 20.0 to 30.0 g TOC/kg DM of the soil (Figure.1). According to the classification in Gonet (2007), the average TOC content was 21.0 to 60.0 g per kg DM in prevailing number of results and only in few the TOC content was lower (10.0–20.0 g per kg DM). According to the international criteria (Gonet 2007), the TOC content of about 20.0 g/kg DM is considered a threshold value indicating the process of desertification.

It was shown that pH < 5.5 of soils fertilized with AN was unfavourable for meadow vegetation and markedly decreased the soil TOC. Probably, strongly acidic meadow soil (pH 4.0–4.9) considerably restricted the development of meadow plants and contributed to progressive degradation of the meadow habitat. In the effect, previously compact turf became loosen and bare land devoid of plants appeared on the meadow.

Fertilization variants:

N120-AN: mineral fertilization with ammonium nitrate 0.01 mol/l $CaCl_2$

N120-CN: mineral fertilization with calcium nitrate 120 kg N/ha per year

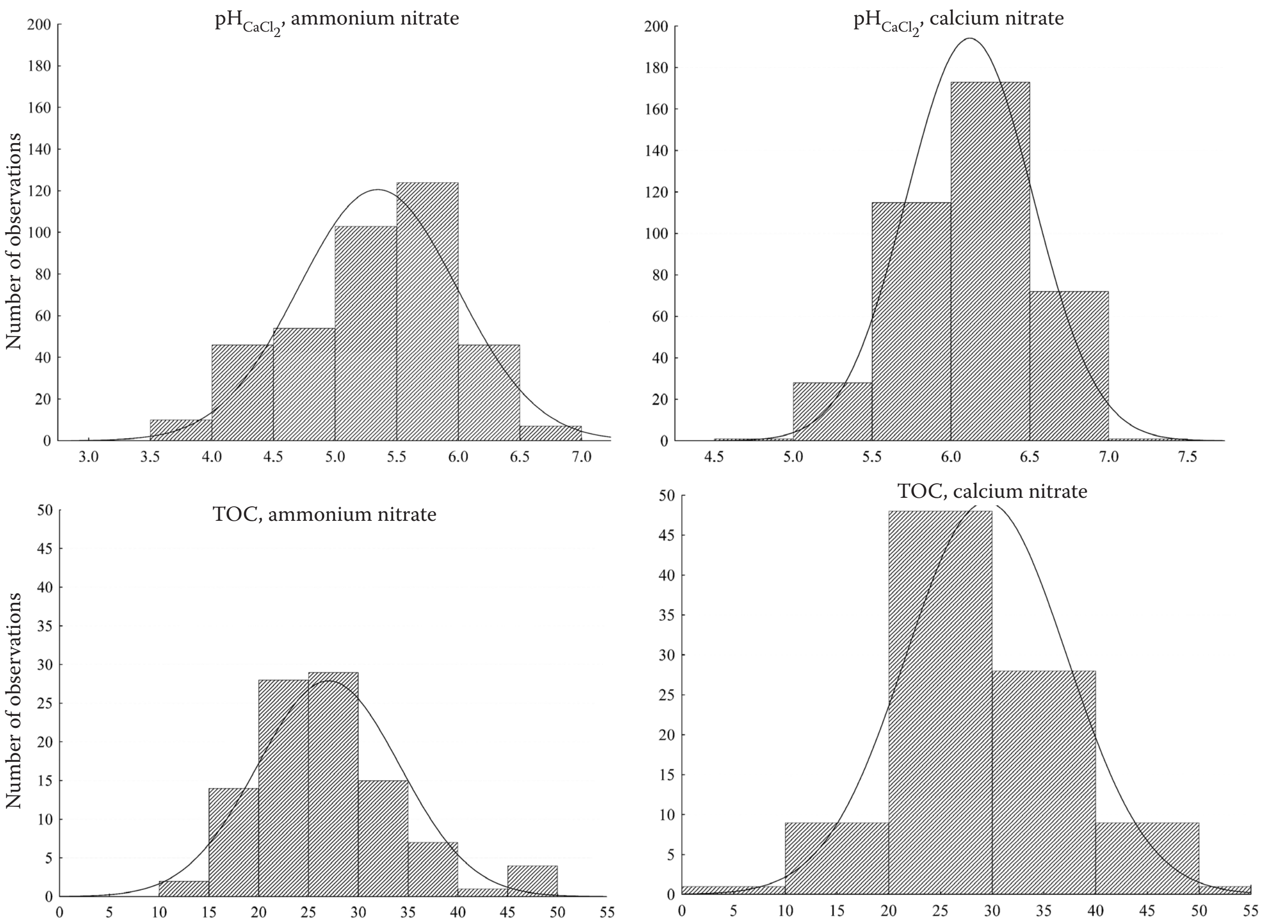

Figure 1. Histogram of pH and total organic carbon (TOC) content in meadow mineral soil (2009–2012)

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Not fertilized meadows:

Kp-AN: meadow fertilized in the past with ammonium nitrate, plants cut and left on the plot

Kp-CN: meadow fertilized in the past with calcium nitrate, plants cut and left on the plot

Kz-AN: meadow fertilized in the past with ammonium nitrate, plants cut and removed from the plot

Kz-CN: meadow fertilized in the past with calcium nitrate, plants cut and removed from the plot

After four years of different utilization of meadows, the TOC content in the top soil layer was observed to decrease in all variants fertilized with AN. On the contrary, long-term fertilization with CN stabilized TOC content in the soil and even contributed to its increase in N120-CN variant (Figure 2).

The obtained results confirm the data from earlier studies (Sapek & Burzyńska 1996; Burzyńska & Sapek 1997) showing that the carbonate form of calcium fertilizer may bring soil pH to a value close to neutral and may stimulate humus formation in the soil, thus preventing from TOC losses due to the application of high nitrogen doses.

Dissolved organic carbon. The range of soil DOC content was wide (Table 1). The highest mean content of DOC was noted in the soil from productive meadow, fertilized with AN (N120-AN 180.60 mg DOC/kg DM). The smallest DOC content (154.22 mg DOC/kg DM) was found in the soil from non-productive meadow with regular mowing and removal of vegetation (Kz-AN). With the exception of the Kp-AN variant, the DOC content in soils showed a right-skewed distribution, evidenced by the positive value of skewness.

During the four-year study, the process of DOC release was much more intensive in the topsoil (to the depth of 10 cm) than in the deeper soil layers (Figure 3). The DOC content in the topsoil of non-productive variant Kz-AN significantly decreased over the study period, while in other meadows fertilized with AN (Kp-AN and N120-AN) it decreased only till 2011. The tendency of reducing soluble forms of organic carbon was not observed in variants fertilized with CN (Figure 3). Similar results were also obtained in this meadow in earlier experiment (Burzyńska 2004). The obtained results partly confirmed those of Schauman (2000) demonstrating that the reserve of calcium ions in the soil stabilized the structure of organic matter and reduced the solubility of SOC. DOC in soils fertilized with CN slightly varied until the year 2011. In the following year, however, a significantly increased solubility of this carbon form was observed in all meadow soils (Figure 3). This phenomenon is difficult to assess and needs further studies.

Pearson's correlation index. Significant positive Pearson's correlations were obtained between soil pH and TOC content for particular variants: Kz-AN (r = 0.457**), N120-AN (r = 0.491**), and N120-CN (r = 0.424**) and for all meadows fertilized with AN (r = 0.243**) (Table 2). Statistically significant posi-

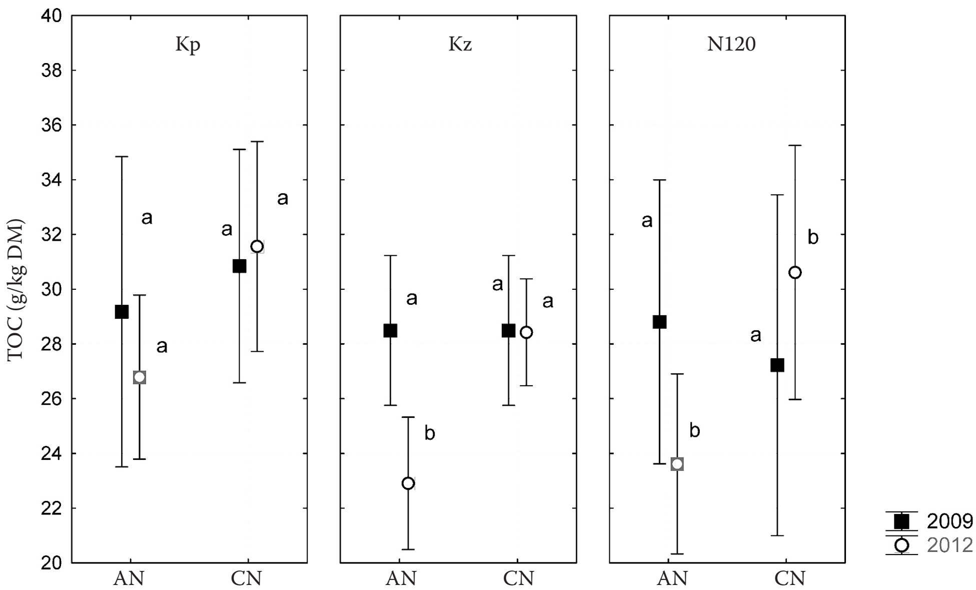

Figure 2. Changes of total organic carbon (TOC) content in the 0–10-cm top soil layer from experimental variants (2009–2012); AN – ammonium nitrate; CN – calcium nitrate; Kp, Kz – meadows without fertilization; N120 – fertilized meadow; a, b – statistically significant difference in TOC content

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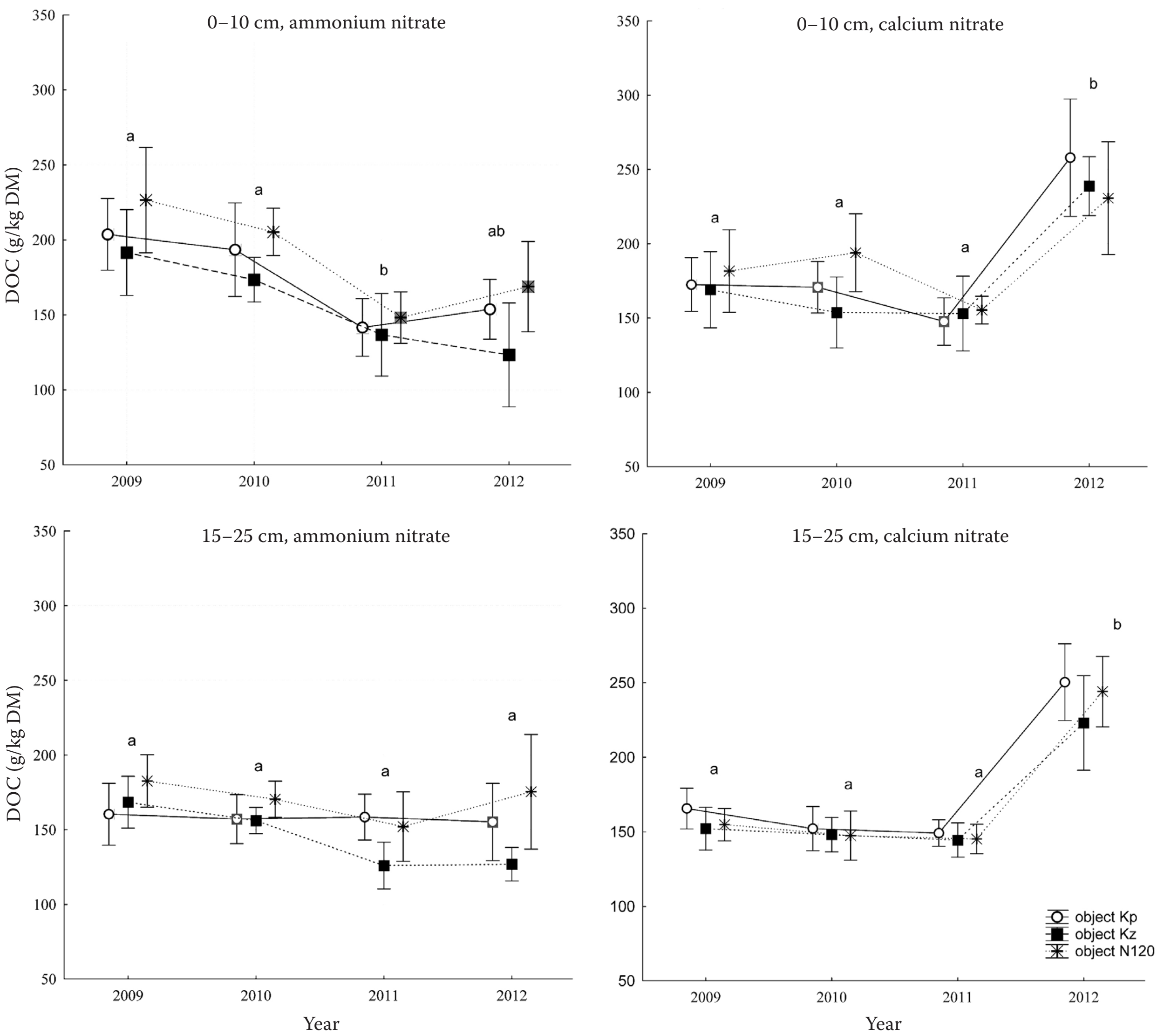

Figure 3. Dissolved organic carbon (DOC) concentration in the 0–10-cm and 15–25-cm mineral soil layer in relation to different utilization of meadows; Kp, Kz – meadows without fertilization; N120 – fertilized meadow; a, b – statistically significant difference in TOC contents

tive or negative linear correlations were also obtained between soil pH and DOC content for non-productive variants: Kz-AN (r = 0.424*) and Kp-CN (r = –0.455***) and for all meadows fertilized with CN (r = –0.258**). Negative correlation coefficients for meadows fertilized with CN indicate that DOC content in the mineral meadow soil decreased with decreasing soil acidity. Vegetation mown and systematically left on the plots (variant Kp-CN) limited the loss of soluble forms of organic carbon from mineral soil. On the other hand, systematic removal of mown vegetation in meadow variant Kz-AN at acidic soil pH (4.34–6.76) increased carbon losses. This observation was confirmed by positive correlation between pH and DOC content (0.424*) and between TOC and DOC (0.480**) in mineral meadow soil from the Kz-AN variant.

Soil pH is considered the main factor controlling the solubility of organic carbon. Soil acidification may exert a positive or negative effect on this process. According to some authors (Shi *et al.* 2012), soil pH was positively correlated with total inorganic carbon (TIC) and TIC/total carbon (TC) TC in the upper layers of meadow soils.

CONCLUSION

The obtained positive linear correlation coefficients between pH and TOC indicate that the SOC may be

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Table 2. Person's correlation coefficients between some parameters measured in a 0–10-cm meadow top soil layer (2009–2012)

Nitrate form and variant	Correlated parameters	No. of samples	r	r^2
Kz-AN	pH × TOC	32	0.457**	0.209
	pH × DOC	32	0.424*	0.160
	TOC × DOC	32	0.480**	0.231
N120-AN	pH × TOC	32	0.491**	0.241
AN (all variants)	pH × TOC	100	0.243**	0.070
	TOC × DOC	100	0.243**	0.060
Kp-CN	pH × DOC	32	–0.455***	0.207
N120-CN	pH × TOC	32	0.424**	0.180
CN (all variants)	pH × DOC	100	–0.258**	0.067

TOC – total organic carbon; DOC –dissolved organic carbon; r – correlation coefficient; r^2 – coefficient of determination; AN – ammonium nitrate; CN – calcium nitrate; Kp, Kz – meadows without fertilization; N120 – fertilized meadow; *, **, ***statistically significant at P = 0.05, 0.01 and 0.001

lost as a result of progressing soil acidification. The highest TOC content was detected in the meadow soil fertilized with CN (in variants N120-CN and Kp-CN). The present results indicate that calcium ion contained in the mineral fertilizer reduced soil acidity and controlling of the SOC losses. The content of dissolved organic carbon in mineral meadow soils increased in the following order:

TOC: Kz-AN > N120-AN > Kz-CN > Kp-AN > N120-CN > Kp-CN

DOC: Kz-CN > Kp-AN > Kz-CN > N120-CN > Kp-CN > N120-AN

Different utilization of meadows and pratotechnical treatments could play an important role in the accumulation or losses of SOC, which is especially important in view of the global climate change.

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