Soil organic carbon and nitrogen characteristics in differently used grasslands at sites with drainage and without drainage

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ABSTRACT

Extensive management (absence of management) of unfertilized permanent grasslands was examined for five years from the aspect of its influence on soil chemical properties of horizon A in a floodplain locality of the Crystalline Complex, in relation to water regime regulation, reclamations and liming. These treatments: without mowing (0), one cut (1) and two cuts (2) per year were used at sites without drainage (WD), with drainage (D) and with drainage water retardation (R). These average values were measured at all sites and for all treatments: content of soil organic carbon C_{org} 2.3–3.4%, combustible substances CS 12–15%, humic to fulvic acids ratio C_{HA}/C_{FA} 0.81–0.94, C/N 8–9, humification rate 0.6–0.7, exchange pH 3.9–5.1. All sites have deteriorated conditions for the activity of soil microorganisms (low pH). Determinations of the contents of organic carbon (C_{org} by thermal combustion, water soluble and hot water soluble carbon, C_{HA} and C_{FA}), CS and total nitrogen indicated decreases as a result of the influence of factors (drainage, liming, mowing) supporting mineralization and the cycle of soil organic matter. Mowing improved humus quality.

Keywords: grasslands; floodplain area; drainage; use; soil organic carbon and nitrogen; humus quality; pH

A reduction in cattle stocks in this country over the past fifteen years has been accompanied by a corresponding change in permanent grassland management. Much grassland is used extensively (without supplies of nutrients from fertilizers, and a lower number of cuts) or they are left unused (fallow lands). The absence of cultural practices such as mowing, water regime regulation, liming and fertilization may influence agrochemical soil properties, e.g. humus quality, amount of soil organic matter and content of available nutrients because microbial activity, transformation processes, organic matter mineralization and humification are reduced.

Soil organic matter (SOM), a carrier of soil productivity, comprises primary organic matter (POM) and humus. POM has a minimum ion-exchange capacity, is transformed during mineralization (POM content decreases as a result of CO_2 evolution) and humification, and it is a source of energy for soil microorganisms (Kolář 1997, Kolář et al. 2000). POM is either inert or degradable that can be expressed as e.g. content of active organic carbon (i.e. hot water soluble carbon C_{hws}). Ghani et al. (2003) recommended C_{hws} as an integrated characteristic of soil organic matter quality. C_{hws} is in good correlation with the content of easily degradable saccharides, mineralizable nitrogen and microbial biomass (Körschens et al. 1990). The content of water-soluble organic carbon C_{cws} is also closely correlated with soil productivity.

The other component of SOM, humus, has a high ion-exchange and sorption capacity and is very stable. One of the most frequently used methods of humus quality determination (degree of condensation and polymerization of humus substances) is to calculate the humic acids to fulvic acids ratio of carbon content (C_{HA}/C_{FA}), carbon to nitrogen ratio (C/N) and the measuring of optical properties of alkaline extracts of humus substances and the calculation of colour quotients ($Q_{4/6}$). Average C/N values in humus substances correspond to the ratio 10:1. The narrower ratio indicates a humus of higher quality (Prax et al. 1995). With a higher rate of humification the value of humus substance extinction increases, i.e. $Q_{4/6}$ decreases and C_{HA}/C_{FA} increases (high-quality humus is indicated by $C_{HA}/C_{FA} > 1$).

The objective of the paper was to evaluate how in relation to previous regulation of water regime and reclamations extensive systems of permanent grassland use (or absence of use) influence chemical

Supported by the Ministry of Agriculture of the Czech Republic, Project No. MZE 0002704901.

properties of soil horizon A in a floodplain locality of the Crystalline Complex.

MATERIAL AND METHODS

In accordance with the set objective results of three meadows sites in the experimental locality Velký Rybník (Vysočina Region) were evaluated. Long-term precipitation sums over the period 1951–2000 for Pelhřimov and Humpolec stations of Czech Hydrometeorological Institute are 660 and 666 mm, and 425 and 417 mm during the growing season. The average air temperature (Přibyslav, 1951–2000) is 6.7°C, and 12.8°C during the growing season. The locality is situated in a potato production area (B3, Němec 2001), at a height of 460 m above sea level. Two sites (1 and 2) are in the floodplain of the Jankovský stream, the third site lies in the floodplain of the Kopaninský stream, ca 1000 m from each other. The soil type of sites 1 and 2 is gleyic Fluvisol, locally modal Gleysol, the soil texture is sandy-loam or loamy. The soil type of site 3 is modal Gleysol, locally gleyic Fluvisol; the soil texture is sandy-loam or loamy. Both soil types overlie the gravel or gravel-sand terrace at a depth of 0.8–1.0 m. The parent rock is cordierite paragneiss. Water regimes of the sites are different (Table 1). Site 1 is without drainage, without reclamations, with natural grass sward and waterlogging with surface water from near springs mainly in the spring season. The groundwater level (GWL) at site 1 fluctuates according to the flow rates in the stream and precipitation. Systematic drainage was built at site 2 and 3 in 1986–1988 while the regulation and retardation of drainage water was in operation at site 3 (Kvítek 1992).

In May 1988 after a preceding fertilization with NPK and liming (5 t/ha of ground limestone) grass sward was established at sites 2 and 3 as underseeding of oats for green feed (*Trifolium repens*, *Phleum pratense*, *Festuca pratensis*, *Festuca rubra*, *Poa pratensis*, *Alopecurus pratensis*).

Table 1. Characteristics of the sites in Velký Rybník locality

Site	Mean GWL 1999–2003	Drainage 1986–1988	Reclamations 1988
1	67	no	no
2	79	yes	yes
3	46	yes, now drainage water retardation	yes

There are 9 parcels at each of the three sites; the area of experimental parcels is 15 m^2. These treatments of grassland management were introduced in 1993: without mowing, one cut and two cuts in three replications while different nitrogen doses were applied by 1997, no fertilization has been carried out since 1998.

Phytocoenological classification of the sites:

Site 1 (without drainage, without reclamations): class *Molinio-Arrhenatheretea*, order *Molinietalia*, alliance *Calthion*, association *Angelico-Cirsietum palustris*, i.e. the stand indicates Canada thistle meadows of foot-hills locations, with rather acid soils poor in nutrients, ground or spring water, and gleyzation in the upper part of soil profile.

Site 2 (drainage, reclamations): class *Molinio-Arrhenatheretea*, order *Arrhenatheretalia*, alliance *Arrhenatherion*, association *Angelico-cirsietum palustris* – a rather arid form, at transition to the association *Trifolio-Festucetum rubrae*, before drainage the alliance *Calthion*.

Site 3 (drainage, drainage water retardation, reclamations): association *Angelico-Cirsietum palustris*, the wettest form, with decreasing intensity of management the population *Carex brizoides* increases (Blažková 2001, unpubl.).

In 1999–2003 samples of soil (from the depth of 0.03–0.2 m) were taken to determine the content of: organic carbon by thermal combustion C_{org} (1350°C), hot water soluble carbon C_{hws} (Körschens et al. 1990), water soluble carbon C_{cws} from dry samples (Vaněk et al. 1997), carbon of humic acids C_{HA} and fulvic acids C_{FA} (Hraško et al. 1962) and combustible substances CS (550°C). We also measured the content of total nitrogen N_t1 (mineralization according to Kjeldahl, Skalar photometric determination), total nitrogen N_t2 by thermal combustion (1350°C) and quotient $Q_{4/6}$. The above characteristics were used to calculate: humification rate $R_H = (C_{HA} + C_{FA})/C_{org}$, C_{org}/N ratio, C_{HA}/C_{FA} ratio and C_{org}/CS ratios. Active pH value (act. pH) and exchange pH value (exch. pH) were also determined. Samples were always taken in autumn (2nd half of September – 1st half of October) in unfertilized strips between parcels (used in the same way as adjacent parcels) in each treatment (one cut, two cuts, without mowing) at all three sites in two replications. Groundwater level was measured at 14-day intervals throughout the year, in 4 casings at each site. Analysis of variance (ANOVA, Scheffe's test, significance level $\alpha = 0.05$) in Statgraphics 7.0 software was used for statistical evaluation of data sets. The characteristics were evaluated by

Table 2. Average values of pH, C_{org}, C_{cws}, C_{hws}, C_{HA}, C_{FA}, CS, N_t for the particular sites and for the treatments at these sites (Velký Rybník, 1999–2003)

Site	Treatment	Act. pH	Exch. pH	C_{org} (%)	C_{cws} (mg/kg)	C_{hws} (mg/kg)	C_{HA} (%)	C_{FA} (%)	CS (%)	N_t1 (%)	N_t2 (%)
1	no cut	4.74	3.87	3.37	739	2 373	1.02	1.16	14.98	0.40	0.40
	one cut	4.88	3.95	2.89	629	2 107	0.97	1.05	13.83	0.38	0.35
	two cuts	4.98	3.96	2.47	549	1 868	0.82	0.97	11.99	0.33	0.30
	mean	4.87	3.93	2.91	639	2 116	0.94	1.06	13.59	0.37	0.35
2	no cut	5.74	4.95	2.47	576	1 401	0.76	0.87	13.16	0.33	0.30
	one cut	5.90	5.11	2.68	572	1 483	0.84	0.93	13.47	0.35	0.33
	two cuts	5.84	4.92	2.34	490	1 258	0.68	0.84	12.86	0.32	0.29
	mean	5.83	4.99	2.50	546	1 380	0.76	0.88	13.16	0.33	0.31
3	no cut	5.47	4.63	2.55	593	1 478	0.76	0.84	12.59	0.31	0.29
	one cut	5.58	4.72	2.80	604	1 620	0.87	0.96	13.81	0.34	0.33
	two cuts	5.68	4.92	2.28	513	1 327	0.72	0.77	12.20	0.29	0.27
	mean	5.58	4.76	2.54	570	1 475	0.78	0.86	12.91	0.31	0.30

ANOVA according to treatments (one-cut, two-cut, without mowing), water regimes (sites 1, 2, 3) and according to treatments at the particular sites and according to the sites with particular treatment. Between-year dynamics of the characteristics was not evaluated due to a low number of replications of the analyses.

RESULTS AND DISCUSSION

Comparison of sites

pH. pH values were below the optimum for grasslands (5.5–6.5). Exchange pH was extremely low, especially at the site without reclamations (Table 2). Act. pH values were considerably different from exch. pH, documenting a high proportion of exchange cations H^+ and low base saturation of the sorption complex.

Carbon. Various forms of carbon content (Table 2) showed differences between the sites. The differences in C_{org}, C_{hws}, C_{HA} and C_{FA} were significant (Table 4) between the site without reclamations (higher values) and the sites with reclamations and drainage. Similarly, the content of C_{cws} and CS was higher at the site without drainage, but the differences were not significant. Sites 2 and 3 (drainage, reclamations) did not differ in carbon content significantly but all carbon determinations (except C_{FA} and CS) were higher at site 3 with a higher groundwater level. An explanation of these differences is that microbial activity, mineralization and organic matter cycle were promoted by the drainage, liming and higher pH (Alexander 1977). On the other hand, in grassland without reclamations (without liming and low pH) and at the site with drainage water retardation (Tesařová et al. 2001) the rate of organic matter accumulation was higher. Fiala (1990, 1997) reported that water surplus or deficit, acid pH and nutrient deficiency prevented the microbial degradation of plant residues and increased the amount of root biomass. Čížek et al. (1992) also reported that a higher soil moisture supported an increase in root and shoot biomass. Differences in soil and sward conditions may have a significant influence on different contents of carbon at the sites. The values of C_{cws} and C_{hws} were relatively high. It can be explained by the fact (Kolář et al. 2000) that the microbicidal effects of R_2O_3 (Al, Fe) sols and mummification of soil organic matter cause the accumulation and nondegradability of this fraction of carbon sources at acid sites.

Nitrogen. Nitrogen contents were highest at the site without reclamations and drainage; differences between sites without drainage and drained sites were significant (Tables 2 and 4). The explanation of differences in nitrogen content is organic matter mineralization after drainage (aeration), higher pH value at reclaimed sites and higher accumulation of organic matter at the site without reclamation, liming and drainage.

Humus quality. Humus quality is indicated at all sites by the C_{HA}/C_{FA} ratio 0.81–0.94; it is due to the relatively young age of Fluvisols (Pospíšil 1980, Makovníková et al. 2003), narrow C/N ratio

Table 3. Average values of C_{org}/N_t2, C_{HA}/C_{FA}, C_{org}/CS, R_H, $Q_{4/6}$ for the particular sites and for the treatments at these sites (Velký Rybník, 1999–2003)

Site	Treatment	C_{org}/N_t2	C_{HA}/C_{FA}	C_{org}/CS	R_H	$Q_{4/6}$
1	no cut	8.38	0.88	0.22	0.65	4.99
	one cut	8.21	0.94	0.21	0.70	4.97
	two cuts	8.11	0.84	0.21	0.72	5.13
	mean	8.23	0.89	0.21	0.69	5.03
2	no cut	8.12	0.89	0.19	0.66	4.98
	one cut	8.18	0.91	0.20	0.66	4.82
	two cuts	7.95	0.81	0.19	0.65	4.86
	mean	8.08	0.87	0.19	0.66	4.89
3	no cut	8.92	0.92	0.20	0.63	4.96
	one cut	8.50	0.90	0.20	0.65	4.99
	two cuts	8.37	0.94	0.19	0.65	5.26
	mean	8.60	0.92	0.20	0.64	5.07

and high R_H (Table 3). The calculated C/N ratio showed a low availability of C for the production of microbial biomass; its C/N is mentioned ca 25 (Čížek et al. 1992). The high rate of humification is a result of the long-term stability of humic acids that persist from the period when quite different relations were established at the sites. The results do not identify the site with the highest humus quality. The highest C_{HA}/C_{FA} ratio was found at site 3 where the highest soil moisture facilitated the process of enzymatic polymerizations and polycondensations (Kolář 2004, unpubl.). The highest R_H was at site 1 without drainage. A statistically significant difference in C_{org}/N_t2 was found between sites 2 and 3, and in R_H between sites 1 and 3 (Table 5). Based on colour quotient $Q_{4/6}$ and C/N ratio humus quality was highest at site 2, the most arid one with drainage (Table 3).

Table 4. Statistically significant differences in pH and in C and N content between the treatments at the sites and between the particular sites (Velký Rybník, 1999–2003)

Site	Treatment	Act. pH	Exch. pH	C_{org} (%)	C_{cws} (mg/kg)	C_{hws} (mg/kg)	C_{HA} (%)	C_{FA} (%)	CS (%)	N_t1 (%)	N_t2 (%)
1	no cut	×	×	×	×	×	×	×	×	×	×
	one cut	××	×	××	×	×	×	×	××	×	××
	two cuts	×	×	×	×	×	×	×	×	×	×
2	no cut	×	×	××	×	×	××	×	×	×	××
	one cut	×	×	×	×	×	×	×	×	×	×
	two cuts	×	×	×	×	×	×	×	×	×	×
3	no cut	×	×	×	×	×	××	××	×	××	×
	one cut	×	××	×	×	×	×	×	×	×	×
	two cuts	×	×	×	×	×	×	×	×	×	×
1		×	×	×	×	×	×	×	×	×	×
2		×	×	×	×	×	×	×	×	×	×
3		×	×	×	×	×	×	×	×	×	×

Table 5. Statistically significant differences in humus quality characteristics between the treatments at the sites and between the particular sites (Velký Rybník, 1999–2003)

Site	Treatment	C_{org}/N_t2	C_{HA}/C_{FA}	C_{org}/CS	R_H2	$Q_{4/6}$
1	no cut	×	×	×	×	×
	one cut	×	×	×	×	×
	two cuts	×	×	×	×	×
2	no cut	×	×	××	×	×
	one cut	×	×	×	×	×
	two cuts	×	×	×	×	×
3	no cut	×	×	×	×	×
	one cut	×	×	×	×	×
	two cuts	×	×	×	×	×
1		××	×	×	×	×
2		×	×	×	××	×
3		×	×	×	×	×

Comparison of treatments

pH. The pH value of soil decreases with decreasing intensity of grassland use. It is connected with pH of degradable phytomass: its highest portion remains in the soil surface of treatments without mowing while its portion on the soil surface of two-cut treatments is lowest. But the arising differences were not statistically significant in any case.

Carbon. Mowing promotes microbial activity and accelerates organic matter degradability and utilization (Tesařová 1992). The lowest values of all C contents (Table 6) and significant differences (Table 8) were determined in two-cut treatments and significant differences were mostly recorded

Table 6. Average values of pH, C_{org}, C_{cws}, C_{hws}, C_{HA}, C_{FA}, CS, N_t for the treatments and for the sites with particular treatment (Velký Rybník, 1999–2003)

Site	Treatment	Act. pH	Exch. pH	C_{org} (%)	C_{cws} (mg/kg)	C_{hws} (mg/kg)	C_{HA} (%)	C_{FA} (%)	CS (%)	N_t1 (%)	N_t2 (%)
No cut	1	4.74	3.87	3.37	739	2373	1.02	1.16	14.98	0.40	0.40
	2	5.74	4.95	2.47	576	1401	0.76	0.87	13.16	0.33	0.30
	3	5.47	4.63	2.55	593	1478	0.76	0.84	12.59	0.31	0.29
	mean	5.32	4.48	2.80	636	1750	0.85	0.96	13.58	0.35	0.33
One cut	1	4.88	3.95	2.89	629	2107	0.97	1.05	13.83	0.38	0.35
	2	5.90	5.11	2.68	572	1483	0.84	0.93	13.47	0.35	0.33
	3	5.58	4.72	2.80	604	1620	0.87	0.96	13.81	0.34	0.33
	mean	5.45	4.59	2.79	601	1736	0.89	0.98	13.70	0.36	0.34
Two cuts	1	4.98	3.96	2.47	549	1868	0.82	0.97	11.99	0.33	0.30
	2	5.84	4.92	2.34	490	1258	0.68	0.84	12.86	0.32	0.29
	3	5.68	4.92	2.28	513	1327	0.72	0.77	12.20	0.29	0.27
	mean	5.50	4.60	2.36	517	1484	0.74	0.86	12.35	0.31	0.29

Table 7. Average values of C_{org}/N_t2, $C_{HA}/_{FA}$, C_{org}/CS, R_H, $Q_{4/6}$ for the treatments and for the sites with particular treatment (Velký Rybník, 1999–2003)

Treatment	Site	C_{org}/N_t2	C_{HA}/C_{FA}	C_{org}/CS	R_H	$Q_{4/6}$
No cut	1	8.38	0.88	0.22	0.65	4.99
	2	8.12	0.89	0.19	0.66	4.98
	3	8.92	0.92	0.20	0.63	4.96
	mean	8.47	0.90	0.20	0.65	4.98
One cut	1	8.21	0.94	0.21	0.70	4.97
	2	8.18	0.91	0.20	0.66	4.82
	3	8.50	0.90	0.20	0.65	4.99
	mean	8.30	0.92	0.20	0.67	4.93
Two cuts	1	8.11	0.84	0.21	0.72	5.13
	2	7.95	0.81	0.19	0.65	4.86
	3	8.37	0.94	0.19	0.65	5.26
	mean	8.14	0.86	0.19	0.67	5.08

between two-cut treatments on the one hand and one cut and no cut treatments on the other hand (Table 8). The results correspond to the findings in Zhůří meadow locality (Šumava Mts.) with extreme agrochemical properties where the content of organic carbon (wet oxidation) slightly increased in the treatment without mowing (Kvítek et al. 2001). Klobušický (1994, unpubl.) also reported a decrease in humus and total nitrogen under permanent grassland in connection with a higher frequency of grassland use when organic matter mineralization and nitrogen uptake for the production of shoot biomass are more intensive.

Nitrogen. The same conclusions as for carbon hold good for the content of total nitrogen: in two-cut treatments the content of total nitrogen was significantly lowest compared to treatment without mowing and also to the one-cut treatment (Tables 6 and 8).

Humus quality. The humus quality was higher in mown treatments (Table 7). The evaluation of differences in humus quality between the treat-

Table 8. Statistically significant differences in pH and in C and N content between the sites with particular treatment and between the treatments (Velký Rybník, 1999–2003)

Treatment	Site	Act. pH	Exch. pH	C_{org}	C_{cws}	C_{hws}	C_{HA}	C_{FA}	CS	N_t1	N_t2
No cut	1	×	×	×	×	×	×	×	×	×	×
	2	×	×	×	×	×	×	×	×	×	×
	3	×	×	×	×	×	×	×	×	×	×
One cut	1	×	×	×	×	×	×	×	×	×	×
	2	×	×	×	×	×	×	×	×	×	×
	3	×	×	×	×	××	×	×	×	×	×
Two cuts	1	×	×	×	×	×	×	×	×	×	×
	2	×	×	×	×	×	×	××	×	×	×
	3	×	×	×	×	×	×	×	×	×	×
No cut		×	×	×	×	×	×	××	×	×	×
One cut		×	×	×	××	×	×	×	×	×	×
Two cuts		×	×	×	×	×	×	×	×	×	×

Table 9. Statistically significant differences in humus quality characteristics between the sites with particular treatment and between the treatments (Velký Rybník, 1999–2003)

Treatment	Site	C_{org}/N_t2	C_{HA}/C_{FA}	C_{org}/CS	R_H	$Q_{4/6}$
	1	×	×	×	×	×
No cut	2	×	×	×	×	×
	3	×	×	×	×	×
	1	×	×	×	×	×
One cut	2	×	×	×	×	×
	3	×	×	××	×	×
	1	××	×	×	×	×
Two cuts	2	×	×	×	×	×
	3	×	×	×	×	×
No cut		×	×	×	×	×
One cut		××	×	×	×	×
Two cuts		×	×	×	×	×

ments showed a significant difference in C_{org}/N_t2 between the treatment without mowing and two-cut treatment (Table 9). The highest C_{HA}/C_{FA} ratio and the lowest values of $Q_{4/6}$ were measured in one-cut treatments. R_H was always higher in mown treatments. Tesařová (1992) also reported that mowing improved the quality of humic acids in natural grasslands. In the treatment without mowing she found out that a high reserve of humus sources that were not utilized for humus synthesis efficiently (adverse acid composition of organic residues and deteriorated conditions for mineralization and synthetic activity of soil organisms).

Conditions for the activity of soil microorganisms were deteriorated at all sites (low pH). Different treatments influenced quantitative characteristics of humus to a larger extent than the qualitative ones. Higher pH (liming), mowing and higher aeration of the soil at a site with drainage contributed to faster mineralization and cycle of soil organic matter. Mowing improved the SOM quality.

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Received on October 14, 2004

ABSTRAKT

Ukazatele půdního organického uhlíku a dusíku rozdílně využívaných travních porostů na odvodněném a neodvodněném stanovišti

Po dobu pěti let byl sledován vliv extenzivních způsobů využití (nevyužití) nehnojených trvalých travních porostů na půdní chemické vlastnosti A horizontu v nivní lokalitě krystalinika v závislosti na dřívější úpravě vodního režimu, rekultivaci a vápnění. Byly zvoleny varianty: nesečená (0), sečená jednou (1) a dvakrát (2) ročně, a to na stanovištích: neodvodněném, odvodněném a s retardací drenážní vody. Na všech stanovištích a variantách byly zjištěny průměrné hodnoty obsahu půdního organického uhlíku C_{org} 2,3–3,4 %, spalitelných látek SL 12–15 %, poměr obsahu uhlíku huminových kyselin a fulvokyselin C_{HK}/C_{FK} 0,81–0,94, C/N 8–9, stupeň humifikace 0,6–0,7, výměnné pH 3,9–5,1. Všechna stanoviště vykazují zhoršené podmínky pro činnost půdních mikroorganismů (nízké pH). Provedená stanovení obsahů organického uhlíku (metodou termického spalování C_{org}, vodorozpustného a extrahovatelného horkou vodou, C_{HK} a C_{FK}), SL a celkového dusíku prokázala snížení v důsledku činitelů (odvodnění, vápnění a sečení) podporujících mineralizaci a koloběh půdní organické hmoty. Sečení zvýšilo kvalitu humusu.

Klíčová slova: travní porosty; nivní oblast; odvodnění; využití; půdní organický uhlík a dusík; kvalita humusu; pH

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