Soil biological quantity and quality parameters of grasslands in various landscape zones

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ABSTRACT

In three landscape zones of a permanent grassland catchment (discharge zone, D; transient zone, T; and recharge zone, R; Crystallinicum, Czech Republic), soil moisture by volume (θ) and soil biological quantity and quality parameters, e.g. oxidizable C (C_{ox}), hot water soluble C (C_{hws}), microbial biomass C (C_{mic}), nitrification (NITR), aerobic N mineralization (MIN) and basal respiration rates (R_{bas}), metabolic quotient (qCO_2: R_{bas}/C_{mic}) and microbial quotient (C_{mic}/C_{ox}) were estimated in the surface soil layer. We found out positive correlation of C_{mic} and C_{mic}/C_{ox} with θ, or NITR, MIN, R_{bas} and C_{mic} with C_{hws}, but no relationship between θ on the one hand and NITR, MIN, R_{bas} or C_{ox} on the other. The wettest zone D with extremely low pH displayed the highest C_{mic} and C_{mic}/C_{ox} (1081 mg/kg, 5.29%) and the lowest qCO_2 (31 μgC/day/mgC_{mic}). Soil drought in zones T and R reduced C_{mic} and C_{mic}/C_{ox} (939, 1029, and 3.72, 3.83, respectively) and augmented qCO_2 (42; 51). Rainfall following a prolonged dry period reduced MIN and NITR in permeable zone R as a result of fast microbial regeneration (average in D: 2.24; 2.48 kg N/ha/day, T: 2.62; 2.82 kg N/ha/day, R: 1.51; 1.95 kg N/ha/day).

Keywords: soil moisture; drought; microbial activity; soil chemical properties; permanent grassland

The spatial distribution of soil biological quality and quantity parameters is determined by the soil properties, terrain relief, climate and land use. In particular, soil organic C (SOC) is generally directly related to soil moisture, but inversely related to temperature (Brye and Gbur 2010). Larger available water generally promotes greater microbial biomass C (C_{mic}). Parameters of soil biological quality as basal respiration (R_{bas}), aerobic N mineralization (MIN) and nitrification rates (NITR) indicate the availability of SOC to microorganisms and of N to plants and show the optimal conditions at 60–80, 50–75 and 50–66% water-holding capacity, respectively (Alexander 1977). These parameters are directly related to the source of labile (easily available) SOC (Angers et al. 2006), with active hot water soluble C (C_{hws}) as its main indicator, and correlate well with the content of easily degradable saccharides, mineralizable nitrogen and microbial biomass (Körschens et al. 1990, Kolář et al. 2003). Ghani et al. (2003) recommended C_{hws} as an integrated characteristic of soil organic matter quality. However, Kolář et al. (2011) reported that SOC transformation is dependent on a number of factors (microbial activity, pH, humidity, temperature, etc.), and C_{hws} cannot therefore be considered as a stable parameter of soil quality without parallel estimation of C_{mic} and metabolic quotient (Uhlířová et al. 2005).

The terrain relief of the catchment can be divided into recharge and discharge zones. The former are located in the highest areas of the catchment with shallow soil and high sand content, and the latter can be found in the lowest parts of the slopes (Serrano 1997), with deep soil and higher clay content. A connection between the recharge and the discharge zones is provided by transient zones (Doležal and Kvítek 2004). Permeable soils or slopes exposed to radiation are more often affected by drought, with increasing qCO_2 (R_{bas}/C_{mic}) and decreasing microbial quotient (C_{mic}/C_{ox}, Anderson and Domsch 2010) as its main indicators besides R_{bas}.

The objective of this paper was to elucidate the impact of landscape zones covered with permanent grassland including drought effect on the parameters of soil biological quality and quantity.

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Table 1. Selected soil physical and chemical properties (3–20 cm)

Soil type	Site		
	D	T	R
	medium SL	light LS	light LS
Clay particle content (< 0.01 mm, %)	23.2	19.9	17.9
Sand content (0.25–2 mm, %)	34.5	38.5	41.9
Porosity (P, %)	52.1	55.0	52.6
Maximum capillary water capacity (θ_{MCC}, %)	41.3	40.8	32.5
C_{HA}/C_{FA}	0.71	1.10	1.15

D – discharge zone; T – transient zone; R – recharge zone; SL – sandy loam; LS – loamy sand

MATERIAL AND METHODS

The experiment was carried out at three sites with permanent grasslands (mesic to mesoxeric *Arrhenatherum* meadows) in Vadčice locality in the south-west part of the Bohemian-Moravian Highland (Želivka catchment, Czech Republic), which represented the discharge (D), transient (T) and recharge (R) zones of the catchment. The soil of D was Colluvic Regosol Humic with extremely acid sandy loam (SL), medium infiltration capacity, high porosity (P) and maximum capillary water capacity (θ_{MCC}) (Pokorný et al. 2007), and with low humus quality (Table 1). In T, there was Haplic Cambisol with south-east exposure and 7° incline, with acid loamy sand (LS), medium infiltration capacity and very high P, medium θ_{MCC} and high-quality humus. The soil of R was Cambic Hyperskeletic Leptosol, with shallow and acid LS, high infiltration capacity, with dynamically oscillating soil moisture, high P, low θ_{MCC} and high-quality humus. At the end of the 1970s, ammonium nitrate with lime was applied in the doses of 40–240 kg N/ha (Haken 1980) to R, and

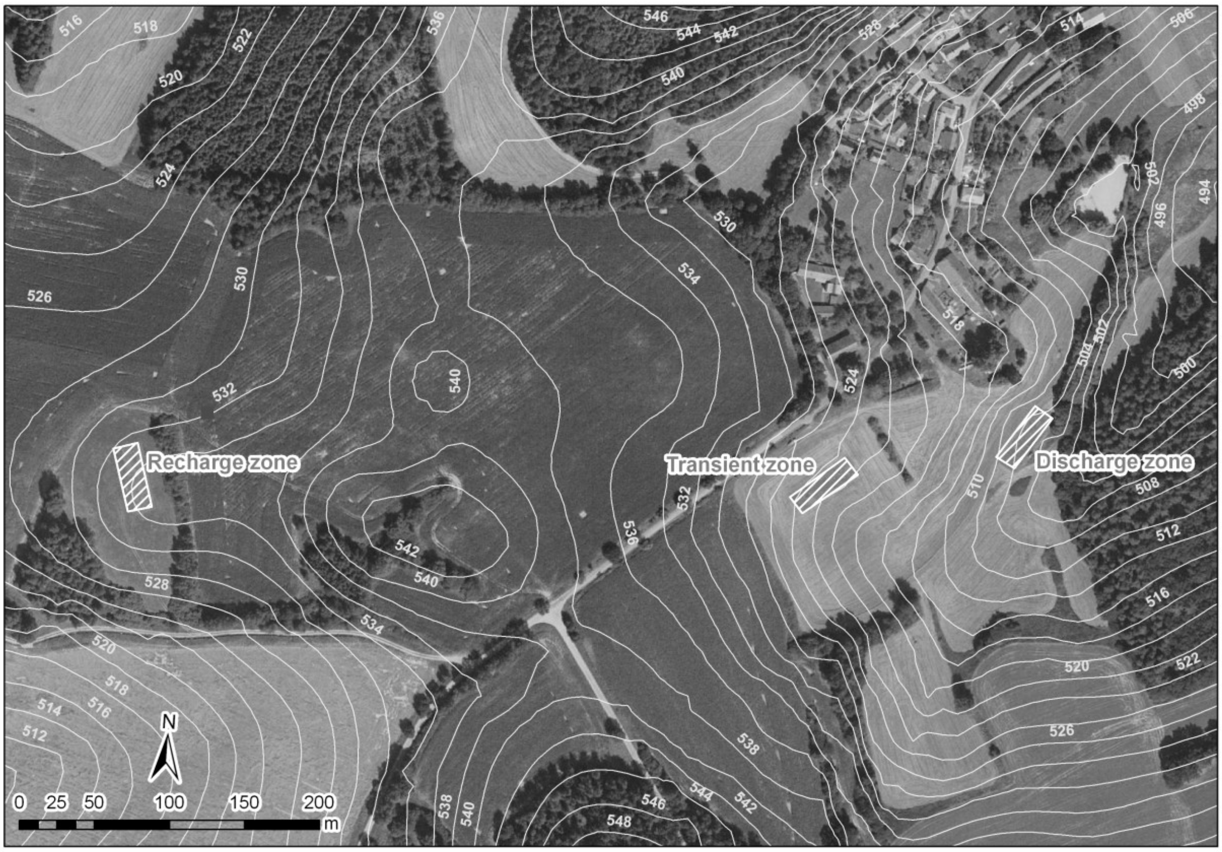

Figure 1. Distribution of experimental sites in cadastral territory Vadčice

Table 2. Survey of selected parameters of soil quantity and quality

Parameters of soil quantity	
Soil moisture by volume (θ)	oxidizable C (C_{ox})
Total N (N_{tot})	microbial biomass C (C_{mic})
Parameters of soil quality	
Exchange pH (KCl)	hot water soluble C (C_{hws})
Potential respiration rate (R_{pot})	basal respiration rate (R_{bas})
R_{bas}/C_{ox}	R_{pot}/R_{bas}
C_{ox}: N_{tot} (C:N)	microbial quotient: $C_{mic}/(C_{ox} \times 100)$
Metabolic quotient (qCO_2): (R_{bas}/C_{mic})	$C_{hws}/(C_{ox} \times 100)$
Nitrification rate (NITR)	aerobic N mineralization rate (MIN)

T received $CaCO_3$ in the doses of 0–10 t/ha in 1984 (Kvítek 1992).

According to Quitt (Tolasz et al. 2007), the local climate is classified as moderately warm. The average annual total precipitation is 660 mm a.s.l. and the air temperature is 7.0°C. The altitude of the sites ranges between 508 (D) and 534 m (R, Figure 1).

Each site containing 21 plots (15 m^2 each) was subjected to seven treatments: uncut, mulched three times a year, or cut with various doses of cattle slurry applied (0, 60, 120, 180 = S3 and 240 kg N/ha/year = S4). Except for S3 and S4, displaying a significant effect on NITR and MIN increase, the treatments had no effect on the parameters of soil biological quality and quantity.

Samples were taken at a depth of 3–20 cm for the parameters given in Table 2. For financial reasons, some parameters were not determined in 2010.

Samples were sieved (< 2 mm) and stored at 4°C for assessment of C_{mic} and aerobic processes (NITR, MIN, R_{bas}), and for soil moisture by volume (θ), pH, C_{ox}, C_{hws} and N_{tot} establishment they were dried and processed to analytical fineness. C_{ox}, N_{tot} and C_{mic} were determined according to ISO 14235 (1998), modified ISO 11261 (1995) and ISO 14240-2 (1998). C_{hws} was estimated after 1 h boiling in 0.01 mol/L $CaCl_2$, which was used because of better filtration instead of water (Körchens et al. 1990). CO_2 released during R_{bas} measurement was trapped in 0.2 mol/L NaOH (ISO 16072 2002) and two days later the excess NaOH was titrated with 0.05 mol/L HCl. The identical measurement was performed for potential respiration rate (R_{pot}) after adding glucose before incubation (50 mg C/10 g). R_{pot}/R_{bas} shows the amount of easily degradable C; the R_{pot}/R_{bas} decrease indicates raising SOC supply, and the R_{pot}/R_{bas} increase indicates the lack of available C or the 'priming' effect, when addition of the easily degradable C augments mineralization of less easily degradable compounds (Šantrůčková 1993). The metabolic quotient (qCO_2) expresses specific respiration activity (R_{bas}/C_{mic}). Its decrease indicates synthesis of new C_{mic} or R_{bas} inhibition and its increase shows substrate quality deterioration, or presence of stress. NITR and MIN were assessed as the $N\text{-}NO_3$ difference and the difference between the sum of $N\text{-}NH_4$ and $N\text{-}NO_3$ extracted with 1 mol/L KCl (ISO 14238 1997) before and after 1-week incubation, respectively. The microbial quotient (C_{mic}/C_{ox}), an important indicator of microbial regeneration (Voříšek et al. 2002) ranging from 0.27% to 7% (Anderson and Domsch 1989), showed reduced availability of SOC to microorganisms when decreased (Joergensen and Emmerling 2006) and favourable conditions for SOC accumulation and synthesis of new biomass when increased. Establishment of weakly bound (free) humus compounds (C humic acids C_{HA} and C fulvic acids C_{FA}) was performed using NaOH solution extraction (Hraško et al. 1962).

To identify the effect of the categorical independent variable (site) upon the dependent variable (soil parameter), Kruskal-Wallis test was used with a significance level α = 0.05. The systematic differences were expressed in rows of Table 3 using letters a–c. The closeness of correlation was established by simple linear regression/correlation (Pearson's correlation coefficient *r*). The results are presented graphically as boxplots. The horizontal sides of the boxes correspond to the lower and upper quartiles; the inner straight line, a cross and the abscissas on both sides of the boxes represent the median, arithmetical mean, and the minimum and maximum, respectively. Crosses outside the boxes represent outliers.

Table 3. Median parameters of the soil biological quantity and quality at all sites and sampling dates (3–20 cm), 2007–2010

Site/ parameter	Autumn 2007 (9.9.)			Autumn 2008 (9.9.)			Spring 2009 (5.5.)			Autumn 2009 (13.10.)			Spring 2010 (6.5.)			Autumn 2010 (7.10.)			Mean of individual samplings		
	D	T	R	D	T	R	D	T	R	D	T	R	D	T	R	D	T	R	D	T	R
θ vol. (%)	38.7	35.7	37.9	26.5	17.0	22.1	21.3	15.5	14.5	39.0	34.2	36.6	44.8	36.4	37.2	43.4	36.8	38.5	37.7^b	33.7^a	35.2^a
pH (KCl)	4.21	5.46	5.07	4.42	5.40	5.15	4.27	5.45	5.07	4.36	5.37	5.19	4.27	5.30	5.05	-	-	-	4.30^a	5.37^c	5.11^b
NITR (kg N/ha/day)	1.91	2.84	2.49	2.50	2.32	1.45	2.84	3.90	2.73	1.88	1.81	-1.11	3.08	3.51	3.21	3.07	2.74	1.39	2.48^b	2.82^c	1.95^a
MIN (kg N/ha/day)	1.37	2.59	1.18	1.86	1.65	0.59	2.75	3.32	2.44	1.54	1.76	-1.17	2.39	3.43	2.68	2.98	2.80	1.36	2.24^b	2.62^c	1.51^a
R_{bas} (kg C/ha/day)	83.5	110.4	127.8	74.4	90.6	160.4	105.5	126.6	151.8	76.8	64.2	84.17	–	–	–	76.2	95.4	118.6	79.3^a	100.2^b	126.6^c
N_{tot} (%)	0.25	0.26	0.25	0.28	0.32	0.3	0.23	0.26	0.26	0.24	0.25	0.26	0.26	0.30	0.29	–	–	–	0.25^a	0.27^b	0.27^b
C_{ox} (%)	2.16	2.33	2.33	2.55	3.06	3.1	1.91	2.41	2.35	1.80	1.99	2.16	2.31	2.78	2.93	–	–	–	2.13^a	2.43^b	2.51^b
C_{hws} (mg/kg)	952	928	968	1194	1202	1292	948	975	839	938	723	780	1135	1109	1004	–	–	–	1023^a	989^a	958^a
C_{mic} (mg/kg)	1152	1042	1074	976	789	1047	1039	818	685	1097	1095	1175	1288	1013	1015	–	–	–	1081^c	939^a	1029^b
C:N	8.7	8.9	9.3	9.0	9.4	10.1	8.5	9.0	9.0	7.5	8.2	8.4	9.2	9.1	9.8	–	–	–	8.8^a	9.0^b	9.3^c
R_{bas}/C_{ox} (%/day)	0.15	0.19	0.21	0.11	0.12	0.20	0.22	0.21	0.25	0.17	0.13	0.15	–	–	–	–	–	–	0.15^a	0.16^a	0.20^b
R_{pot}/R_{bas}	11.9	8.2	7.4	9.7	9.7	6.7	7.2	7.5	6.3	9.1	14.2	9.2	–	–	–	11.5	9.3	8.2	9.8^b	9.4^b	7.3^a
$C_{mic}:C_{ox}$ (%)	5.04	4.00	4.82	3.80	2.91	3.54	5.52	3.44	3.40	6.15	5.30	5.44	5.41	3.56	3.52	–	–	–	5.29^b	3.72^a	3.83^a
qCO_2^+	31.1	41.7	43.4	30.4	43.7	60.8	40.0	62.1	74.0	28.1	22.9	28.0	–	–	–	–	–	–	31.1^a	41.7^b	51.2^c
$C_{hws}:C_{ox}$ (%)	4.57	4.05	4.27	4.82	4.05	4.09	5.07	4.00	3.58	5.34	3.64	3.59	4.85	4.08	3.36	–	–	–	4.82^c	3.93^b	3.75^a
Previous precipitation (mm)	31.8.–9.9. = 88			14.–16.8. = 45.8 17.8.–6.9. = 12.2 7.9. = 10.8			1.–28.4. = 4.7 29.4.–5.5. = 12.8			1.9.–9.10. = 18.4 10–13.10. = 24			10.–15.4. = 17.8 30.4.–6.5. = 38			25.–29.9. = 80 30.9.–7.10. = 0					

$^+$μg C/day/mg Cmic; D – discharge; T – transient; R – recharge

RESULTS AND DISCUSSION

The erosive wash of Cambisol (D) originating from the subsurface horizon of the higher part of the slope (Vopravil, pers. com.) caused lower humus quality, with prevailing soluble and mobile FA (Table 1) and reduced C_{ox}, N_{tot} and pH (Table 3). Application of Ca-containing compounds decades of years ago had a positive effect on the humus quality, with prevailing stable inert HA (Kolář 1992) and higher pH in T and R. At all the sites, microbial regeneration (C_{mic}, C_{mic}/C_{ox}) showed positive correlation with θ (*r*: 0.40–0.83); however, causative relationship between θ and aerobic processes, C_{ox} or N_{tot} was not established, which might have reflected adaptation of the communities to the water regime (Sierra 1997). The highest microbial regeneration was observed in the wettest D (Figure 2a), despite the lack of C indicated by R_{pot}/R_{bas} higher than 9–10 (the optimum is 6–8, Table 3, Růžek, pers. com.). No dependence of C_{mic} on R_{pot}/R_{bas} or C:N was found. In contrast, R_{bas} or specific microbial activity (qCO_2, R_{bas}/C_{ox}) in D were generally suppressed (Figure 2b) due to excessive θ and soil acidity (pH optimum 6.6–8.0, Alexander 1977). The metabolic quotient (Table 3) at this site decreased below the level of values reported by Hamer et al. (2008) not only in dry seasons (67–72 μg C/day/mg C_{mic}), but also in the periods of optimal θ (48). The other sites, because of the south-east exposure (T) or soil permeability (R), were prone to drought, which reduced microbial regeneration and increased qCO_2, R_{bas}, or R_{bas}/C_{ox} (spring 2009, Table 3). Similarly, Franzluebbers et al. (1996) reported an increase of these parameters in coarser-textured soils with higher O_2 content, and Killham (1985) also found out increased R_{bas} during soil drought, aimed to maintain the cell integrity at the expense of immobilization. In this way, communities enhanced their tolerance against osmotic shocks and prospered well after wetting (Gleeson et al. 2008). This was shown in the autumn of 2008 and 2009 in R, where after a prolonged dry period the soil

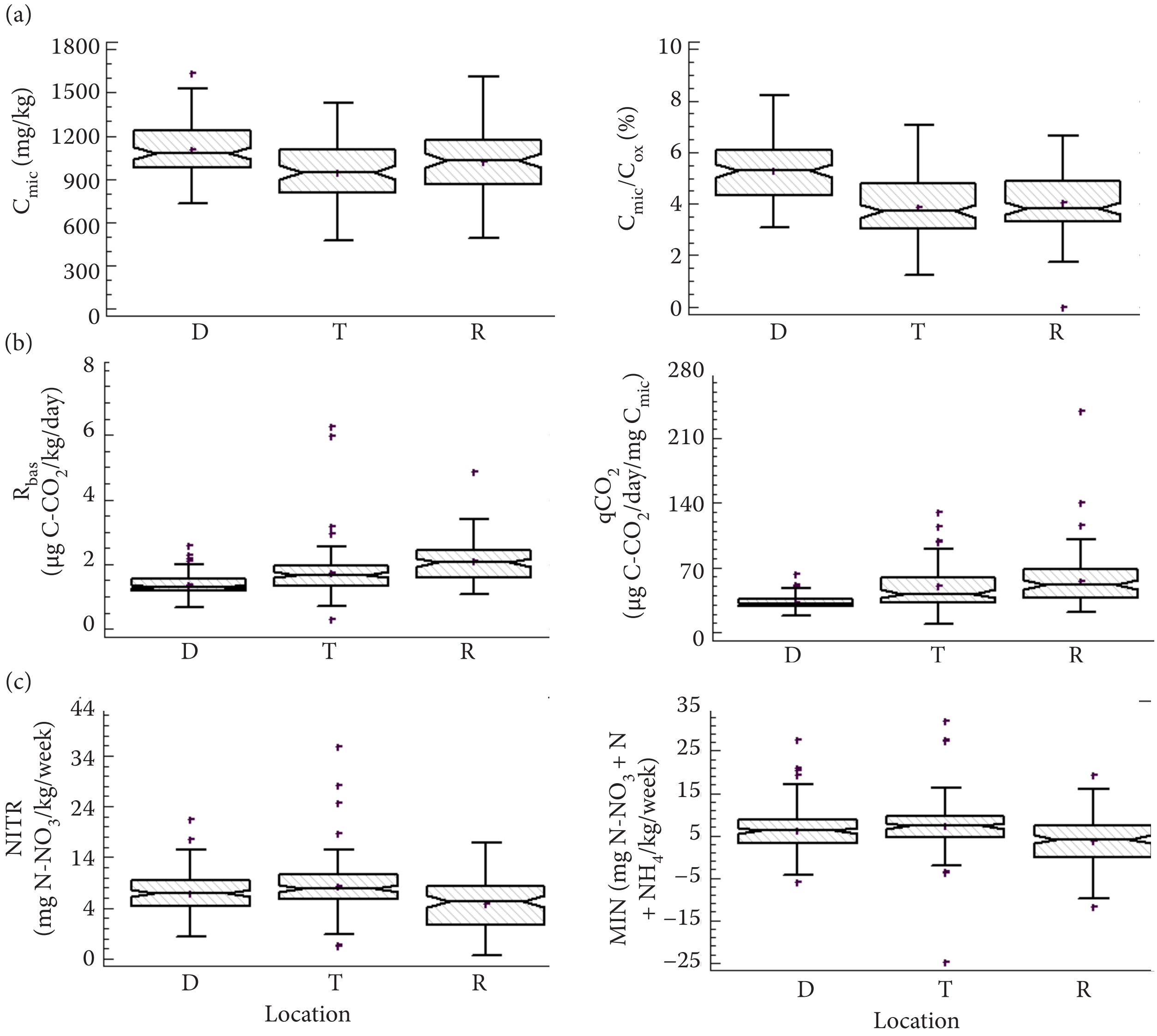

Figure 2. Boxplots of C_{mic}; C_{mic}/C_{ox}; R_{bas}; qCO_2; NITR and MIN at all sites (2007–2010). D – discharge zone; T – transient zone; R – recharge zone

profile was moistened, with simultaneous C_{mic} increase and MIN and NITR reduction (Table 3, Figure 2c), which was confirmed by moderate negative correlation of MIN with C_{mic}/C_{ox} (2008: $r = -0.45$, 2009: $r = -0.60$) and of NITR with C_{mic}/C_{ox} (2008, $r = -0.55$). Contrary to that, Corre et al. (2002) found out higher NITR in the higher part of the slope with better aerobic conditions. In D and T, no relationships were found between C_{mic} and aerobic processes. In the autumn 2009, in agreement with the findings by Angers et al. (2006) and Körschens et al. (1990), a positive correlation was found between MIN and C_{hws} ($r = 0.61$), and C_{mic} and C_{hws} ($r = 0.51$) in R, which was also confirmed during sampling with higher θ in 2007 and in spring 2010 ($r = 0.52$ and $r = 0.58$, respectively). Certain samplings (2008, spring 2009: D, 2007, 2008: T, spring 2009: R) also showed a relatively strong dependence of R_{bas} on C_{hws} ($r = 0.62$–0.77). Soil wetting in T was slower than in R due to medium permeability and higher evaporation in the slope with south-east exposure.

REFERENCES

Alexander M. (1977): Introduction to Soil Microbiology. John Wiley & Sons, New York.

Anderson T.-H., Domsch K.H. (1989): Ratios of microbial biomass carbon to total organic carbon in arable soils. Soil Biology and Biochemistry, *21*: 471–479.

Anderson T.-H., Domsch K.H. (2010): Soil microbial biomass: The eco-physiological approach. Soil Biology and Biochemistry, *42*: 2039–2043.

Angers D.A., Chantigny M.H., Rochette P., Gagnon B. (2006): Dynamics of soil water-extractable organic C following application of dairy cattle manures. Canadian Journal of Soil Science, *86*: 851–858.

Brye K.R., Gbur E.E. (2010): Regional differences in soil carbon and nitrogen storage as affected by land use and soil moisture regime. Soil Science, *175*: 339–348.

Corre M.D., Schnabel R.R., Stout W.L. (2002): Spatial and seasonal variation of gross nitrogen transformations and microbial biomass in a Northeastern US grassland. Soil Biology and Biochemistry, *34*: 445–457.

Doležal F., Kvítek T. (2004): The role of recharge zones, discharge zones, springs and tile drainage systems in peneplains of Central European highlands with regard to water quality generation processes. Physics and Chemistry of the Earth, Parts A/B/C, *29*: 775–785.

Franzluebbers A.J., Haney R.L., Hons F.M., Zuberer D.A. (1996): Active fractions of organic matter in soils with different texture. Soil Biology and Biochemistry, *28*: 1367–1372.

Ghani A., Dexter M., Perrott K.W. (2003): Hot-water extractable carbon in soils: sensitive measurement for determining impacts of fertilisation, grazing and cultivation. Soil Biology and Biochemistry, *35*: 1231–1243.

Gleeson D.B., Herrmann A.M., Livesley S., Murphy D.V. (2008): Influence of water potential on nitrification and structure of nitrifying bacterial communities in semiarid soils. Applied Soil Ecology, *40*: 189–194.

Haken D. (1980): Enrichment of Grasslands on Shallow Meadow Soils. Final Report. Research Institute for Improving the Agricultural Soils, Prague. (In Czech)

Hamer U., Makeschin F., Stadler J., Klotz S. (2008): Soil organic matter and microbial community structure in set-aside and intensively managed arable soils in NE-Saxony, Germany. Applied Soil Ecology, *40*: 465–475.

Hraško J., Červenka L., Focek Z., Komár J., Němeček J., Pospíšil F., Sirový V. (1962): Soil Analysis. Slovenské vydavatelsťvo podohospodarskej literatury Bratislava. (In Slovak)

ISO 11261 (1995): Soil quality – Determination of total nitrogen – Modified Kjeldahl method, International Organization for Standardization, Geneva.

ISO 14235 (1998): Soil quality – Determination of organic carbon by sulfochromic oxidation, International Organization for Standardization, Geneva.

ISO 14238 (1997): Soil quality – Biological methods – Determination of nitrogen mineralization and nitrification in soils and the influence of chemicals on these processes, International Organization for Standardization, Geneva.

ISO 14240-2 (1998): Soil quality – Determination of soil microbial biomass – Part 2: Fumigation-extraction method, International Organization for Standardization, Geneva.

ISO 16072 (2002): Soil quality – Laboratory methods for determination of microbial soil respiration, International Organization for Standardization, Geneva.

Joergensen R.G., Emmerling Ch. (2006): Methods for evaluating human impact on soil microorganisms based on their activity, biomass, and diversity in agricultural soils. Journal of Plant Nutrition and Soil Science, *169*: 295–309.

Killham K. (1985): A physiological determination of the impact of environmental stress on the activity of microbial biomass. Environmental Pollution Series A, Ecological and Biological, *38*: 283–294.

Kolář L. (1992): Relationships between humus, soil properties and soil fertility. In: Kubát J. (ed): Humus, its Structure and Role in Agriculture and Environment. Elsevier Science Publishers, Amsterdam, 175–184.

Kolář L., Klimeš F., Ledvina R., Kužel S. (2003): A method to determine mineralization kinetics of a decomposable part of soil organic matter in the soil. Plant, Soil and Environment, *49*: 8–11.

Kolář L., Vaněk V., Kužel S., Peterka J., Borová-Batt J., Pezlarová J. (2011): Relationships between quality and quantity of soil labile fraction of the soil carbon in Cambisols after liming during a 5-year period. Plant, Soil and Environment, *57*: 193–200.

Körchens I., Schulz E., Behm R. (1990): Hot water extractable carbon and nitrogen of soils as criteria of their ability for N-release. Zentralblatt für Mikrobiologie, *145*: 305–311.

Kvítek T. (1992): Variability of exchangeable reaction under permanent grasslands. Rostlinná Výroba, *38*: 81–88. (In Czech)

Pokorný E., Šarapatka B., Hejátková K. (2007): Evaluation of Soil Quality in the Organic Farm. Methodological Tool. Zemědělská a Ekologická Regionální Agentura, Náměšť nad Oslavou. (In Czech)

Serrano S.E. (1997): Hydrology for Engineers, Geologists and Environmental Professionals. HydroScience Inc. Lexington, Kentucky.

Sierra J. (1997): Temperature and soil moisture dependence of N mineralization in intact soil cores. Soil Biology and Biochemistry, *29*: 1557–1563.

Šantrůčková H. (1993): Soil respiration as a measure of soil biological-activity. Rostlinná výroba, *39*: 769–778. (In Czech)

Tolasz R., Míková T., Valeriánová A. (eds.) (2007): Climatic Atlas of Czechia. Czech Hydrometeorological Institute and Palacký University Olomouc. 1st Edition, Prague.

Uhlířová E., Šimek M., Šantrůčková H. (2005): Microbial transformation of organic matter in soils of montane grasslands under different management. Applied Soil Ecology, *28*: 225–235.

Voříšek K., Růžek L., Svobodová I., Šantrůček J., Strnadová S., Popelářová E. (2002): The influence of grassing and harvest management on microbial parameters after arable land setting-aside. Rostlinná výroba, *48*: 382–388.

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