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Characteristics of microbial biomass carbon and respiration activities in arable soil and pasture grassland soil

Charakteristika uhlíka mikrobiálnej biomasy a respiračných aktivít v orných pôdach a pasienkoch

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Abstract

The aim of our work was to survey and state the representative values and range of the microbial biomass carbon (C_{mic}) and microbial respiration activities in arable soils of three types (Chernozem, Luvisol, Planosol) and in pasture grassland soil (Cambisol). In arable soils no significant differences between the soil types were found concerning the content of C_{mic}. Way of soil use significantly influenced C_{mic} with higher values on pasture grassland soil. In Cambisol, a relatively strong relationships between C_{mic} and C_{org} (r = 0.919) as well as between C_{mic} and N_{tot} (r = 0.922) were determined. The basal respiration (BR) was no affected neither by a soil type nor by a way of soil use. On all monitored sites microbes responded positively to the addition of glucose (potential respiration - PR), but the strongest response was observed on the soil types with good mineralisation ability, such as Chernozems and Luvisols. On pasture grassland soil, the substrate availability index (PR/BR) with values of 2.32 was observed, which is lower compared to 7.60 of arable soil. This fact to indicate that pasture grassland soil had more easy decomposable organic compounds than arable soils.

Keywords: arable soil; pasture grassland soil; microbial biomass carbon; respiration.

Abstrakt

Cieľom našej práce bolo preskúmať a stanoviť reprezentatívne hodnoty a rozsah hodnôt uhlíka mikrobiálnej biomasy (C_{mic}) a respiračnej aktivity ornej pôdy troch pôdnych typov (černozem, hnedozem, pseudoglej) a pôdy pasienka (kambizem). V ornej pôde neboli zistené preukazné rozdiely v obsahu C_{mic} medzi pôdnymi typmi. Spôsob využívania pôdy preukazne ovplyvnil C_{mic}, s vyššími hodnotami pri pasienku. V kambizemi boli zistené relatívne silné vzťahy medzi C_{mic} a C_{org} (r = 0,919) a C_{mic} a N_{tot} (r = 0,922). Bazálna respirácia (BR) nebola ovplyvnená pôdnym typom ani spôsobom využívania pôdy. Na všetkých sledovaných stanovištiach mikroorganizmy pozitívne reagovali na prídavok glukózy (potenciálna respirácia - PR), ale najsilnejšia odpoveď bola pri pôdnych typoch s dobrou mineralizačnou aktivitou ako černozem a hnedozem. Index substrátovej dostupnosti (PR/BR) bol na pasienkoch nižší (2,32) v porovnaní s ornou pôdou (7,60). Tento fakt svedčí o tom, že pôda pasienka má viac ľahkorozložiteľných organických zlúčenín ako orná pôda.

Kľúčové slová: orná pôda; pasienok; uhlík mikrobiálnej biomasy; respirácia.

DETAILNÝ ABSTRAKT

Uvedenou štúdiou sme zmonitorovali veľkosť uhlíka mikrobiálnej biomasy a respiračnú aktivitu v štyroch najrozšírenejších pôdnych typoch Slovenska využívaných ako orná pôda a pasienok. Medzi pôdnymi typmi hnedozem (8 lokalít), černozem (7 lokalít) a pseudoglej (6 lokalít) na ornej pôde sme v množstve uhlíka biomasy mikroorganizmov nezistili preukazné rozdiely (pseudoglej od 107 do 777, s priemernou hodnotou 456 µg C g^{-1}; černozem od 146 do 802 s priemernou hodnotou 362 µg C g^{-1}; hnedozem od 108 do 714 s priemernou hodnotou 257 µg C g^{-1}). Avšak pri tomto type využívania pôdy bolo štatisticky preukazne nižšie zastúpenie uhlíka biomasy mikroorganizmov ako v pôde pasienka (kambizem od 1024 do 1592 s priemernou hodnotou 1294 µg C g^{-1}). Bazálna respirácia (BR) nebola ovplyvnená pôdnym typom ani spôsobom využívania pôdy. Na prídavok glukózy (potenciálna respirácia PR) pozitívne reagovali mikroorganizmy zo všetkých sledovaných stanovíšť, najintenzívnejšie však v pôdnych typoch černozem a hnedozem. Zo všetkých sledovaných pôd boli energeticky najvýkonnejšími, teda s najnižšími hodnotami metabolického kvocientu odvodeného z bazálnej a potenciálnej respirácie (qCO_2-BR a qCO_2-PR), mikroorganizmy v pôde pasienka. Nižší „index substrátovej dostupnosti – PR/BR“ sme zaznamenali v pôde pasienka v porovnaní s ornou pôdou. Ďalší výskum by mal byť orientovaný na sledovanie diverzity pôdnych mikrobiálnych spoločenstiev použitím molekulárnych metód, čím sa rozšíria poznatky ohľadne toku uhlíka a energie mikrobiálnou biomasou rôznych pôdnych typov a spôsobov ich využívania.

Introduction

The quantification of microbial biomass and microbial activity of soil has been an important research issue for soil scientists for many years [21]. One of the basic functions of soil microorganisms is decomposition and transformation of organic materials, which are mostly derived from above and below-ground plant residues. Thus, soil microbial communities play a critical role in ecosystem processes, such as carbon cycling, nutrient turnover, production of trace gases, or pollutant degradation [1]. Microbial activities, populations, and communities are governed by environmental variables, such as soil type and texture, temperature, moisture, or pH, and management practices such as cropping, fertilization, and type of ecosystem also affect soil microbial activities [19, 5, 6]. Nevertheless, scientists published many papers about the monitoring and impact of soil properties on the biological parameters of soil types in many regions of the world [20, 17, 12], but the soils the Slovak Republic have rarely been studied. Biological monitoring can extend information about environmental pollution and about the soil physical-chemical properties in every soil survey [10].

Parameters describing the amount, activities, and diversity of soil microorganisms are also used as biological indicators of soil quality and health [8]. There is no individual parameter that could be considered as a biological index of soil quality. It is suitable to characterise parameters on the base of applied methods that include microscopic, chemical, molecular, biological and physiological methods. The basic problem concerning soil bio-monitoring is a natural seasonal variability of most parameters. A certain solution in this case could be the so-called eco-physiological quotients [4] that characterise the flow of nutrients and energy through a microbial biomass.

The aim of our work was to survey and state representative values and range of the microbial biomass and microbial respiration activities of four soil types in Slovakia. An additional aim was to compare the monitored parameters in arable soil and pasture grassland soil and to identify relations between biomass/respiration activities and selected chemical parameters of soil.

Material and methods

Soil sampling

In years 2001-2007, microbial characteristics of four soil types in Slovakia were investigated. Basic characterization of soil sampling localities is shown in Table 1. Soils were classified according to type and way of use (arable soil, pasture grassland soil). Samples from arable soil were taken in the springtime (April) after pre-sowing preparation and from pasture grassland in the summer (July). Twenty-one samples from arable soils (eight Luvisols, seven Chernozems and six Planosols) and four samples from pasture grassland soils (Cambisols in National parks of Slovakia) were investigated. There were collected stratified random samples, but in the present paper only the results from humus horizons were evaluated (Luvisols 0.0-0.28m; Chernozems 0.0-0.30m; Planosols 0.0-0.47m; Cambisols 0.0-0.32m). All observed pasture grassland soils were harmed (extreme eutrophication, ruderalization and degradation) by fold-grazing of cattle (for more than 30 years).

Soil samples were quickly transported to the laboratory and sieved through a 2mm mesh. Samples for chemical analyses were dried at laboratory temperature and samples for microbiological analyses were stored (pre-incubated) at 4±1°C 8 weeks [11, 23]. After pre-incubation, the samples were moistened up to 50% maximum water holding capacity (MWHC) and further microbial characteristics were determined.

Soil analysis

Soil moisture was determined gravimetrically after drying at 105°C for 24 h. Soil pH was evaluated as pH/H_2O (1:2.5). The content of soil organic carbon (C_{org}) was determined according to the standard Tyurin titrimetric method by dichromate oxidation, total nitrogen (N_{tot}) by the distillation method according to the standard Kjeldahl wet oxidation and hot water extractable carbon (C_{hwe}) by Körschens et al. procedure [13].

Microbial biomass carbon (C_{mic}) was measured by the chloroform fumigation-extraction (FE) method according to Vance et al. [25]. The microbial quotient (C_{mic}/C_{org}) was calculated as ratios of microbial biomass carbon (C_{mic}) to soil organic carbon [2].

Soil respiration was determined after trapping CO_2 in 0.1 mol.dm^{-3} KOH solution and automated titration with 0.1 mol.dm^{-3} HCl according to Števlíková et al. [24]. All samples were corrected for the CO_2 content of blanks. The factor 2.2 mg was used for the conversion of KOH to the µg CO_2. Basal respiration (BR) and potential respiration (PR) (addition of 2g glucose per kg of soil) were measured after 24h. Soil samples were incubated in the dark at 28°C and adjusted with distilled water to 50% MWHC during the entire incubation. Results of the basal and potential soil respiration were expressed as µg CO_2-C per g dry soil per hour. All analyses were realised in triplicate (respiration quadruplicate) and all results were calculated on soil dry matter (d. m.).

The metabolic quotient (qCO_2) [3] represents the amount of CO_2-C mineralised per unit of microbial biomass carbon per hour. qCO_2 was derived from basal respiration (qCO_2-BR) and potential respiration (qCO_2-PR) and calculated as follows: $[(BR/C_{mic}).(1000)]$ and $[(PR/C_{mic}).(1000)]$= µg mineralised CO_2-C per hour calculating on 1 mg of microbial biomass carbon. PR/BR was derived in order to evaluate the substrate availability according to Parkinson and Coleman [18].

Statistical data analyses

Statistical analyses were carried out with the STATGRAPHICS 5.0 program. Analysis of variance (ANOVA) was used for the statistical evaluation of soil type effect (in arable soil), and evaluation of way of soil use effect on measured parameters. In the case of significant F –statistics, LSD test ($P<0.05$) was selected to separate the means. A linear model of regression analysis was used for determination of correlations among the measured parameters.

Results and discussion

Evaluation included 19 different sites from various territories of the Slovak Republic (Table 1). Twenty one arable soil samples (84% of the samples) and four pasture grassland soil samples (16% of the samples) were analysed. In arable soil, the soil types were Luvisols (38%), Chernozems (33%), Planosols (29%), and pasture grassland one soil type Cambisols (100%).

Tabuľka 1 Charakteristika odberových miest
Table 1 Characteristics of soil sampling sites

Way of soil use	Soil type	Site	Geographic coordinates	Soil texture*
Arable soil	Haplic Luvisols	Golianovo	48°16´3.77´´ N; 18°11´20.11´´ E	loam
		Kolíňany	48°21´47.94´´ N; 18°11´49.59´´ E	loam
		Plavé Vozokany	48°4´7.62´´ N; 18°28´25.47´´ E	loam
		Nové Sady	48°25´8.2´´ N; 17°58´52.17´´ E	loam
		Nitra–Malanta (two territories)	48°19´22.07´´ N; 18°7´41.16´´ E	loam
		Rišňovce	48°22´9.51´´ N; 17°53´25.23´´ E	nd
		Veľké Ripňany	48°29´56.16´´ N; 17°58´40.12´´ E	nd
	Calcari-Haplic Chernozems	Drážovce	48°21´3.72´´ N; 18°3´35.50´´ E	loam
		Sládkovičovo	48°12´2.26´´ N; 17°38´21.04´´ E	sandy-loam
		Voderady	48°16´29.21´´ N; 17°33´30.71´´ E	loam
		Kalná n/ Hronom	48°10´13.26´´ N; 17°35´28.07´´ E	sandy-loam
	Haplic Chernozems	Štefanovičová	48°15´10.62´´ N; 17°38`21.35´´ E	sandy-loam
		Svätoplukovo	48°13´44.78´´ N; 18°3´18.83´´ E	sandy-loam
		Borovce	48°22´9.51´´ N; 17°53´25.23´´ E	nd
	Dystric Planosols	Vígľaš-Pstruša (six territories)	48°32´45.03´´ N; 19°19´10.62´´ E	clay-loam
Pasture grassland soil (National parks)	Eutric Cambisols	Pod Ploskou (Veľká Fatra)	48°94´08.40´´ N; 19°09´91.50´´ E	sandy-loam
	Stagnic Cambisols	Strungový prislop (Malá Fatra)	49°21´24.20´´ N; 19°12´75.60´´ E	loam
	Distric Cambisols	Pod Kečkou (Nízke Tatry)	48°85´64.70´´ N; 19°25´40.50´´ E	sandy-loam
	Molli-Eutric Cambisols	Diel (sierra Stolické vrchy)	48°33´57.66´´ N; 19°44´3.06´´ E	loamy-sand

* valuation according to Novak classification scale; nd - non determined

Tabuľka 2 Sledované chemické vlastnosti pôdnych typov
Table 2 Studied chemical properties of soil types

Arable soil	C_{org} (%)	C_{hwe} (µg g^{-1})	N_{tot} (%)	C/N	pH_{H20}
Luvisols (n=8)	1.22^{a}	358^{a}	0.152^{b}	8.1^{a}	6.85^{a}
Chernozems (n=7)	1.74^{b}	418^{a}	0.215^{a}	8.1^{a}	7.58^{b}
Planosols (n=6)	1.08^{a}	254^{b}	0.098^{c}	11.0^{b}	6.78^{a}
Way of soil use					
Arable soil (n=21)	1.35^{a}	348^{a}	0.158^{a}	8.9^{a}	7.07^{b}
Pasture grassland soil - Cambisols (n=4)	4.69^{b}	788^{b}	0.349^{b}	13.2^{b}	5.67^{a}

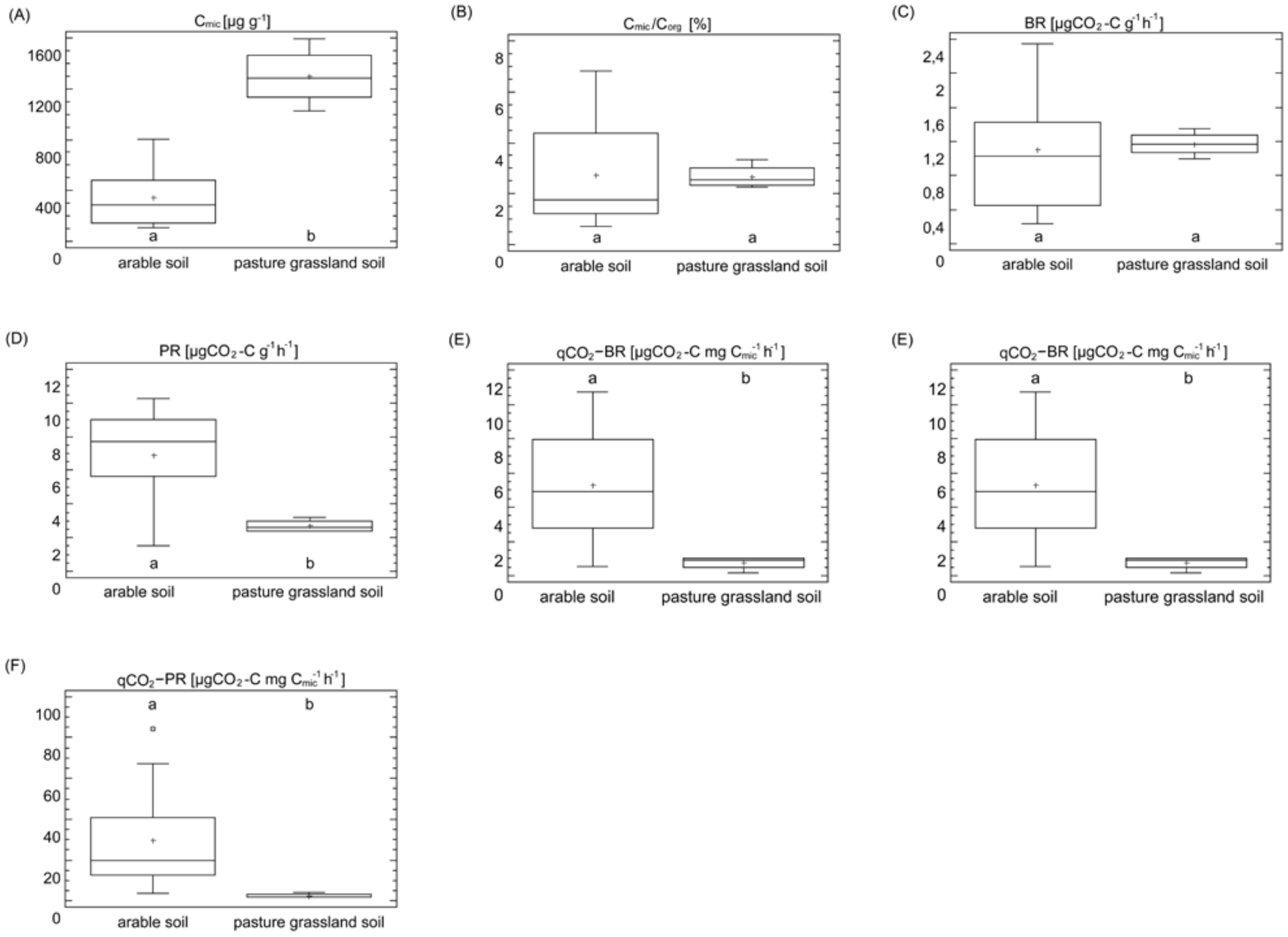
Different letters mark significant differences (LSD; $p \leq 0.05$)

Chemical parameters, microbial biomass carbon and microbial quotient

The factors of soil forming process that contribute to the formation of individual soil types have also influenced the biomass of soil microorganisms, composition of microbial communities as well as their activities. Reason for the variability of biological compound of soil is different way of soil use and land management on sampling sites. In arable soils, changes are accomplished mainly through various plants residues that enter into the soil and differ in quantity as well as quality. In addition, the biological compound of soil is influenced by seasonal as well as spatial distribution of plant residues [14], but also by soil fertilization with inorganic as well as organic fertilizers. In arable soils, the highest values of C_{org}, C_{hwe} and N_{tot} were identified in Chernozems soil type (1.74%, 418µg g^{-1}, 0.215%), followed by Luvisols (1.22 %, 358µg g^{-1}, 0.152%) and Planosols (1.08%, 254µg g^{-1}, 0.098%). Decomposition of organic compounds is more intensive in Chernozems and Luvisols than Planosols due to a narrower C/N ratio (Tab. 2). That is related to the fact that Planosols developed on water-logged areas which have impervious subsoil. In arable soil prevailing soil texture was sandy loam and loam.

In contrary to arable soils, pasture grassland soils were characterised by an intense root zone, higher fraction of organic compounds, but in particular by a permanent vegetative cover that is photosynthetic active during most of the year. On all pasture grassland soils (Tab. 2), high amounts of C_{org} and N_{tot} were found with an average value of 4.69% and 0.349%, respectively. According to the C/N ratio (13.2) in Cambisols, the humification processes prevailed over mineralization. Cambisols had slightly acidic reaction and texture reached from sandy loam to loam.

On monitored arable soils, microbial biomass carbon fluctuated from 107 to 802µg C g^{-1} (Tab. 3). The highest values of this parameter were identified in Planosols: 456 µg C g^{-1} and the lowest values were identified in Luvisols: 257µg C g^{-1}. However, no differences between of arable soils were statistically confirmed. On monitored Cambisols used as pasture grassland, C_{mic} content was statistically significantly higher (in range from 1024 to 1592 µg g^{-1}, Fig. 1 - A) compared to arable soils. On pasture grassland soils (Tab. 5), relatively strong correlations of C_{mic} with C_{org} (r = 0.919) and N_{tot}, (r = 0.922) were identified.



Obr. 1 Porovnanie výsledných hodnôt (A) C_{mic}; (B) C_{mic}/C_{org}; (C) BR; (D) PR; (E) qCO_2-BR; (F) qCO_2-PR; (G) BR/PR v ornej pôde a pasienku. Boxy zobrazujú - horný a dolný kvartil; horizontálna čiara vo vnútri boxu - median; “+” - priemer; “malý štvorček” - extrémne hodnoty; chybové úsečky – minimum a maximum s vynechanými extrémnymi hodnotami. Rozdielne písmená (a, b) vyjadrujú preukazné rozdiely (LSD; p≤0.05).

Fig. 1 The comparison of results (A) C_{mic}; (B) C_{mic}/C_{org}; (C) BR; (D) PR; (E) qCO_2-BR; (F) qCO_2-PR; (G) BR/PR in arable soil and pasture grassland soil. Boxes display lower and upper quartile; horizontal line inside box – median; “+” - average; “small square”- outlier; whiskers – minimum and maximum excluding outlier. Different letters (a, b) display significantly (LSD; p≤0.05) different results.

Microbial quotient (C_{mic}/C_{org}) represents the amount of metabolic active carbon in the total soil organic matter. C_{mic}/C_{org} is generally considered as sensitive changes indicator of soil organic matter quality [2, 22]. In arable soils with neutral to weak alkali pH values, statistically ($P < 0.05$) the highest C_{mic}/C_{org} (4.41%) was identified in Planosols compared to Chernozems and Luvisols (Tab. 3). Our measured values are consistent with the data presented by Anderson [4], who showed that the microbial quotient of agricultural soils at a neutral pH was in the range between 2.0 and 4.4% C_{mic} of total C_{org}, depending on the nutrient status and soil management. Meyer et al.

Tabuľka 3 Sumárna štatistika mikrobiologických parametrov pôdnych typov využívaných ako orná pôda
Table 3 Summary statistics of microbial parameters of soil types used as arable soil

Soil type in arable soil	Mean	Min	Max	Median
Microbial biomass carbon – C_{mic} (μg Cg^{-1})				
Luvisols (n=8)	257^{a}	108	714	158
Chernozems (n=7)	362^{a}	146	802	291
Planosols (n=6)	456^{a}	107	777	467
C_{mic}/C_{org} (%)				
Luvisols (n=8)	2.09^{a}	0.99	5.99	1.57
Chernozems (n=7)	1.98^{a}	0.73	5.37	1.56
Planosols (n=6)	4.41^{b}	0.72	6.79	4.68
Basal respiration – BR (μg CO_2-C g^{-1} h^{-1})				
Luvisols (n=8)	1.21^{a}	0.77	1.94	1.04
Chernozems (n=7)	1.61^{a}	0.96	2.35	1.42
Planosols (n=6)	0.36^{b}	0.24	0.45	0.35
Potential respiration with glucose – PR (μg CO_2-C g^{-1} h^{-1})				
Luvisols (n=8)	8.45^{a}	7.42	10.25	8.18
Chernozems (n=7)	8.07^{a}	4.77	10.20	8.59
Planosols (n=6)	3.53^{b}	1.53	6.68	2.74
qCO_2-BR (μg CO_2-C mg C_{mic}^{-1} h^{-1})				
Luvisols (n=8)	6.60^{a}	1.71	10.7	7.71
Chernozems (n=7)	5.08^{a}	2.75	7.6	4.38
Planosols (n=6)	3.82^{a}	0.51	8.98	2.12
qCO_2-PR (μg CO_2-C mg C_{mic}^{-1} h^{-1})				
Luvisols (n=8)	47.16^{a}	11.00	84.00	48.65
Chernozems (n=7)	27.79^{b}	12.70	58.80	20.00
Planosols (n=6)	9.07^{b}	3.57	16.35	7.98
Substrate availability index - PR/BR				
Luvisols (n=8)	7.55^{ab}	3.82	11.9	7.50
Chernozems (n=7)	5.39^{a}	3.36	8.45	4.62
Planosols (n=6)	10.26^{b}	4.11	20.24	7.50

Different letters mark significant differences (LSD; p≤0.05)

[16] published that in surface horizons microbial quotient <1.0 usually indicates a disturbed turnover of soil organic matter. In Cambisols with an acidic soil reaction, the value of C_{mic}/C_{org} was 2.99%. In evaluation of C_{mic}/C_{org} according to ways of soil use (arable soil and grassland soil), the differences were not confirmed (Fig.1 - B), in spite of the fact that soils under pasture grassland had higher accumulation of organic substances and root system of grass should create better conditions for the growth of microbial biomass. The values of C_{mic}/C_{org} were a little bit higher in pasture grassland compared to arable soils, but our monitoring confirmed degradation of pasture grassland due to a long-term pasture. In evaluated pasture grassland carbon immobilization into the microbial biomass can be lower than expected.

Respiration activities

The determination of CO_2 production is one of the effective methods used for assessing the microbial activity in soil. Basal respiration (BR) represented the mineralisation of native organic substances in the soil samples. In arable soils Chernozem and Luvisol (Tab. 3), the basal respiration (1.61 and 1.21µg CO_2-C g^{-1}soil h^{-1}) was higher than in Planosol (0.36 µg CO_2-C g^{-1}soil h^{-1}). The higher respiration activity of these soil types was related to a narrower C/N ratio and higher content C_{hwe} compared to the Planosol (Tab. 2). Different ways of soil use did not influence the basal respiration (Fig. 1 - C).

The effect of glucose on soil microbial communities is well-known and has been observed by many scientists [9]. Microorganisms reacted positively to the addition of glucose (potential respiration – PR) at all studied sites (Tab. 3, Fig. 1 - D), but the highest potential ability to utilise this easily accessible form of carbon was found in Luvisol and Chernozem (8.45 and 8. 07 µg CO_2-C g^{-1} h^{-1}). Dilly [7] published that respiratory activity and respiratory quotient (ratio of moles CO_2 evolved per moles of O_2 consumed) increased with increasing amount of available C, but the microbial communities in the agricultural soil were less efficient in C use than those in the forest soil.

From the ratio of potential respiration to the basal respiration (PR/BR) i.e. “substrate availability index” can be concluded lower substrate availability in pasture grassland soils (Fig. 1 - G), which is probably related to a wider C/N ratio, acidic soil reaction, and way of soil use. In pasture grassland, the PR/BR index was strongly influenced by C_{org}, N_{tot}, pH and C_{mic} parameters (Tab. 5).

The metabolic quotient (qCO_2) is a reliable eco-physiological indicator. Soil disturbance and stress cause a decrease in microbial efficiency and enhance the qCO_2. The increase of qCO_2 can by caused by an increased amount of organic carbon metabolized for the maintenance of soil microorganisms followed by a lower amount of organic carbon incorporation into the microbial biomass. Leita et al. [15] reported higher qCO_2 in metal-contaminated than in uncontaminated soil. The values of the metabolic quotient qCO_2 for neutral soils in a range from 0.5 to 2.0 µg CO_2-C mg C_{mic}^{-1} h^{-1} were reported by Anderson [4]. We investigated the lowest values of

qCO_2-BR and qCO_2-PR (Fig. 1 – E, F) in pasture grassland soil (0.75 and 2.54 µg CO_2-C mg C_{mic}^{-1} h^{-1}, respectively).

In arable soils, the parameters qCO_2-BR and qCO_2-PR negatively correlated with microbial biomass carbon (Tab. 4). The negative relations can be explained by supposed higher diversity and higher microbial biomass. In generally, soils with higher diversity are able better utilise the substrate what leads to lower values of metabolic quotient. From arable soil these hypotheses are the most significant in Planosols (Tab. 3).

In pasture grassland soils with an acidic soil reaction, the parameters qCO_2-BR and qCO_2-PR were strongly influenced by pH (Tab. 5). In acidic soil the biomass of microscopic fungi prevail over biomass of bacteria. This explains the strong positive correlation of qCO_2-BR with C_{mic}/C_{org}.

Conclusion

In this study, we monitored the amount of microbial biomass carbon and respiration activities in four of the most widespread soil types in Slovakia used as arable soils and pasture grassland soils. In arable soils no significant differences between the soil types were found concerning the content of carbon microbial biomass. Way of soil use significantly influenced carbon microbial biomass with higher values on pasture grassland soil. The basal respiration was no affected neither by the soil type nor by way of use. On all monitored sites microbes responded positively to the addition of glucose, but the strongest response was observed in Chernozem and Luvisol. The lowest values of qCO_2-BR and qCO_2-PR were investigated in pasture grassland soil. Lower substrate availability index (PR/BR) was observed on pasture grassland soils compared to arable soils. Further research needs to be conducted in order to measure the diversity of the microbial community in monitored sites by using molecular techniques. Results would contribute to the present study concerning the flow of carbon and energy through the microbial biomass in various soil types and ways of soil use.

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References

[1] Ananyeva N.D., Susyan E.A., Chernova O.V., Wirth S., Microbial respiration activities of soils from different climatic regions of European Russia. European Journal of Soil Biology. (2008) 44: 147-157.

[2] Anderson T.H., Domsch K.H., Ratios of microbial biomass carbon to total organic carbon in arable soil. Soil Biol Biochem. (1989) 21: 471-479.

[3] Anderson T.H., Domsch K.H., Application of eco-physiological quotients (qCO_2 and qD) on microbial biomass from soils of different cropping histories. Soil Biol Biochem. (1990) 22: 251-255.

[4] Anderson T.H., Microbial eco-physiological indicators to asses soil quality. Agric Ecosyst Environ. (2003) 98: 285-293.

[5] Blagodatskii S.A., Bogomolova I.N., Blagodatskaya E.V., Microbial biomass and growth kinetics of microorganisms in Chernozem soils under different land use modes. Microbiology. (2008) 77: 99-106.

[6] Chu H., Lin X., Fujii T., Morimoto S., Yagi K., Hu J., Zhang J. Soil microbial biomass, dehydrogenase activity, bacterial community structure in response to long-term fertilizer management. Soil Biol Biochem. (2007) 39: 2971-2976.

[7] Dilly O., Regulation of the respiratory quotient of soil microbiota by availability of nutrients. FEMS Microbiology Ecology. (2003) 43: 375-381.

[8] Filip Z., International approach to assessing soil quality by ecologically-related biological parameters. Agric Ecosyst Environ. (2002) 88: 169-174.

[9] Griffiths B.S., Ritz K., Wheatley R., An examination of the biodiversity–ecosystem function relationship in arable soil microbial communities. Soil Biol. Biochem. (2001) 33: 1713-1722.

[10] Hofman J., Dušek L., Klánová J., Bezchlebová J., Holoubek I., Monitoring microbial biomass and respiration in different soils from the Czech Republic-a summary of results. Environmental International. (2004) 30: 19-30.

[11] Insam, H., Parkinson, D., Domsch K.H., Influence of macroclimate on soil microbial biomass. Soil Biol Biochem. (1989) 21: 211-221.

[12] Kandeler E., Tscherko D., Spiegel H., Long-term monitoring of microbial biomass, N mineralization and enzyme activities of a Chernozem under different tillage management. Biol Fertil Soils. (1999) 28: 343-351.

[13] Körschens M., Schulz E., Behm R., Heisswasserlöslicher C und N im Boden als Kriterium für das N-Nachliferungsvermögen. Mikrobiology. (1990) 145: 305 – 311.

[14] Lavahun M.F.E., Joergensen R.G., Meyer B., Activity and biomass of soil microorganisms at different depths. Biol Fertil Soils. (1996) 23: 38-42.

[15] Leita, L.; De Nobili M.; Muhlbachova,G.; Mondini, C.; Marchiol, L; Zerbi G. Bioavailability and effects of heavy metals on soil microbial biomass survival during laboratory incubation. Biol Fertil Soils. (1995) 19: 103-108.

[16] Meyer K., Joergensen R.G., Meyer B., The effects of reduced tillage on microbial biomass C and P in sandy loess soils. Applied Soil Ecology. (1996) **5:** 71–79.

[17] Palojarvi A., Nuutinen V., The soil quality concept and its importance in the study of Finnish arable soils. Agricultural and food science in Finland. (2002) 11: 329-342.

[18] Parkinson D., Coleman D.C., Methods for assessing soil microbial populations, activity and biomass. Microbial communities, activity and biomass. Agric Ecosyst Environ. (1991) 34: 3-33.

[19] Raiesi F., Asadi E., Soil microbial activity and litter turnover in native grazed and ungrazed rangelands in a semiarid ecosystem. Biol Fertil Soils. (2006) 43: 76-82

[20] Růžek L., Voříšek K., Strnadová S., Nováková M., Barabasz W., Microbial characteristics, carbon and nitrogen content in cambisols and luvisols. Plant Soil Environ. (2004) 50: 196-204.

[21] Sanchez-Monedero M.A., Mondini C., Cayuela M.L., Roig A., Contin M., De Nobili M., Fluorescein diacetate hydrolysis, respiration and microbial biomass in freshly amended soils. Biol Fertil Soils. (2007) 44: 885-890.

[22] Sparling G.P., Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. Aust. J. Soil Res. (1992) 30: 195-207.

[23] Šimek M., Šantrůčková H., Influence of storage of soil samples on microbial biomass and its activity. Rostlinná výroba. (1999) 45: 415-419.

[24] Števlíková T., Javoreková, S., Tančinová, D., Vjatráková, J., Microbiology. 1. Part, SUA, Nitra, 2001. (In Slovak).

[25] Vance E.D., Brookes P.C., Jenkinson D.S., An extraction method for measuring soil microbial biomass. Soil Biol Biochem. (1987) 19: 703 – 707.

Tabuľka 4 Hodnoty korelačných koeficientov medzi sledovanými parametrami v ornej pôde

Table 4 Correlation coefficients between analyzed parameters in arable soil

	C_{org}	C_{hwe}	N_{tot}	pH	C_{mic}	C_{mic}/C_{org}	BR	PR	qCO_2-BR	qCO_2-PR	PR/BR
C_{org}	-										
C_{hwe}	0.775	-									
N_{tot}	0.823	0.757	-								
pH	0.358	0.213	0.517	-							
C_{mic}	-0.142	-0.239	-0.159	0.175	-						
C_{mic}/C_{org}	-0.422	-0.502	-0.471	-0.022	0.911	-					
BR	0.475	0.530	0.663	0.596	0.043	-0.271	-				
PR	0.311	0.381	0.501	0.202	-0.016	-0.259	0.694	-			
qCO_2-BR	-0.078	0.154	0.080	-0.068	-0.658	-0.561	0.220	0.008	-		
qCO_2-PR	0.079	0.237	0.154	-0.240	-0.701	-0.691	0.182	0.508	0.587	-	
PR/BR	-0.333	-0.496	-0.446	-0.279	0.181	0.336	-0.545	0.054	-0.495	-0.022	-

$P<0.05$

Tabuľka 5 Hodnoty korelačných koeficientov medzi sledovanými parametrami v pasienku

Table 5 Correlation coefficients between analyzed parameters in pasture grassland soil

	C_{org}	C_{hwe}	N_{tot}	pH	C_{mic}	C_{mic}/C_{org}	BR	PR	qCO_2-BR	qCO_2-PR	PR/BR
C_{org}	-										
C_{hwe}	0.064	-									
N_{tot}	0.968	0.110	-								
pH	0.594	0.026	0.439	-							
C_{mic}	0.919	0.297	0.922	0.700	-						
C_{mic}/C_{org}	0.885	0.372	0.832	0.646	0.776	-					
BR	0.602	0.007	0.736	0.279	0.440	0.445	-				
PR	0.393	0.192	0.187	0.949	0.450	0.543	0.491	-			
qCO_2-BR	0.818	0.266	0.657	0.900	0.583	0.908	0.057	0.840	-		
qCO_2-PR	0.757	0.010	0.625	0.975	0.824	0.781	0.059	0.876	0.954	-	
PR/BR	0.953	0.243	0.846	0.749	0.850	0.986	0.372	0.625	0.948	0.869	-

$P<0.05$