Microbial characteristics, carbon and nitrogen content in cambisols and luvisols

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ABSTRACT

Tested soils (1991–2002) were defined by chemical, textural and microbial characteristics. From the tests which describe cambisols, the following parameters have to be stressed. The higher level of C_{org} (1.20–1.76%), which resulted in quite high microbial biomass carbon content (396–625 µg/g dry soil), high control respiration (0.45–0.80 mg CO_2/h/100 g dry soil) and potential nitrification with $(NH_4)_2SO_4$ (6.7–18.4 mg N-NO_3/8 days/100 g dry soil). Studied luvisols reached typical levels: C_{org} (0.97–1.22%), C_{MB} (398–503 µg/g dry soil), control respiration (0.46–0.57 mg CO_2/h/100 g dry soil), potential nitrification with $(NH_4)_2SO_4$ (3.2–9.9 mg N-NO_3/8 days/100 g dry soil). Lower levels of organic carbon and a medium level of microbial biomass raised in higher ratio C_{MB}/C_{org} (average 4.0%). Highly significant differences ($p < 0.01$) between cambisols and luvisols were determined for C_{org}, N_t, pH(KCl), C_{MB}, C_{MB}/C_{org}, C_E, control respiration and potential nitrification, while the difference in potential ammonification with peptone was at level $p < 0.05$. With the exemption of ratio C_{MB}/C_{org} all cambisol characteristics were higher than luvisol ones. Studied soils were evaluated by six biological criteria (C_{MB}; ratios: C_{MB}/C_{org}, C_E/C_{MB}, potential/control respiration, potential/control ammonification, potential/control nitrification). These criteria distinguished tested soils into three groups. The first one includes two localities in the mountain region (Červená Voda 809, 810; altitude 565–590 m) defined as stagnic cambisols with higher content of C_{org} (1.40, respective 1.76%) and simultaneously with the highest biomass of micro-organisms from all tested soils (C_{MB}, 625, respective 621 µg/g dry soil). It is not surprising that microbial activities (respiration, nitrification) at these localities were also high. The majority of the studied localities (one eutric cambisol and four luvisols) belongs to the medium group. The third group includes two localities (Neumětely – haplic luvisol, Čistá u Rakovníka – eutric cambisol) where biological criteria was mostly the worst. In the period 1993–2002 microbial biomass carbon was for both sites in the range of 357–458 µg/g dry soil which are not so bad values, but in comparison with localities in mountain wet region they are low. This status was issued in the lower ratio C_{MB}/C_{org} (2.71–3.77%).

Keywords: cambisols; luvisols; microbial biomass carbon; K_2SO_4 extractable carbon; respiration; ammonification; nitrification

Soil quality (Filip 2001) represents an integral value of the compositional structures and functions of terrestrial soils in relations to their different uses and to long-term environmental conditions on site. Among the indigenous soil structural components, edaphon, and especially micro-organisms play a key role in different ecologically important functions of the soil. Microorganisms (Alexander 1977) play an important role in the functioning of any soil ecosystem: they are involved in litter breakdown, cycling of nutrients, formation of stable microagregates, and structural development.

For sustainable soil use soil quality is an essential presumption. According to Elliott et al. (1996) the term soil quality can be defined as the capacity of the soil to produce healthy and nutritious crops, resist erosion, and reduce the impact of environmental stresses on plants. According to their opinion soil quality does not depend only on the physical and chemical properties of soil but it is very closely linked with the biological properties of soil mostly on microbiological processes. These authors stress the idea that soil quality is a dynamic feature, and any significant indicators must be sensitive to small changes in key soil properties.

Some authors (Nannipieri et al. 1990) substitute the term soil biological quality with the term soil biological or soil microbiological activity. It is widely know that it is not possible to measure the soil microbiological activity with one method. In

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Projects MSM 412100004 and FRVŠ 1409/G4, and the Ministry of Agriculture of the Czech Republic, Grants MZe QC 1254 and MZe QD 1329.

literature several recommendations could be found. In the U.S.A. Soil Working Group (Pappendick 1991) proposed framework of eight tests for determination of the soil biological characteristics: soil organic carbon, soil microbial biomass carbon, respiration/biomass ratio, N-mineralization, labile organic carbon, soil respiration, composition of vegetation and an abundance of earthworms.

Filip (2001) in his review paper stressed the following ecologically important soil characteristics: microbial biomass, composition of microflora (ratio bacteria/fungi, microflora of the C-cycle and N-cycle), mineralization processes (CO_2 and NH_4^+ release), and synthesising processes. This author underlined that there is no doubt that firm linkages exist between microbial communities, their activities, and ecologically important processes. Developments of defined species in soil population and composition of soil microbial community have specific importance for the sustainable biodiversity in soil ecosystems. On the other hand the level of soil microbial processes, such as decomposition, transformation and organic matter synthesis has a specific importance for the functional sustainability of soil ecosystem Černý et al. (2003). Having used two parameters (microbial biomass nitrogen and extractable organic nitrogen) to evaluate different fertilisation in long-term experiments with maize. Voříšek et al. (2002) studied the influence of grassing and harvest management using three respective eight parameters (microbial biomass carbon [C_{MB}]; ratio C_{MB}/C_{org}; ratio C_E/C_{MB}; potential respiration with glucose; potential ammonification with peptone; potential nitrification with ammonium sulphate and two model predicted values).

This article evaluates the twelve-year results of microbiological parameters of selected Czech cambisols and luvisols.

MATERIAL AND METHODS

Cambisols, haplic and albic luvisols belong to main soil types in Czech Republic because they form important parts (58, respective 10.5%) of agricultural and afforested soils. During the years 1991–2002 soil samples were collected at four cambisol localities (a total of 185 samples) and five luvisol localities (a total of 234 samples). The localities description can be found in Tables 1 and 2.

Soil samples from the profile (0–200 mm) were collected using sampler *Eijkelkamp agrisearch equipment* in spring and autumn months during the period 1991–2002, respective 1993–2002. The samples were transported in the cooling box (temperature 6–12°C); they were adjusted, sieved (mesh 2 mm) and stored in a refrigerator (4–6°C). 24 hours before analyses the samples were pre-incubated at room temperature (22 ± 2°C).

The list of tests used for soil samples characterisation and microbial activity determination:

- organic carbon (C_{org}) – colorimetric determination (Sims and Haby 1971)
- microbial biomass carbon (C_{MB}) – rehydration method (Blagodatskiy et al. 1987)
- K_2SO_4 extractable carbon (C_E) – extraction with 0.5 mol/l K_2SO_4 (Badalucco et al. 1992)
- total nitrogen (N_t) – Kjeldahl method
- pH(H_2O), pH(KCl)
- respiration: basal, potential with glucose – interpherometric CO_2 detection (Novák and Apfelthaler 1964)
- actual content of NH_4^+
- ammonification: potential with peptone – titrimetric detection (Pokorná-Kozová et al. 1964)
- actual content of NO_3^-
- nitrification: potential with ammonium sulphate – ion-selective electrode detection (Löbl and Novák 1964)

The following ratios were calculated:

- $(C_{MB}/C_{org}) \times 100$
- $(C_E/C_{MB}) \times 100$
- potential/basal respiration
- potential ammonification/actual content of NH_4^+
- potential nitrification/actual content of NO_3^-

Results (46 replications during the years 1991–2002) were statistically evaluated using the analyses of variance (multiple range test) including Fisher's *LSD* method.

RESULTS AND DISCUSSION

Cumulative characteristics (Tables 1 and 2)

Soil organic carbon (C_{org}): Cambisol were characterised with high C_{org} level (average 1.46%, *SD* 0.34%) with the range of 1.20–1.76%. The extreme variant (Čistá u Rakovníka, 1.20%) was highly statistically different from others. It is not surprising that the average of luvisols (1.14%) was lower, and the range (0.97–1.22%) was more compact and resulted in lower frequency of statistical differences among luvisols and the lowest locality Sloupnice (0.97%) was also statistically highly different.

Soil microbial biomass carbon (C_{MB}): For the study of environmental and anthropogenic influences on living part of soils the determination of C_{MB} is widely used (Pappendick 1991, Shibahara and Inubushi 1997, Filip 2001, etc.). Expected high level of biomass was determined in cambisols (average 556 μg/g dry soil, *SD* 167), while three

Table 1. Studied cambisols (1991–2002)

Locality/ Parameter	Čistá 125[1] eutric cambisol altitude 460 m	Červený Potok 808 eutric cambisol altitude 625 m	Červená Voda 809 stagnic cambisol altitude 590 m	Červená Voda 810 stagnic cambisol altitude 565 m	Average ± *SD*	*LSD*[2] $d_{\alpha\ min}$ 0.05 (0.01)
C_{org} (%)	1.20 ± 0.09	1.50 ± 0.19	1.40 ± 0.26	1.76 ± 0.44	1.46 ± 0.34	0.11 (0.14)
N_t (%)	0.14 ± 0.02	0.16 ± 0.03	0.16 ± 0.04	0.18 ± 0.04	0.16 ± 0.04	0.02 (0.02)
pH KCl	6.0 ± 0.1	5.9 ± 0.4	6.9 ± 0.0	5.8 ± 0.2	6.1 ± 0.5	0.1 (0.1)
C_{MB} (μg/g)	396 ± 45	599 ± 125	625 ± 166	621 ± 177	556 ± 167	57 (75)
Ratio (C_{MB}/C_{org}) × 100[3]	3.3 ± 0.4	4.0 ± 0.5	4.3 ± 0.7	3.5 ± 0.5	3.8 ± 0.7	0.2 (0.3)
C_E (μg/g)	43 ± 8	56 ± 17	56 ± 23	40 ± 19	48 ± 19	7 (10)
Control respiration[4]	0.45 ± 0.24	0.63 ± 0.18	0.72 ± 0.33	0.80 ± 0.35	0.65 ± 0.31	0.12 (0.16)
Potential respiration[5]	3.56 ± 1.55	3.66 ± 0.84	3.58 ± 0.75	4.31 ± 1.29	3.77 ± 1.19	0.48 (0.64)
Potential ammonification[6, 7]	148 ± 35	188 ± 44	190 ± 50	181 ± 50	176 ± 48	19 (25)
Potential nitrification[8] with $(NH_4)_2SO_4$	6.7 ± 3.2	8.9 ± 7.5	18.4 ± 14.6	14.1 ± 16.5	12.0 ± 12.5	4.9 (6.4)

[1]state number of locality, [2]Fisher's Least Significant Difference, [3]in per cent of C_{org}, [4]mg CO_2/h/100 g dry soil, [5]with glucose, [6]mg N-NH_4/24 h/100 g dry soil, [7]with peptone, [8]mg N-NO_3/8 days/100 g dry soil

localities in the mountain area were quite high in biomass (599–625 μg/g dry soil). The fourth one in a hilly country was lower (396 μg/g dry soil). The average of luvisols C_{MB} was 455 μg/g dry soil with low *SD* (98), which is a sign for homogeneity of tested localities.

Ratio C_{MB}/C_{org}: This ratio gives the information about metabolic active carbon in a total soil organic matter; 3% is a usual level for arable soils (Insam and Domsch 1988). Our tested localities were quite active because they ranged from 3.3% (both luvisols and cambisols) to 4.4% (luvisol) with the average for cambisols 3.8% (*SD* 0.7) and 4.0% (*SD* 0.8) for luvisols. The difference between luvisols and cambisols reaches statistical significance ($p < 0.05$). Albic luvisols, with the highest ratio (4.4%), are statistically different not only from other luvisols but also from all cambisols. The same could be said for the lowest ratio (3.3%; haplic luvisol, eutric cambisol), which is statistically different from the rest of soils.

K_2SO_4 extractable carbon (C_E): C_E is a trophically easily usable organic carbon of microbial origin and its low content is a sign of active microbial metabolism (Škoda et al. 1997). Luvisols were more active in the use of C_E (40 μg/g dry soil) than cambisols (48 μg/g dry soil); this difference was significant.

Respiration: Control respiration of cambisols (0.65 mg CO_2/h/100 g dry soil) statistically significantly differs from luvisols (0.50 mg CO_2/h/100 g dry soil), while in potential respiration with glucose this activity was similar (3.77, respective 3.68 mg CO_2/h/100 g dry soil). The lowest values of C_E, both for cambisols (Červená Voda 810) and for luvisols (Neumětely), were connected with the highest level of potential respiration. The statement could be issued that trophically available carbon

Table 2. Studied luvisols (1991–2002)

Locality/ Parameter	Neumětely 111[1] haplic luvisol altitude 325 m	Mostek 806 haplic luvisol altitude 370 m	Mostek 807 stagnic luvisol altitude 410 m	Nový Dům 127 albic luvisol altitude 430 m	Sloupnice 805 albic luvisol altitude 390 m	Average ± *SD*	*LSD*[2] $d_{\alpha\ min}$ 0.05 (0.01)
C_{org} (%)	1.22 ± 0.14	1.16 ± 0.10	1.14 ± 0.21	1.16 ± 0.10	0.97 ± 0.15	1.14 ± 0.17	0.07 (0.09)
N_t (%)	0.15 ± 0.03	0.13 ± 0.03	0.13 ± 0.03	0.13 ± 0.04	0.12 ± 0.04	0.13 ± 0.03	0.01 (0.02)
pH KCl	6.1 ± 0.1	6.0 ± 0.1	6.1 ± 0.2	4.9 ± 0.2	5.9 ± 0.0	5.8 ± 0.5	0.1 (0.1)
C_{MB} (μg/g)	398 ± 53	483 ± 98	459 ± 117	503 ± 57	428 ± 113	455 ± 98	38 (50)
Ratio (C_{MB}/C_{org}) × 100[3]	3.3 ± 0.4	4.1 ± 0.8	4.0 ± 0.6	4.4 ± 0.5	4.4 ± 0.8	4.0 ± 0.8	0.3 (0.4)
C_E (μg/g)	33 ± 9	49 ± 12	37 ± 17	37 ± 11	45 ± 18	40 ± 15	6 (8)
Control respiration[4]	0.48 ± 0.32	0.49 ± 0.16	0.57 ± 0.33	0.47 ± 0.27	0.46 ± 0.31	0.50 ± 0.29	0.12 (0.16)
Potential respiration[5]	4.42 ± 1.77	3.54 ± 1.28	3.75 ± 1.49	3.30 ± 1.59	3.31 ± 1.39	3.68 ± 1.57	0.64 (0.85)
Potential ammonification[6, 7]	164 ± 41	182 ± 42	170 ± 41	134 ± 46	189 ± 43	167 ± 46	18 (24)
Potential nitrification[8] with $(NH_4)_2SO_4$	8.2 ± 2.5	7.3 ± 5.0	9.9 ± 8.3	3.2 ± 1.8	7.4 ± 6.0	7.3 ± 5.7	2.2 (2.9)

[1]state number of locality, [2]Fisher's Least Significant Difference, [3]in per cent of C_{org}, [4]mg CO_2/h/100 g dry soil, [5]with glucose, [6]mg N-NH_4/24 h/100 g dry soil, [7]with peptone, [8]mg N-NO_3/8 days/100 g dry soil

could be a limitation for microbial activities but the potential activities were kept in good repair.

Potential ammonification with peptone: Similarly as for respiration there were no significant differences among cambisols (176 mg $N\text{-}NH_4$/24 h/100 g dry soil) and luvisols (167 mg $N\text{-}NH_4$/24 h/100 g dry soil). Our data also confirmed that in soils with neutral and alkaline pH there is a close relationship between high microbial biomass C content and high potential ammonification.

Potential nitrification with $(NH_4)_2SO_4$: Extreme differences were observed between cambisols (12.0 mg $N\text{-}NO_3$/8 days/100 g dry soil) and luvisols (7.3 mg $N\text{-}NO_3$/8 days/100 g dry soil). Acid albic luvisol (locality Nový Dům) was very different from other luvisol localities especially in the lowest nitrification (3.2 mg $N\text{-}NO_3$/8 days/100 g dry soil) and potential ammonification (134 mg $N\text{-}NH_4$/24 h/100 g dry soil) activities. Similar tendency (low activity) was in glucose mineralization tested by potential respiration. These negative changes of microbial metabolism are surely connected with very low pH(KCl) (4.9).

Soil quality evaluation with biological criteria (Table 3)

For complex soil evaluation the use of several criteria or their ratios is recommended (Pappendick 1991, Filip 2001). Six biological criteria (C_{MB} and five ratios: C_{MB}/C_{org}; C_E/C_{MB}; potential/control respiration; potential/control ammonification; potential/control nitrification) were applied in this study. These criteria (Table 3) distinguished all tested soils into three groups.

The first one includes two localities in the mountain region (Červená Voda 809, 810; altitude 565–590 m) defined as stagnic cambisols with higher content of C_{org} (1.40, respective 1.76%) and simultaneously with the highest biomass of microorganisms (C_{MB}; 625, respective 621 μg/g dry soil). It is not surprising that microbial activities (respiration, nitrification) of these localities were also high. The ratio C_{MB}/C_{org} (2.6–5.1%, average 4.3%, respective 3.5%) in several analyses was extremely high.

The majority of studied localities (one eutric cambisol and four luvisols) belongs to the medium group (C_{org}: 0.97–1.50%; C_{MB}: 428–599 μg/g dry soil; ratio C_{MB}/C_{org}: 4.0–4.4%).

The third group includes two localities (Neumětely – haplic luvisol; Čistá u Rakovníka – eutric cambisol) where biological criteria was mostly the worst. In the period 1993–2002 microbial biomass carbon was for both sites in the range 357–458 μg/g dry soil (average for Neumětely 398 μg/g dry soil; average for Čistá 396 μg/g dry soil) which are not very bad values. But in comparison with localities in the mountain wet region they are low. This status issued in lower ratio C_{MB}/C_{org} (2.7–3.9%, average both localities 3.3%).

Table 3. Ranking based on six biological criteria[1]

1. Červená Voda 809, stagnic cambisol, altitude 590 m
2. Červená Voda 810, stagnic cambisol , altitude 565 m
3. Červený Potok 808, eutric cambisol, altitude 625 m
4. Mostek 806, haplic luvisol, altitude 370 m
5. Mostek 807, stagnic luvisol, altitude 410 m
6. Nový Dům 127, albic luvisol, altitude 430 m
7. Sloupnice 805, albic luvisol, altitude 390 m
8. Neumětely 111, haplic luvisol, altitude 325 m
9. Čistá 125, eutric cambisol, altitude 460 m

[1]six biological criteria:
1. μg C_{MB}/g dry soil (C_{MB} = microbial biomass carbon)
2. ratio: $(C_{MB}/C_{org}) \times 100$
3. ratio: $(C_E/C_{MB}) \times 100$ (C_E = K_2SO_4 extractable carbon)
4. ratio: potential/control respiration (potential respiration with glucose)
5. ratio: potential/control ammonification (potential ammonification with peptone)
6. ratio: potential/control nitrification [potential nitrification with $(NH_4)_2SO_4$]

Ten (respective twelve) years' dynamics of selected three parameters (Figures 1–3)

Soil microbial biomass carbon (C_{MB}) (Figure 1): It could be stated that there are some differences at all tested localities, which were characterised with the decrease of C_{MB}. This decline in the soils of central Bohemia region was very gentle while soils of mountain region were characterised with marked C_{MB} decrease. Formerly (1970–1990) the soil management in this region was based on high input of organic fertilisers (> 25 tons/hectare/year of farmyard manure and/or slurry) supplemented with mineral fertilisers. The highest values of C_{MB} determined in the years 1991–1992 were probably connected with the mentioned soil management.

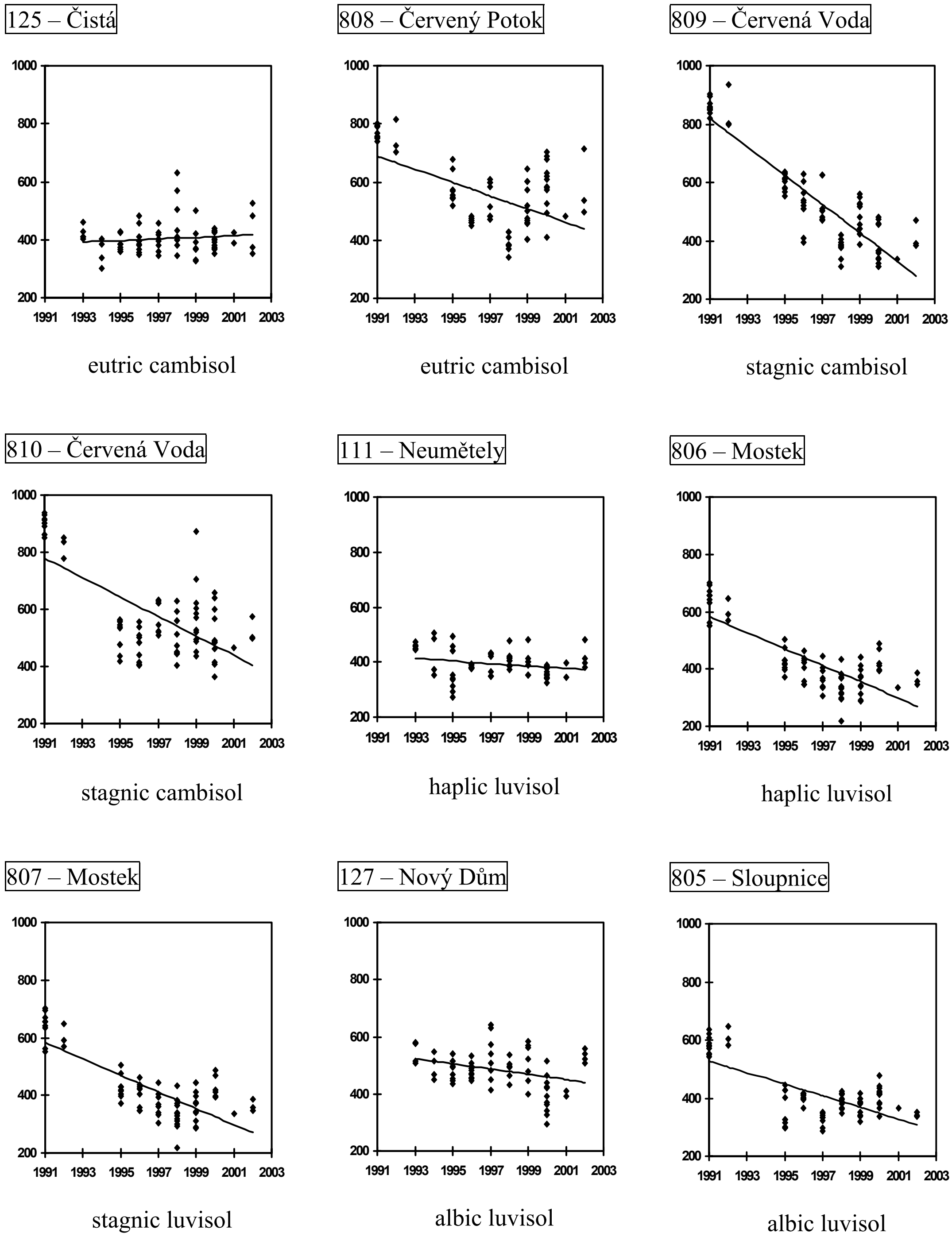

Figure 1. Dynamics of microbial biomass (μg/1 g dry soil)
◆ *y*, —– expected *y*

The significant changes in agriculture practice after 1989 resulted in the strong decrease in cattle breeding what induced low production of organic fertilisers and simultaneously with the use of mineral fertilisers dropped dramatically down. These changes resulted in massive C_{MB} decrease in 1995 with the tendency C_{MB} stabilisation during future years at this new level.

Ratio C_{MB}/C_{org} (Figure 2): In all tested soils (exception locality Čistá – eutric cambisol) a decrease was observed. In some localities it was quite remarkable: Červená Voda 809; Mostek 806 – both decrease about 40%. These changes are connected with two typical tendencies: [1] decrease of C_{MB} content (see paragraph above); [2] relatively stabile level of C_{org}.

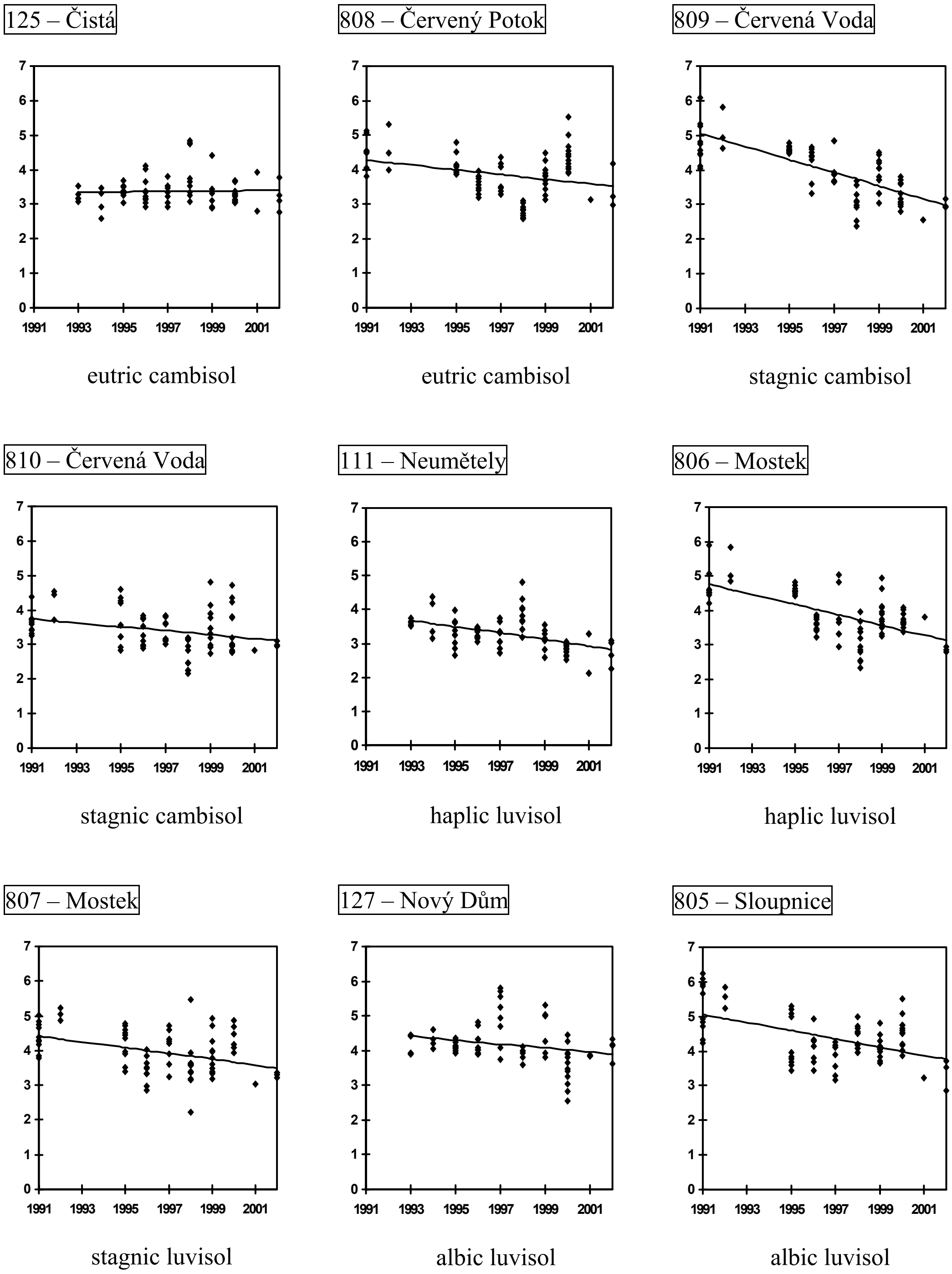

Figure 2. Dynamics of ratio (C_{MB}/C_{org}) × 100 (in per cent)
◆ *y*, ––– expected *y*

Ratio C_E/C_{MB} (Figure 3): This ratio is important for the better understanding of soil microbial metabolism. Higher levels mark deprivation of the use of this labile easily accepted carbon source as a result of the stressed soil microflora or of a high input of organic fertilisers (Badalucco et al. 1992). Similarly, like for C_{MB}, the general decreasing tendency was also observed for C_E/C_{MB} ratio, usually from about 10 to 7%. This development is a sign for good soil microbial population status because as a result of its active metabolism only a low amount of C_E is resting out of microbial cells. It should be stressed again that in all localities the input of organic fertilisers was lowered.

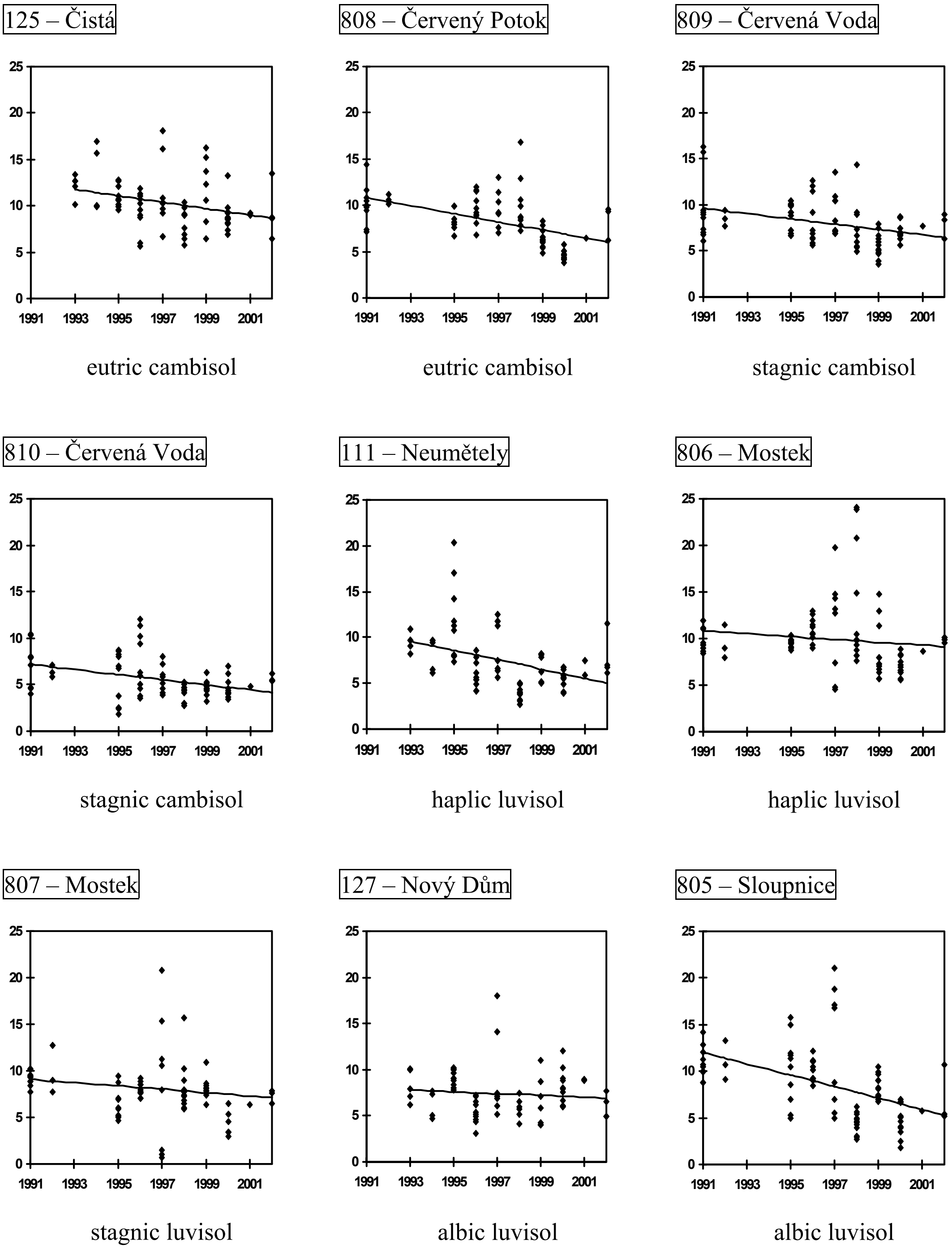

Figure 3. Dynamics of ratio ($C_{E/}C_{MB}$) × 100 (in per cent)
◆ *y*, —— expected *y*

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Received on September 15, 2003

ABSTRAKT

Mikrobiologické charakteristiky a obsah uhlíku a dusíku v kambizemích, hnědozemích a luvizemích

Testované půdy (1991–2002) byly charakterizovány chemickými, zrnitostními a mikrobiologickými parametry. Pro kambizemě je charakteristický vyšší obsah C_{org} (1,20–1,76 %). Odráží se ve vyšší biomase půdních mikroorganismů (396–625 μg C_{MB}/g sušiny), vyšší bazální respiraci (0,45–0,80 mg CO_2/h/100 g sušiny) a ve vyšší potenciální nitrifikaci se síranem amonným (6,7–18,4 mg N-NO_3/8 dní/100 g sušiny). Hnědozemě a luvizemě dosahují u sledovaných parametrů následujících hodnot: C_{org} (0,97–1,22 %), C_{MB} (398–503 μg/g sušiny), bazální respirace (0,46–0,57 mg CO_2/h/100 g sušiny), potenciální nitrifikace s $(NH_4)_2SO_4$ (3,2–9,9 mg N-NO_3/8 dní/100 g sušiny). Nižší hladina uhlíku půdní organické hmoty společně se středním obsahem mikrobní biomasy vedou k vyššímu poměru C_{MB}/C_{org} (průměr 4,0 %). Statisticky vysoce významný rozdíl ($p < 0,01$) mezi kambizeměmi na straně jedné a hnědozeměmi a luvizeměmi na straně druhé byl zjištěn u osmi chemických a mikrobiologických parametrů [C_{org}, N_t, pH(KCl), C_{MB}, C_{MB}/C_{org}, C_E, bazální respirace a potenciální nitrifikace], zatímco rozdíl u potenciální amonifikace s peptonem byl pouze na hladině významnosti $p < 0.05$. S výjimkou poměru C_{MB}/C_{org} všechny parametry kambizemí byly statisticky významně vyšší než parametry hnědozemí a luvizemí. Celkové zhodnocení bylo provedeno za pomoci šesti biologických kritérií (C_{MB} a pěti poměrů: C_{MB}/C_{org}, C_E/C_{MB}, potenciální/bazální respirace, potenciální/kontrolní amonifikace, potenciální/kontrolní nitrifikace). Tato kritéria rozdělila monitorované půdy do tří skupin. Nejlepší skupina zahrnovala dvě lokality v horské oblasti (Červená Voda 809, 810; v nadmořské výšce 565–590 m) definované jako pseudogleje kambické s vyšším obsahem půdní organické hmoty (1,40, resp. 1,76 % C_{org}) a současně nejvyšším obsahem mikrobní biomasy z monitorovaných půd (625, resp. 621 μg C_{MB}/g sušiny). Není překvapením, že mineralizační a nitrifikační aktivita byla na těchto lokalitách také vysoká. Střední skupina zahrnovala pět lokalit: modální kambizem, modální hnědozem, pseudoglej luvický, modální a dystrickou luvizem. Třetí skupinu, u níž biologické parametry byly nejhorší, tvořily dvě zbývající lokality: modální hnědozem na lokalitě Neumětely a modální kambizem na lokalitě Čistá u Rakovníka. V období 1993–2002 uhlík mikrobní biomasy dosahoval na těchto lokalitách průměrné úrovně: 357–458 μg/g sušiny, avšak významně nižší úrovně ve srovnání s lokalitami ve vlhké horské oblasti. Tato skutečnost se odrazila i v poměru C_{MB}/C_{org} (2,71–3,77 %).

Klíčová slova: kambizemě; hnědozemě; luvizemě; uhlík biomasy mikroorganismů; organický uhlík extrahovatelný do K_2SO_4; respirace; amonifikace; nitrifikace

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