Soil enzymatic characterization of different soil types under meadow

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Bodenenzymatische Charakterisierung verschiedener Bodentypen unter Wiese

1 Introduction

Studies to the feasibility to characterize soil types by soil microbiological and biochemical analysis focus on the existence of microbial and biochemical characteristics distinctive to individual soil types. Many authors have attempted to elucidate relationships between microbiological and physico-chemical properties of different soil types (DUTZLER-FRANZ, 1977a, b; KHAZIYEV and KHABIROV, 1983; POLYANSKAYA et al., 1996). Early investigations predominantly dealt with the density of the microbial colonization of different soil types and the occurrence of special groups of microorganisms. Later studies also considered biochemical properties. Efforts were also made to investigate the stability of different enzymes in different soil types. In most studies the soil types used for comparative microbial and biochemical investigations differed with regard to soil management.

Our aim was to detect relationships between biochemical and chemical soil properties across different soil types, and to determine whether different soil types under the same land use might be discriminated on the basis of biochemical soil properties. To follow this, a total of fifty soils belonging to seven different soil types from the temperate zone, all under unfertilized meadow, were analysed. We have recorded basal respiration and the activities of the enzymes dehydrogenase, protease, alkaline phosphatase and xylanase. Basal respiration results from the degradation of organic matter. This activity is considered to reflect the availability of carbon for microbial maintenance. Soil dehydrogenase activity was investigated as an indicator of the overall microbiological activity of soils. As important representatives of enzymes participating in the cycles of nitrogen, phosphorus and carbon, we have determined the activities of the enzymes protease, alkaline phosphatase and xylanase.

Zusammenfassung

Sieben Bodentypen der gemäßigten Zone wurden biochemisch und physikalisch-chemisch analysiert. Alle Böden befanden sich unter ungedüngter Wiese. Die Bodentypen zeigten unterschiedliche Aktivitätsmuster. Auf Basis der biochemischen Gesamtaktivität wurden die Bodentypen wie folgt gereiht a) zum Junitermin: Braune Auböden > Graue Auböden > Löß-Braunerde-Parabraunerden, Löß-Parabraunerden > Parabraunerden > Silikatische Felsbraunerden > Kalkfreie Schlier-Kulturrohböden, sowie b) zum Septembertermin: Braune Auböden > Löß-Parabraunerden, Graue Auböden > Parabraunerden > Löß-Braunerde-Parabraunerden, Silikatische Felsbraunerden, Kalkfreie Schlier-Kulturrohböden. Zum Junitermin wiesen die Dehydrogenase-, Atmungs- und Xylanaseaktivitäten die gröbsten Unterschiede in den Auböden und Böden des Typs Silikatische Felsbraunerde, Kalkfreier Schlier-Kulturrohboden und Parabraunerde auf. Im September war der Unterschied in der Phosphataseaktivität zwischen Kalkfreien Schlier-Kulturrohböden sowie Silikatischen Felsbraunerden und Böden des Typs Löß-Braunerde-Parabraunerde, Parabraunerde und Auböden am größten. Die Proteaseaktivität unterschied sich sowohl im Silikatischen Felsbraunerden gegenüber kalkfreien Schlier-Kulturrohböden als auch in den beiden letztgenannten im Vergleich zu den übrigen Bodentypen. Zwischen biochemischen und physikalisch-chemischen Bodeneigenschaften waren signifikante Korrelationen nachweisbar.

Schlagworte: Bodentyp, Atmung, Bodenenzyme, physikalisch-chemische Bodeneigenschaften.

Summary

Seven soil types from the temperate zone were analysed for biochemical and physico-chemical soil properties. All soils were under unfertilized meadow. Biochemical activity patterns differed across soil types. Based on their overall biochemical activity soil types were ranked a) at the June sampling: Calcaric Fluvisols 2 > Calcaric Fluvisols 1 > Calcic Luvisols > Haplic Luvisols > Dystric Cambisols > Dystric Regosols, and b) at the September sampling: C. Fluvisols 2 > C. Luvisols 1, C. Fluvisols 1 > H. Luvisols > C. Luvisols 2, D. Cambisols, D. Regosols. In June dehydrogenase, respiratory and xylanase activities distinguished mostly between C. Fluvisols and soils of the type D. Cambisol, D. Regosol and H. Luvisol. In September phosphatase activity distinguished mostly between D. Regosols as well as D. Cambisols and soils of the type Luvisol and Fluvisol. Protease discriminated between D. Cambisols and D. Regosols as well as both of the latter and the other soil types. Across soil types significant correlations between physico-chemical and biochemical properties occurred.

Key words: Soil type, respiration, soil enzymes, physico-chemical soil properties.

2 Materials and methods

2.1 Soils and site description

Fifty soils of the temperate zone, all under unfertilized meadow, were sampled down to a depth of 10 cm using an auger. Soils were sampled in June and in September. All soils were located in Upper Austria. Soil profiles 1 m deep served to characterize the soil types. Soils were classified according to FAO-UNESCO (1989). The German designation of the soil type, as well as the number of sample plots are in parentheses. Calcaric Fluvisol 1 (Grauer Auboden, 6), Calcaric Fluvisol 2 (Brauner Auboden, 6), Calcic Luvisol 1 (Löß-Parabraunerde, 9), Calcic Luvisol 2 (Löß-Braunerde-Parabraunerde, 5) and Haplic Luvisol (Parabraunerde, 6): located in a flat area in the south and west of Linz at 260 to 300 m above sea level, yearly mean temperature (y. m. t.) 9 °C, average annual precipitation (a. a. p.) 700–1000 mm. Dystric Cambisol (Silikatische Felsbraunerde, 11): located in a hilly area in the north-west of Linz at 620 and 660 m above sea level, exposure to W and S, y. m. t. 8 °C, 800–1000 mm a. a. p. Dystric Regosol (Kalkfreier Schlier-Kulturrohboden, 7): situated in a gently hilly area in the south of Schärding at 400 to 470 m above sea level, exposure to SW and SE, y. m. t. 8 °C, a. a. p. 800–1000 mm. After sampling the field-moist soil material was sieved at 5 mm and stored at 4 °C. For analyses to be carried out on air-dried soil material, part of the sieved soil material was dried at room temperature and sieved again at 2 mm. The water content of soil samples was adjusted to 60 % of the maximum water-holding capacity for measurements not to be performed on air-dried soil.

2.2 Soil analysis

Soil dry matter and soil water content were determined from the weight loss after heat treatment (105 °C, until constancy of weight). To determine maximum water-holding capacity field-moist soil was weighed into cylinders and saturated with water (ÖHLINGER, 1996a). The surplus water was sucked off under defined conditions using a sand bed; the remaining water content represents the maximum water-holding capacity. Soil humus content was determined by wet combustion using a dichromat-sulfuric acid mixture and the colorimetrical determination of Cr^{3+} (KANDELER, 1996). Soil pH-value was determined with a glass electrode using one part of soil mixed with 2.5 parts of 10 mM $CaCl_2$ solution (soil : solution ratio-1 : 3.5). Austrian standard methods were used for the determination of soil clay content (ÖNORM L1061, 1988), plant available P and K content (ÖNORM L1087, 1993), and carbonate content (ÖNORM L1084, 1999). The principle of the method to determine soil particle size distribution is to suspend soil material in water by waterlogging. After sieving the sandy fraction, the distribution of the particle sizes is determined by sedimentation and expressed as percentage. Calcium-acetate-lactate-soluble phosphate and potassium were determined by flame photometry. The method used for the determination of soil carbonate measures the volume of CO_2 from the reaction of soil carbonate minerals and HCl using the Scheibler apparatus.

Soil respiration by titration was performed according to JÄGGI (1976). The method described by THALMANN (1968) using triphenyltetrazolium chloride (TTC) as substrate was employed to determine dehydrogenase activity. Soil xylanase activity was determined using the method of SCHIN-

NER and HOFMANN (1978). The method involved the incubation of soil samples with xylane as a substrate for 48 h at 30 °C. Released reducing sugars were determined photometrically at 490 nm using 3,5-dinitrosalicylic acid as a reagent. Soil protease activity was assayed according to Ladd and BUTLER (1972) by measuring the concentration of tyrosine released after a 2-h incubation at 50 °C with casein solution. Soil alkaline phosphatase activity was measured by incubating soil samples with phenylphosphate as a substrate at 37 °C for 3 h. Released phenol was coloured with 2,6-dibromchinone-chlorimide and determined photometrically as described by ÖHLINGER (1996b).

2.3 Statistical treatment of data

The results of the soil biochemical analysis were calculated g^{-1} soil dry mass and are given as arithmetic means of n samples and their standard deviations. The number of replicates were 6 (C. Fluvisol 1), 6 (C. Fluvisol 2), 9 (C. Luvisol 1), 5 (C. Luvisol 2), 6 (H. Luvisol), 11 (D. Cambisol) and 7 (D. Regosol). The data passed the Kolmogorov-Smirnov test for normal distribution and the Levene test for the homogeneity of variances. Analysis of variance was carried out to test for significant effects of soil type and sampling date on biochemical soil properties (LINDMAN, 1992). Least Significant Difference test (LSD-test) was carried out to test for significant differences in biochemical activity means between soil types. Discriminant function analysis was performed to evaluate the power of the biochemical properties to discriminate between soil types. The Spearman correlation coefficient *R* was calculated between biological and physico-chemical soil properties to assess relationships between abiotic and biochemical soil properties. Significance was accepted at the $P \leq 0.05$ level of probability.

3 Results

3.1 Biochemical activity of different soil types

Significant effects of soil type and sampling date on biochemical soil properties were confirmed (Table 1). Biochemical properties differed significantly among soil types (Figures 1–2). The results obtained with June samples are presented first.

Basal respiration: Measured values ranged from 302 (D. Cambisol) to 614 (C. Fluvisol 1) µg CO_2 g^{-1} soil dry mass. Differences in respiratory activity between C. Fluvisols and C. Luvisols were not significant. Haplic Luvisols had a significantly lower respiration than C. Fluvisols, but H. Luvisols did not differ from C. Luvisols in this property. The sig-

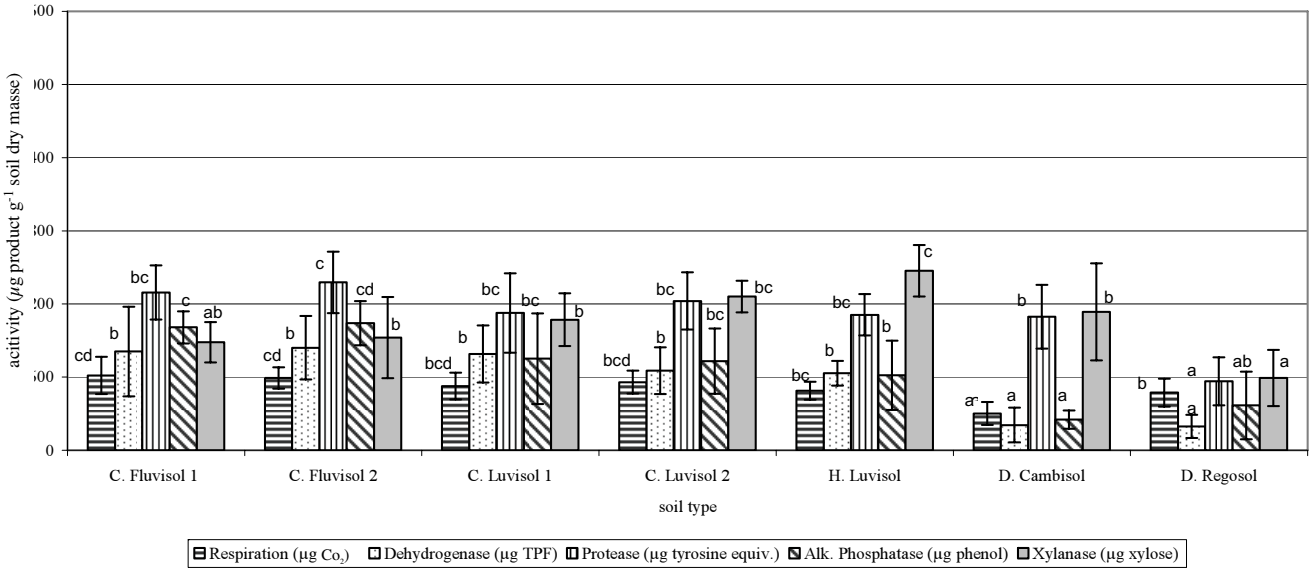

Figure 1: Biochemical activity of seven soil types (sampling date June).Whiskers: standard deviation. Statistically significant differences ($P \leq 0.05$) in means of a particular activity between soil types are indicated by different letters (the same letters indicate that values are not significantly different)

Abbildung 1: Biochemische Aktivität von sieben Bodentypen (Probenahmetermin Juni). Fehlerbalken: Standardabweichung. Zwischen den Bodentypen auftretende statistisch signifikante Unterschiede ($P \leq 0.05$) in den Mittelwerten einer bestimmten Aktivität werden durch unterschiedliche Buchstaben dargestellt (gleiche Buchstaben zeigen nicht signifikant unterschiedliche Werte an)

Table 1: Effect by analysis of variance of soil type and sampling date on soil biochemical properties (n= 50). Probability values (P) are indicated by asterisk. *, **, ***, **** = significant at P <0.05, 0.01, 0.001, 0.0001. n.s.= not significant

Tabelle 1: Effekt des Bodentyps und des Beprobungstermines auf biochemische Bodeneigenschaften (n= 50). Sternsymbole geben die Wahrscheinlichkeitswerte (P) wieder. *, **, ***, **** = signifikant bei P <0.05, 0.01, 0.001, 0.0001. n.s.= nicht signifikant

Responsive variable	Effect		Interaction
	soil type	sampling date	(soil type x season)
respiration	****	n.s.	****
dehydrogenase	***	****	**
protease	****	n.s.	***
alkaline phosphatase	****	****	****
xylanase	n.s.	****	***

nificantly lowest respiratory activity among the soil types was measured for D. Cambisols. Dystric Regosols had significantly lower respiratory activities than C. Fluvisols.

Dehydrogenase activity: Measured values ranged from 196 (D. Regosol) to 841 (C. Fluvisol 2) µg triphenylformazan (TPF) g^{-1} soil dry mass. Fluvisols and Luvisols did not differ significantly in dehydrogenase activity. However, these soil types differed significantly from D. Cambisols and D. Regols in this property. Dystric Cambisols and D. Regosols did not differ significantly from one another in dehydrogenase activity.

Protease activity: Measured values ranged from 566 (D. Regosol) to 1377 (C. Fluvisol 2) µg tyrosine equivalents g^{-1} soil dry mass. Differences in protease activity between Fluvisols and Luvisols were not significant. These soil types and D. Cambisols had significantly higher protease activities than D. Regosols.

Alkaline phosphatase activity: Observed activities ranged from 252 (D. Cambisol) to 1043 (C. Fluvisol 2) µg phenol g^{-1} soil dry mass. Calcaric Fluvisols 2 did not significantly differ in this activity from C. Fluvisols 1, but the differences between C. Fluvisols 2 and the other soil types were significant. Differences in phosphatase activities between Luvisols were not significant. The lowest phosphatase activity was observed for D. Cambisols; phosphatase activity of these soils differed significantly from those of Fluvisols and Luvisols but not from those of D. Regosols. Dystric Regosols had significantly lower phosphatase activity than C. Fluvisols and C. Luvisols.

Xylanase: Measured activities ranged from 593 (D. Regosol) to 1427 (H. Luvisol) µg xylose g^{-1} soil dry mass. Haplic Luvisols differed significantly from Fluvisols, C. Luvisols 1, D. Cambisols and D. Regosols in xylanase activity.

Results of biochemical investigations carried out with September samples are presented in Figure 2.

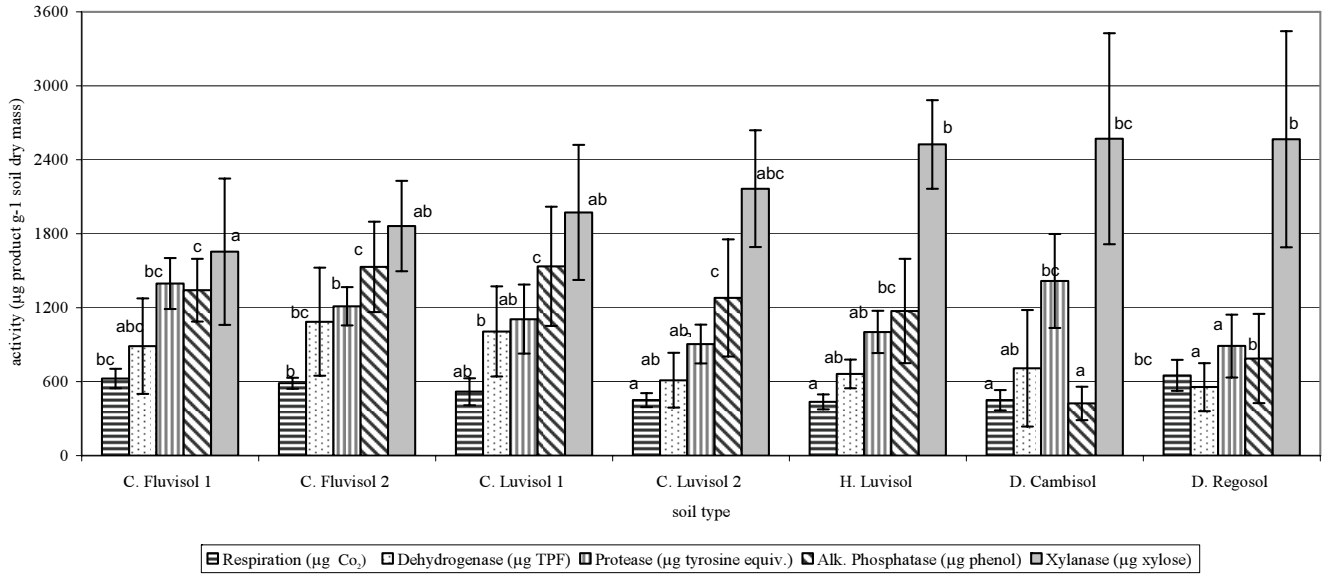

Figure 2: Biochemical activity of seven soil types (sampling date September). Whiskers: standard deviation. Statistically significant differences ($P \leq 0.05$) in means of a particular activity between soil types are indicated by different letters (the same letters indicate that values are not significantly different)

Abbildung 2: Biochemische Aktivität von sieben Bodentypen (Probenahmetermin September). Fehlerbalken: Standardabweichung. Zwischen den Bodentypen auftretende statistisch signifikante Unterschiede ($P \leq 0.05$) in den Mittelwerten einer bestimmten Aktivität werden durch unterschiedliche Buchstaben dargestellt (gleiche Buchstaben zeigen nicht signifikant unterschiedliche Werte an)

Basal respiration: Activities ranging from 436 (H. Luvisol) to 651 (D. Regosol) µg CO_2 g^{-1} soil dry mass were measured. Calcaric Fluvisols 1 and D. Regosols did not differ significantly in this property from C. Fluvisols 2, but they had significantly higher activities than Luvisols and D. Cambisols. Differences in respiration between Luvisols and D. Cambisols were not significant.

Dehydrogenase activity: The observed activities ranged from 556 (D. Regosol) to 1086 (C. Fluvisol 2) µg TPF g^{-1} soil dry mass. The activity of C. Fluvisol 2 differed significantly from those observed for C. Luvisol 2, H. Luvisol, D. Cambisol and D. Regosol. Dehydrogenase activities of D. Regosols were significantly lower compared to those observed for C. Luvisol 1 and Fluvisol 2.

Protease activity: Activities from 889 (D. Regosol) to 1416 (D. Cambisol) µg tyrosine equivalents g^{-1} soil dry mass were measured. Dystric Cambisols and C. Fluvisols had higher protease activities than Luvisols and D. Regosols.

Alkaline phosphatase activity: Values ranging from 423 (D. Cambisol) to 1535 (C. Luvisol 1) µg phenol g^{-1} soil dry mass were measured. Fluvisols and Luvisols had high phosphatase activity and did not differ significantly from one another in this property. Dystric Cambisols had the significantly lowest phosphatase activity among the studied soils. Dystric Regosols showed significantly lower phosphatase activity than C. Fluvisols and C. Luvisols, but they did not differ from H. Luvisols in this property.

Xylanase activity: Activities ranging from 1654 (C. Fluvisol 1) to 2571 (D. Cambisol) µg xylose g^{-1} soil dry mass were measured. In this property D. Cambisols differed significantly from C. Fluvisols and C. Luvisols 1. Differences in xylanase activity between C. Fluvisols and C. Luvisols were not significant.

Seasonal changes in soil biochemical activity depended on the soil type and the respective biochemical property (Table 2). In D. Cambisols and D. Regosols all activities were significantly higher in September than in June. For the other soil types no significant differences in respiration, dehydrogenase and protease activity were observed between June and September samples. An exception was C. Luvisol 2 which had significantly lower protease activities in September compared to June. Irrespective of the soil type xylanase activity was higher in September than in June samples. With the exception of C. Luvisol 2, alkaline phosphatase activities were higher in September than in June.

The results of discriminant function analysis are presented in Table 3.

For June samples two significant discriminant functions (DFs) were confirmed. DF1 explained 60.4 % of the total variance of the data and was dominated by dehydrogenase activity. DF2 was dominated by respiration and xylanase activity. Together, DF1 and DF2 explained 90 % of the discriminatory power. DF 3 to 5 were not significant. From the mean values of the canonical variables it became apparent that DF1 mostly distinguished between C. Fluvisols and soils of the type D. Cambisol, D. Regosol and H. Luvisol. To a lesser extent DF1 distinguished between C. Fluvisols and C. Luvisols. This function also distinguished between C. Luvisols and soils of the type D. Cambisol, D. Regosol and H. Luvisols. Dystric Cambisols and D. Regosols were not distinguished by DF1. The second discriminant function (DF2), dominated by respiration and xylanase activity, distinguished mostly between C. Fluvisols and soils of the type D. Cambisol, D. Regosol and H. Luvisol. Calcaric Fluvisols and C. Luvisols were distinguished to a lesser extent by DF2. This function discriminated between D. Regosols and the following soil types in a decreas-

Table 2: Comparison of the biochemical activities of seven soil types at two sampling dates. Values of a particular activity in the respective soil type followed by different letters (a, b) are statistically significant different (the same letters indicate that values are not significantly different). For unities see figures 1 and 2

Tabelle 2: Gegenüberstellung der biochemischen Aktivitäten von sieben Bodentypen zu zwei Beprobungszeitpunkten. Von verschiedenen Buchstaben (a, b) gefolgte Werte individueller Aktivitäten im entsprechenden Bodentyp sind statistisch signifikant unterschiedlich (gleiche Buchstaben zeigen nicht signifikante Unterschiede zwischen Werten an). Einheiten sind Abbildungen 1 und 2 zu entnehmen

Soil type	Respiration		Dehydrogenase		Protease		Alk. phosphatase		Xylanase	
	June	Sept.	June	Sept.	June	Sept.	June	Sept.	June	Sept.
C. Fluvisol 1	614 a	625 a	810 a	887 a	1294 a	1396 a	1008 a	1342 b	886 a	1654 b
C. Fluvisol 2	593 a	587 a	841 a	1086 a	1377 a	1211 a	1043 a	1531 b	925 a	1862 b
C. Luvisol 1	527 a	518 a	790 a	1007 a	1126 a	1107 a	751 a	1535 b	1071 a	1972 b
C. Luvisol 2	559 a	450 a	653 a	611 a	1224 b	905 a	731 a	1279 a	1261 a	2165 b
H. Luvisol	489 a	436 a	632 a	662 a	1111 a	1003 a	615 a	1173 b	1427 a	2524 b
D. Cambisol	302 a	449 b	207 a	708 b	1096 a	1416 b	252 a	423 b	1135 a	2571 b
D. Regosol	473 a	651 b	196 a	556 b	566 a	889 b	368 a	788 b	593 a	2566 b

Table 3: Discriminant function analysis of soil biochemical properties from seven soil types. Significant discriminant functions (DF) are indicated by †)

Tabelle 3: Analyse der Diskriminanzfunktionen biochemischer Eigenschaften aus sieben verschiedenen Bodentypen. Signifikante Diskriminanzfunktionen (DF) sind mit †) gekennzeichnet

	June					September				
	DF 1 †)	DF 2 †)	DF 3	DF 4	DF 5	DF 1†)	DF 2 †)	DF 3 †)	DF 4	DF 5
Eigenvalue	3.06	1.50	0.36	0.12	0.00	2.09	1.43	1.16	0.07	0.009
Cumulative explained variance %	60.4	90.0	97.3	99.8	100	43.8	73.8	98.2	99.8	100
Wilks' lambda	0.063	0.257	0.644	0.880	0.992	0.056	0.174	0.424	0.921	0.990
Degree of freedom	30	20	12	6	2	30	20	12	6	2
Standardised coefficients for canonical variables										
Dehydrogenase	-0.683	-0.197	-0.047	-1.004	0.247	0.144	0.220	-0.392	-1.101	0.255
Xylanase	0.276	-0.765	-0.757	0.351	-0.241	-0.548	0.265	0.751	-0.117	-0.736
Protease	-0.429	-0.332	0.771	0.282	0.465	0.444	-0.956	-0.510	0.424	-0.378
Alkaline phosphatase	-0.411	-0.153	-0.078	0.403	-0.987	0.964	0.186	0.439	0.370	-0.404
Respiration	-0.006	0.821	-0.385	0.652	0.595	-0.604	0.708	-0.741	0.037	-0.113
Mean values of canonical variables										
C. Fluvisol 1	-1.957	0.688	0.378	0.208	0.007	0.879	-0.102	-1.740	0.479	-0.030
C. Fluvisol 2	-2.215	0.253	0.586	0.134	-0.095	1.213	0.564	-0.825	-0.288	-0.022
C. Luvisol 1	-0.978	-0.103	-0.238	-0.616	0.057	1.406	0.382	0.171	-0.255	0.029
C. Luvisol 2	-0.477	-0.372	-0.540	0.556	0.172	0.572	0.265	1.478	0.319	0.186
H. Luvisol	0.149	-1.135	-1.046	0.115	-0.132	0.271	-0.081	1.640	0.141	-0.184
D. Cambisol	1.887	-1.134	0.609	-0.004	0.007	-1.127	-1.790	-0.154	-0.104	0.020
D. Regosol	2.082	2.348	-0.195	0.008	-0.019	-2.472	1.806	-0.242	-0.020	0.001

ing degree: H. Luvisols, D. Cambisols, C. Luvisols and C. Fluvisols. DF2 distinguished between D. Cambisols and C. Luvisols.

For September samples three significant discriminant functions were confirmed. DF1 explained 43.8 % of the total variance of the data and was dominated by alkaline phosphatase activity. Protease activity dominated DF2. Together, DF1 and DF2 explained 73.8 % of the discriminatory power. DF3 covered 24 % of the variance and was dominated by respiration and xylanase activity. DF4 and DF5 were not significant. The mean values of canonical variables indicated that DF1 did not distinguish between D. Regosols and D. Cambisols, however, between these soil types and soils of the type Luvisol and Fluvisol. DF2 which was dominated by protease activity, distinguished mostly between D. Cambisols and D. Regosols but also between both of these soil types and the following ones: H. Luvisol, C. Luvisol, C. Fluvisol. DF2 distinguished between C. Fluvisols 1 and 2 as well as between Luvisols and C. Fluvisols. DF3 which was dominated by respiration and xylanase activity, did not distinguish between D. Cambisols and D. Regosols, however, between these both soil types and soils of the type H. Luvisol, C. Luvisol and C. Fluvisol, although to a varying degree.

Table 4: Physico-chemical properties of the soil types. Data represent means of n samples of the particular soil type. All values were calculated on the basis of soil dry mass. Standard deviation (±) in parentheses. MWHC: maximum water holding capacity

Tabelle 4: Physikalisch-chemische Eigenschaften der Bodentypen. Daten stellen die Mittelwerte aus n Proben des jeweiligen Bodentyps dar. Berechnung sämtlicher Werte auf Bodentrockengewichtsbasis. Standardabweichung (±) in Klammer. MWHC: Maximale Wasserhaltekapazität

Soil type	clay %	$CaCO_3$ %	K_2O mg 100 g^{-1} soil	P_2O_5 mg 100 g^{-1} soil	pH %	Humus %	MWHC %
Calcaric Fluvisol 1 (n=6)	10.8 (3.1)	16.7 (4.4)	12.8 (5.1)	11.2 (13.3)	6.9 (0.1)	5.9 (1.2)	34.7 (5.2)
Calcaric Fluvisol 2 (n=6)	11.3 (2.4)	14.6 (7.2)	14.3 (6.4)	19.0 (20.0)	6.9 (0.1)	5.9 (0.8)	37.0 (11.7)
Calcic Luvisol 1 (n=9)	13.2 (2.9)	6.0 (4.3)	19.7 (9.6)	12.7 (9.5)	6.4 (0.6)	5.9 (0.4)	34.3 (10.0)
Calcic Luvisol 2 (n=5)	13.6 (3.5)	3.1 (2.4)	26.2 (11.8)	13.8 (10.3)	6.2 (0.7)	5.8 (0.5)	31.6 (4.3)
Haplic Luvisol (n=6)	14.6 (1.6)	1.0 (0.4)	29.3 (30.5)	18.8 (17.5)	5.6 (0.7)	5.7 (0.4)	32.9 (5.1)
Dystric Cambisol (n=11)	12.4 (1.3)	1.0 (0.2)	18.4 (8.2)	10.4 (6.5)	5.3 (0.7)	5.3 (1.6)	40.1 (5.6)
Dystric Regosol (n=7)	23.0 (2.8)	1.2 (1.0)	13.6 (4.4)	6.6 (3.3)	6.5 (0.2)	5.4 (1.0)	45.9 (11.4)

3.2 Relations between biochemical and physico-chemical soil properties

Soil respiration correlated significantly and positive with soil pH-value, soil carbonate and humus content (Table 5). Soil dehydrogenase activity also correlated positively with these soil properties but negatively with soil clay content. The relationship between protease activity and soil clay content also was negative, while a highly positive relation was confirmed between this biochemical property and the soil humus content. Alkaline phosphatase activity correlated positively with soil pH-value and humus content, but negatively with soil clay content and maximum water-holding capacity. The relation between soil xylanase activity and soil humus content also was a positive one. However, this enzyme activity differed from other activities in correlating negatively with soil pH-value and carbonate content.

4 Discussion

Our study shows that soil biochemical activities are significantly affected by soil type. Physical and chemical soil properties contribute to the establishment of different biochemical patterns in different soil types. With the exception of the enzyme xylanase we have confirmed positive relations between soil pH-value and biochemical soil activities. The biochemical properties correlated positively with soil humus content. Enzyme activities have frequently been related to soil organic matter content e.g. dehydrogenase (LEHNHARD, 1956; GALSTYAN and AVUNDZHYAN, 1970; DUTZLER-FRANZ, 1977a; ABRAMYAN, 1993), protease (ALEF et al., 1988), alkaline phosphatase (ROSS and SPEIR, 1979; DE PRADO et al., 1982; SPARLING et al., 1986) and xylanase (HOFMANN and PFITSCHER, 1982; VON MERSI and SCHINNER, 1990). For dehydrogenase, protease and alkaline phosphatase we have determined negative correlations with soil clay content. DUTZLER-FRANZ (1977a) did not find such a relationship between soil clay content (20 to 50 %) and dehydrogenase activity. However, FRANK and MALKOMES

Table 5: Correlation matrix (Spearman`s coefficients and significance levels) of soil properties (n= 100). MWHC: maximum water holding capacity. Resp = respiration, Dehy = dehydrogenase, Prot = protease, APhos = alkaline phosphatase, Xyl = xylanase

Tabelle 5: Korrelationsmatrix (Spearman Koeffizienten und Signifikanzniveaus) der Bodeneigenschaften (n = 100). MWHC: maximale Wasserhaltekapazität. Resp = Atmung, Dehy= Dehydrogenase, Prot= Protease, APhos= alkalische Phosphatase, Xyl= Xylanase

	Carbonate	Clay	K_2O	P_2O_5	pH	Humus	MWHC	Resp	Dehy	Prot	APhos
Clay	-0.4641 0.0000****	/									
K_2O	-0.0778 0.4416	0.0055 0.9565	/								
P_2O_5	0.2685 0.0068**	-0.0397 0.6944	0.3936 0.0000****	/							
pH	0.8011 0.0000****	0.2365 0.0178*	-0.0720 0.4759	0.2040 0.0417*	/						
Humus	0.0563 0.5774	0.1078 0.2853	-0.2158 0.0310*	-0.0036 0.9712	0.0467 0.6441	/					
MWHC	-0.3835 0.0000****	0.1387 0.1684	-0.0082 0.9352	-0.1800 0.0731	-0.1324 0.1889	0.1978 0.0488*	/				
Resp	0.5218 0.0000****	-0.0458 0.6502	-0.1912 0.0566	0.0042 0.9665	0.6058 0.0000****	0.2960 0.0027**	-0.1835 0.0675	/			
Dehy	0.3941 0.0000****	-0.2889 0.0040**	-0.1462 0.1464	-0.0493 0.6255	0.3048 0.0020**	0.5503 0.0000****	-0.1312 0.1929	0.4924 0.0000****	/		
Prot	0.1866 0.0629	-0.5120 0.0000****	-0.1716 0.0877	-0.0692 0.4936	-0.0279 0.7825	0.4012 0.0000****	0.1055 0.2958	0.2219 0.0264*	0.4452 0.0000****	/	
APhos	0.6375 0.0000****	-0.2433 0.0147*	-0.0571 0.5723	0.1808 0.0717	0.6721 0.0000****	0.2976 0.0026**	-0.3607 0.0002***	0.5521 0.0000****	0.6226 0.0000****	0.1001 0.3114	/
Xyl	-0.2395 0.0163*	0.0387 0.7015	0.0095 0.9244	-0.0952 0.3456	-0.3390 0.0005***	0.2383 0.0169*	-0.0246 0.8075	0.0524 0.6045	0.3375 0.0005***	0.2451 0.0139*	0.2218 0.0256*

* $P<0.05$, ** $P<0.01$, *** $P<0.001$, **** $P<0.0001$

(1993) found lower dehydrogenase activity in Pelosols (soils rich in clay) than in Brown Earths and Leached Brown Earths. These authors found higher phosphatase activities in clay rich Pelosols than in Brown Earths and Leached Brown Earths. Negative relations between soil protease activity and soil clay content have been reported by DUTZLER-FRANZ (1977a) and MAYAUDON et al. (1975). Fluvisols reacted neutral and were lower in clay and higher in humus and calcium carbonate content than other soil types. These properties might largely be responsible for the high biochemical activity of Fluvisols. Compared to the other soil types, H. Luvisols had medium clay contents and lower pH-values. The biochemically less active soil types, D. Cambisols and D. Regosols, were very low in calcium carbonate content. Dystric Regosols also had the highest clay content among the seven soil types. In contrast to the other soil types, the soil water regime of D. Regosols had the tendency to periodical wettness. The low biochemical activity of D. Cambisols and D. Regosols might be, at least partly, explained by these factors. In all soil types xylanase activity was higher in September than in June. Similar observations were reported by TSCHERKO and KANDELER (1999). These authors have found that xylanase activity followed a periodical pattern, irrespective of the site (Cambisol, Fluvisol, grassland, arable soil). Excepted for C. Luvisols 2, we have measured higher soil alkaline phosphatase activities in September than in June samples. Increases in available litter at the end of the vegetation period might be, to some degree, responsible for increased activities of enzymes involved in organic matter decomposition.

From the results of our study we conclude that biochemical soil characteristics allow for a discrimination between different soil types under the same land use. Sets of properties that discriminate between soil types are affected by the sampling season.

References

ABRAMYAN, S.A. (1993): Variation of enzyme activity of soil under the influence of natural and anthropogenic factors. Eurasian Soil Science 25, 57–74.

ALEF, K., T. BECK, L. ZELLES and D. KLEINER (1988): A comparison of methods to estimate microbial biomass and N-mineralization in agricultural and grassland soils. Soil Biology and Biochemistry, 18, 233–235.

DE PRADO R., M. TENA and J. A. PINILLA (1982): Relationship between soil phosphatase activity and organic matter content. Agronomie, 2, 539–544.

DUTZLER-FRANZ, G. (1977): Der Einfluß einiger chemischer und physikalischer Bodenmerkmale auf die Enzymaktivität verschiedener Bodentypen. Zeitschrift für Pflanzenernährung und Bodenkunde, 140, 329–350.

FAO-UNESCO (1989): Soil Map of the World. Revised Legend.

FRANK, T. and H. P. MALKOMES (1993): Mikrobielle Aktivitäten in landwirtschaftlich genutzten Böden Niedersachsens. II. Bodencharakterisierung anhand mikrobieller Stoffwechselaktivitäten. Zeitschrift für Pflanzenernährung und Bodenkunde, 156, 491–494.

GALSTYAN, A. S. H. and Z.S. AVUNDZHYAN (1970): Dehydrogenases in the clay fraction of soils. Soviet Soil Science, 2, 721–723.

HOFMANN, J. and A. PFITSCHER (1982): Korrelationen von Enzymaktivitäten im Boden. Zeitschrift für Pflanzenernährung und Bodenkunde, 145, 36–41.

JÄGGI, W. (1976): Die Bestimmung der CO_2-Bildung als Maß der bodenbiologischen Aktivität. Schweizerische Landwirtschaftliche Forschung, 15, 371–380.

KANDELER, E. (1996): Organic matter by wet combustion. In: Schinner, F., R. Öhlinger, E. Kandeler and R. Margesion (Eds.): Methods in Soil Biology. Springer Verlag, Berlin Heidelberg, New York, pp. 397–398.

KHAZIYEV, F. K. and I. K. KHABIROV (1983): Physiographic factors and enzymatic activity of soils. Soviet Soil Science, 15, 23–32.

LADD, J. N. and J. H. A. BUTLER (1972): Short-term assays of soil proteolytic enzyme activities using proteins and dipeptide derivaties as substrates. Soil Biology and Biochemistry, 4, 19–30.

LEHNHARD, G. (1956): Die Dehydrogenaseaktivität des Bodens als Maß für die Mikroorganismentätigkeit im Boden. Zeitschrift für Pflanzenernährung, Düngung und Bodenkunde, 73, 1–11.

LINDMAN, H. (1992): Analysis of Variance in experimental Design. Springer Verlag, New York.

MAYAUDON, J., L. BASTISTIC and J. M. SARKAR (1975): Propriétés des activités protéolytiques extraites des sols frais. Soil Biology and Biochemistry, 7, 281–286.

ÖHLINGER, R. (1996a): Maximum water-holding capacity. In: Schinner, F., R. Öhlinger, E. Kandeler and R. Margesin (Eds.): Methods in Soil Biology. Springer Verlag, Berlin Heidelberg, New York, pp. 385–386.

ÖHLINGER, R. (1996b): Phosphomonoesterase activity with the substrate phenylphosphate. In: Schinner, F., R. Öhlinger, E. Kandeler and R. Margesin (Eds.): Methods

in Soil Biology. Springer Verlag, Berlin, Heidelberg, New York, 210–213.

ÖNORM L1061 (1988): Physical determination of particle size distribution of soils less than 2 mm particle size. Austrian Standards Institute, Heinestraße 38, A-1021 Vienna, Austria.

ÖNORM L1087 (1993): Determination of plant-available phosphate and potassium by calcium-acetate-lactate (CAL)-method. Austrian Standards Institute, Heinestraße 38, A-1021 Vienna, Austria.

ÖNORM L1084 (1999): Chemical analyses of soils – determination of carbonate. Austrian Standards Institute, Heinestraße 38, A-1021 Vienna, Austria.

POLYANSKAYA, L. M., V.V. GEIDERBREKHT, A. L. STEPANOV and D.G. ZVYAGINTSEV (1996): Distribution of population and biomass of microorganisms with regard to profiles of zonal types. Eurasian Soil Science, 28, 85–94.

ROSS, D. J. and T. W. SPEIR (1979): Biochemical activities of organic soils from subantartic tussock grasslands on Campell Island New Zealand. 2. Enzyme activities. New Zealand Journal of Science, 22, 173–182.

SCHINNER, F. and J. HOFMANN (1978): Zellulase-, Xylanase- und Pektinaseaktivitätsmessungen in verschiedenen Böden der oberen alpinen Stufe. In: Österreichische Akademie der Wissenschaften (Ed.): Veröffentlichungen des Österreichischen MaB-Hochgebirgsprogrammes Hohe Tauern. Universitätsverlag Wagner, Innsbruck, 290–298.

SPARLING, G. P., T. M. SPEIR and K. N. WHALE (1986): Changes in microbial biomass-C, ATP content, soil phosphomonoesterase and phosphodiesterase activity following air-drying of soils. Soil Biology and Biochemistry, 18, 363–370.

THALMANN, A. (1968): Zur Methodik der Bestimmung der Dehydrogenaseaktivität im Boden mittels Triphenyltetrazoliumforamzan (TTC). Landwirtschaftliche Forschung, 21, 249–258.

TSCHERKO, D. and E. KANDELER (1999): Classification and monitoring of soil microbial biomass, N-mineralization and enzyme activities to indicate environmental changes. Die Bodenkultur, 50, 215–224.

VON MERSI, W. and F. SCHINNER (1990): Xylanase, CM-cellulase- and invertase activity in soil: an improved method. Soil Biology and Biochemistry, 22, 511–515.

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