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Microbial Activities and Biomass Along an Altitudinal Profile in the Northern Tyrolean Limestone Alps

By

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Key words: Soil microbial biomass, forest, alps, altitude profile.

S u m m a r y

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Soil microbiological properties were investigated along an altitudinal gradient of forest stands in the Calcareous Alps in Austria (1050 m, 1250 m and 1400 m sea level). The parameters studied were organic carbon, microbial biomass (substrate-induced-respiration) and basal respiration. The microbial biomass C ranged from 1340 - 2253 $\mu\text{g C}_{\text{mic}} \text{g}^{-1}$ dry soil. Basal respiration reached 7 to 13 $\mu\text{g CO}_2 \text{g}^{-1}$ dry soil h^{-1} . Neither of these parameters, nor the metabolic quotient of CO_2 (13 to 16 ($\mu\text{g CO}_2\text{-C } \mu\text{g}^{-1} \text{C}_{\text{mic}} \text{h}^{-1}$)* 10^{-4}) and the $\text{C}_{\text{mic}}/\text{C}_{\text{org}}$ ratio (14 to 19 $\text{mg C}_{\text{mic}} \text{g}^{-1} \text{C}_{\text{org}}$) were influenced by altitude. The altitudinal effects were superimposed by other site properties (humidity, topography).

I n t r o d u c t i o n

This ecophysiological study of the soil microflora is part of the "Ecosystem Studies in the Calcareous Alps - Altitudinal Profile Achenkirch" of the Federal Forest Research Centre, Austria (HERMAN 1992, 1994).

The present study contributes the following to this ecosystem study:

- Characterization of the soil microflora in the experimental area;
- Effect of an altitudinal gradient (1040 m - 1400 m a.s.l.) on the soil

microflora.

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Altitudinal gradient

Based on the changing macroclimatic factors, alpine plants are subjected to an increasing selection pressure with increasing altitude (LARCHER 1970). If one considers the close relationships among vegetation cover, climate and soil, one can conclude that the environmental conditions for the soil microflora will also change.

The extent by which the soil microflora is affected by macroclimatic factors like air temperature, precipitation and number of frost-free days is described by INSAM & al. 1989 and INSAM 1990 for agricultural soils in North America. With increasing temperature (2.0 - 23.3 °C annual mean), the microbial biomass as well as the basal respiration decreased, whereas the qCO_2 (respiration/biomass) increased (INSAM & al. 1989, INSAM 1990). Thus, in warmer climatic regions, the biomass decreases, whereas the basal respiration, relative to the biomass, increases. This would result in a decrease in organic carbon. ANDERSON & DOMSCH 1985a,b found that the maintenance requirement - the amount of C required for the basic metabolism but not supporting cell reproduction - will almost double for an increase in temperature of 13 °C. However, those soils were taken from an area with a mean annual temperature of 10 °C and then incubated in the laboratory at 15 and 28 °C. NICOLARDOT & al. 1994 investigated the carbon and nitrogen cycle in calcareous soils and found an increase in the catabolism of organic matter with increasing incubation temperature (from 4 - 28 °C). The N immobilization rate increased accordingly. At 28 °C, a re-mineralization of N was observed. Aside from air temperature, precipitation is one of the most important climate factors. The C_{mic}/C_{org} ratio is not related to temperature (INSAM 1990), but is closely correlated with the precipitation/evaporation ratio (P/E; INSAM & al. 1989). The C_{mic}/C_{org} relationship is lowest where precipitation and evaporation are approximately equal (P/E = 1). If $P > E$, or $P \ll E$, catabolic processes would be slowed down. It was the aim of the present study to determine if such climatic effects can not only be found for agricultural soils, but also in forest stands of different altitudes.

Quantity and ecophysiological characterization of the microflora

The microbial community in a forest ecosystem has mainly two tasks: first to degrade the litter, and second it acts as a pool for plant nutrients.

The primary producers form organic matter. Dead organic matter accumulates in the soil litter layer which is then degraded by microorganisms and transformed into recalcitrant secondary compounds (e.g. humic substances) or mineralized to the inorganic stage. Important plant nutrients like nitrogen, sulphur and phosphorus that would otherwise be leached are stored in the microbial biomass to a considerable extent (DIAZ-RAVINA 1993a). At times of abundance, this microbial pool is filled. If microbial numbers or biomass decrease due to changing environmental conditions, these nutrients are slowly released (MARUMOTO & al. 1982) and can then be taken up by the plants.

Aside from its function as a nutrient pool, the microbial biomass can also act as an indicator for an input of pollutants to forests. BAATH & al. 1979 observed a decreased microbial activity and biomass with simulated acid rain. OTHONEN & al. 1990 also found a decrease in soil respiration with increasing air pollution in areas of heavy industry. BAATH & al. 1991 reports a decrease in microbial biomass in copper and zinc polluted forest soils around metal smelters. FLIESSBACH & al. 1994 investigated slightly acidic agricultural soils in Northern Germany that were fertilized with sewage sludges with varying heavy metal concentrations. Upon increasing heavy metal concentration, the microbial biomass decreased, and the qCO_2 increased. Similar results were also described by BROOKES & al. 1986.

Based on ecophysiological parameters like the metabolic quotient (respiration/biomass) and the C_{mic}/C_{org} ratio, one can draw some conclusions on the successional maturity of an ecosystem. INSAM & DOMSCH 1988 and INSAM & HASELWANDTER 1989 showed that both qCO_2 and the C_{mic}/C_{org} ratio decreased with maturation of an ecosystem.

Materials and Methods

The area of investigation was located along an altitudinal gradient on the Christlum mountain near Achenkirch in the Northern Calcareous Alps of the Tyrol (Austria). A detailed description of this area and the sample plots can be found in ENGLISH 1992. The steeper slopes and convex formations are dominated by shallow raw soils and poorly developed rendzinas, the gentle slopes by shallow to intermediate mull or moder rendzinas (ENGLISH 1992). The soils are well supplied with nutrients and are alkaline (pH 7.2 to 7.6), high cation exchange capacity (over 250 mmol kg^{-1} soil) and a high base saturation of 100 % down to 20 cm depth (BERGER & GLATZEL 1994).

Soil sampling and preparation: The three sampling plots are located along an altitudinal gradient (1050 m, 1250 m and 1400 m a.s.l.). In the vegetation period of 1992, 31 samples were collected from each plot in May, July and October with a corer of 7 cm diameter. The litter layer was removed, and three horizons (0-10 cm, 10-20 cm, 20-30 cm) were kept separate. In the growing period of 1993, eight samples were taken from each plot in May, July, September and November and split into two horizons (0-10 cm, 10-20 cm). In the laboratory, the samples were sieved to 2 mm and the water content was adjusted to approximately 300 kPa suction tension with distilled water.

Analyses: Basal respiration was determined with an infrared gas analyser (HEINEMEYER & al. 1989). Microbial biomass was determined with the substrate induced respiration method according to ANDERSON & DOMSCH 1978. Organic carbon (C_{org}) was measured by dry combustion. The metabolic quotient (qCO_2 ; ANDERSON & DOMSCH 1993) and the C_{mic}/C_{org} -ratio (ANDERSON & DOMSCH 1986) were calculated. pH was determined in water as well as in 0.01 M $CaCl_2$. Basal respiration can be defined as the release of CO_2 of a sieved soil without the addition of C or nutrient source. Microbial biomass is per definition part of the organic matter, and is comprised of bacteria and fungi. The qCO_2 describes the physiological status of microbial communities, which is considered to indicate stress. The C_{mic}/C_{org} -ratio indicates if soil organic matter is in a state of decline or accumulation (INSAM & al. 1992).

Statistics: The results were evaluated by one-factor analysis of variance, followed by the Tukey Honest Significant Difference Test for comparing means.

Results and Discussion

Basal respiration decreased with depth. In the top 10 cm of the soil, basal respiration varied from 10 to 13 $\mu\text{g CO}_2 \text{ g}^{-1} \text{ soil h}^{-1}$ in 1992 and from 7 to 9 $\mu\text{g CO}_2 \text{ g}^{-1} \text{ soil h}^{-1}$ in 1993. The values for 10 - 20 cm depth ranged from 4 to 6 in 1992 and from 3 to 5 $\mu\text{g CO}_2 \text{ g}^{-1} \text{ soils h}^{-1}$ in 1993. The 20 - 30 cm soil horizon was only sampled in 1992 and contained 2 - 3 $\mu\text{g CO}_2 \text{ g}^{-1} \text{ soil h}^{-1}$. In forest soils, nutrient transport from the upper, nutrient-rich layer into lower soil horizons takes place only by bioturbation and water movement (GISI 1990). The natural stratification - the decrease in C and energy source with depth - is reflected in undisturbed forest soils by a decreased microbial population density and a lower CO_2 -production.

CO_2 production was lower in the growing season of 1993 than in 1992 (Fig. 1 and 2). In the top horizon, the CO_2 evolution in 1993 was $3.6 \pm 0.9 \mu\text{g CO}_2 \text{ g}^{-1} \text{ soil h}^{-1}$ and thus significantly lower than in 1992. Due to the high precipitation in 1993 (SMIDT & al. 1994), the samples had to be air-dried prior to CO_2 analysis. According to ALEF 1991, air drying significantly decreases the basal respiration. In 1993, the rainy weather could also have had a negative effect on the microbial activity. INSAM 1990 showed that the basal respiration in soils from arid climate zones was higher than in soils from humid climates. Further, decomposition should also decrease upon an increased P/E ratio (INSAM & al.1989, INSAM 1990), as it was the case in the growing period of 1993 in the present study. The amount of precipitation was much higher in 1993 when compared to 1992, whereas the average air temperature (from May to October) was only 1 °C lower in 1993 (SMIDT & al. 1994).

We found no effect of altitude on the parameters measured (Fig. 1 and 2). The change in climatic conditions with increasing altitude was too small to affect microbial activity. The comparison of the three sampling plots revealed that the top horizon of the site at 1250 m had a significantly higher respiration than the other sites. This could be due to the different forest type at this site where beeches dominated. The almost complete shading from the beech trees could possibly delay the dessication of the top layers. This would not be the case at the more sparsely-wooded sites at 1050 m and 1400 m a.s.l.

The results of the present study are comparable to results from undisturbed forest sites. WOLTERS & JOERGENSEN 1991 investigated the microbial C metabolism in beech forest soils that differed in their pH. Those soils with a pH similar to that in the present study exhibited basal respiration values of 6.7 to 8 $\mu\text{g CO}_2 \text{ g}^{-1} \text{ soil h}^{-1}$. For pine forest soils in Spain with a pH (H_2O) of 6.5, DIAZ-RAVINA 1993a,b,c determined a basal respiration of 4.7 $\mu\text{g CO}_2 \text{ g}^{-1} \text{ soil h}^{-1}$.

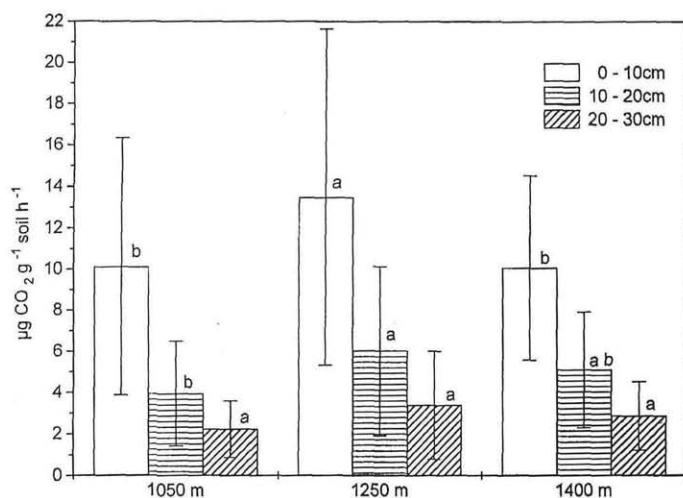


Fig. 1. Basal respiration ($\mu\text{g CO}_2 \text{ g}^{-1} \text{ soil h}^{-1}$), mean $\pm$ standard deviation (sd) of all three sampling events ($n=93$) in the vegetation period of 1992. Different letters indicate significant differences between sites (Tukey-HSD Test with $p < 0.05$).

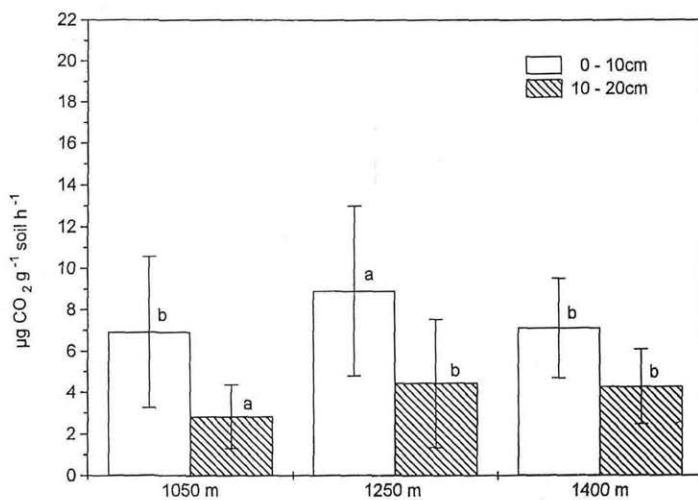


Fig. 2. Basal respiration ($\mu\text{g CO}_2 \text{ g}^{-1} \text{ soil h}^{-1}$), mean $\pm$ sd of all four sampling events ($n=24$) in the vegetation period of 1993. Different letters indicate significant differences between sites (Tukey-HSD Test with $p < 0.05$).

Due to the natural layering of the forest soils, C_{mic} decreased significantly with soil depth (Fig. 3 and 4). In 1992 and 1993, C_{mic} in the top horizon ranged from 2006 to 2253 and from 1340 to 1548 $\mu\text{g } C_{mic} \text{ g}^{-1}$ soil. For the 10 - 20 cm horizon, C_{mic} ranged from 610 to 900 $\mu\text{g } C_{mic} \text{ g}^{-1}$ soil in 1992 and from 370 to 600 $\mu\text{g } C_{mic} \text{ g}^{-1}$ soil in 1993. The 20 - 30 cm horizon exhibited biomass values of 259 to 403 $\mu\text{g } C_{mic} \text{ g}^{-1}$ soil in 1992.

In 1993, C_{mic} in the upper horizon decreased by $725.1 \pm 24.1 \mu\text{g } C_{mic} \text{ g}^{-1}$ soil when compared to 1992. Similar to basal respiration, C_{mic} might have decreased due to the drying of the samples in the laboratory. It is also possible, however, that the large amount of precipitation at unchanged air temperatures caused this decrease in 1993. According to CLARK & GILMOUR 1983, catabolic processes are slowed down in water-logged soils. Like with basal respiration, no altitude effect was found.

For a better comparison, the annual means of the microbial biomass on basis soil dry mass [$\mu\text{g } C_{mic} \text{ g}^{-1}$ soil] were converted into the per hectare units more common in forestry [t ha^{-1}] (Table 1). The biomass-nitrogen [t N ha^{-1}] was calculated based on the assumption of a microbial C/N-ratio of 7:1.

Table 1. Mean microbial biomass-C and -N [t ha^{-1}] in the vegetation period 1992 (n=93) and 1993 (n=24).

		horizon	1992	1993	1992	1993	1992	1993
			1050 m	1050 m	1250 m	1250 m	1400 m	1400 m
biomass-C	0 - 30 cm		1443	1045	1464	1059	1314	875
	[t ha^{-1}]							
biomass-N	0 - 30 cm		206	149	209	151	188	125
	[t ha^{-1}]							

This comparison, which includes information on the profile depth, shows no significant differences between the sites. The values at the site at 1250 m a.s.l. were not significantly higher than those from the other two sites. WOLTERS & JOERGENSEN 1991 investigated soils from an unpolluted beech forest. Soils with a pH (H_2O) between 7.5 and 8.3 had a C_{mic} ranging from 1170 to 1520 $\mu\text{g } C_{mic} \text{ g}^{-1}$ soil. INSAM & DOMSCH 1988 investigated samples from coal strip mine revegetation sites and found biomass values of 222 $\mu\text{g } C_{mic} \text{ g}^{-1}$ soil. The soils studied here had a significantly higher microbial biomass. These results indicate that the sites from the present study are part of an unpolluted forest ecosystem with a good nutrient supply.

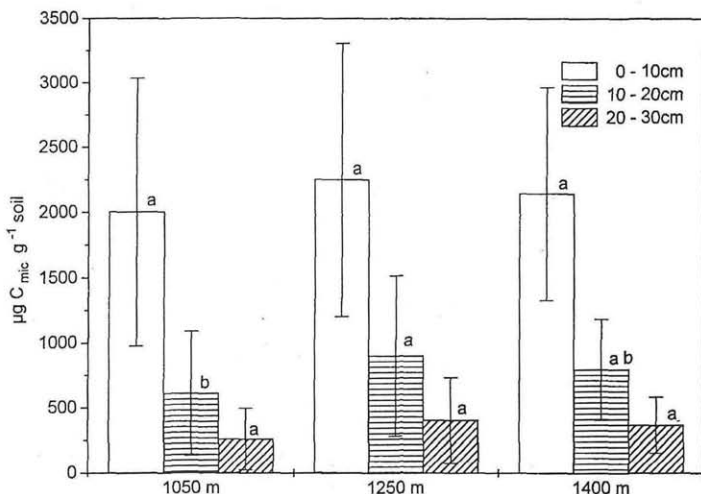


Fig. 3. Microbial biomass [$\mu\text{g C}_{\text{mic}} \text{g}^{-1} \text{ soil}$], mean $\pm$ sd of all three sampling events ($n=93$) in the vegetation period of 1992. Different letters indicate significant differences between sites (Tukey-HSD Test, $p = 0.05$).

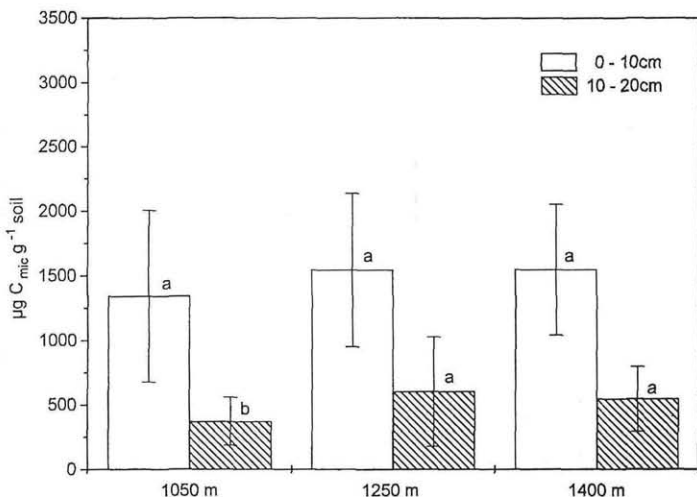


Fig. 4. Microbial biomass [$\mu\text{g C}_{\text{mic}} \text{g}^{-1} \text{ soil}$], mean $\pm$ sd of all four sampling events ($n=24$) in the vegetation period of 1993. Different letters indicate significant differences between sites (Tukey-HSD Test, $p = 0.05$).

The metabolic quotient ($q\text{CO}_2$) decreased with soil depth (Fig. 5 and 6). This indicates a decreased availability of carbon at greater soil depths and is characteristic of undisturbed forest ecosystems. The $q\text{CO}_2$ of the two sampling years did not differ significantly. However, at the sites at 1400 m and 1050 m, the $q\text{CO}_2$ in the top horizon was somewhat higher in the second year. In spite of the

different values of basal respiration and biomass, the $q\text{CO}_2$ data suggest that the physiological condition has not changed much in these two years. A comparison of the $q\text{CO}_2$ between the three different sites did not reveal any differences based on altitude in the two years (Fig. 5 and 6).

Compared with recently recultivated forest soils, the data from the Christlumpkopf sites were lower. Recultivated soils exhibited a $q\text{CO}_2$ of 22.5 (INSAM & DOMSCH 1988). Soils from an undisturbed, mature beech forest in the Göttinger Forest (Germany) had $q\text{CO}_2$ values ranging from 9 to 18 (ANDERSON & DOMSCH 1993). INSAM & HASELWANDTER 1989 hypothesized that the $q\text{CO}_2$ decreases with the maturity of an ecosystem, possibly due to a more efficient substrate utilization caused by a population shift from r- to K-strategists. The $q\text{CO}_2$ values of 13 to 16 found in the present study thus indicate a mature ecosystem which is in a state of equilibrium.

The $C_{\text{mic}}/C_{\text{org}}$ - ratio decreased significantly with soil depth, which is typical for forests and due to the decreasing availability of C-sources with increasing depth. In 1993, the $C_{\text{mic}}/C_{\text{org}}$ ratios were somewhat lower than in 1992 caused mainly by the lower biomass values. There was, however, no significant effect of altitude on the $C_{\text{mic}}/C_{\text{org}}$ -ratio (Fig. 7 and 8).

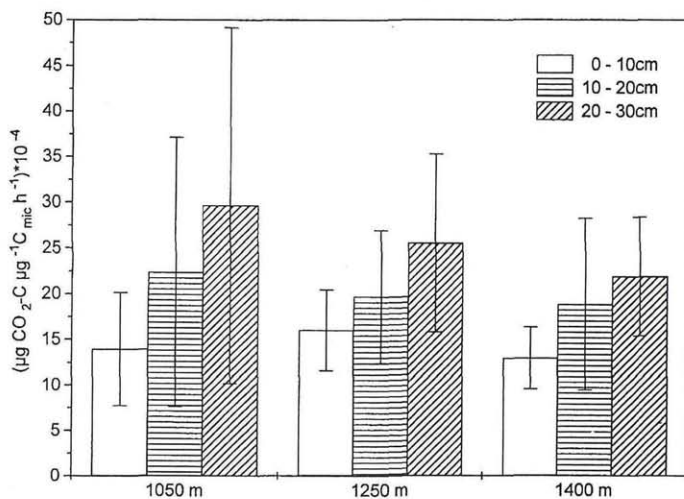


Fig. 5. Metabolic quotient $[(\mu\text{g CO}_2\text{-C } \mu\text{g}^{-1} C_{\text{mic}} \text{ h}^{-1}) * 10^{-4}]$, mean $\pm$ sd of all three sampling events (n=93) in the vegetation period of 1992.

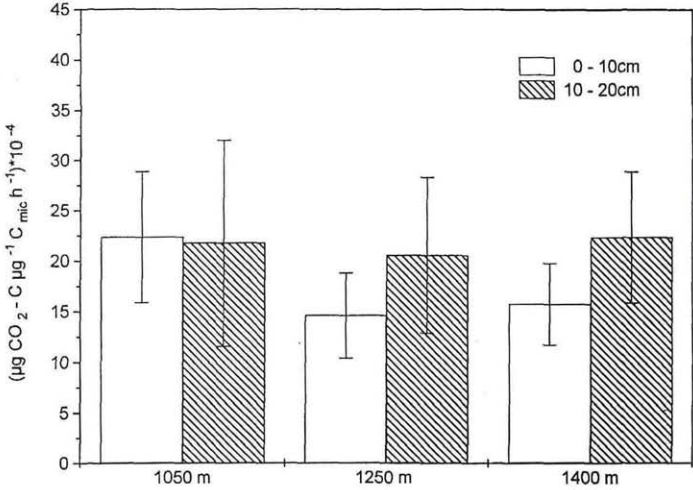


Fig. 6. Metabolic quotient $[(\mu\text{g CO}_2\text{-C } \mu\text{g}^{-1} \text{C}_{\text{mic}} \text{h}^{-1}) * 10^{-4}]$, mean $\pm$ sd of all four sampling events (n=24) in the vegetation period of 1993.

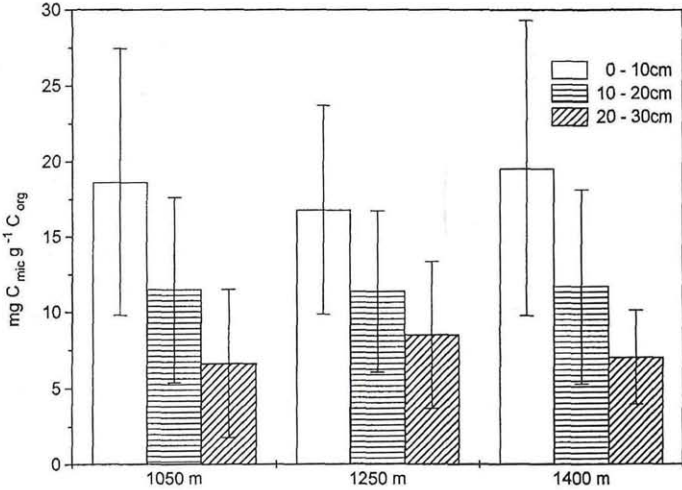


Fig. 7. $\text{C}_{\text{mic}}/\text{C}_{\text{org}}$ ratio $[\text{mg C}_{\text{mic}} \text{g}^{-1} \text{C}_{\text{org}}]$, mean $\pm$ sd of all three sampling events (n=93) in 1992 at the Christlum altitudinal gradient.

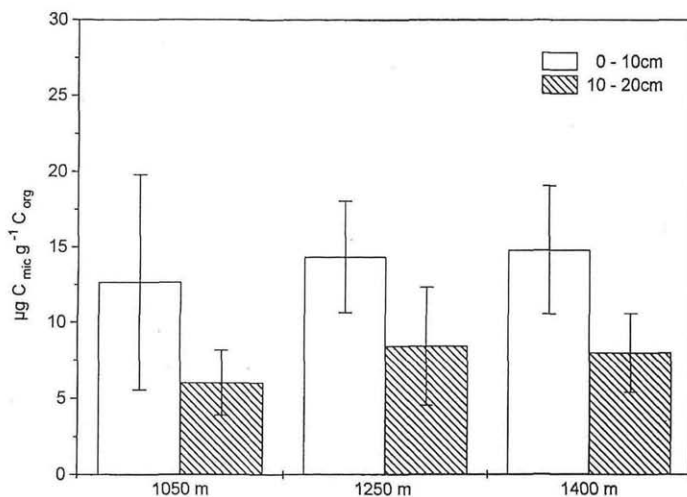


Fig. 8. C_{mic}/C_{org} ratio [$mg C_{mic} g^{-1} C_{org}$], mean $\pm$ sd of all four sampling events ($n=24$) in 1993 at the Christlum altitudinal gradient.

In natural forest soils with neutral pH, the microbial C has been found to contribute 2 - 3 % to the organic C (ANDERSON & DOMSCH 1993). Soils in the present study had a C_{mic}/C_{org} ratio of 1.4 to 1.9. Disturbances of the carbon cycle can not be concluded from these results.

Conclusions

The parameters investigated in the present study did not exhibit any effects of altitude and the related climatic differences. The macroclimatic factors like temperature and precipitation did not differ enough between sites to cause any significant effects or were superimposed by other factors. The sites differed more in small topographic factors like vegetation, soil type, pH and water content. The soil at the site at 1250 m was shallower than that of the other sites and had a higher litter input because of a larger fraction of deciduous trees. Its greater extent of shading further minimized the dessication of the upper soil layers. These conditions contributed most likely to the higher microbial activity and biomass at this site.

Generally it can be concluded that microbial activity and biomass as well as the ecophysiological parameters indicate that the soils were taken from relatively undisturbed, natural sites. This was further confirmed by results from the other investigations conducted at these sites: MUTSCH 1994 found no elevated heavy metals at these sites. BERGER 1994 found only small effects of atmospheric pollutants and a good nutrient supply in the soils. GÖBL 1994 found damaged mycorrhizae not so much in the areas around the trees but more out in the open and concluded that these damages are more likely due to compression by cattle grazing.

PEINTNER 1994 found no differences in heavy metal content of fungal fruiting bodies between the present and a comparable site.

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References

- ALEF K. 1991. Methodenhandbuch Bodenmikrobiologie.- Ecomed. Landsberg/Lech.
- ANDERSON J.P.E. & DOMSCH K.H. 1978. A Physiological method for the quantitative measurements of microbial biomass in soils.- *Soil Biol. Biochem.* 10: 215 - 221.
- ANDERSON T.H. & DOMSCH K.H. 1985a. Determination of ecophysiological maintenance carbon requirements of soil microorganisms in a dormant state.- *Biol. Fert. Soils* 1: 81-89.
- & --- 1985b. Maintenance carbon requirements of actively-metabolizing microbial populations under in situ conditions.- *Soil Biol. Biochem.* 17: 197-203.
- & --- 1986. Carbon link between microbial biomass and soil organic matter.- *Proc. of the Fourth Int. Symp. on Microbial Ecology*. Ljubljana: 467-471.
- & --- 1993. The metabolic quotient for CO₂ as a specific activity parameter to assess the effects of environmental conditions, such as pH, on the microbial biomass of forest soils.- *Soil Biol. Biochem.* 25: 393-395.
- BÄÄTH E., LUNDGREN B. & SODERSTROM B. 1979. Effects of artificial acid rain on microbial activity and biomass.- *Bull. Environ. Contam. Toxicol.* 23: 737-740.
- , ARNEBRANT K. & NORDGREN A. 1991. Microbial biomass and ATP in smelter-polluted forest humus.- *Bull. Environ. Contam. Toxicol.* 47: 278-282.
- BERGER T.W. 1994. Meeting Federal Forest Research Centre Vienna/Austria, March 25-26.
- & GLATZEL G. 1994. Eintrag und Umsatz langzeitwirksamer Luftschadstoffe in Waldökosystemen der Nordtiroler Kalkalpen.- 2. Interim Report.
- BROOKES P.C., HEIJNEN C.E., MCGRATH S.P. & VANCE E.D. 1986. Soil microbial biomass estimates in soils contaminated with metals.- *Soil Biol. Biochem.* 18: 383-388.
- CLARK M.D. & GILMOUR J.T. 1983. The effect of temperature on decomposition at optimum and saturated soil water contents.- *Soil Sci. Soc. Am. J.* 47: 927-929.
- DIAZ-RAVINA M. 1993a. Seasonal fluctuations in microbial populations and available nutrients in forest soils.- *Biol. Fert. Soils* 16: 205-210.
- 1993b. Microbial biomass and its contribution to nutrient concentrations in forest soils.- *Soil Biol. Biochem.* 25: 25-31.
- 1993c. Microbial biomass and C and N mineralization in forest soils.- *Bioresource Technology* 43: 161-167.
- ENGLISCH M. 1992. Standortliche Grundlagen im Bereich der Höhenprofile Achenkirch.- FBVA-Berichte (Federal Forest Research Centre, ed.) 70: 13-18.
- FLIESSBACH A., MARTENS R. & REBER H.H. 1994. Soil microbial biomass and microbial activity in soils treated with heavy metal contaminated sewage sludge.- *Soil Biol. Biochem.* 26: 1201-1205.
- GISI U. 1990. Bodenökologie.- Stuttgart, New York. Thieme.
- GÖBL F. 1994. Meeting Federal Forest Research Centre Vienna/Austria, March 25-26.

- HEINEMEYER O., INSAM H., KAISER E. & WALENZIK G. 1989. Soil microbial biomass measurements: An automated technique based on infra-red gas analysis.- *Plant Soil* 116: 191-195.
- HERMAN F. 1992. Höhenprofile Achenkirch Ökosystemare Studien im Kalkalpin.- FBVA-Berichte (Federal Forest Research Centre, ed.) 70: 5-11.
- 1994. Ökosystemare Studien im Kalkalpin Höhenprofile Achenkirch.- FBVA-Berichte (Federal Research Centre, ed.) 78: 9-15.
- INSAM H. 1990. Are the soil microbial biomass and basal respiration governed by the climatic regime?- *Soil Biol. Biochem.* 22: 525-532.
- & DOMSCH K.H. 1988. Relationship between soil organic carbon and microbial biomass on chronosequences of reclamation sites.- *Microb. Ecol.* 15: 177-188.
- & HASELWANDTER K. 1989. Metabolic quotient of the soil microflora in relation to plant succession.- *Oecologia* 79: 174-178.
- , PARKINSON D. & DOMSCH K.H. 1989. Influence of macroclimate on soil microbial biomass.- *Soil Biol. Biochem.* 21: 211-221.
- , BERRECK M. & HASELWANDTER K. 1992. Neue Anwendungen und Meßtechniken für Atmungsmessungen bei Waldböden.- *Österr. Forstztg.* 6: 36-39.
- LARCHER W. 1970. Aufgaben und Möglichkeit ökophysiologischer Forschung im Gebirge.- *Mittl. Ostalpin-dinar. Ges. f. Veget.kde.* 11: 95-100.
- MARUMOTO T., ANDERSON J.P.E. & DOMSCH K.H. 1982. Mineralization of nutrients from soil microbial biomass.- *Soil Biol. Biochem.* 14: 469 - 475.
- MUTSCH F. 1994. Meeting Federal Forest Research Centre Vienna/Austria, March 25-26.
- NICOLARDOT B., FAUVET G. & CHENEY D. 1994. Carbon and nitrogen cycling through soil microbial biomass at various temperatures.- *Soil Biol. Biochem.* 26: 253-261.
- OTHONEN R., MARKKOLA A.M., HEINONEN-TANSKI H. & FRITZE H. 1990. Soil biological parameters as indicators of changes in scots pine forests caused by air pollution.- In: KAUPPI & al. Berlin, Heidelberg, Springer, 373-393.
- PEINTNER U. 1994. Meeting Federal Forest Research Centre Vienna/Austria, March 25-26.
- SMIDT S., LEITNER J. & HERMAN F. 1994. Höhenprofile Achenkirch - Meßbericht 1993, Metereologische Messungen.- Bericht G3 -2/1994, Federal Forest Research Centre Vienna / Austria.
- WOLTERS V. & JOERGENSEN R.G. 1991. Microbial carbon turnover in beech forest soils at different stages of acidification.- *Soil Biol. Biochem.* 23: 897-902.

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