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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.

Summary

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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 µg C_{mic} g^{-1} dry soil. Basal respiration reached 7 to 13 µg CO_2 g^{-1} dry soil h^{-1}. Neither of these parameters, nor the metabolic quotient of CO_2 (13 to 16 (µg CO_2-C µg^{-1} C_{mic} h^{-1})*10^{-4}) and the C_{mic}/C_{org} ratio (14 to 19 mg C_{mic} g^{-1} C_{org}) were influenced by altitude. The altitudinal effects were superimposed by other site properties (humidity, topography).

Introduction

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 compoundst (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. BÅÅTH & 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. BÅÅTH & 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 decribed 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 ENGLISCH 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 (ENGLISCH 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 kP 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 µg CO_2 g^{-1} soil h^{-1} in 1992 and from 7 to 9 µg CO_2 g^{-1} soil h^{-1} in 1993. The values for 10 - 20 cm depth ranged from 4 to 6 in 1992 and from 3 to 5 µg CO_2 g^{-1} soils h^{-1} in 1993. The 20 - 30 cm soil horizon was only sampled in 1992 and contained 2 - 3 µg CO_2 g^{-1} 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 ± 0.9 µg CO_2 g^{-1} 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 dedreases the basal repiration. 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 µg CO_2 g^{-1} 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 µg CO_2 g^{-1} soil h^{-1}.

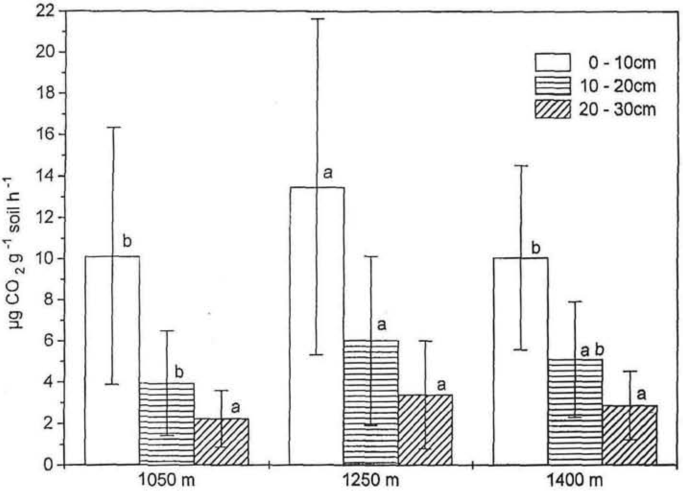

Fig. 1. Basal respiration (µg CO_2 g^{-1} soil h^{-1}), mean ± standard deviation (sd) of all three sampling events (n=93) in the vegetation period of 1992. Different letters indicate significant differences between sites (Tukey-HSD Test with $p < 0.05$).

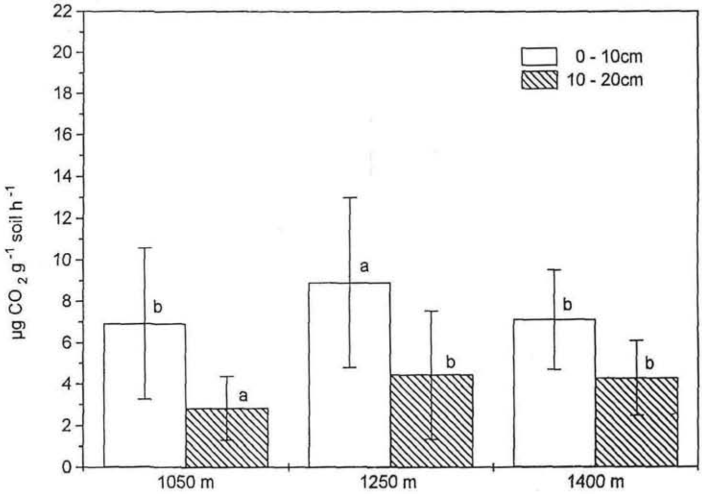

Fig. 2. Basal respiration (µg CO_2 g^{-1} soil h^{-1}), mean ± sd of all four sampling events (n=24) in the vegetation period of 1993. Different letters indicate significant differences between sites (Tukey-HSD Test with $p < 0.05$).

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 µg C_{mic} g^{-1} soil. For the 10 - 20 cm horizon, C_{mic} ranged from 610 to 900 µg C_{mic} g^{-1} soil in 1992 and from 370 to 600 µg C_{mic} g^{-1} soil in 1992. The 20 - 30 cm horizon exhibited biomass values of 259 to 403 µg C_{mic} g^{-1} soil in 1992.

In 1993, C_{mic} in the upper horizon decreased by 725.1 ± 24.1 µg C_{mic} 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 [µg C_{mic} 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 1050 m	1993 1050 m	1992 1250 m	1993 1250 m	1992 1400 m	1992 1400 m
biomass-C [t ha^{-1}]	0 - 30 cm	1443	1045	1464	1059	1314	875
biomass-N [t ha^{-1}]	0 - 30 cm	206	149	209	151	188	125

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 µg C_{mic} g^{-1} soil. INSAM & DOMSCH 1988 investigated samples from coal strip mine revegetation sites and found biomass values of 222 µg C_{mic} 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.

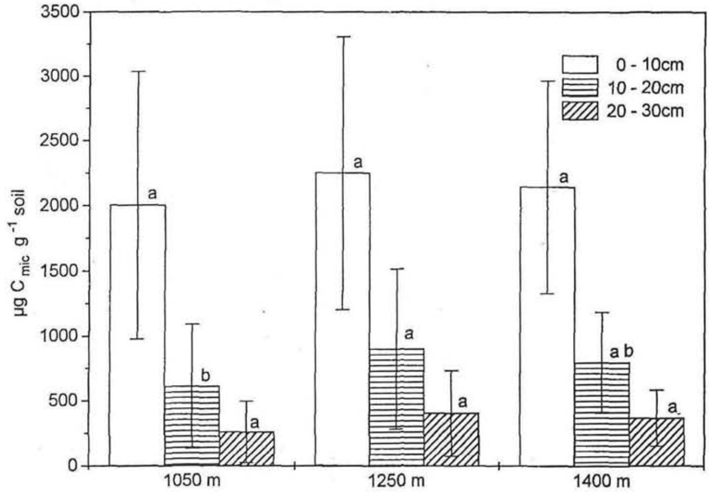

Fig. 3. Microbial biomass [µg C_{mic} g^{-1} soil], mean ± sd of all three sampling events (n=93) in the vegetation period of 1992. Different letters indicate significant differences between sites (Tukey-HSD Test, p = 0.05).

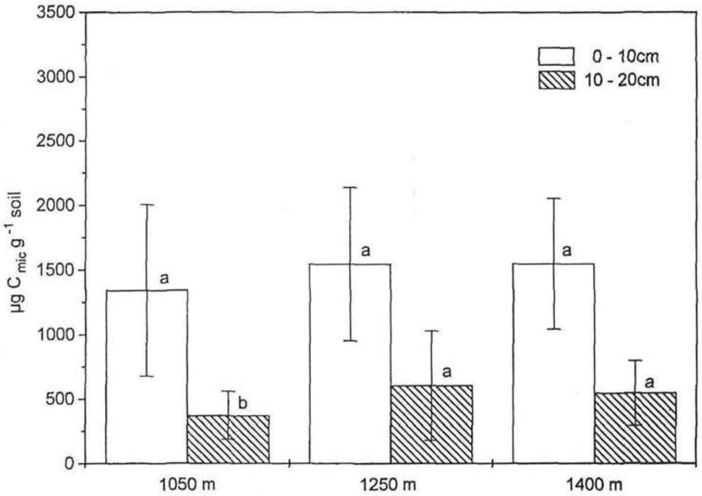

Fig. 4. Microbial biomass [µg Cmic g-1 soil], mean ± sd of all four sampling events (n=24) in the vegetation period of 1993. Different letters indicate significant differences between sites (Tukey-HSD Test, p = 0.05).

The metabolic quotient (qCO_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 qCO_2 of the two sampling years did not differ significantly. However, at the sites at 1400 m and 1050 m, the qCO_2 in the top horizon was somewhat higher in the second year. In spite of the different values of basal respiration and biomass, the qCO_2 data suggest that the physiological condition has not changed much in these two years. A comparison of the qCO_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 Christlumkopf sites were lower. Recultivated soils exhibited a qCO_2 of 22.5 (INSAM & DOMSCH 1988). Soils from an undisturbed, mature beech forest in the Göttinger Forest (Germany) had qCO_2 values ranging from 9 to 18 (ANDERSON & DOMSCH 1993). INSAM & HASELWANDTER 1989 hypothesized that the qCO_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 qCO_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_{mic}/C_{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_{mic}/C_{org} ratios where somewhat lower than in 1992 caused mainly by the lower biomass values. There was, however, no significant effect of altitude on the C_{mic}/C_{org}-ratio (Fig. 7 and 8).

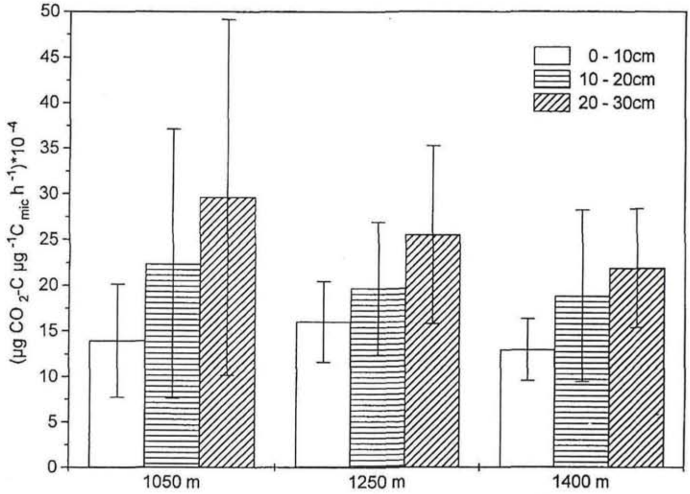

Fig. 5. Metabolic quotient [(µg CO_2-C µg^{-1} C_{mic} h^{-1}) * 10^{-4}], mean ± sd of all three sampling events (n=93) in the vegetation period of 1992.

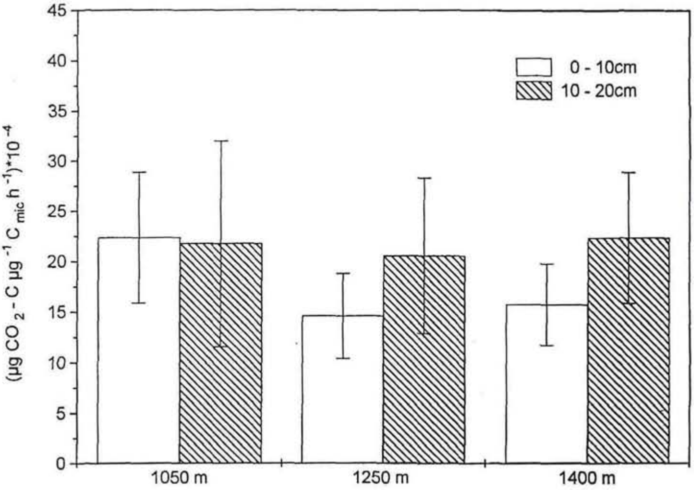

Fig. 6. Metabolic quotient [(µg CO_2-C µg^{-1} C_{mic} h^{-1}) * 10^{-4}], mean ± sd of all four sampling events (n=24) in the vegetation period of 1993.

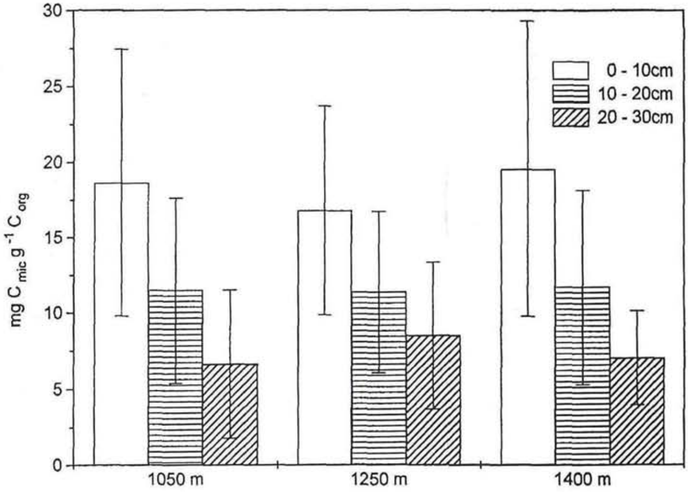

Fig. 7. C_{mic}/C_{org} ratio [mg C_{mic} g^{-1} C_{org}], mean ± sd of all three sampling events (n=93) in 1992 at the Christlum altitudinal gradient.

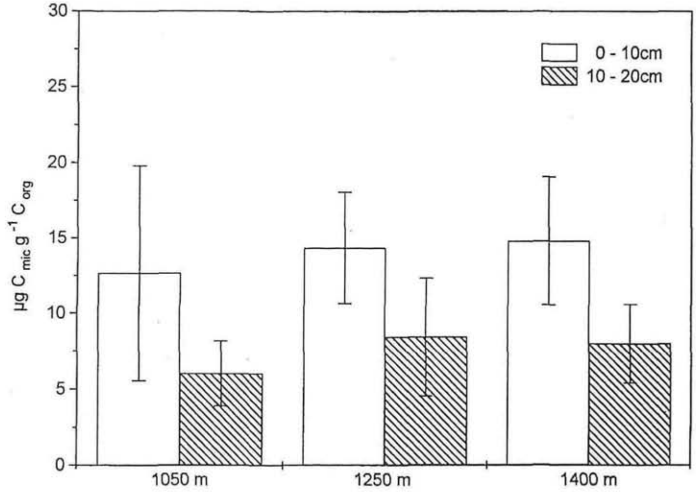

Fig. 8. C_{mic}/C_{org} ratio [mg C_{mic} g^{-1} C_{org}], mean ± sd of all four sampling events (n=24) in 1993 at the Christlum altitudinal gradient.

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 decidious 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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