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INFLUENCE OF SOIL MANAGEMENT PRACTICES AND SUBSTRATE AVAILABILITY ON MICROBIAL BIOMASS AND ITS ACTIVITIES IN SOME HAPLIC LUVISOLS

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ABSTRACT

Soil microbial biomass and activities are sensitive indicators of management effects. Higher contents of microbial biomass and higher activities, for example, are found with crop rotations in contrast to bare fallow and monoculture systems. The main reason for these differences is a higher input of crop and root residues in crop rotation systems, leading to more microbial available substrate. The objectives of this study were to describe indices for microbial available substrate in arable soils depending on management practices, and to relate them with soil microbial biomass and activities. At two locations ("Muttergarten" and "Ihinger Hof" near the University of Hohenheim, Stuttgart, SW-Germany), adenosine triphosphate (ATP) contents and microbial activities were measured in haplic Luvisols. As indices for microbial available substrate, water soluble organic carbon compounds in soils were determined and "decomposable young soil organic matter" was calculated from organic fertilizers and crop and root residues using empirical decomposition functions. Higher ATP contents and microbial activities were observed along with organic fertilization (liquid cattle manure) than with mineral fertilization. Shallow cultivation with a rotary cultivator led to higher values of microbial properties in the upper part of the Ap horizon than ploughing. Soil microbial parameters were higher in plots under a rape-cereals crop rotation, compared to a legumes-cereals crop rotation. Microbial biomass and its activities were related more closely to "decomposable young soil organic matter" than to soil humus content or to any other soil property. Water soluble organic carbon compounds did not prove as an indicator of microbial available substrate.

Key words: Edaphology, soil management, microbial available substrate, microbial biomass, haplic Luvisols.

RESUMEN

La biomasa y la actividad microbianas son indicadores sensibles de los efectos del manejo del suelo. Por ejemplo, con la rotación de cultivos se obtiene un contenido y una actividad mayores de la biomasa microbiana en contraste con el simple barbecho y con los sistemas de monocultivo. La razón principal de estas diferencias es un abastecimiento más grande con residuos de cosecha y raíces en los sistemas de rotación de cultivos, que conduce a un mayor sustrato disponible para microorganismos. Los objetivos del estudio presente fueron describir los índices del sustrato disponible para microorganismos en suelos arables, dependiendo de las prácticas de manejo de suelos, y relacionarlos con la biomasa y la actividad microbianas. En dos localidades (Muttergarten e Ihinger Hof, cerca de la Universidad de Hohenheim, Stuttgart, sudoeste de Alemania) fueron medidos los contenidos de trifosfato de adenosina y la actividad microbiana en Luvisoles háplicos. Como índices del sustrato disponible para microorganismos fueron determinados los compuestos orgánicos de carbón solubles en agua y se calculó la "materia orgánica de suelos jóvenes susceptible a descomponerse" en los fertilizantes orgánicos y en los residuos de cosecha y de raíces, usando funciones de descomposición empíricas. Los contenidos más altos de ATP y las actividades microbianas más altas fueron observados con la fertilización orgánica (abono líquido de ganado), antes que con la fertilización mineral. La labranza somera con un cultivador rotatorio condujo a valores más altos de las propiedades microbianas en la parte superior del horizonte Ap que con la labranza con arado. Los parámetros microbianos del suelo fueron más altos en parcelas bajo una rotación de cultivos de colza-cereales, en comparación con una rotación de cultivos de legumbres-cereales. La biomasa microbiana y sus actividades estuvieron relacionadas más estrechamente a materia orgánica de suelos jóvenes susceptible a descomponerse que al contenido de humus o a cualquiera otra propiedad del suelo. Los compuestos orgánicos de carbón solubles en agua no demostraron ser un indicador del sustrato disponible para microorganismos.

Palabras clave: Edafología, manejo del suelo, sustrato disponible para microorganismos, biomasa microbiana, Luvisoles háplicos.

INTRODUCTION

SIGNIFICANCE OF SOIL MICROFLORA

As a consequence of an increasing sensibility to environmental topics, during the last years the question has been discussed, whether soil fertility is endangered by intensive forms of land use. Critical issues are tillage and crop rotation on one hand, and the use of mineral fertilizers and pesticides on the other.

Impacts on soil fertility are often recorded by soil microbial parameters, because microbial activities are closely related to soil fertility. Microorganisms have numerous functions in soils. The most important among them are:

— participation in almost all transferential processes
— decomposition of litter and crop residues
— humus formation and maintainance

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— nutrient cycling and supplying to plants
— stabilizing soil structure.

METHODS FOR INVESTIGATING SOIL MICROFLORA

The main methods to characterize soil microbial elements and processes (Figure 1) are:
— investigations into soil microbial populations
— determinations of soil microbial biomass
— activity assays

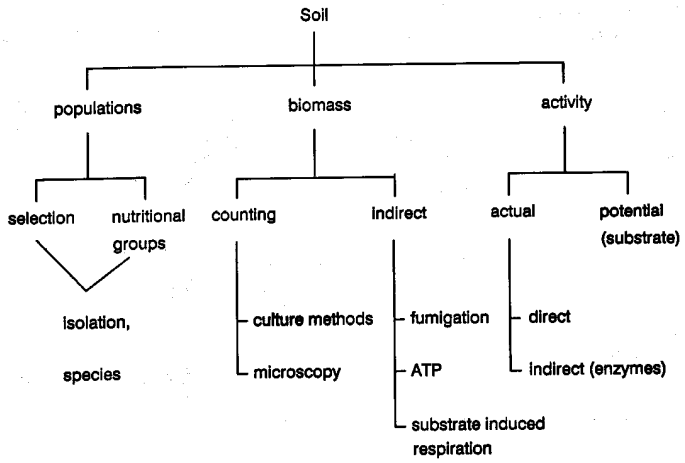

Figure 1. Methods for investigating soil microbial elements and processes (Beck and Bengel, 1992, modified).

Investigations into microbial populations are mainly done for special purposes (*e. g.*, isolating organisms capable of nitrogen fixation or pesticide degradation), because they are often very time consuming and hard to practice (Beck and Bengel, 1992).

Microbial biomass can be determined by biochemical assays (*e. g.*, adenosine triphosphate extraction) or physiological methods (fumigation incubation, fumigation extraction, substrate induced respiration). The ratio of biomass carbon to total organic carbon is a sensitive indicator for management effects on the soil microbial community (Beck, 1988).

The capacity of microorganisms in turnover processes of soil C, N, and P can be determined by measuring actual activities or potential activities (= adding readily available substances under optimal conditions). Actual activities (*e. g.*, basal respiration, N-mineralization, enzymatic activities) are important indicators of microbial ecosystems, for example, to determine long-term effects of different management systems. Potential activities can reflect the abilities of the microbial biomass under optimum conditions.

INFLUENCE OF SOIL MANAGEMENT ON MICROBIAL BIOMASS AND ITS ACTIVITIES, AND RELATIONSHIPS TO SUBSTRATE INPUT AND SUBSTRATE AVAILABILITY

When changing soil management, it usually takes some years for the microbial community to equilibrate under the new conditions. Therefore, management effects can most clearly be found in long-term experiments.

The results of a 35-year experiment at the location Puch, Bavaria, S-Germany, on a haplic Luvisol from loess with crop rotation (including bare fallow, potato monoculture, crop rotation and grassland) and fertilization variants (Beck, 1988) are one example. Least microbial biomass (Cmic), least ratio of biomass carbon to total organic carbon (Cmic/Corg), and least ß-glucosidase activity were observed in bare fallow and highest in crop rotation systems, with monocultures in between (Figure 2). The range in Cmic/Corg ratio shows that changes in microbial biomass contents are more evident than in soil humus contents. Soil Cmic/Corg ratio can therefore be regarded as an indicator for changes in the total organic carbon content. The main reasons for differences in the microbial status among the variants can be seen in a reduced input of organic substances and an intensified cultivation (leading to an intensified organic matter degradation) with bare fallow and potato monoculture. Unfortunately, the input of organic substances was not recorded in this experiment (like in most of the investigations of management effects on soil microbial parameters). Thus, it was not possible to confirm these relations quantitatively.

The objective of our investigations at the University of Hohenheim was to measure the effect of different soil management practices on microbial biomass and its activities, and to relate them with substrate input and substrate availability.

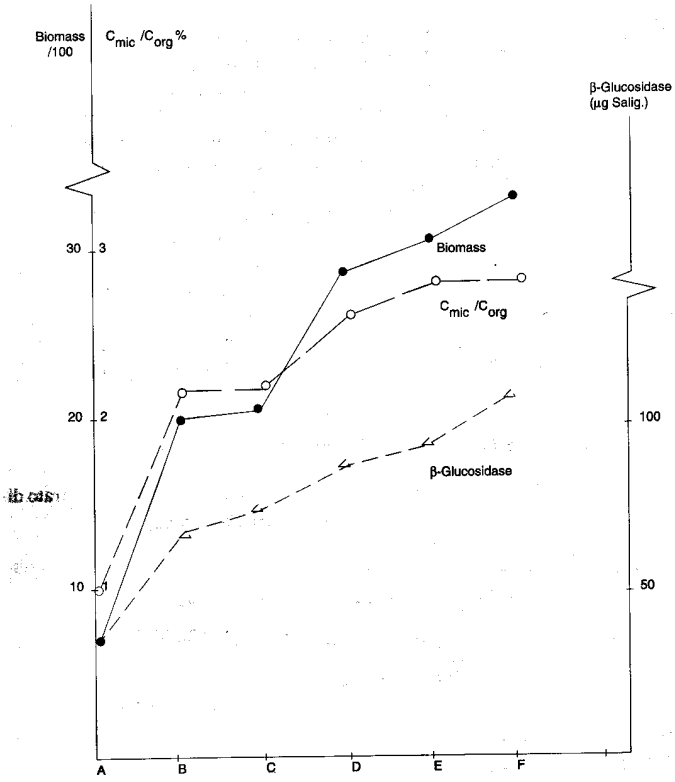

Figure 2. Microbiological properties of soils (related to amount of soil [g]), location Puch (spring 1988). Start of experiment in 1953 (Beck, 1988, modified).

MATERIAL AND METHODS

SOILS AND MANAGEMENT VARIANTS

Investigations were carried out at two locations ("Muttergarten" and "Ihinger Hof" near the University of Hohenheim, Stuttgart, SW Germany). Haplic Luvisols from loess occur in both cases. At the location "Muttergarten", the clay content was 18%, the pH was about 6.1 and organic carbon contents ranged from 0.9% to 1.1% in the Ap horizon. A field experiment with different fertilization systems (four replicates) was established in 1985 on maize. Soil samples were taken by auger from two layers of the Ap horizon in March 1990.

Fertilization variants:

"mineral fertilizer":	mineral fertilizer in 1985-1989
"manure 1":	unfertilized in 1985-1987, mineral fertilizer in 1988, liquid cattle manure in 1989
"manure 2":	liquid cattle manure in 1986-1989 (fertilizer amounts in Friedel, 1993a, from Horlacher, 1992).

At the "Ihinger Hof", clay contents were 26%, pH was 6.1, and organic carbon contents were 1.1% on the average, in the Ap horizons. Different cultivation and crop rotation variants were established as a split plot design with two replicates in 1976. Soil samples were taken by auger in March, June, September and November 1990, from two layers of the Ap horizon.

cultivation:	(a) plough
	(b) rotary cultivator
crop rotations:	(a) legumes - cereals:
	lucerne - lucerne - winter wheat - oats -
	clover - w. wheat - oats (1990) - w. barley
	(b) rape - cereals:
	rape - winter wheat - oats (1990) -
	w. barley;
variants:	"plough, leg."
	"plough, rape"
	"rotary cult., leg."
	"rotary cult., rape"

Soil samples were passed through a 2.3 mm sieve after removing roots, and stored at field moisture until analysis. For determining adenosine triphosphate (ATP) contents, samples were adjusted to 50% water holding capacity. Organic C was determined on air dried samples.

ANALYTICAL METHODS

Soil pH was measured in 0.01 *M* $CaCl_2$. Organic carbon content was determined by $K_2Cr_2O_7$ oxidation (Schlichting and Blume, 1966).

ATP was extracted from soil samples with dimethylsulfoxide, trisodium phosphate buffer and ultrasonic process according to Bai and others (1988). It was measured after adding NRB^R with a purified luciferin luciferase enzyme system in a luminometer (Friedel, 1991). Prior to extraction, soil samples were incubated at room temperature for five days. Under these conditions, ATP contents can be regarded as a measure for microbial biomass contents (Eiland, 1985).

Soil dehydrogenase activity was assayed with the triphenyl tetrazolium chloride (TTC) method (Thalmann, 1968), according to the modification of Friedel and others (1994). ß-glucosidase activity measurements were performed by splitting saligenine form salicine (Hoffmann and Dedeken, 1965). Protease activity was assayed according to Kandeler (1986), and urease activity according to Tabatabai and Bremner (1972).

Carbon and net nitrogen mineralization potentials were determined in breeding experiments with a moisture content of 50% water holding capacity, at 28°C during a period of 21 days. Only soil samples from September and November 1990 were used here.

Soil aggregate stability was analyzed by Clemens and others (1992) by percolation stability measurements according to Becher and Kainz (1983).

METHODS TO RECORD SUBSTRATE INPUT AND SUBSTRATE AVAILABILITY

In a model of Janssen (1984), decomposition and accumulation of "young" soil organic matter was estimated from crop and root residues and organic fertilizers added to the soil. Informations on quantities of the various organic substances were either put at our disposal by colleagues in the "Sonderforschungsbereich 183" or were taken from the literature (data and references in Friedel, 1993a). The amount of organic substances added in previous years, that was not yet decomposed in the year of investigation (f[t]), was summed up for all substances. The different amounts of the added substances, the time of addition and their different decomposition rates were taken into account. For this investigation, only the amount decomposed in the year of investigation (not the whole accumulated "young" soil organic matter) was regarded as important for microbial turnover processes. For each of the added substances a percentage resulted from the difference of the share present in the year of investigation (f[t]) minus the percentage remaining in the following year (f[t+1]) (Table 1). Summing up the decomposable amounts of the different substances leads to the "decomposable young soil organic matter" in the year of investigation (Friedel, 1993a, 1993b). The input of crop residues in different soil depths that depended on different forms of cultivation (ploughing: 0-25 cm; rotary cultivation: 0-10 cm) also was taken into account. An example of this is given in Table 2. At the location "Muttergarten", only organic substances from the years 1985 to 1989 were taken into account, whereas at the "Ihinger Hof", where more data were available, organic residues of the years 1982 to 1989 were used as data basis.

Table 1. Factors for calculating "young" soil organic matter f [t] (Janssen, 1984) and "decomposable young soil organic matter" (f[t]-f[t+1]).

Substance	Years after addition	f [t]	f[t]-f[t+1]	Substance	Years after addition	f [t]	f[t]-f[t+1]
Straw	0	1.000	0.651	Roots	0	1.000	0.430
	1	0.3749	0.142		1	0.570	0.164
	2	0.207	0.057		2	0.406	0.084
	3	0.150	0.030		3	0.322	0.051
	4	0.120	0.018		4	0.271	0.034
	5	0.102	0.012		5	0.237	0.024
	6	0.090	0.009		6	0.213	0.017
	7	0.081	0.007		7	0.196	0.014
	8	0.074	0.005		8	0.182	0.011
	9	0.069			9	0.171	

Water soluble organic carbon compounds were extracted from moist soil samples within 48 h of sampling by shaking with deionized water at a ratio of 1 : 3 for 20 minutes, followed by centrifugation at 5,600 g for 15 minutes (Burford and Bremner, 1975, modified according to Friedel, 1993a). The supernatant was filtered through 0.45 m membrane filters and evaporated at 80°C. Carbon was determined by $K_2Cr_2O_7$ oxidation.

STATISTICAL METHODS

Analyses of variance were used to determine differences attributed to fertilization effects ("Muttergarten"), or soil cultivation and crop rotation ("Ihinger Hof") on soil properties for each sampling date. Residues were tested for normal distribution. To fulfill this requirement, original values were transformed, if necessary.

RESULTS AND DISCUSSION

As a result of the different fertilization at the location "Muttergarten", soil organic carbon contents (Figure 3) were higher in mineral fertilized plots ("mineral fertilizer"), than in those unfertilized from 1985 to 1987, and fertilized with manure in 1988 ("manure 1") that also had the lowest maize yields and the lowest amount of root residues of all variants. Soils in "manure 2" plots, that had received organic fertilizer from 1986 to 1989, had the highest carbon contents.

Contents of "decomposable young soil organic matter" also were highest in the "manure 2" soils (Figure 3), but different from the total organic carbon contents, "decomposable young soil organic matter" was higher in the "manure 1" than in the "mineral fertilizer" variant. This is due to the fact that a high amount of the manure that was added to the "manure 1" plots in 1989, was decomposable by 1990. Water soluble organic carbon compounds showed no differentiation among the variants (Figure 3).

Table 2. Example for calculating "decomposable young soil organic matter" at the location "Ihinger Hof" with the rape-cereal crop rotation in 1990.

Input of crop and root residues			Degradable percentage in 1990	"Decomposable young soil organic matter"	
Year	Residues	Dry matter [dt ha^{-1}]	f[t]-f[t+1] [%]	above surf. [dt ha^{-1}]	below surf. [dt ha^{-1}]
1982	Oats straw	53	0.5	0.3	
	Oats roots	20	1.1		0.2
1983	Barley straw	58	0.7	0.4	
	Barley roots	25	1.4		0.4
1984	Rape straw	90	0.9	0.8	
	Rape roots	15	1.7		0.3
1985	Wheat straw	52	1.2	0.6	
	Wheat roots	25	2.4		0.6
1986	Oats straw	53	1.8	1.0	
	Oats roots	20	3.4		0.7
1987	Barley straw	58	3.0	1.7	
	Barley roots	25	5.1		1.3
1988	Rape straws	90	5.7	5.1	
	Rape roots	15	8.4		1.3
1989	Wheat straw	52	14.2	7.4	
	Wheat roots	25	16.4		4.1
	Sum			17	9

Cultivation	Calculation	0-10 cm [dt ha-1]	10-25 cm [dt ha-1]
Ploughing	40% of (above surf. + below surf.) in 0-10 cm 60% of (above surf. + below surf.) in 10-25 cm	10	16
Rotary cult.	100% of above surface in 0-10 cm 40% of below surface in 0-10 cm 60% of below surface in 10-25 cm	21	5

The highest soil ATP contents and enzymatic activities (dehydrogenase, protease) occurred in "manure 2" plots (Figure 3). Differences between "mineral fertilizer" and "manure 1" plots were not significant, but values were mostly higher with the "manure 1" variant.

Soil microbial biomass and its activities were usually parallel to soil organic carbon contents (Domsch *et al.*, 1979; Beck, 1984; Alef *et al.*, 1988). At the "Muttergarten" location, ATP content, dehydrogenase activity, and protease activity in "manure 1" plots were at least as high as in "mineral fertilizer" plots, although organic carbon contents were less in "manure 1" plots. This discrepancy can be explained by the different contents of "decomposable young soil organic matter" between both variants, that were considerably higher in "manure 1" plots. Water soluble organic carbon compounds, however, which according to Burford and Bremner (1975) should reflect microbial available carbon, could not contribute to an explanation of the differentiation of soil microbial biomass and activities. This is in accordance with results of McGill and others (1986) and Sikora and McCoy (1990), who found water

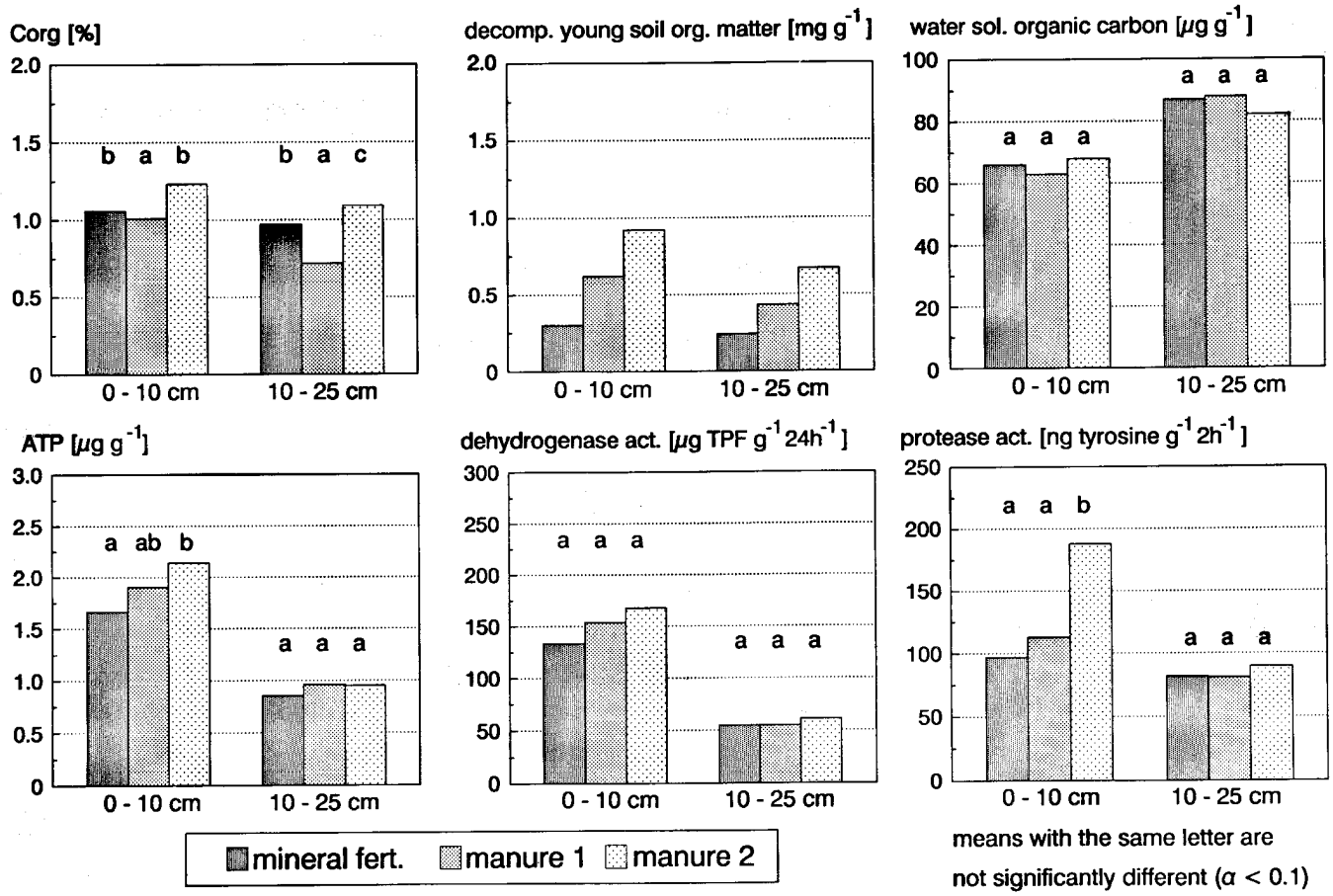

Figure 3. Soil chemical and microbiological properties with different fertilization at the location "Muttergarten". Variants: *A*: bare fallow; *B:* potato monoculture; *C*: potato monoculture + manure; *D*: wheat monoculture + straw; *E*: wheat monoculture + straw + green manure; *F*: wheat crop rotation.

soluble organic carbon compounds not to be closely related with microbial properties.

At the location "Ihinger Hof", rotary cultivation led to higher total organic carbon contents, higher values of "decomposable young soil organic matter", higher ATP contents, higher enzymatic activities, higher carbon mineralization potentials, and higher aggregate stability in the upper soil layer (0-10 cm) of the plots, compared to ploughing (Figures 4 and 5). In the second soil layer (10-25 cm), there was either no significant difference between cultivation systems (total carbon contents, ATP contents, ß-glucosidase and protease activity, nitrogen mineralization potential) or values were lower with rotary cultivation ("decomposable young soil organic matter", dehydrogenase and urease activity, and carbon mineralization potential) (Figures 4 and 5). This higher range in soil properties between the two layers of the Ap horizon with rotary cultivation is mainly a consequence of crop residues input only in the upper soil layer for many years, whereas with ploughing crop residues were worked into the whole Ap horizon every year. According to Carter and Rennie (1982), the accumulation of "young", easily-decomposable humus close to the soil surface with rotary cultivation is the main reason for increased contents of microbial biomass and enzymatic activities in the top soil. Water soluble organic carbon compounds did not reflect this difference in distribution of organic substances between the two cultivation systems (Figure 4).

The above mentioned soil properties (except water soluble organic carbon compounds) were higher in the upper layer of soil plots with rape-cereals crop rotation, than with legumes-cereals crop rotation (Figures 4 and 5). In the second layer, no uniform differentiation between the crop rotations was found. Positive effects of higher amounts of crop and root residues on soil microbial properties were described by McGill and others (1986) and Havlin and others (1990). In accordance with these results, higher amounts of crop residues in the upper soil layer with the rape-cereals crop rotation (rape straw!) were the main influencing factors. The combination of rape-cereals crop rotation with rotary cultivation ("rotary cult.; rape"), where high amounts of rape straw were concentrated in the upper soil layer, resulted in values for this layer that were twice as high as with ploughing for some soil properties (urease activity, N-mineralization potential, aggregate stability).

Relative differences in soil microbial biomass and its activities of the plots were higher than differences in soil humus contents. This is shown, for example, by the ATP/Corg ratio (Figure 4). This was caused by a higher range in microbial

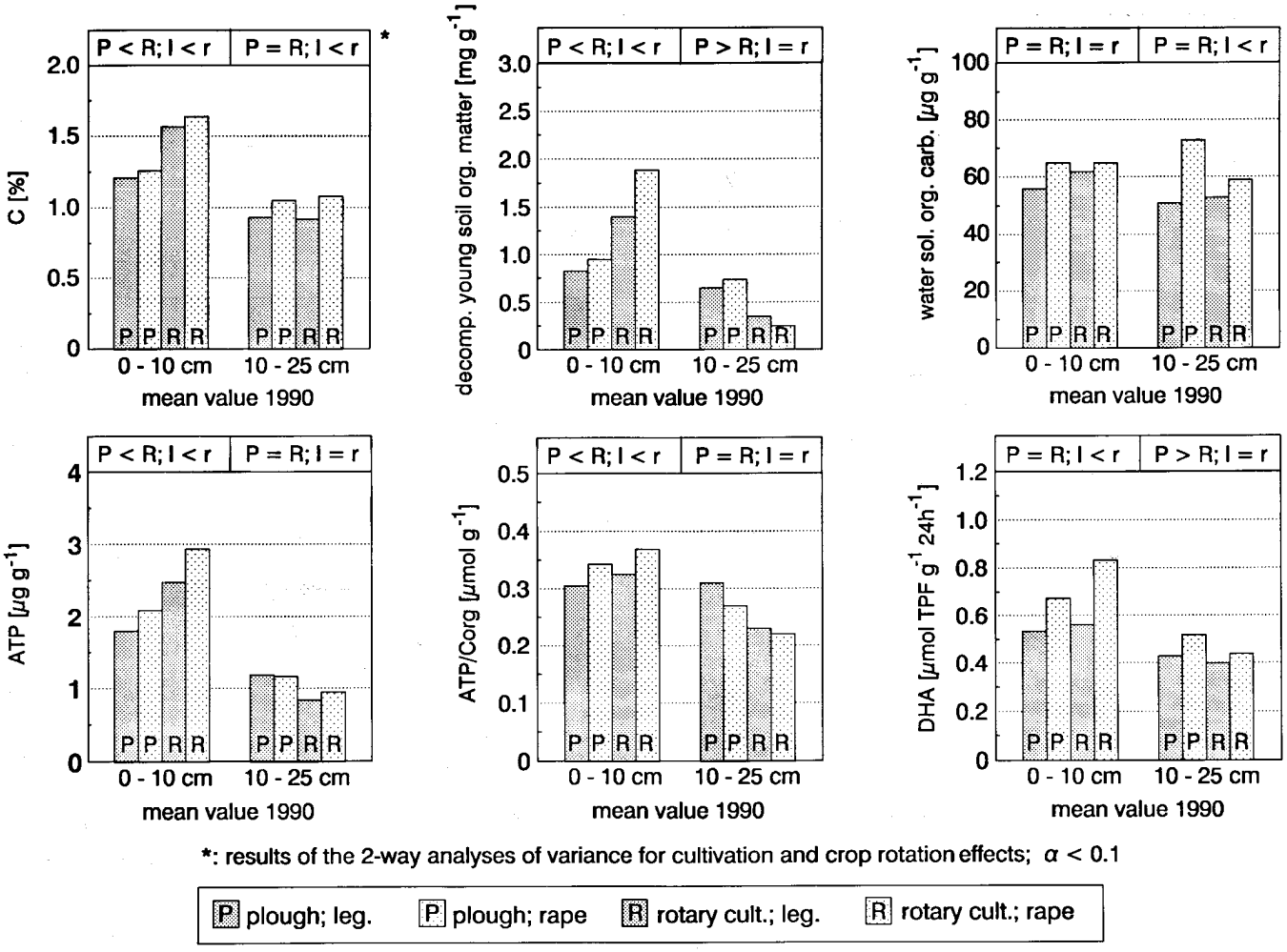

Figure 4. Soil chemical and microbiological properties with different cultivation and crop rotation at the location "Ihinger Hof". Explanation for variants from *A* to *F* in Figure 3.

available "young" soil organic matter (as it is reflected by the "decomposable young soil organic matter") compared to total organic carbon contents. Water soluble organic carbon compounds did not show this tendency, and they did not seem to reflect microbial available carbon.

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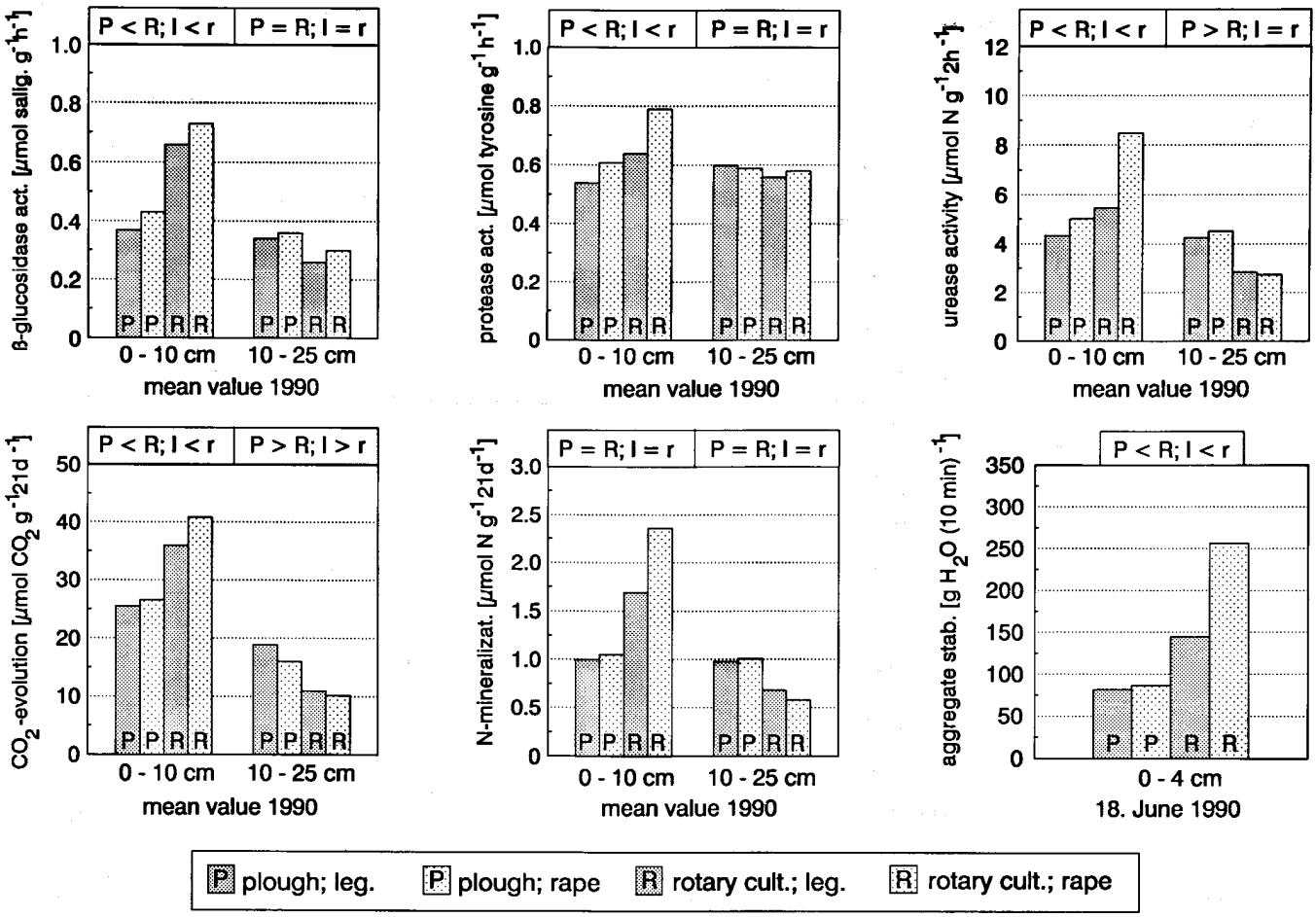

Figure 5. Soil microbiological and physical properties with different cultivation and crop rotation at the location "Ihinger Hof". Explanation for variants from A to *F* in Figure 3.

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