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Comparative studies on the soil life in ecofarmed and conventionally farmed fields and grasslands of Austria

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ABSTRACT

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The soil fauna of ecofarmed and conventionally farmed fields and grasslands was investigated in various regions of Austria. The results obtained from the evaluation of a total of 13 paired sites are reviewed in this contribution: (1) many of the investigated soil zoological parameters do not differ statistically in ecofarmed and conventionally farmed fields and grasslands; (2) there are no striking differences in species composition and dominance structure of the protozoa, an important group of indicator organisms due to their delicate external membranes, their short generation time and their high contribution to energy flow and nutrient cycling; (3) all differences which can be guaranteed with an error probability of $\alpha = 10\%$ or less invariably show higher biological activity in the ecofarmed plots. The soil physical and chemical investigations which accompanied the zoological studies on some sites indicate that the higher biological activity is caused by the higher humus content and the lower soil compaction. The organic matter content is significantly higher in the ecofarmed plots, whereas soil compaction is more pronounced under conventional cultivation; (4) conventional agriculture has a more detrimental effect on soil fauna in semi-arid regions without stockfarming than in atlantic regions with mixed husbandry. A short review of the literature shows our results to be consistent with those of other studies. It is increasingly evident that generalizations like ‘Conventional farming destroys life in the soil’ or ‘Ecofarming stimulates soil life’ are only partially supported by the available data. A far more comprehensive view taking into account especially climate, soil type and farm management is necessary. However, the discernible detrimental effects on the soil organisms caused by conventional farming call for serious consideration and ought to stimulate the development of soft agricultural technology and intensified soil biological research. Future research should include studies on productivity of soil animals under various management systems, the analysis of single factors (e.g. the special admixtures used in biodynamic farming) to elucidate causative mechanisms, and studies on the relationship between soil animals, crop production and sustained yield.

INTRODUCTION

In recent years ‘ecological’ or ‘biological’ farming has been increasingly emphasized and the use of fast-acting synthetic mineral fertilizers (‘artificial fer-

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tilizers'), pesticides and growth regulators largely or entirely dispensed with. The idea is that activation of soil life and/or sustained high yield is achieved by means of carefully prepared natural fertilizers (e.g. manure, liquid manure, stone-meal) and 'soft' cultivation (no heavy farm machinery, non-tillage agriculture, etc.). Opponents of the 'ecofarmers', however, correctly point out that there is little scientific evidence to support this view (e.g. Jahn, 1984). A thorough search in the various relevant publications, in fact, turned up practically no precise, statistically supported data and, more especially, almost none concerning soil fauna (Johannsen et al., 1985). A typical example here is 'Ecological Viticulture' by Preuschen (1980). It must be added, however, that several studies are at present in progress or have been very recently published (e.g. El Titi and Ipach, 1989; Kromp, 1990).

To compensate for the long prevalent deficiency, a 4 year research project regarding soil fauna in ecologically and conventionally farmed fields and grasslands in Austria was granted by the 'Fonds für die wissenschaftliche Forschung'. The project's most important findings form the subject of this review. The presentation is brief and intended as being comprehensible to the educated layman. The allotted framework did not permit an extensive discussion of the literature, site descriptions and methodology; the reader is therefore referred to the literature cited. The most important background data are provided in the footnotes to the tables. The statistical evaluation was undertaken by means of variance analysis, whereby differences which could be guaranteed with an error probability of 10% or less were deemed 'significant'. Among the parameters investigated, the single-celled protozoa received particular attention, both because we are specialized in this field and, more important, because they are excellent indicators due to their rapid growth, delicate external membranes and heterotrophic nutrition (for review, see Foissner, 1987a). Protozoa furthermore make up an average of about one-third of the soil animals' standing crop and account for two-thirds of their respiration, consuming approximately 10% of the total carbon input (Foissner, 1987a, 1991) (see Fig. 1).

Extensive descriptions of the various ecofarming methods used worldwide and in Austria are provided by Dierks (1983) and the Ludwig Boltzmann-Forschungsstelle für Biologischen Landbau (1981). We investigated 'organic' and 'biodynamic' farming, both of which are widely practised in Austria. The organic method, in particular, propagates soil microbiology, non-tillage agriculture and the frequent application of a film of fresh manure ('Frischmistschleier'). The biodynamic method is based not only on the natural sciences but also on rather more esoteric principles as proposed by R. Steiner, (for literature, see Dierks, 1983), whereby cosmic influences like the lunar cycle are also taken into account. Fertilization includes special biodynamic preparations such as meat-meal and compost manure.

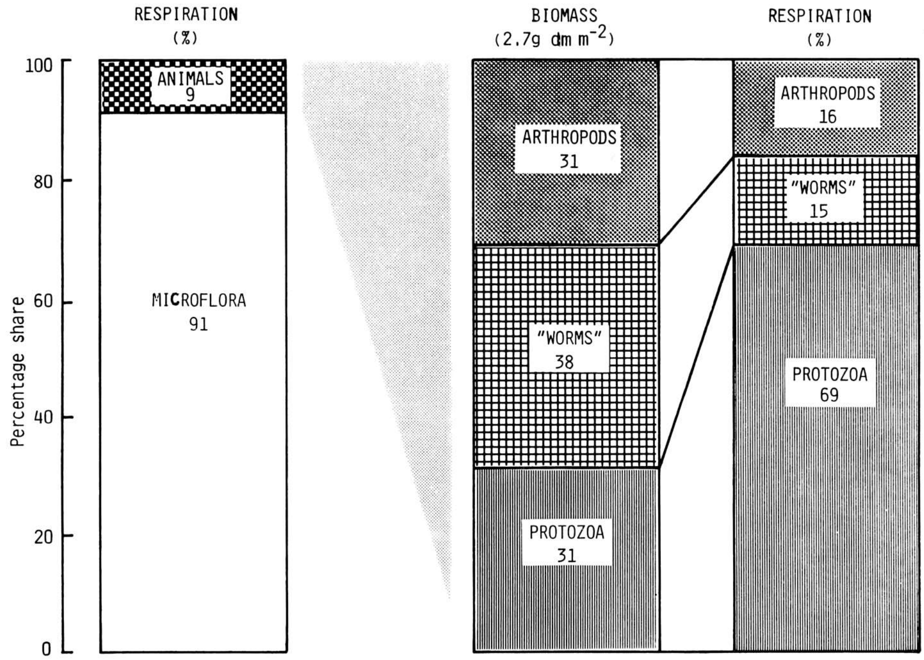

Fig. 1. Contribution of protozoa to the biomass and respiration of the soil animals. The graphs show the mean of 14 ecosystem studies from various sites around the world (from Foissner, 1987a). dm = dry mass.

RESULTS

Study sites in Salzburg

In the course of two years, five comparison pairs (four fields and six meadows belonging to six farms in the vicinity of Salzburg) were subjected to particularly intensive investigation. See Foissner et al. (1987) and footnote in Table 1 for investigation methods used, site descriptions and detailed data. Only very slight, often not statistically verifiable differences could be registered for both fields and meadows. However, differences which were statistically significant proved the ecofarmed sites to be inhabited by a slightly greater number of organisms. Most differences relate to protozoa and nematodes, whereas the earthworm population did not change significantly. This indicates that for a system as complex as that of the soil, the unfortunately often-practised investigation of the single indicator 'earthworms' simply does not suffice. The number and composition of species for both earthworms and protozoa shows no differences between conventionally and ecofarmed sites (Seewald, 1987) (see Fig. 2).

TABLE 1

Comparison of ecologically and conventionally farmed fields (F) and meadows (M) in the Salzburg area[1]

Parameter	Biotope	Organic farming	Conventional farming	Statistics
Protozoa (testate amoebae)				
Number g^{-1} DM[2]	F	868	661	S[3]
	M	1264	1136	NS[4]
Biomass in mg kg^{-1} DM	F	35	22	S
	M	43	34	S
Species number	F	30	29	S
	M	30	30	S
Nematodes				
Number g^{-1} DM	F	60	51	NS
	M	153	126	S
Earthworms (Lumbricidae)				
Number m^{-2}	F	67	77	NS
	M	184	207	NS
Biomass in g m^{-2}	F	51	28	NS
	M	139	178	NS
Microflora (bacteria and fungi)				
CO_2 release in mg g^{-1} DM	F	54	59	NS
	M	104	102	NS
Catalase activity in ml O_2 g^{-1} DM	F	1.8	1.8	NS
	M	4.2	3.7	S
Abiotic factors				
Organic matter ('humus') in %	F	4.6	4.5	NS
	M	8.0	7.3	NS
Penetration resistance in kg	F	0.7	1.1	S
	M	1.4	1.6	NS

[1]This region has humid summers and mild winters. Average temperature and precipitation are 8.2°C and 1309 mm, respectively. The sites are about 500 m above sea level and based on brown earth. The change-over from conventional to biological cultivation took place 10 years prior to our study. The meadows are moved two to four times $year^{-1}$; the fields are ploughed. The biologically farmed meadows are fertilized with aerated liquid farmyard manure (about 30 t ha^{-1} $year^{-1}$) mixed with about 400 kg ha^{-1} $year^{-1}$ stone-meal, some fresh solid farmyard manure and thomasphosphate, hyperphosphate and potassium (150 kg ha^{-1} $year^{-1}$). The conventionally farmed meadows get synthetic NPK-fertilizer (about 200 kg ha^{-1} $year^{-1}$) and rather large amounts of non-aerated liquid and solid farmyard manure. The biologically farmed fields are fertilized with rotted farmyard manure (15 t ha^{-1} $year^{-1}$), some fresh solid farmyard manure, green manure and stone-meal (700 kg ha^{-1} $year^{-1}$). Plant protection is by natural methods and crop rotation. The conventionally farmed fields get 200–400 kg ha^{-1} $year^{-1}$ NPK fertilizer and some solid farmyard manure. Plant protection is by pesticides.

The values are the arithmetic mean from the study of two ecologically and two conventionally cultivated wheat fields as well as three ecologically and three conventionally cultivated meadows. In the course of 2 years, protozoa, nematodes and microflora were each investigated eight times for all ten sites. The sample size for the statistics is thus 32 and 48 respectively. For the earthworms the sample size is 6 and 9, for the humus content 10 and 15, and for the penetration resistance 76 and 114, respectively.

[2]DM, dry mass of soil.

[3]S, statistically significant differences, i.e. error probability not exceeding 10%.

[4]NS, no statistically significant differences, i.e. error probability greater than 10%.

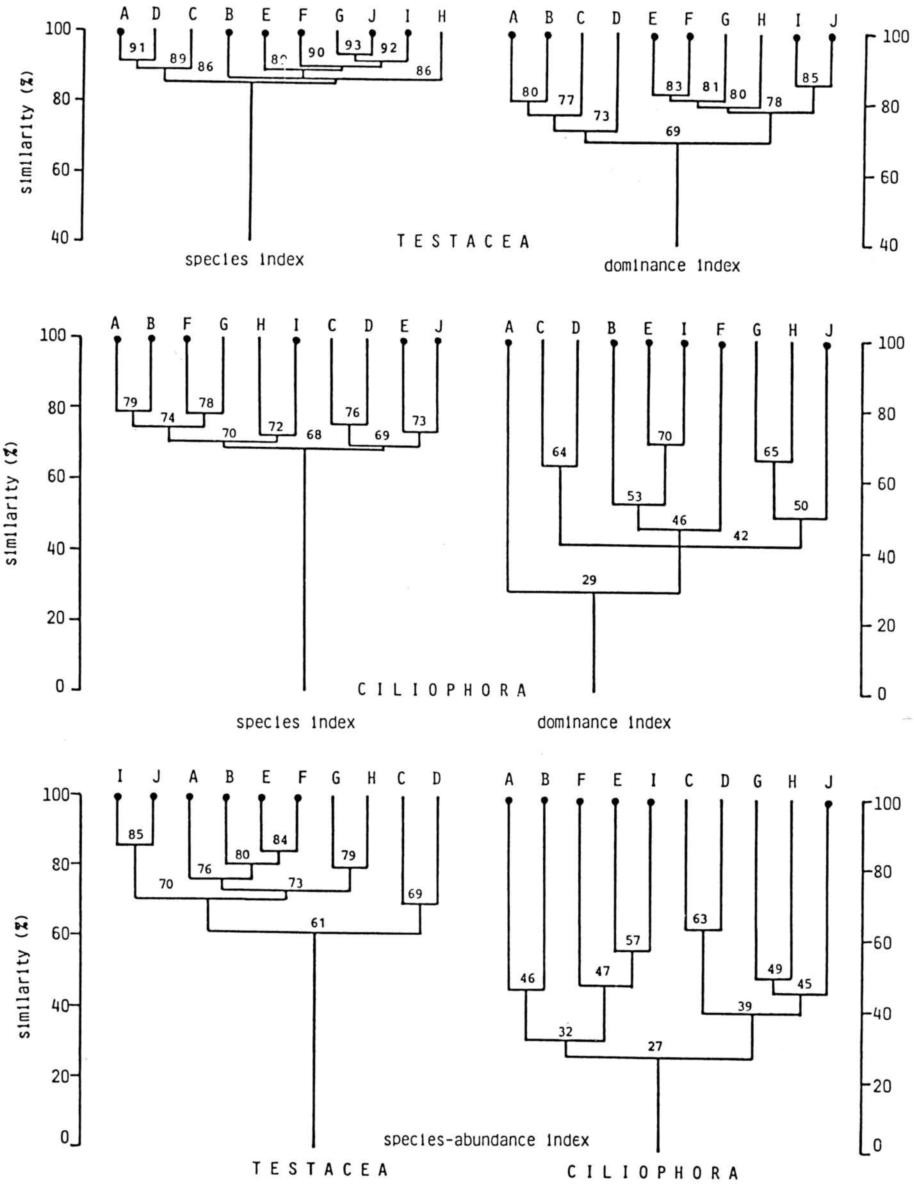

Fig. 2. Clustered similarity indices according to Sorensen (species similarity), Renkonen (dominance similarity) and Bray and Curtis (species-abundance similarity) for the testate amoebae and ciliates in the Salzburg sites. Five pairs (A/B, C/D, E/F, G/H, I/J; A,C ... ecofarmed, B,D ... conventionally farmed) were investigated eight times during 2 years. Black dots on top of vertical lines indicate meadow sites, others are crop fields. Sites evidently cluster mainly according to habitat type (meadow, field) and spatial distance (sites A–F are not in the same region as sites G–J) and not according to the management type (ecological, conventional).

Of various microbiological parameters (CO_2 release, and catalase, urease and saccharase activity) only the catalase, an ecto-enzyme of soil bacteria (bacteria 'eat' by means of external digestion), shows a slight increase under organic cultivation.

The decisive environmental factors for soil life are organic matter ('humus'), which nourishes organisms directly or via the decomposer cycle, and soil density, which determines the size and number of pores and hence the available living space. In the Salzburg sites the differences in the organic matter content and the degree of resistance to penetration (as a measure of soil density) are slight but verifiable with an error probability between 1% and 10% when all data (fields and meadows) are pooled.

The differences between the Salzburg sites are, in sum, only slight. We take this to be the result of mixed farming (agriculture and livestock) practised in this region and the atlantic climate (abundant precipitation), which together provide advantageous conditions for soil life. The conventional farmers, too, predominantly use natural fertilizers (manure, liquid manure, limited use of artificial fertilizers), which are, however, not as carefully processed (e.g. not aerated) as those used by the ecofarmers. This, together with the softer cultivation, may be responsible for the only minor differences.

Study sites in Styria

The sites in Salzburg are not experimental plots but a reflection of the practical situation. We therefore supposed this to be the cause of the blurred results. However, this was not substantiated on grassland sites laid out under similar climatic and cultural conditions by Buchgraber (1984). This experiment was designed as randomized blocks, allowing a particularly precise statistical evaluation. See Foissner et al. (1990) and footnote in Table 2 for investigation methods used, site description and detailed data. We could not establish significant differences between the conventional and ecological sites regarding either protozoa, nematodes or earthworms. Species composition was also rather similar in all treatments. However, the abundance of the ciliate *Homalogastra setosa* was often considerably higher, and that of *Colpoda inflata* often considerably lower in the fertilized plots than in the unfertilized control site. The number of nematodes and the biomass (but not the number) of earthworms tended to be higher in the fertilized plots.

Yield and quality of fodder and vegetation were also rather similar under all procedures. One of the biodynamic blocks (decomposed farmyard manure, aerated liquid manure, special admixtures) had a significantly greater proportion of legumes and a significantly lower yield. The annual crop yield was significantly higher for the organic than for biodynamic blocks. The labor input was higher for the organic blocks, and markedly so for the biodynamic variants than for the conventional blocks.

TABLE 2

Comparison of ecologically and conventionally farmed grassland plots in Styria[1]

Parameter	Organic farming	Biodynamic farming	Conventional farming	Statistics (organic vs. conventional)
Protozoa (testate amoebae)				
Number g^{-1} DM[2]	351	367	342	NS[3]
Biomass in mg kg^{-1} DM	11	12	11	NS
Species number	23	24	23	NS
Diversity	2.76	2.83	2.78	–
Evenness	0.91	0.89	0.88	–
Protozoa (ciliates)				
Number g^{-1} DM	757	1023	1212	NS
Biomass in mg kg^{-1} DM	19	14	38	NS
Species number	40	35	31	NS
Diversity	2.12	1.97	1.75	–
Evenness	0.60	0.60	0.51	–
Nematodes				
Number g^{-1} DM	173	170	158	NS
Earthworms (Lumbricidae)				
Number m^{-2}	288	264	323	NS
Biomass in g m^{-2}	76	108	102	NS
Annual grass yield (DM) in dt ha^{-1}	82	78	79	NS
Legumes (area percentage)	42	56	65	NS

[1]This region has wet and rather cold summers and winters. Average temperature and precipitation are 5.7 °C and 936 mm, respectively. The sites are 650 m above sea level and based on brown earth. Soil zoological investigations were undertaken during the ninth year of the experiment. The conventional treatment gets 100 kg ha^{-1} $year^{-1}$ synthetic PK fertilizer. An equal amount of these nutrients is applied to the biological plots, however, by organic fertilizers (organic treatment: fresh solid farmyard manure and aerated liquid manure mixed with basalt-meal; biodynamic treatment: composted manure, aerated liquid manure, basalt-meal and several special preparations. i.e. nos. 500, 501).

The plots (25 m^2) are randomized blocks. Six replications were evaluated for the zoological investigations. The annual yield and the percentage of legumes are the average for the years 1979–1986. All values are arithmetic means.

[2]DM, dry mass of soil and grass respectively.

[3]NS, no statistically significant differences, i.e. error probability greater than 10%.

Study sites in Lower Austria

No marked differences in the numbers and kinds of soil animals in conventionally and ecologically farmed fields and grasslands could be ascertained in Salzburg and Styria. This is probably due to the favourable climates and the abundant organic fertilization (liquid and solid farmyard manure) practised also by ‘conventionalists’. Far more profound, and from a soil zoological point of view more troubling, differences were found in vineyards and fields in the pannonic climate zone. Here low precipitation is a minimum factor for plant cultivation and soil life. There is, moreover, hardly any animal husbandry and artificial fertilizers are therefore used almost exclusively. The organic matter content of the soil is low (< 3%).

Vineyards

The experimental sites are in Mailberg, about 5 km from the Czechoslovakian border. See Lüftenegger and Foissner (1989) and footnote in Table 3 for investigation methods used, site description and detailed data. The eco-farmed plots generally showed a higher soil moisture and a richer soil life than the conventionally farmed sites. The highest abundance, biomass and species number of testate amoebae and the highest abundance of nematodes were found in a semi-biological treatment (compound fertilizer plus compost). Lumbricids occurred in significantly higher numbers in organically and bio-

TABLE 3

Comparison of ecologically and conventionally farmed vineyard plots in Lower Austria[1]

Parameter	Organic farming	Biodynamic farming	Conventional farming	Statistics[2]
Protozoa (testate amoebae)				
Number g^{-1} DM[3]	347	239	156	S/NS[4]
Biomass in mg kg^{-1} DM	24	14	7	S/S
Species number	14	13	13	S/NS
Nematodes				
Number g^{-1} DM	152	213	46	NS/S
Earthworms (Lumbricidae)				
Number m^{-2}	91	36	4	S/S
Biomass in g m^{-2}	38	16	4	S/NS

[1]This region has dry and hot summers and cold winters. Average temperature and precipitation are 8.9°C and 480 mm, respectively. The sites are 220 m above sea level and based on loess. Soil zoological investigations were undertaken during the ninth year of the experiment. The organic treatment gets fresh solid farmyard manure (2 t ha^{-1} $year^{-1}$) and dried chicken dung (800 kg ha^{-1} $year^{-1}$). Plant protection is by sulphur and special plant extracts. The biodynamic treatment is fertilized with compost mixed with stone-meal and other special preparations (2 t ha^{-1} $year^{-1}$) and green-manure. Plant protection as in the organic treatment. The conventional treatment is fertilized with 300 kg ha^{-1} NPK fertilizer and treated 10 times per vegetation period with pesticides.

No replicates are available for these large plots. Thus, parallel samples from different areas of the plots were evaluated for protozoa and nematodes. The data for earthworms are based on eight parallel samples of 0.25 m^2 each. All values are arithmetic means.

[2]The left value compares organic and conventional cultivation; the right, biodynamic and conventional cultivation.

[3]DM, dry mass of soil.

[4]NS, no statistically significant differences, i.e. error probability greater than 10%; S, statistically significant differences, i.e. error probability not exceeding 10%.

dynamically farmed sites than in conventionally and minimally farmed ones. The abundance of lumbricids and biomass of testaceans were higher in the organic than in the biodynamic plot. The ecofarmed and conventionally farmed strips showed distinct differences in the species composition of the testate amoebae. Remarkably, the animal abundance in the unfertilized plot was similar to that in the conventional (NPK fertilized) one.

Fields

The biodynamically cultivated fields are in the Marchfeld near Vienna. They are not experimental sites but, as in Salzburg, intensively farmed grain and vegetable fields. Of the two comparison pairs investigated, only that with the more distinct differences is presented here. See Foissner (1987b) and footnote in Table 4 for investigation methods used, site description and detailed data. A marked and usually statistically verifiable trend towards richer soil

TABLE 4

Comparison of ecologically and conventionally farmed wheat fields in Lower Austria[1]

Parameter	Biodynamic farming	Conventional farming	Statistics
Protozoa (testate amoebae)			
Number g^{-1} DM[3]	76	23	NS[2]
Biomass in mg kg^{-1} DM	1.9	0.7	NS
Species number	6	6	NS
Nematodes			
Number g^{-1} DM	91	24	S[4]
Microflora (bacteria and fungi)			
CO_2 release in mg g^{-1} DM	0.3	0.2	S
Catalase in ml O_2 g^{-1} DM	1.2	0.6	S
Urease in mg N g^{-1} DM	0.08	0.07	S
Organic matter ('humus') in %	2.2	1.8	S

[1]This region has dry and hot summers and cold winters. Average temperature and precipitation are 9.6 °C and 572 mm, respectively. The sites are 160 m above sea level and were cropped with wheat in the year of investigation. They are located on calcareous alluvial soil. The change-over from conventional to biological cultivation took place 7 years prior to the study. The biodynamically cultivated field gets 10 t ha^{-1} compost mixed with stone-meal $year^{-1}$. The conventionally cultivated field is fertilized with 350 kg ha^{-1} NPK fertilizer. Plant protection is by natural methods and pesticides, respectively. Both sites are ploughed.

The values are the arithmetic means of four samples taken during the course of 1 year. Note marked differences in number of protozoa. The differences would probably become significant with an increased sample size.

[2]NS, no statistically significant differences, i.e. error probability greater than 10%.

[3]DM, dry mass of soil.

[4]S, statistically significant differences, i.e. error probability not exceeding 10%.

life was evident in the ecofarmed fields whereas the soil fauna in the conventionally farmed fields was drastically reduced. Microflora and organic matter content showed similar differences.

DISCUSSION AND RESEARCH NEEDS

Our results concur with those of similar investigations which are, however, restricted to the mesoedaphon (e.g. Gehlen and Schroeder, 1985; Bosch and Moura-Peáo, 1987; El Titi and Ipach, 1989) or to the epigaeic arthropod fauna (e.g. Ingrisch et al., 1989; Kromp, 1990). The available data indicate that climate and farm type are decisive factors irrespective of ecofarming effects on soil animals. Conventional farming decreases soil life only slightly and, in our opinion, to a tolerable extent in regions with sufficient precipitation and mixed farming (crop and livestock production), whereas it seriously depresses soil life in arid regions, in naturally poor soils and in areas without livestock production, i.e. lacking farmyard manure. Seen on a large scale the data show that ecological and integrated cultivation are more conducive to soil life than conventional systems, soil animals are more abundant under organic than biodynamic cultivation (which does not however necessarily imply better soil quality!), fallows or extensive cultivation are equal or inferior to conventional systems.

What causes the richer soil life under ecological cultivation? There is certainly no single factor responsible, but quality and quantity of organic matter and bulk density are presumably of major importance. Other activities such as insect pest and weed control by means of synthetic pesticides and a too careless utilization of fast-acting synthetic ('mineral') fertilizers can also be detrimental to soil animals (e.g. Foissner, 1987a; Petz and Foissner, 1989), especially the epigaeic fauna (Ingrisch et al., 1989; Kromp, 1990 and literature cited therein). It is well established that organic matter is decisive for soil life. It is however not the quantity which is of prime importance, but rather the proportion of easily decomposable matter, which is best increased by fertilization with solid farmyard manure (Franz, 1975; Pokorná-Kozová, 1984; Johnston, 1986; Gröblinghoff et al., 1989). Bulk density regulates space, air and water available to soil organisms. Even slight compactions are detrimental to soil animals, decrease soil fertility and increase soil erosion (Foissner, 1987a). Thus any system that reduces soil compaction is beneficial to soil organisms. Ecofarming certainly causes less compaction than conventional cultivation due to softer agricultural techniques and green manuring (Table 1).

The investigations available are mainly phenomenological in nature. In the next research period, experimental evidence has to be collected and the productivity of soil animals under various management systems must be studied. Single factors need to be analyzed in field and microcosm experiments to elucidate the causative mechanisms. Are, for instance, cosmic constellations and the application of special admixtures (e.g. plant drugs) in homeopathic doses under biodynamic farming really beneficial to soil life and production? Some reports support this and show increases in microbial activity, humus quality and yield (Boguslawski, 1977; Dewes and Ahrens, 1989), but data on soil animals are however entirely lacking. Zoologists are also frequently confronted (and frustrated!) with other questions posed by farmers: "What do I stand to gain by having say about 10% more animals in my soil? Will my yield also go up by 10%? Or will I get a more sustainable yield?" Soil zoologists can unfortunately not provide definite answers to these important questions as data are much too scarce and often not related to crop yield. There is thus an urgent need for studies integrating zoological and crop yield studies. Only if we can provide conventional farmers with conclusive evidence as to the importance of soil animals may we expect to convince them of the benefits of ecofarming. In addition financial matters have to be taken into account. These are, however, beyond the scope of this paper.

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