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Title: **Abundance and biodiversity of soil microarthropods as influenced by different types of organic manure in a long-term field experiment in Central Spain**

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**Abstract**

We studied the effects of long-term organic and mineral fertilization on soil microarthropods and soil chemical parameters in a field experiment under semi-arid conditions in Central Spain. Two different regimes of organic manuring, i.e. farmyard manure applied once in three years vs. annual manuring with crop residues were compared. Soil carbon and nitrogen contents were increased markedly by farmyard manure, whereas straw and green manure had no significant effect. In contrast, the abundance of soil microarthropods was increased by annual application of straw and green manure, but not by farmyard manure last applied 2.5 years before sampling. We conclude that in the field experiment under study the abundance of soil microarthropods was influenced by the immediate food supply rather than by soil chemical parameters such as carbon and nitrogen content or the pH. Biodiversity of soil microarthropods, as estimated by the Shannon index, was not affected significantly by straw and green manure. Obviously, other management practices, especially tillage, are limiting the species composition of soil microarthropods and thereby overshadow possible effects of fertilization on diversity.

**Keywords**

**Mites, Collembola, Organic manure, Mineral N-fertilization, Long-term field experiment**

## 1. Introduction

Soil microarthropods are considered to play an important role in the nutrient turnover of soils. Although the contribution of microarthropods to the total nutrient turnover is marginal (Verhoef and Brussaard 1990), it is assumed that soil microarthropods have an indirect effect on soil nutrients due to their ability to fragment decaying organic material and thereby increase its availability for micro-organisms (Petersen and Luxton 1982). Furthermore, Petersen (2002b) emphasizes catalytical effects of soil microarthropods on nutrient turnover. It has been reported that under laboratory conditions soil microarthropods have a significant impact on microbial mineralization processes (Mebes and Filser 1998) but in the field the connections between soil microarthropods and micro-organisms may be overshadowed by temperature, humidity, population density, predation and concurrence (Filser et al. 2002). Cole et al. (2004) report from a microcosm experiment, that nutrient release from a mixture of plant litter and soil increased with increasing microarthropod density but decreased with increasing species density.

In arable soils, microarthropods depend on the input of crop and root residues or organic manure for their food. Amount and quality of organic input is decisively determined by the farming system. Dairy farms produce farmyard manure or slurry that may be used as organic fertilizers. In contrast, on farms without animal production soil organic matter may be reproduced by straw and green manure.

Farmyard manure is known to have a stimulative effect on microarthropods (Curry and Purvis 1982, Scholte and Lootsma 1998). Various studies have shown the impact of green manuring and crop rotation on the population densities of microarthropods (e.g. Axelsen and Kristensen 2000, Frampton and van den Brink 2002). As shown by Andrén (1984) mineral fertilization normally increases mesofaunal abundance, however several studies revealed no effects (e.g. Maraun et al. 2001, Lindberg and Persson 2004). A comprehensive review on the impact of land management on microarthropods is presented by Bardgett and Griffiths (1997).

Although there is an abundance of investigations on the effects of different fertilizer regimes on microarthropods, direct comparisons between different farming systems are rare. The aim of this study was to evaluate the impact of different types of organic manuring (farmyard manure vs. straw and green manure) on soil microarthropods in a long-term field experiment. We hypothesized that different regimes of organic manuring result in differences in the population densities and the species composition of soil microarthropods.

## 2. Materials and methods

### 2. 1 Description of the study area

The investigation took place in the International Long-term Fertilization Experiment (IOSDV) located on the experimental station "La Higueruela" in Central Spain (40° 03' N, 04° 26' W) at 450 m above sea level. The soil texture is classified as loamy sand (62 % sand, 23 % silt, 15 % clay). In the $A_p$ horizon the P and K contents are 8.4 and 18.8 mg 100 $g^{-1}$ soil respectively (López-Fando et al. 1999). On the experimental station, the average annual precipitation (1981 - 2000) is 434.1 mm and the average temperature is 14.6 °C. The experiment was set up in 1985 in a split-plot design with organic manure as whole plot factor and mineral N-fertilization as split plot factor (split plot size 6 x 8 m). There were three blocks, representing three field replicates for each treatment. The crop rotation consists of sorghum, winter wheat and spring barley. All are crops grown in parallel fields so that they are permanently present in the experiment. As basic fertilization 30 kg $ha^{-1}$ P and 40 kg $ha^{-1}$ K are given to sorghum and cereals. More information on the field experiment is presented in López-Fando et al. (1999) and Dorado et al. (2003). Three different regimes of organic manuring were sampled in combination with additional variants with or without additional mineral N-fertilization (Tab. 1). In the first year of investigation, soil temperature and moisture were generally higher than in the second year (Tab. 2).

### 2.2 Soil sampling and extraction

Soil samples for chemical analysis were taken from spring barley plots (three field replicates) in late winter in two consecutive years (2001-2002). Samples were collected at 10 sampling points per plot using a drill corer (0 – 30 cm depth) and pooled, air-dried and finally sieved (2 mm mesh size). Soil carbon content was analyzed through oxidation in oxygen flow. Total nitrogen content was determined according to Kjeldahl. For the determination of hot-water soluble carbon ($C_{hwc}$) a hydrolysate was extracted from the soil samples and the carbon content was analyzed by wet oxidation with potassium dichromate as described by Schulz et al. (2003).

Soil samples for the study of microarthropods were taken twice in each late winter of 2001 and 2002 from spring barley plots (three replicate plots per treatment). Samples were collected at 3 sampling points per plot using steel cylinders (0 – 5 cm depth, 100 $cm^3$). Soil microarthropods were extracted from the soil samples using an extractor based on the method by Tullgren (1918). Soil samples remained in the steel cylinders during the extraction. The funnels were provided with sieves of 2.5 mm mesh size. We used standard 40 W electric light bulbs that were regulated by a dimmer. Light intensity was increased subsequently during the extractions. Microarthropods were collected in small plastic bottles filled with 70 % isopropanol and glycerine. The extractions were terminated after seven days.

If necessary, the animals were macerated with lactic acid (30 min, 50 °C). Collembolans were determinated to species level according to Gisin (1960) and the internet-key of Bellinger et al. (2003). For the determination of predatory mites we used the key of Karg (1971).

In both years all samples were taken from spring barley plots. Due to the crop rotation, barley was grown in different plots in the second year of investigation. Thus, soil microarthropod abundances were statistically analyzed for both years separately. Two-way ANOVAs were preformed with treatment and sampling date (within one year) as factors. The effect of the year was not tested as a factor due to the experimental design. The datasets were log-transformed in order to achieve homogeneity of variance. The LSD procedure was used as a post-hoc test. For soil chemical parameters, significant differences between treatments were tested by ANOVA followed by Tukey-tests. Correlations between abundances and chemical parameters were analyzed by means of the Spearman Rank Order Correlation Coefficient ($r_s$). Biodiversity was estimated by means of the Shannon index ($H_s$). All statistical analyses were preformed using the software package SPSS version 11.5 (SPSS Inc., Chicago, USA).

## 3. Results

### 3.1 Soil chemical parameters

In the field experiment under study, total carbon, total nitrogen and hot-water soluble carbon in soil were most clearly influenced by farmyard manure, especially when combined with mineral nitrogen fertilization (Tab. 3). Conversely, straw and green manuring (treatments E and F) had no significant effect on these parameters. In the second year of investigation the C:N-ratio was significantly increased in all treatments with organic manure as compared to the unfertilized control. Without organic and mineral nitrogen fertilization (treatment A) the pH was 6.5 in both years of investigation (Tab. 3). In treatments with farmyard manure the pH was about 7. The lowest pH-values (4.9 to 6.3) were found in the treatments manured with crop waste.

### 3.2 Soil microarthropods

In 2001 the abundances of soil microarthropods were significantly influenced by the fertilization regime. In 2002 both fertilization and sampling date had an effect on the abundances. Interactions between treatment and sampling date were not detected in either year (Tab. 4).

With up to 9500 individuals $m^{-2}$, the highest total abundances of soil microarthropods were found in the treatments with straw and green manure (Fig. 1). As compared to treatment A, the abundance of soil microarthropods was significantly higher in both treatments with straw and green manure. In contrast, both treatments with farmyard manure as well as mineral nitrogen fertilization alone had no significant influence on the population densities (Tab. 5). The total abundances varied between the two years of investigation. In 2002 generally more individuals were found then in 2001.

Overall, 9 species of collembolans and 13 species of predatory mites were determined in the field experiment (Tab. 6). Oribatida, Acaridae, Prostigmata and Thysanoptera were recorded as groups. The collembolan *Cryptopygus thermophilus* was the dominant species. *Dendrolaelaps rectus* and *Hypoaspis aculeifer* were the most abundant predatory mites. In contrast to the abundances of soil microarthropods, biodiversity as determined by the Shannon index was not affected significantly by straw and green manure (Tab. 7). Significant correlations with soil carbon or nitrogen contents were not found for either collembolans or predatory mites, but the total numbers of soil microarthropods were positively correlated with total nitrogen in the second year of investigation. The total abundances of collembolans, predatory mites and soil microarthropods in total tended to correlate negatively with the pH, but no significant correlation could be established (Tab. 8).

**4. Discussion**

Soil carbon is closely connected with all chemical, physical and biological soil properties (Körschens et al. 1997). In our study, the soil organic carbon content was similar to the average values for the period 1991 – 1999 as presented by Dorado et al. (2003). For total nitrogen, our results from 2001 tended to be higher than the 9-year mean (Dorado et al. 2003), however in 2002 they were close to the average. The significant increases in soil carbon and nitrogen content indicate that under the conditions of the experimental field farmyard manure increases soil organic matter, whereas crop waste does not.

Abundances of soil microarthropods were increased markedly by straw and green manuring. In contrast, farmyard manure had no significant effect which is not in line with the results of other investigations. According to Curry (1994) decomposer populations often benefit from organic amendments including animal manures. Nakamura (1976) found that the microarthropod decomposer community temporarily increased after cow dung application, and Bolger and Curry (1984) reported that moderate applications of cattle and pig slurry resulted in moderate increases of hemiedaphic Collembola. In our investigation the farmyard manure had been applied to sorghum, about 2.5 years before our sampling was conducted under spring barley. Thus, the absence of a response to FYM probably reflects this long interval between the last application and the sampling. We assume that the farmyard manure was well decomposed at the time of investigation, thus, no direct impact on soil microarthropods was detected.

In the straw and green manure treatment organic material was annually incorporated into the soil. According to Vreeken-Buijs et al. (1998) collembolans prefer habitats that provide a continuous supply of organic matter. Straw manuring is known to have positive effects on soil structure, which in turn might support higher abundances of soil microarthropods. Martin Patino and Hernando Fernández (1978) found more micro-pores in a soil manured with straw than in an unmanured soil. Pommer et al. (1982) report that straw manure leads to an increased pore volume and higher air permeability. Moreover, it is assumed that straw manuring with additional mineral nitrogen fertilization provides good conditions for the development of soil microorganisms. Thus, the increased abundances of soil microarthropods in the treatments with straw manure may be interpreted as a reaction to improved soil physical properties and better food supply. Consequently, our results support the hypothesis that different regimes of organic manuring result in differences in the population densities of soil microarthropods.

The application of mineral nitrogen resulted in higher yield of all crops in the crop rotation (López-Fando et al. 1999). Higher yield is connected with increased production of plant biomass and higher amounts of root residues that are supposed to serve as food sources for soil life. Nevertheless, on most sampling dates, mineral nitrogen fertilization increased slightly, but not significantly, the abundance of soil microarthropods. Obviously, for the microarthropods in the uppermost soil layer the improvement in food supply by increased root production was - in terms of quantity and accessibility – not as beneficial as organic manuring with crop waste.

Only a few species of soil microarthropods are characterized with regard to their ecological preferences. Among the collembolans, the most abundant species *Cryptopygus thermophilus* is described by Arbea and Blasco-Zumeta (2001) as hemiedaphic, with the ability to periodically withstand high temperatures and low soil humidity. Analysis of gut content revealed that *C. thermophilus* mostly feeds on bacteria and fungal hyphae (Arbea and Blasco-Zumeta 2001). In fact, *C. thermophilus* was found in all investigated treatments but the highest abundances occurred in the field plots with straw and green manure. Thus, we conclude that under the conditions of our field experiment the feeding of *C. thermophilus* is mainly based on microorganisms associated with the decomposition of plant material. Moreover, this species was favoured by straw and green manure more than other soil microarthropods.

Generally, the diversity as calculated by the Shannon-index did not differ significantly between the investigated treatments. We assume that other management practices, especially tillage, are limiting the species composition of soil microarthropods and thereby overshadow possible effects of fertilization on diversity. This assumption is supported by the results of Cortet et al. (2002) who compared a deep tillage system with a minimum tillage system and found the highest biodiversity of soil microarthropods in the latter one. Petersen (2002a) found the abundance of total collembolans strongly reduced after tillage. Ploughing profoundly affects soil as a living space for microarthropods. Obviously, between the tillage operations there is not enough time for a significant fertilizer-induced modification of the species composition, so only effects on abundance may be observed.

Among the predatory mites, the genera *Hypoaspis, Pergamasus* and *Pachylaelaps* are known as indicators for intensive decomposition processes in arable soils with high humus content (Karg 1982). The genera *Dendrolaelaps* and *Rhodacarellus* are supposed to be indicators for advanced decomposition processes in sandy soils (Karg 1982). Some species of the above mentioned genera are found in the investigated field experiment (*Hypoaspis aculeifer*, *Pachylaelaps regularis, Pergamasus suecius*, *Dendrolaelaps rectus* and *Rhodacarellus silesiacus)*. Koehler (1999) describes *D. rectus* as a common species in arable land that mainly occurs in sandy soils. *R. silesiacus* is known as one of the most frequent species of predatory mites in European arable soils but is generally associated with deeper soil layers (Koehler 1999). Thus, it is not surprising that it was only found occasionally in the present investigation. The species composition of predatory mites may be characterized as a typical decomposer community, but no differences between the investigated treatments were detected. Since we found the highest abundances of soil microarthropods in the treatments with straw and green manure but the highest soil carbon and nitrogen contents in treatments with farmyard manure, it is plausible that no correlations between the arthropods and the chemical parameters exist.

The finding that soil microarthropods tend to be negatively correlated with the pH indicates that under the given conditions their abundance was not primarily determined by acidity. Different species of soil microarthropods differ considerably in their pH preferences (van Straalen and Verhoef 1997). However, for the collembolans Butcher et al. (1971) report tolerances between 6.0 and 9.6, with an optimum of pH 7.2-7.5. In the investigated field experiment the pH was generally beneath 7. Lowest pH-values and highest abundances of soil microarthropods were found in the plots manured with crop residues. Thus, we conclude that the improved food supply provided by the straw and green manure had a stronger effect on the activity of microarthropods than the potentially unfavourable decrease in the pH.

Abiotic edaphic factors like humidity and temperature are known to have a marked influence on soil organisms and may even mark the effects of different management practices. In our investigation, soil temperature was between 13.5 and 14.0 °C in 2001 and between 7.0 and 8.0 °C in 2002 and the abundances of soil microarthropods were generally higher in the second year. In fact, among the most frequent collembolans, *C. thermophilus* is characterized as a species adapted to high temperatures. Nevertheless, we assume that under the specific conditions of the field experiment the community of soil microarthropods in general is negatively rather than positively affected by high soil temperatures, which is connected with the effects of evaporation and decreasing soil humidity.

It is well known that low humidity results in migration, lower reproduction and higher mortality of soil microarthropods (Butcher et al. 1971). Therefore, drought stress may reduce abundance and diversity of collembolans (Pflug and Wolters 2001). Consequently, it was not in line with our expectations to find higher abundances of soil microarthropods in the second year when soil humidity was generally lower. However, our first sampling in 2001 took place under very wet conditions, i.e. more than 18 % soil water content. This might have affected the soil microarthropods because the air filled soil pores most likely were partly filled with water.

## Conclusion

We conclude that in the field experiment under study the abundance of soil microarthropods was influenced by the immediate food supply rather than by soil chemical parameters such as carbon and nitrogen content or the pH. The annual supply with crop waste was more favourable for the development of large microarthropod communities than the addition of farmyard manure every three years. No differences in diversity were observed between the treatments, probably because in the experiment under study the effects of tillage are primarily determining the species composition of soil microarthropods.

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**References**

Andrén, O., 1984: Soil mesofauna of arable land and its significance for decomposition of organic matter. Dissertation. Swedish University of Agricultural Sciences, Uppsala.

Arbea, J. I., Blasco-Zumeta, J., 2001. Ecología de los Colémbolos (Hexapoda, Collembola) en Los Monegos (Zaragoza, España). Bol.S.E.A. 28: 35-48. <http://entomologia.rediris.es/aracnet/7/03ecolembolos>.

Axelsen, J. A., Kristensen, K. T., 2000. Collembola and mites in plots fertilized with different types of green manure. Pedobiologia 44: 556-566.

Bardgett, R. D., Griffiths, B. S., 1997. Ecology and Biology of Soil Protozoa, Nematodes, and Microarthropods. In: Van Elsas, J. D., Trevors, J. T., Wellington, E. M. H. (Eds.): Modern Soil Microbiology. Dekker, New York.

Bellinger, P. F., Christiansen, K. A., Janssens, F., 2003. Checklist of the collembola of the world. <http://www.collembola.org/taxa/collembo.htm>

Bolger, T., Curry, J. P., 1984. Influences of pig slurry on soil microarthropods in grassland. Rev. Ecol. Biol. Sol 21: 269-281.

Butcher, J. W., Snider, R., Snider, R. J., 1971. Bioecology of edaphic collembola and acarina. Ann. Rev. Entomol. 16: 249-288.

Cole, L., Dromph, K. M., Boaglio, V., Bardgett, R. D., 2004. Effect of density and species richness of soil mesofauna on nutrient mineralization and plant growth. Biol. Fertil. Soils 39: 337-343.

Cortet J., Ronce, D., Poinsot-Balaguer, N., Beaufreton, C., Chabert, A., Viaux, P., Cancela de Fonseca, J. P., 2002. Impacts of different agricultural practices on the biodiversity of microarthropod communities in arable crop systems. Eur. J. Soil Biol. 38: 239-244.

Curry, J. P., 1994. Grassland Invertebrates. Ecology, Influence on Soil Fertility and Effects on Plant Growth Chapman and Hall, London, 437 pp.

Curry, J. P., Purvis, G., 1982. Studies on the influence of weeds and farmyard manure on the arthropod fauna of sugar beet. J. Life Sci. R. Dubl. Soc. 3: 397-408.

Dorado, J., Zancada, M.-C., Almendros, G., López-Fando, C., 2003. Changes in soil properties and humic substances after long-term amendments with manure and crop residues in dryland farming systems. J. Plant Nutr. Soil Sci. 166: 31-38.

Filser, J., Mebes, K. H., Winter, K., Lang, A., Kampichler, C., 2002. Long-term dynamics and interrelationship of soil collembola and microorganisms in an arable landscape following land use change. Geoderma 105: 201-221.

Frampton, G. K., van den Brink, P. J., 2002. Influence of cropping on the species composition of epigeic Collembola in arable fields. Pedobiologia 46: 328-337.

Gisin, H., 1960. Collembolenfauna Europas. Museum d'Histoire Naturelle, Genf.

Karg, W., 1971. Acari (Acarina), Milben. Unterordnung Anactinochaeta (Parasitiformes). Die freilebenden Gamasina (Gamasides), Raubmilben. In: Dahl, F. (Ed.): Die Tierwelt Deutschlands. 59. Teil. Fischer. Jena

Karg, W., 1982. Untersuchungen über Habitatansprüche, geographische Verbreitung und Entstehung von Raubmilbengattungen der Cohors Gamasina für ihre Nutzung als Bioindikatoren. Pedobiologia 24: 241-247.

Koehler, H. H., 1999. Predatory mites (Gamasina, Mesostigmata). Agric. Ecosyst. Environ. 74: 395-410.

Körschens, M., Schulz, E., Klimanek, E.-M., Franko, U., 1997. Die Organische Bodensubstanz - Bedeutung, Definition, Bestimmung. Arch. Agr. Soil Sci. 41: 427-433.

Lindberg, N., Persson, T., 2004. Effects of long-term fertilisation and irrigation on the microarthropod community in a boreal Norway spruce stand. Forest Ecol. Manag. 188: 125-135.

López-Fando, C., Pardo, M., Wegener, H.-R., 1999. Erträge und N-Bilanzen im IOSDV Madrid im Laufe von vier Rotationen. Arch. Agr. Soil Sci. 44: 489-505.

Maraun, M., Alphei, J., Beste, P., Bonkowski, M., Buryn, R., Migge, S., Peter, M., Schaefer, M., Scheu, S., 2001. Indirect effects of carbon and nutrient amendments on the soil meso- and microfauna of a beechwood. Biol. Fertil. Soils 34: 222-229.

Martin Patino, M. T., Hernando Fernández, V., 1978. Estudio por SEM y EDAX de las variaciones en la estructura de los suelos como consecuencia de la aplicación de paja. Anales de Edafología y Agrobiología 37: 1177-1184.

Mebes, K. H., Filser, J., 1998. Does the species composition of Collembola affect nitrogen turnover? Appl. Soil Ecol. 9: 241-247.

Nakamura, Y., 1976. Decomposition of organic materials and soil fauna in pastures. 4. Disappearance of cow dung and succession of the associated soil-microarthropods. Pedobiologia 16: 243-257.

Petersen, H., 2002a. Effects of non-inverting deep tillage vs. conventional ploughing on collembolan populations in an organic wheat field. Eur. J. Soil Biol. 38: 177-180.

Petersen, H., 2002b. General aspects of collembolan ecology at the turn of the millennium. Pedobiologia 46: 246-260.

Petersen, H., Luxton, M., 1982. A comparative analysis of soil fauna populations and their role in decomposition process. Oikos 39: 288-389.

Pflug, A., Wolters, V., 2001. Influence of drought and litter age on Collembola communities. Eur. J. Soil Biol. 37: 305-308.

Pommer, G., Beck, T., Borchert, H., Hege, U., 1982. Auswirkung von Zwischenfruchtbau und Strohdüngung auf Ertragsleistung, Bodenstruktur und Bodenmikroorganismentätigkeit in einseitigen Getreidefruchtfolgen. Bayerische Landwirtschaftliche Jahrbücher 59.

Scholte, K., Lootsma, M., 1998. Effect of farmyard manure and green manure crops on populations of mycophagous soil fauna and Rhizoctonia stem canker of potato. Pedobiologia 42: 223-231.

Schulz, E., Deller, B., Hoffmann, G., 2003. Heisswasserextrahierbarer Kohlenstoff und Stickstoff. In: VDLUFA-Methodenbuch I. 4. Teilfg. VDLUFA-Verlag, Bonn.

Tullgren, A., 1918. Ein sehr einfacher Ausleseapparat für terricole Tierfaunen. Z. angew. Entomol. 4: 149-150.

van Straalen, N. M., Verhoef, H. A., 1997. The development of a bioindicator system for soil acidity based on arthropod pH preferences. J. appl. Ecol. 34: 217-232.

Verhoef, H. A., Brussaard, L., 1990. Decomposition and nitrogen mineralization in natural and agro-ecosystems: the contribution of soil animals. Biogeochemistry 11: 175-201.

Vreeken-Buijs, M. J., Hassink, J., Brussaard, L., 1998. Relationship of soil microarthropod biomass with organic matter and pore size distribution in soils under different land use. Soil Biol. Biochem. 30: 97-106.

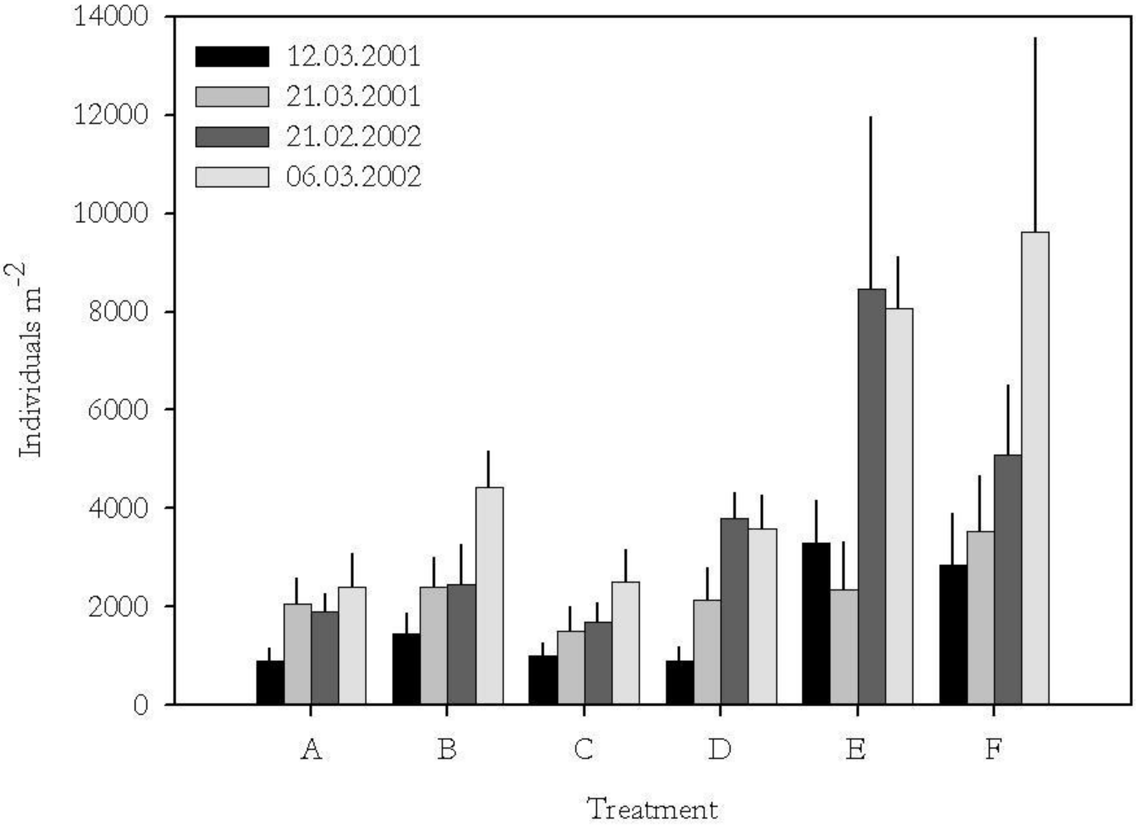


**Figure 1:** Abundance of soil microarthropods in a sandy arable soil, as influenced by different long-term fertilizer regimes. A: No added OM-N 0, B: No added OM-N 3, C: FYM-N 0, D: FYM-N 3, E: Straw-/Green-N 0, F: Straw-/Green-N 3. Error bars represent standard errors.

**Table 1:** Fertilization regimes under study (fresh matter input by fertilizers per hectare and year). Samples were taken from spring barley plots.

| | Treatment | sorghum | winter wheat | spring barley |
|---|---|---|---|---|
| **A** | **No added OM-N 0** | - | - | - |
| **B** | **No added OM-N 3** | 120 kg mineral N | 120 kg mineral N | 120 kg mineral N |
| **C** | **FYM-N 0** | 300 dt FYM | - | - |
| **D** | **FYM-N 3** | 300 dt FYM<br>120 kg mineral N | 120 kg mineral N | 120 kg mineral N |
| **E** | **Straw-/Green-N 0** | 30 dt sorghum leaf green manuring[2] | 30 dt straw[1] | 30 dt straw[1] |
| **F** | **Straw-/Green-N 3** | 30 dt sorghum leaf green manuring[2]<br>120 kg mineral N | 30 dt straw[1]<br>120 kg mineral N | 30 dt straw[1]<br>120 kg mineral N |

[1] with additional 30 kg mineral-N, [2] green manuring with rape, FYM Farmyard manure, OM Organic matter

**Table 2:** Temperature and soil humidity at sampling dates (daily means)

| Sampling date | air temperature (°C) | soil temperature 20 cm (°C) | soil moisture content 0-20 cm (%) |
|---|---|---|---|
| **12.03.01[1,2]** | 14.0 | 14.0 | 18.3 |
| **21.03.01[1]** | 15.3 | 13.5 | 12.7 |
| **21.02.02[1,2]** | 8.0 | 7.0 | 7.2 |
| **06.03.02[1]** | 9.3 | 8.0 | 11.2 |

[1] sampling for investigation of soil microarthropods
[2] sampling for soil chemical investigation

**Table 3:** Soil chemical parameters as influenced by different long-term fertilizer regimes. A: No added OM-N 0, B: No added OM-N 3, C: FYM-N 0, D: FYM-N 3, E: Straw-/Green-N 0, F: Straw-/Green-N 3. $C_t$: Total carbon content, $N_t$: Total nitrogen content, $C_{hwc}$: Hotwater soluble carbon content. Treatments with the same letter at one date are not significantly different (ANOVA with Tukey-HSD, $p < 0.05$).

| Sampling date | Parameter | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|
| 12.03.01 | $C_t$ (mg 100 $g^{-1}$ soil) | 546.3 ab | 434.5 a | 717.7 ab | 932.7 b | 649.3 ab | 698.3 ab |
| | $N_t$ (mg 100 $g^{-1}$ soil) | 93.3 a | 72.0 a | 101.0 ab | 108.3 b | 97.7 ab | 96.3 ab |
| | C:N | 5.9 a | 6.0 a | 7.1 a | 8.6 a | 6.6 a | 7.2 a |
| | $C_{hwc}$ (mg 100 $g^{-1}$ soil) | 13.0 a | 13.4 ab | 28.0 b | 26.8 ab | 20.9 ab | 22.9 ab |
| | pH | 6.5 ab | 6.8 ab | 7.1 b | 6.8 ab | 5.3 a | 6.3 ab |
| 21.02.02 | $C_t$ (mg 100 $g^{-1}$ soil) | 469.0 a | 496.7 a | 735.7 ab | 888.0 b | 597.7 ab | 647.7 ab |
| | $N_t$ (mg 100 $g^{-1}$ soil) | 66.3 a | 66.3 a | 86.3 ab | 105.7 b | 64.7 a | 74.7 ab |
| | C:N | 7.1 a | 7.5 a | 8.5 b | 8.4 b | 9.2 b | 8.7 b |
| | $C_{hwc}$ (mg 100 $g^{-1}$ soil) | 19.1 a | 20.2 ab | 29.6 ab | 30.9 b | 25.2 ab | 25.8 ab |
| | pH | 6.5 ab | 5.5 ab | 6.9 b | 6.4 ab | 6.1 ab | 4.9 a |

**Table 4:** Effects of treatment and sampling time (within one year) on the abundance of soil microarthropods (ANOVA, F-Test). For results of post-hoc tests see table 5.

| year | 2001 | 2002 |
|---|---|---|
| treatment | ** | *** |
| sampling time | n.s. | ** |
| treatment x sampling time | n.s. | n.s. |

** $p < 0.01$, *** $p < 0.001$, n.s.: not significant

**Table 5:** Differences in the abundances of soil microarthropods between different fertilization treatments. Results of post-hoc Tests (LSD) for the factor "treatment" from ANOVA presented in table 4. A: No added OM-N 0, B: No added OM-N 3, C: FYM-N 0, D: FYM-N 3, E: Straw-/Green-N 0, F: Straw-/Green-N 3.

| 2001 | B | C | D | E | F |
|---|---|---|---|---|---|
| A | n.s. | n.s. | n.s. | * | ** |
| B | | n.s. | n.s. | n.s. | n.s. |
| C | | | n.s. | * | ** |
| D | | | | n.s. | ** |
| E | | | | | n.s. |
| 2002 | B | C | D | E | F |
| A | n.s. | n.s. | n.s | ** | ** |
| B | | n.s. | n.s. | ** | * |
| C | | | * | *** | *** |
| D | | | | n.s. | n.s. |
| E | | | | | n.s. |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, n.s.: not significant

**Table 6:** Species of soil microarthropods as influenced by different long-term fertilizer regimes. Numbers represent total individuals extracted during investigation. A: No added OM-N 0, B: No added OM-N 3, C: FYM-N 0, D: FYM-N 3, E: Straw-/Green-N 0, F: Straw-/Green-N 3.

| Taxon | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| **Collembola** | | | | | | |
| *Choreutinula inermis* (Tullberg, 1871) Stach, 1955 | 3 | 13 | - | 7 | 16 | 16 |
| *Cryptopygus thermophilus* (Axelson,1900) | 45 | 85 | 34 | 65 | 198 | 137 |
| *Isotoma* sp. | - | - | - | - | 4 | - |
| *Lepidocyrtus cyaneus* Tullberg, 1871 | - | - | 1 | - | - | - |
| *L. lanuginosus* (Gmelin, 1788) | 2 | - | 3 | - | 4 | 14 |
| *Pseudanurophorus isotoma* Börner, 1903 | - | - | 1 | - | 2 | - |
| *Sminthurinus aureus* (Lubbock, 1862) | 3 | 2 | 2 | 8 | 3 | 4 |
| *S. niger* (Lubbock, 1867) Börner, C., 1901 | 23 | - | - | - | - | - |
| *Sminthurus viridis* (Linnaeus, 1758) | - | - | 1 | - | - | - |
| Total | **76** | **100** | **42** | **80** | **225** | **171** |
| **Mesostigmata** | | | | | | |
| *Arctoseius cetratus* (Sellnick, 1940) | - | 1 | - | - | - | - |
| *Dendrolaelaps rectus* Karg, 1962 | 2 | 2 | 2 | 2 | 12 | 7 |
| *Gamasellus* sp. | - | - | - | - | - | 1 |
| *Hypoaspis aculeifer* (Canestrini, 1883) | 6 | 1 | 4 | 2 | 1 | 1 |
| *Hypoaspis procera* Karg, 1965 | - | - | - | 1 | - | - |
| *Hyposapis* sp. | - | - | 1 | - | - | 1 |
| *Neojordensia levis* (Oudemans & Voigts, 1904) | - | - | - | - | 1 | - |
| *Olopachys scutatus* Berlese, 1910 | 1 | 1 | - | - | - | - |
| *Pachylaelaps regularis* Berlese, 1920 | 2 | 1 | - | 1 | - | 2 |
| *Pergamasus* sp. | - | 1 | - | - | - | - |
| *Pergamasus suecicus* (Trägardh, 1936) | - | - | 1 | - | 1 | - |
| *Rhodacarellus silesiacus* Willmann, 1934 | 2 | - | - | - | 4 | - |
| *Rhodacarus calcarulatus* Berlese, 1921 | - | - | - | - | 1 | 4 |
| Total | **13** | **7** | **8** | **6** | **20** | **16** |
| **Oribatida** | **3** | **14** | **16** | **18** | **29** | **15** |
| **Acaridae** | **19** | **25** | **21** | **9** | **21** | **90** |
| **Prostigmata** | **7** | **17** | **5** | **13** | **34** | **34** |
| **Thysanoptera** | **19** | **17** | **9** | **21** | **27** | **30** |
| **Other** | **12** | **6** | **7** | **21** | **20** | **12** |

**Table 7:** Biodiversity indices ($H_s$) as influenced by different long-term fertilizer regimes. A: No added OM-N 0, B: No added OM-N 3, C: FYM-N 0, D: FYM-N 3, E: Straw-/Green-N 0, F: Straw-/Green-N 3. Treatments with the same letter at one date are not significantly different (ANOVA with Tukey-HSD, $p < 0.05$).

| Sampling date | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 12.03.2001 | 1.35 b | 0.96 ab | 1.18 b | 0.65 a | 1.16 ab | 0.84 ab |
| 21.03.2001 | 0.79 a | 1.15 a | 1.56 a | 1.16 a | 1.19 a | 1.02 a |
| 21.02.2002 | 1.44 a | 0.91 a | 1.24 a | 1.42 a | 1.10 a | 1.15 a |
| 06.03.2002 | 1.42 a | 1.39 a | 1.17 a | 1.23 a | 1.16 a | 1.37 a |

**Table 8:** Correlations ($r_s$) of soil microarthropods with soil chemical parameters (∑SMA: Sum of all soil microarthropods)

| Sampling date | Parameter | Collembolans | Predatory mites | ∑SMA |
|---|---|---|---|---|
| 12.03.01 | $C_t$ | -0.03 | 0.01 | -0.09 |
| | $N_t$ | -0.09 | 0.10 | -0.16 |
| | C:N | -0.13 | 0.08 | -0.18 |
| | $C_{hwc}$ | 0.05 | 0.10 | 0.06 |
| | pH | -0.27 | -0.29 | -0.16 |
| 21.02.02 | $C_t$ | -0.10 | 0.17 | 0.38 |
| | $N_t$ | -0.02 | 0.17 | 0.41* |
| | C:N | -0.20 | -0.10 | 0.26 |
| | $C_{hwc}$ | -0.05 | 0.12 | 0.32 |
| | pH | -0.14 | 0.15 | -0.33 |

* correlation is significant ($p < 0.1$)