The effect of fertilization and crop rotation on biological activity in a 90 year long-term experiment

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Die Auswirkung von Düngung und Fruchtfolge auf die biologische Aktivität in einem 90jährigen Langzeitversuch

1. Introduction

A long-term field experiment has been studied for more than 90 years on the testing ground of the University of Agricultural Sciences, Vienna, situated in Großenzersdorf, Lower Austria. The effects of monoculture versus crop rotation and different fertilizers – farmyard manure, mineral fertilizer, no fertilizer – on the yield of spring barley (*Hordeum vulgare*), winter rye (*Secale cereale*) and on soil parameters was investigated. For results of these long-term experiments see STEINECK and RUCKENBAUER (1976).

As no biological data existed, we used the bait-lamina-test, as developed by VON TÖRNE (1990 a, b), to assess the biological activity, and in addition, we determined the abundance of potworms (*Oligochaeta; Enchytraeidae*) as potential feeders on the bait substances (PFEIFF et al., 1998). The bait-lamina-test is a possibility for measuring biological activity, which can be disturbed in the complex soil ecosystem. Organic matter is exposed in the upper layer of the soil and its reduction in time is determined. Soil organisms are attracted by the exposed bait substance and feed on it. The evaluation of the feeding activity on the bait is done by a simple yes/no classification. The bait-lamina-test has already been used several times as a screening test for ecological monitoring (HOFFMANN et al., 1991; KRATZ et al., 1992; LARINK and LÜBBEN; 1990; LARINK, 1993).

Forty to ninety percent of the organic matter in the soil is decomposed by biotic processes, whereas the contribution of abiotic degradation is 5–30 %. Soil meso- and macrofauna mainly reduce plant residues to small pieces, thereby expanding the surface area and breaking up complex components. At this stage, organic matter can be more easily reduced by micro-organisms, whose population dynamics are affected by the soil fauna. Through the activity of soil organisms, the plant residues are on the one hand transformed into humic substances and on the other hand mineralized into inorganic matter which is returned into the nutrient cycle (EISENBEIS, 1993).

Soil micro-organisms and fauna in arable fields, where natural cycles are interrupted, are strongly affected by intensive soil management and fertilization. The micro-climate is changed, soil porosity is greatly reduced, many soil animal species are eradicated, and micro-organisms may show enhanced activity (EHRNSBERGER, 1993). To assess the

Zusammenfassung

In Großenzersdorf (Niederösterreich) wird in einem Langzeitversuch seit 1906 die Auswirkung von Monokultur, Fruchtfolge und verschiedenen Düngemaßnahmen auf den Ernteertrag von Sommergerste (*Hordeum vulgare*) und Winterroggen (*Secale cereale*) untersucht. Zusätzlich wurden chemische und physikalische Bodenparameter, jedoch keine biologischen Daten, erhoben.

Wir haben die biologische Aktivität im Boden von 12 unterschiedlichen Parzellen anhand der von VON TÖRNE entwickelten Köderstreifen und die Abundanz der Enchytraeiden, als potentielle Fresser der Ködersubstanz, untersucht. Der Köderstreifentest ergab eine signifikant niedrigere biologische Aktivität in den ungedüngten Parzellen. Im Monokulturboden war die Freßaktivität der Bodentiere höher als in jenem mit Fruchtfolge, was auf die Wirkung der Schwarzbrache zurückzuführen ist. Die Schwarzbrache bewirkte eine Abnahme der biologischen Aktivität und der Enchytraeidenabundanz im darauffolgenden Jahr.

Schlagworte: Köderstreifen, biologische Aktivität, Enchytraeidae, Langzeit-Fruchtfolge, Düngung.

Summary

Since 1906, a long-term field experiment has been carried out in Großenzersdorf (Lower Austria) to determine the effects of monoculture, crop rotation and different fertilization methods on the yield of spring barley (*Hordeum vulgare*) and winter rye (*Secale cereale*). Additionally, chemical and physical soil parameters have been recorded, but no biological data.

To assess the biological activity in the soil of the 12 different plots, we applied the VON TÖRNE's bait-lamina-test and investigated the abundance of enchytraeids as potential feeders on the bait substances. The bait-lamina-test showed a significantly lower biological activity in the unfertilized plots. A higher feeding activity of soil-living animals could be demonstrated in the plots with monoculture versus plots with crop rotation. The consequence of dead fallow in the previous year was reduced biological activity and enchytraeid number.

Key words: bait-lamina-test, biological activity, Enchytraeidae, long-term rotation, fertilization.

effect of different fertilizers and different management on the biological activity in the 12 different plots of the long-term experiment, we exposed 3 x 16 bait-laminae in the upper soil horizon in September 1995 and May 1996.

2. Material and Methods

2.1 Study area

This study was carried out on the testing ground of the University of Agricultural Sciences, Vienna, situated in Großenzersdorf, Lower Austria, in the southern part of the Marchfeld (48° 13'N/16° 33'E). The Pannonian climate is intermediate between the Oceanic West-European climate and the Continental East-European climate. It is characterized by a long vegetation period, long duration of sunshine, high temperatures and little precipitation. The average annual temperature is 9.8° C and average precipitation is 572 mm. During the time the bait-laminae were exposed, the precipitation was 128.4 mm in September 1995 (12 days) and 107.6 mm in May 1996 (13 days).

The soil is Tschernosem-like, hydromorph, medium heavy with increasing clay content in the lower horizons. The pH ($CaCl_2$) was 7.5 on all plots. The long-term crop rotation and fertilization experiment was established in 1906 and the plot arrangements and treatments have been continuously maintained. Only between the years 1938 and 1945 is there no information available (STEINECK and RUCKENBAUER, 1976).

The long-term experiment consists of 4 field plots with exactly 1000 m^2 each (fig. 1). Each plot is split into 3 sub-plots (20x16m). One sub-plot receives no fertilization (1–4C), the second is fertilized with mineral fertilizers (NPK: 1–4B) and the third sub-plot is treated with farmyard manure (1–4A). In the first 3 trial plots, the old three field-rotation with winter rye (*Secale cereale*) – spring barley (*Hordeum vul-*

	1	2	3	4
A	***Farmyard manure*** 1995: winter rye 1996: spring barley	***Farmyard manure*** 1995: spring barley 1996: dead fallow	***Farmyard manure*** 1995: dead fallow 1996: winter rye	***Farmyard manure*** 1995 and 1996: winter rye monoculture
B	***Mineral fertilizer*** 1995: winter rye 1996: spring barley	***Mineral fertilizer*** 1995: spring barley 1996: dead fallow	***Mineral fertilizer*** 1995: dead fallow 1996: winter rye	***Mineral fertilizer*** 1995 and 1996: winter rye monoculture
C	***No fertilizer*** 1995: winter rye 1996: spring barley	***No fertilizer*** 1995: spring barley 1996: dead fallow	***No fertilizer*** 1995: dead fallow 1996: winter rye	***No fertilizer*** 1995 and 1996: winter rye monoculture

Figure 1: Arrangement of the 12 plots with crop rotation (1–3), monoculture (4), and different fertilization (A, B, C)
Abbildung 1: Anordnung der 12 Parzellen mit Fruchtfolge (1–3), Monokultur (4) und verschiedenen Düngemaßnahmen (A, B, C)

gare) – dead fallow was carried out, whereas in the 4th plot a continuous winter rye cropping was maintained.

Mineral fertilizer (consists of: 117 N/100 P_2O_5/ 150 K_2O) was spread on 29 April 1996, farmyard manure 200 dt/ha (consists of: 110–116 N/75–84 P_2O_5/ 116–125 K_2O) on 20 August 1995. During the vegetation period the winter rye and spring barley were sprayed with the plant protective Hedapur DP (Dichlorphenoxypropionacid). In July 1995, the winter rye and spring barley were harvested and the field remained untilled up to October 1995, when winter rye was grown again, and to April 1996, when spring barley was seeded. The dead fallow was kept untilled by a milling machine from July 1995 to October 1996, when winter rye was grown. Plant residuals were removed from the dead fallow.

2.2 Bait-Lamina-Test

Biological activity in the soil was assessed using VON TÖRNE's bait-lamina-test (1990a, b). Sixteen holes of 3 mm diameter were punched 5 mm apart into PVC-rods and filled with the bait substance; this consists of 65 % cellulose, 15 % agar agar, 10 % betonite, and 10 % pulverized pollard. On each of the 12 investigated plots, 3x16 bait-laminae were exposed in the upper soil horizon in September 1995 and May 1996. After 11/12 days, empty holes were evaluated by yes/no-classification and the pooled data converted into percentage feeding activity.

2.3 Enchytraeidae (Annelida; Oligochaeta)

In May 1995, 3 samples, and in September 1995, 7 samples from each plot were taken with a soil corer (6 cm diameter, 10 cm depth). Enchytraeids were extracted with the heat wet-funnel-method (O'CONNOR, 1962) for 3 hours and the species were identified alive.

2.4 Statistical evaluation

To assess the effects of the different cultivations and fertilizers on biological activity (percentage feeding activity/ enchytraeid abundance) the results of the 12 plots were added up in different ways and compared according to the subject. For statistical evaluation, the U-test (Mann-Whitney) and the H-test (Kruskal-Wallis) were applied.

3. Results

Biological activity, calculated as percentage feeding activity, of the 9 plots with crop rotation (fig. 1: 1–3) and of the 3 plots with monoculture (fig. 1: plots 4) were investigated in two seasons – spring and autumn. A significantly higher biological activity was recorded in the field with monoculture in all three fertilization variants (farmyard manure, mineral fertilizer, no fertilization) in May 1996, but only in the plots treated with farmyard manure in September 1995 (fig. 2). Figure 3 shows that enchytraeids were significantly more abundant in the plots with monoculture in May 1995, but no significant difference could be seen in September 1995.

Higher biological activity in the soil of the winter rye monoculture is also evident in figure 4, where the relative feeding activity in the different soil depth are shown. In each plot, biological activity amounted to 9.6 % at a depth of 0–15 mm, 6.0 % in 16–35 mm, 4.6 % in 36–55 mm,

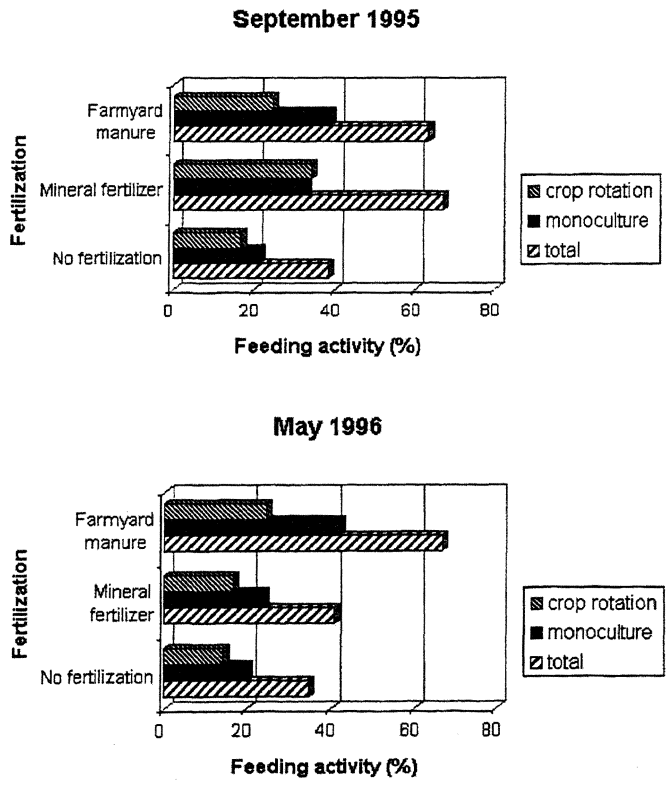

Figure 2: Crop rotation vs. monoculture: biological activity (% feeding activity) in the plots with farmyard manure, mineral fertilizer and no fertilization in September 1995 and May 1996

Abbildung 2: Fruchtfolge vs. Monokultur: biologische Aktivität (% Freßaktivität) in den Parzellen mit Stallmist, Mineraldünger und ohne Düngung im September 1995 und Mai 1996

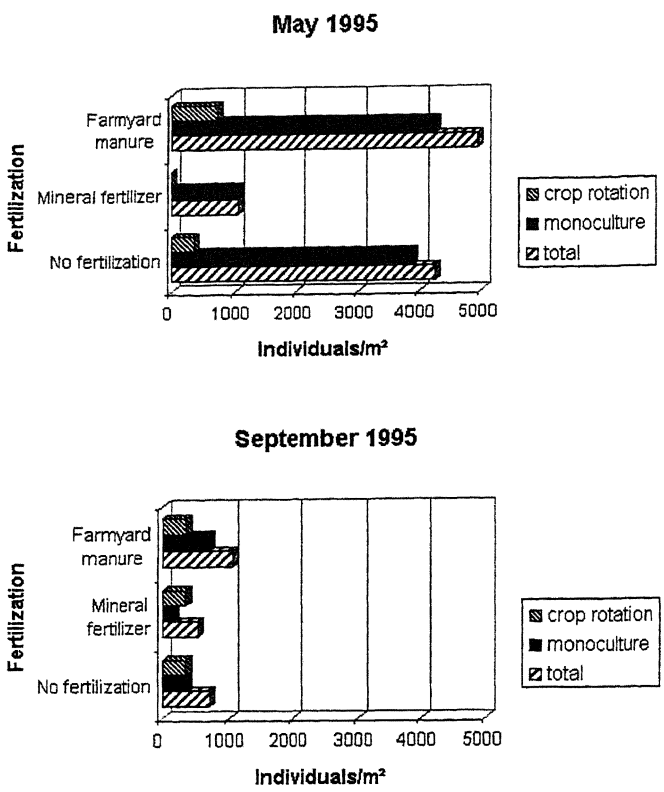

Figure 3: Crop rotation vs. monoculture: enchytraeid abundance (median) in the plots with farmyard manure, mineral fertilizer and no fertilization in May and September 1995

Abbildung 3: Fruchtfolge vs. Monokultur: Enchytraeiden-Abundanz (Median) in den Parzellen mit Stallmist, Mineraldünger und ohne Düngung im Mai und September 1995

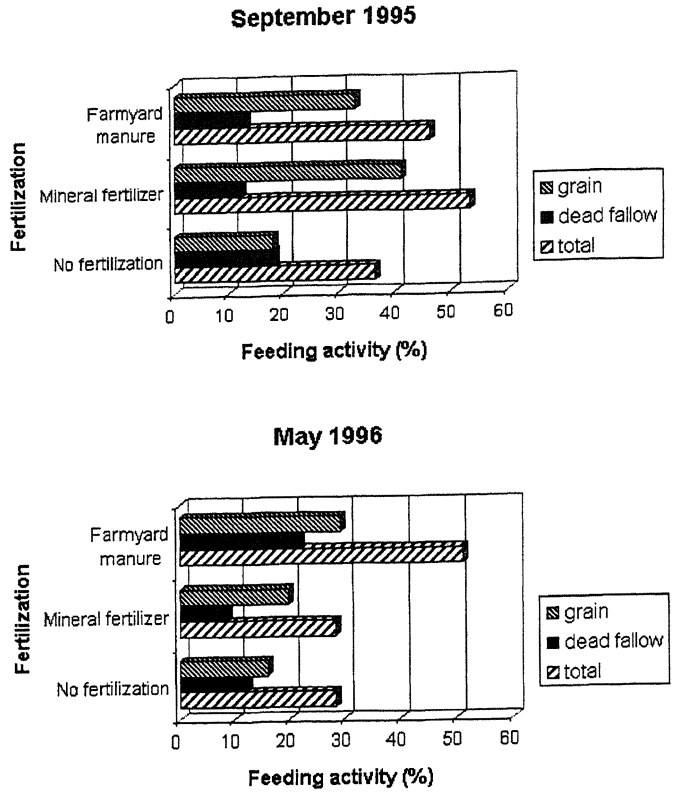

Figure 5: Dead fallow vs. cultivation of grain: biological activity (% feeding activity) in the plots with farmyard manure, mineral fertilizer and no fertilization in September 1995 and May 1996

Abbildung 5: Schwarzbrache vs. Getreideanbau: biologische Aktivität (% Freßaktivität) in den Parzellen mit Stallmist, Mineraldünger und ohne Düngung im September 1995 und Mai 1996

and 6.5 % in 56–75 mm. In May 1995, feeding activity in the 4 depths was as follows: 7.9 %, 4.7 %, 3.5 %, 3.8 %.

Altogether, 26,7 % of the exposed bait was eaten in September 1995 and 19.9 % in May 1996. Because feeding activity in the field depends on weather conditions, the results of different study periods cannot be compared.

A distinct effect of the dead fallow in the year before our investigations was determined: both in spring and autumn, biological activity was significantly higher in the fertilized plots with crop in the previous year, whereas plots without fertilization showed no difference (fig. 5). In May, enchytraeids were completely absent in the field with dead fallow in the previous year (fig. 6). Cultivation methods of the current year affected potworm abundance to a greater extent in September 1995, when the worms were almost evenly distributed in all plots (BAUER, 1996).

4. Discussion

In the present long-term fertilization and crop-rotation experiment, the bait-lamina-test was carried out in spring and autumn. Total activity was clearly higher in September than in May, corresponding to data obtained from Kiss (pers. comm.). However, comparing data from different locations and different seasons requires the consideration of temperature and moisture conditions, and this can only be fulfilled in laboratory experiments. Because feeding activity in the field depends on weather conditions the results of different study periods cannot be compared.

In both months (May and September), feeding activity was highest in the uppermost soil horizon (0–15 mm), probably due to the contribution of both euedaphic and hemiedaphic animal species. Plant cover may have positively influenced the biological activity in the upper layer in May. The presence of a dense wickerwork of roots enhances soil porosity and

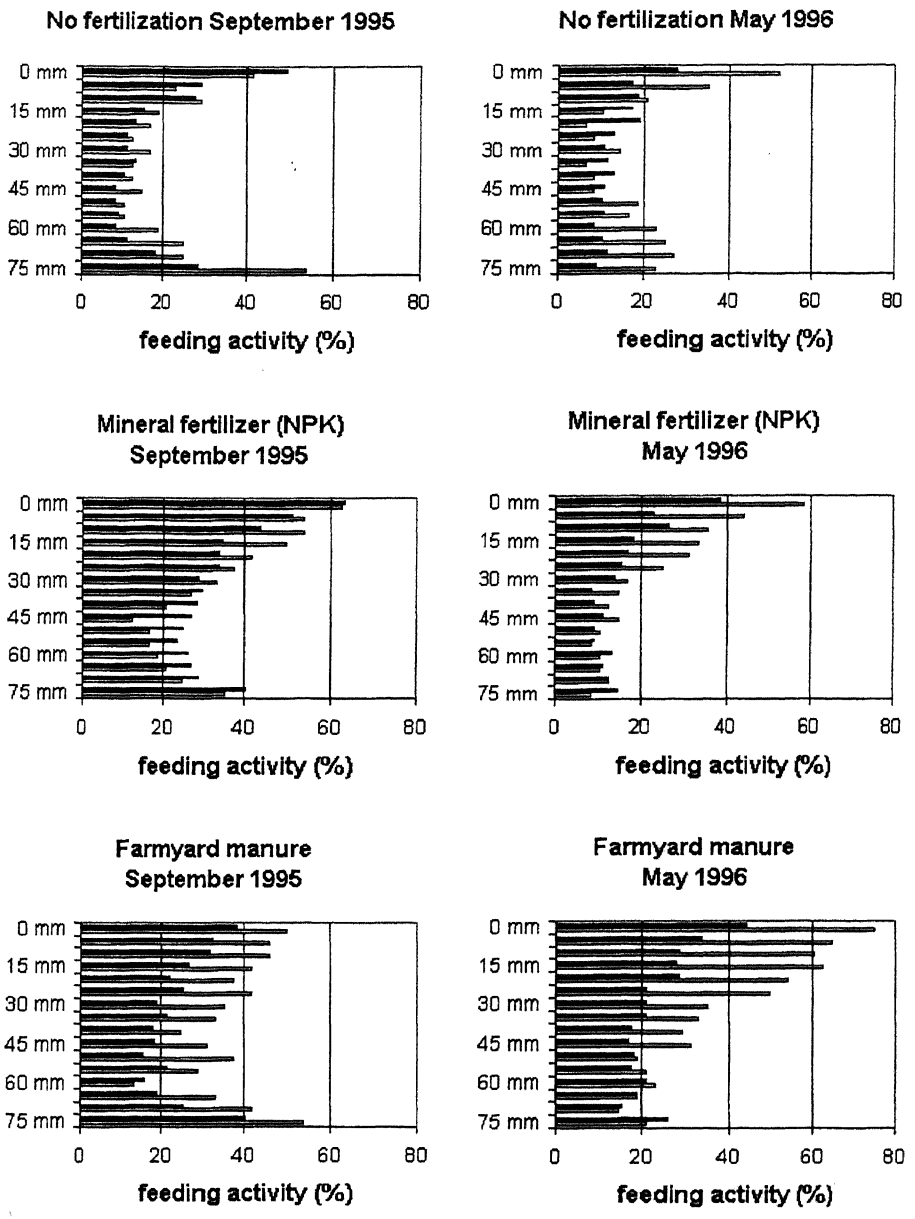

Figure 4: Crop rotation vs. monoculture: biological activity (% feeding activity) in different soil depth from 0–75 mm in the plots with farmyard manure, mineral fertilizer and no fertilization in September 1995 and May 1996. Open bars indicate plots with monoculture, black bars indicate plots with crop rotation

Abbildung 4: Fruchtfolge vs. Monokultur: biologische Aktivität (% Freßaktivität) in unterschiedlichen Bodentiefen von 0-75mm in den Parzellen mit Stallmist, Mineraldünger und ohne Düngung im September 1995 und Mai 1996. Weiße Balken bezeichnen Parzellen mit Monokultur, schwarze Balken Parzellen mit Fuchtfolge

organic matter content, resulting in an increase of soil organisms (FRANZ, 1950). Enchytraeids occur mostly in the uppermost soil layer, where they feed on organic matter, root exudates and micro-organisms (DIDDEN, 1993).

In laboratory experiments, PFEIFF et al. (1998) established that potworms, as an important element of the soil mesofauna, feed on the bait substance. Our investigations pointed out a distinct negative influence of the dead fallow both on the total biological activity in the soil and on the enchytraeid abundance. This reduced feeding activity is only evident in the following year. The reasons for this are that a closed plant cover changes the micro-climate, while residues can be used directly by the soil animals as a food resource or indirectly by feeding on micro-orga-

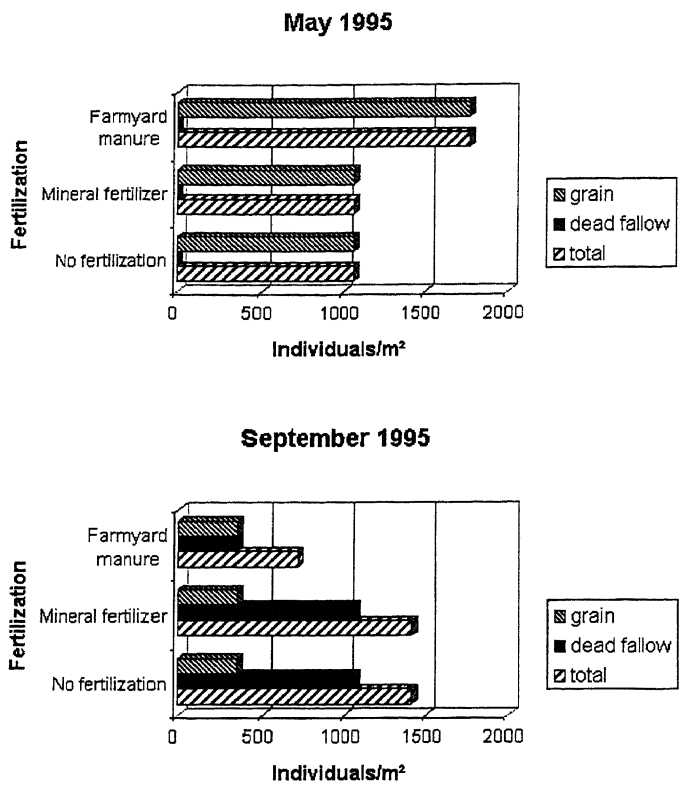

Figure 6: Dead fallow vs. cultivation of grain: enchytraeid abundance (median) in the plots with farmyard manure, mineral fertilizer and no fertilization in May and September 1995

Abbildung 6: Schwarzbrache vs. Getreideanbau: Enchytraeiden-Abundanz (Median) in den Parzellen mit Stallmist, Mineraldünger und ohne Düngung im Mai und September 1995

nisms. Due to the absence of vegetation the upper soil layer is more desiccated and more exposed to harsh environmental conditions. The negative effect of the dead fallow, which was a part of the crop rotation, resulted in a lower biological activity compared to the plots with monocultures.

The continuous cultivation of winter rye in our long-term crop rotation and fertilization experiment depressed the yield, a result which mineral fertilizer or farmyard manure failed to prevent (STEINECK and RUCKENBAUER, 1976). However, no negative effect on the biological activity in the soil was ascertained in the 1995/96-study period. The treatment with farmyard manure caused a lower feeding activity than chemical fertilizer in September 1995. One reason may be that the dung which was ploughed into the upper 10 cm of the soil in mid-August was not completely decomposed by September, when the bait-laminae were exposed. FRANZ (1950) reported that the dominance structures of soil animals in fresh manure differ from those in the surrounding soil. Only after advanced decay, does the dominance structure change towards characteristic soil-living species. The products of decomposition can harm soil organisms. Fertilizers, with high nitrogen content, can be toxic to enchytraeids by changing the soil pH and conductivity (LAGERLÖF et al., 1989). Another reason for the lower biological activity in the plots with farmyard manure in September could be the soil management carried out in late August. Every soil management changes the humidity and content of organic matter: this represents an "elementary catastrophe" for soil dwelling organisms. This affects enchytraeid numbers more than different kinds of cultivation (LAGERLÖF et al., 1989). After a sudden depression of soil biomass due to soil management, biological activity increases again; this increase is mostly interrupted by the harvest crop (FRANZ, 1950).

Our results showed that the bail-lamina-test is a useful method to assess changes of complex soil processes dependent on cultivation, soil management and fertilization. Even after one year the negative effect of the dead fallow could be detected. Enchytraeid abundance recovered within a shorter period than total biological activity. By means of the bait-lamina-test, changes in the soil ecosystem can be detected more efficiently than by determination of the abundance of single soil animal groups.

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