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Article *in* Biology and Fertility of Soils · September 2004

DOI: 10.1007/s00374-004-0772-0

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Biol Fertil Soils (2004) 40: 222–229
DOI 10.1007/s00374-004-0772-0

ORIGINAL PAPER

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Effects of traditional and biodynamic farmyard manure amendment on yields, soil chemical, biochemical and biological properties in a long-term field experiment

Received: 7 October 2003 / Revised: 25 May 2004 / Accepted: 27 May 2004 / Published online: 12 August 2004

Abstract We studied the effects of applications of traditionally composted farmyard manure (FYM) and two types of biodynamically composted FYM over 9 years on soil chemical properties, microbial biomass and respiration, dehydrogenase and saccharase activities, decomposition rates and root production under grass-clover, activity and biomass of earthworms under wheat, and yields in a grass-clover, potatoes, winter wheat, field beans, spring wheat, winter rye crop rotation. The experiment was conducted near Bonn, on a Fluvisol using a randomised complete block design (n=6). Our results showed that plots which received either prepared or non-prepared FYM (30 Mg ha^{-1} year^{-1}) had significantly increased soil pH, P and K concentrations, microbial biomass, dehydrogenase activity, decomposition (cotton strips), earthworm cast production and altered earthworm community composition than plots without FYM application. Application of FYM did not affect the soil C/N ratio, root length density, saccharase activity, microbial basal respiration, metabolic quotient and crop yields. The biodynamic preparation of FYM with fermented residues of six plant species (6 g Mg^{-1} FYM) significantly decreased soil microbial basal respiration and metabolic quotient compared to non-prepared FYM or FYM prepared with only *Achillea*. The biodynamic preparation did not affect soil microbial biomass, dehydrogenase activity and decomposition during 62 days. However, after 100 days, decomposition was significantly faster in plots which received completely prepared FYM than in plots which received no FYM, FYM without preparations or FYM with the *Achillea* preparation. Furthermore, the application of completely prepared FYM led to significantly higher biomass and abundance of endogeic or anecic earthworms than in plots where non-prepared FYM was applied.

Keywords Cattle manure · Organic farming · Soil quality · Soil ecology · Organic fertiliser

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Introduction

Organic agriculture is a production system which avoids or largely excludes the use of synthetically produced fertilisers, pesticides, growth regulators and livestock feed additives relying instead on crop rotations, crop residues, animal manures, legumes, green manures, and aspects of biological pest control to maintain soil productivity and tilth, to supply plant nutrients and to control insects, weeds and other pests (Lampkin 1990). A growing number of studies show that organic farming leads to higher soil quality and more biological activity in soil than conventional farming (e.g. Reganold 1988; Alföldi et al. 1993; Drinkwater et al. 1995; Droogers and Bouma 1996). These organic systems have also been shown to use fertilisers and energy more efficiently than conventionally managed systems (Mäder et al. 2002) and to be just as economically viable as conventional farms (Reganold et al. 1993; Reganold and Palmer 1995).

Biodynamic agriculture has many similarities to other organic agricultural systems and relies heavily on composted farmyard manure (FYM) as a fertiliser. Additionally, biodynamic farming uses field sprays and compost preparations consisting of specific minerals or plants treated or fermented with animal organs, water and/or soil (Steiner 1924). Since biodynamic preparations are added to composting organic material in very low doses of a few grams per ton of compost material, the primary purpose of these preparations is not to add nutrients, but to stimulate the processes of nutrient and energy cycling, hasten decomposition and to improve soil and crop quality (Koepf 1993). Generally, biodynamic compost additives are made from six different plant species (Steiner 1924):

flowers of yarrow (*Achillea millefolium* L.), chamomile (*Matricaria chamomilla* L.), dandelion (*Taraxacum officinale* Web.) and valerian (*Valeriana officinalis* L.), bark of oak (*Quercus robur* L.) and whole plant of stinging nettle (*Urtica dioica* L.). Several studies demonstrated that biodynamically treated composts maintained a significantly higher temperature throughout the composting period, suggesting more thermophilic microbial activity and/or faster development of compost with biodynamic treatment (von Wistinghausen 1984; Koepf 1989; Carpenter-Boggs et al. 2000b). As a fertiliser, biodynamic FYM has been shown to increase soil organic C and N (Abele 1978), microbial biomass and biological activity (Mäder et al. 1995), and decrease extractable P (Penfold et al. 1995) compared to fertilisation without biodynamic preparations. However Carpenter-Boggs et al. (2000a) did not find effects of biodynamic preparations on selected soil parameters. The functional relationships between biodynamic compost preparations and the composting process are still not fully understood.

The objectives of the current work were to determine whether the application of traditionally and/or biodynamically composted cattle manure can affect chemical, biochemical and biological soil parameters, root production and yields in an organically managed six-course crop rotation design. The experiment was established in 1993 and has been maintained ever since by applying the same amount of differently biodynamically prepared FYM. Data presented here are from the eighth and ninth year after starting the experiment.

Materials and methods

Site description and experimental design

The experimental site is located on the Wiesengut certified organic research farm of the Institute of Organic Agriculture, University of Bonn (65 m a.s.l.; 7°17′E, 50°48′N). The mean annual air temperature at this location is 9.5°C, and the mean annual precipitation is about 700 mm. Twenty-four 6 m×10-m experimental field plots were established in 1993 on a Fluvisol and were maintained within the six-course crop rotation design of the research farm. The rotation consists of the six main crops grass-clover, potatoes, winter wheat, field beans, spring wheat, and winter rye with an undersown red clover-grass mixture. Four treatments (see below) were arranged in a randomised complete block design with six replicates. Soil cultivation, sowing and mechanical weed management (e.g. harrowing) which are not part of the experimental design were identical among all experimental plots and were performed on similar dates and in a similar manner to adjacent fields. No substances to raise soil pH levels had been applied to the experimental plots in order to avoid interactions with the treatments under study. Soil conditions at the location were similar prior to the establishment of experimental plots (Table 1).

FYM treatment

Cattle manure from the research farm was composted each autumn in a straw-covered windrow composting system, beginning in November 1992. Four treatments were applied to the experimental plots: (1) no FYM application, (2) application of FYM without addition of biodynamic compost preparations (further called FYM without preparations), (3) application of FYM with biodynamic compost preparation of yarrow blossoms (FYM+*Achillea*), (4) application of FYM with biodynamic compost preparation of flowers of yarrow, chamomile, dandelion, stinging nettle shoots, oak bark and valerian extract (FYM+all preps). On average over the experimental years, about 3-month-old composts (rotting period between 60 days and 110 days) were manually applied to field plots in February or March of each year, beginning in 1993 at 30 Mg fresh mass ha^{-1} (average dry matter content 25%). The three types of composted FYM contained similar concentrations of nutrients: on average 394±8 g organic C kg^{-1}, 22±1 g total N kg^{-1}, 216±2 g available K kg^{-1} and 46±4 g available P kg^{-1}.

Biodynamic FYM was prepared as reported in Koepf et al. (1980). Briefly, after heaping up three similar piles of thoroughly mixed cattle manure (about 1.5 Mg fresh mass each), we bored six 50-cm-deep holes into one compost pile using a rod and poured each preparation into a separate hole. The valerian preparation is a liquid and was stirred into 8 l tap water before being poured on top of the compost pile (FYM+all preps). The FYM+*Achillea* treatment was prepared by pouring the yarrow preparation into a single 50-cm-deep hole of the second compost pile. The holes in the compost piles were then filled with cattle manure. The third compost pile did not receive any preparation (FYM without preps). In total, 9–10 g preparation was added to about 1.5 Mg cattle manure. All compost piles received the same amount of water as was applied with the valerian preparation.

Soil chemistry, soil respiration, microbial biomass and enzyme activity

Ten soil samples per plot were collected from a central area of 3m×8m under grass-clover in September 2001 at 0–10 cm and 10–20 cm soil depth. Samples were pooled, air dried, sieved (<2 mm) and analysed for soil pH, organic C, total N, soluble P and soluble K concentrations. Soil pH was measured in $CaCl_2$ suspension (1:10, mass/vol) using a glass electrode. Soil total C and total N concentration were determined by dry combustion with a CHN analyser (Carlo Erba, Rodano, Italy), available P and K concentrations were determined photometrically after double lactic acid extractions (Riehm 1948). On the samples collected in September 2001 we also determined basal respiration and soil microbial biomass from substrate-induced respiration [mg microbial C

Table 1 Initial soil conditions (soil depth 0–30 cm) for pH, C/N, available P and K on experimental plots in 1993 prior to establishment of treatments [farmyard manure (*FYM*), biodynamic preparation (*prep*)]. Means±SE, *n*=6. Two-way ANOVA with block and treatment as factors showed no significant differences at $P<0.05$ between plots

Imposed treatments	Soil pH	C/N	Available P (mg P kg^{-1})	Available K (mg K kg^{-1})
No FYM	5.35 ± 0.04	11.4 ± 0.2	59.1 ± 6.5	189.6 ± 36.2
FYM without preps	5.39 ± 0.03	9.4 ± 1.7	51.9 ± 5.9	204.4 ± 21.1
FYM+*Achillea* prep	5.36 ± 0.01	11.3 ± 0.2	72.7 ± 2.4	233.5 ± 21.5
FYM+all preps	5.34 ± 0.04	11.2 ± 0.2	63.5 ± 6.1	229.7 ± 13.3

Table 2 Soil conditions in experimental plots under grass-clover (2001) fertilised since 1993 with differently prepared FYM. Results for the same soil depth followed by *different letters* are statistically different at P=0.05 (Tukey-Kramer LSD test). Mean±SE, n=6. For abbreviations, see Table 1

Treatment	Soil pH	C/N	Available P (mg P kg^{-1})	Available K (mg K kg^{-1})
Soil depth 0–10 cm				
No FYM	5.17 ± 0.03 c	11.4 ± 0.1 a	51.0 ± 4.2 b	81.1 ± 3.3 b
FYM without preps	5.36 ± 0.04 a	11.6 ± 0.1 a	63.2 ± 1.4 a	184.9 ± 6.2 a
FYM+*Achillea* prep	5.27 ± 0.03 ab	11.3 ± 0.2 a	66.4 ± 3.3 a	180.1 ± 7.6 a
FYM+all preps	5.25 ± 0.02 bc	11.6 ± 0.1 a	63.4 ± 1.8 a	188.1 ± 8.0 a
Soil depth 10–20 cm				
No FYM	5.09 ± 0.02 b	10.8 ± 0.2 b	52.9 ± 4.4 b	75.0 ± 6.4 b
FYM without preps	5.29 ± 0.03 a	11.3 ± 0.1 a	68.6 ± 1.8 a	171.4 ± 7.3 a
FYM+*Achillea* prep	5.25 ± 0.03 a	11.5 ± 0.2 a	65.6 ± 7.4 a	174.3 ± 8.3 a
FYM+all preps	5.26 ± 0.01 a	11.1 ± 0.1 ab	65.1 ± 6.4 a	179.8 ± 10.6 a

(C_{mic}) g^{-1} soil dry mass] by measuring its O_2 consumption (SAPROMAT, H+P Labortechnik, Oberschleissheim/Munich; Anderson and Domsch 1978). As an indicator of the C dynamics in the soil, we calculated the microbial biomass-to-organic C (C_{org}) ratio (C_{mic}/C_{org}) (Anderson and Domsch 1989). The energetic efficiency of the microbial community is expressed by the metabolic quotient, calculated by dividing basal respiration by microbial biomass (Anderson and Domsch 1990). On these soil samples we also determined dehydrogenase activity by reducing 2,3,5-triphenyltetrazolium chloride to triphenylformazan (Thalmann 1968) and saccharase activity by hydrolysis of sucrose (Hofmann and Hoffmann 1966).

Root length density

Four soil samples per plot (diameter 5 cm, 0–20 cm soil depth) were taken in September 2001 under grass-clover to measure root length density and root biomass. Soil cores were cut into half to be able to differentiate between the 0–10 cm and 10–20 cm soil layers. All apparently fresh roots of the cores were washed free of soil by using a uniform amount of water over the same time span for each core. After washing, roots were preserved in 70% ethanol until further analysis. Root length was measured using an image analysis software (Scion Image for Windows, Scion, Frederick, Md.).

Decomposition

Decomposition activity of soil was measured using 8 cm×10-cm organically produced cotton strips sewn into mesh bags (mesh size: 1 mm). Six decomposition bags were inserted vertically in each experimental plot in spring 2002 at 0–10 cm and 10–20 cm soil depth, respectively. After 62 days, two bags per plot were removed; the remaining bags were collected after 100 days (harvest of spring wheat). Collected decomposition bags were cleaned from attached soil using a household washing machine, oven-dried and weighed. Decomposition rate is expressed as the cotton strip dry mass remaining after decomposition relative to initial dry mass of cotton strips.

Earthworm activity and earthworm population size

Surface cast production was measured on average every 9 days under spring wheat from 5 April to 27 July 2002 on two permanent sampling areas in each experimental plot. Casts were collected, oven-dried (80°C, 24 h) and weighed. Earthworm biomass was determined in October 2002 after a mustard-water extraction (Gunn 1992). To achieve this, we pressed two 50 cm×50-cm metal frames per plot about 5 cm into the soil and filled each with 15 l tap water containing 85 g mustard (Düsseldorfer Löwensenf extra scharf, Düsseldorf). All earthworms appearing on the surface of the sampling area within 30 min were collected, weighed, counted and identified at the species level according to Schaefer (1992) and assigned to one of four ecological groups (epigeic, anecic, endogeic and an intermediate endogeic/anecic group) (Bouché 1977). Epigeic earthworm species live in or near the surface litter feeding primarily on coarse particulate organic matter. Endogeic species live within the soil profile and predominantly feed on soil and associated organic matter, whereas anecic species live in vertical burrow systems and are believed to feed primarily on surface litter which they pull into their burrows. Intermediate species cannot be assigned to a particular ecological group (Bouché 1977; Edwards and Bohlen 1996).

Crop yields

Crops were harvested on a central 3 m×8-m area of each experimental plot using special plot combine harvesting machinery (Hege, Waldenburg, Germany). With the exception of potato yields, all yield data were expressed on a dry mass basis and cereal yields were based on 14% water content. Relative yields of plots which received either prepared or non-prepared FYM were calculated relative to yields in plots which received no FYM within the same experimental block.

Statistical analyses

Initial soil conditions and earthworm population data were analysed by two-way ANOVA with block and treatment as factors. All other soil parameters were analysed using a three-way ANOVA with block, treatment and soil depth as factors. A two-way repeated measurement ANOVA was conducted on the earthworm surface cast production data. Crop yield data were analysed by three-way ANOVA with block, treatment and year as factors. All analyses were conducted using the general linear model procedure in SAS (version 8.02; SAS Institute, Cary, N.C.) and were followed by least squares means comparisons after Tukey-Kramer (Zar 1996). Values given within the text are means±SE (n=6).

Results

Soil pH (P<0.0001), C/N ratio (P=0.016), available P (P=0.002) and available K (P<0.0001) contents were all significantly increased by FYM application (Table 2). With the exception of available P, contents were generally lower in the deeper soil layers than in surface layers (depth effect P=0.016, P=0.002 and P=0.087, for pH, C/N and K,

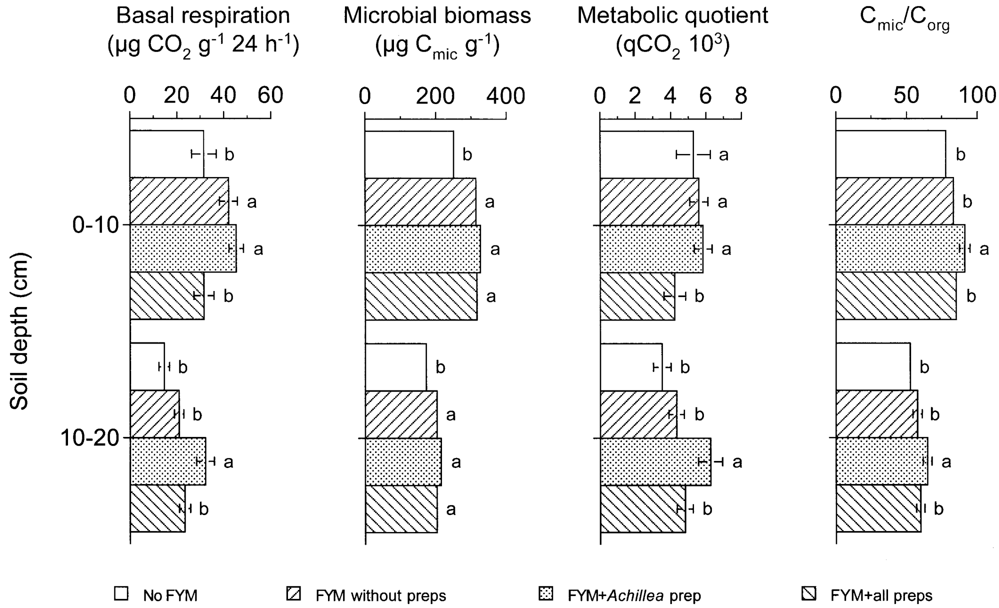

Fig. 1 Basal respiration, microbial biomass and metabolic quotient (*qCO_2*) in soil samples in experimental plots under grass-clover maintained since 1993 either with differently prepared biodynamic farmyard manure [*FYM+Achillea*, FYM +all biodynamic preparations (*FYM+all preps*)], not prepared FYM (*FYM without preps*) or no FYM application (sampling date: September 2001). Means ±SE, *n*=6. Small error bars are not depicted. *Different letters* indicate statistical significant differences at *P*<0.05 within a soil depth (Tukey-Kramer LSD test)

respectively). A significant treatment×depth interaction occurred only for C/N (*P*=0.035). The biodynamic preparation of FYM with all six preparations led to significantly lower soil pH in the upper soil layer (0–10 cm) compared to non-prepared FYM (Table 2). All other chemical soil parameters studied remained unaffected by biodynamic preparations.

FYM application significantly affected the basal respiration (*P*=0.009), microbial biomass (*P*<0.001), metabolic quotient (*P*=0.049) and C_{mic}/C_{org} ratio (*P*<0.001) of soil samples (Fig. 1). Basal respiration, microbial biomass and C_{mic}/C_{org} were significantly lower in deeper soil layers (depth effect *P*<0.001 for all three parameters), whereas metabolic quotient was not affected (depth effect *P*=0.126; Fig. 1). Treatment×depth interaction was significant for microbial biomass (*P*=0.027) and marginally significant for the metabolic quotient (*P*=0.075, Fig. 1). Among the treatments with FYM application, the biodynamic preparations significantly affected basal respiration and C_{mic}/C_{org} ratio at both soil depths. In the upper soil layer, basal respiration in plots receiving FYM prepared with all biodynamic preparations was significantly lower than in plots which received FYM without preparations or FYM just prepared with the *Achillea* preparation (Fig. 1). In the lower soil layer plots which received FYM with the *Achillea* preparation showed significantly higher basal respiration than plots without FYM application or application of FYM with no or the total preparation (Fig. 1). Soil microbial biomass was significantly higher in plots receiving FYM in both soil layers; however, the biodynamic preparation of FYM did not influence microbial biomass in soil samples (Fig. 1). Metabolic quotient in the upper soil layer was significantly lower in plots which received completely prepared FYM than in plots which received no FYM or received FYM without preparations or with the *Achillea* preparation (Fig. 1). In the deeper soil layer, the metabolic quotient in plots receiving FYM with the *Achillea* preparation was significantly higher than in plots receiving no FYM or FYM without preparations or completely prepared FYM (Fig. 1). The C_{mic}/C_{org} ratio was in both layers significantly higher in plots which received *Achillea* than in totally prepared or no FYM plots (Fig. 1). Dehydrogenase activity was significantly affected by imposed treatments (treatment effect *P*<0.001), was significantly lower in deeper soil layers (depth effect *P*<0.001, treatment×depth effect *P*=0.037; Fig. 2), and remained unaffected by biodynamic preparations (Fig. 2). Saccharase activity was significantly lower in deeper soil layers; however, was in neither soil layer affected by the FYM treatments applied (treatment effect *P*=0.158; Fig. 2).

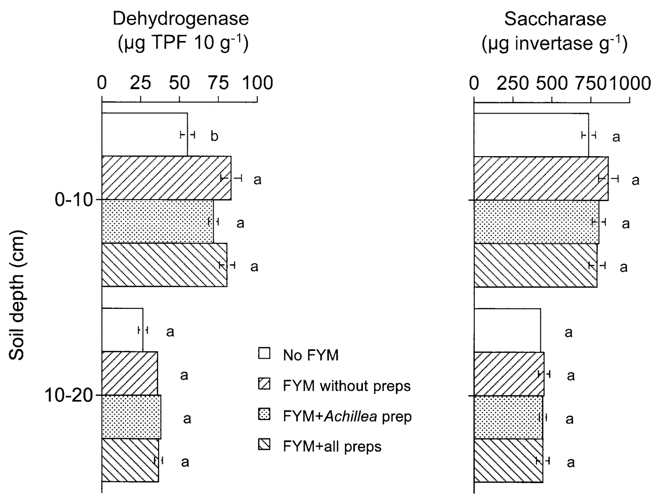

Fig. 2 Dehydrogenase and saccarase activity in experimental plots under grass-clover maintained since 1993 either with differently prepared biodynamic FYM (FYM+*Achillea*, FYM+all preps), FYM without preps or no FYM application (sampling date: September 2001). Means±SE, *n*=6. *Different letters* indicate statistical significant differences at *P*<0.05 within a soil depth (Tukey-Kramer LSD test). *TPF* Triphenylformazan; for other abbreviations and terms, see Fig. 1

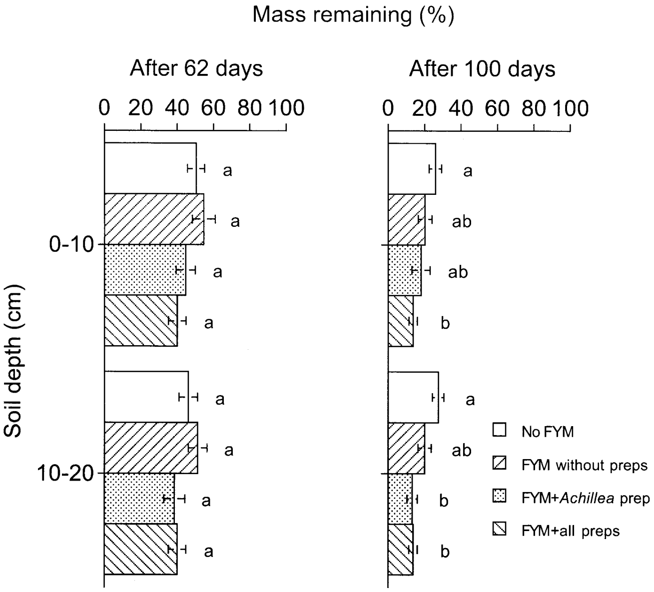

Fig. 3 Decomposition of cotton strips buried in experimental spring wheat plots maintained since 1993 either with differently prepared biodynamic FYM (FYM+*Achillea*, FYM+all preps), FYM without preps or no FYM application (sampling date: spring/summer 2002). Means±SE, n=6. *Different letters above bars* indicate statistical significant differences at P<0.09 (Tukey-Kramer LSD test). For abbreviations and terms, see Fig. 1

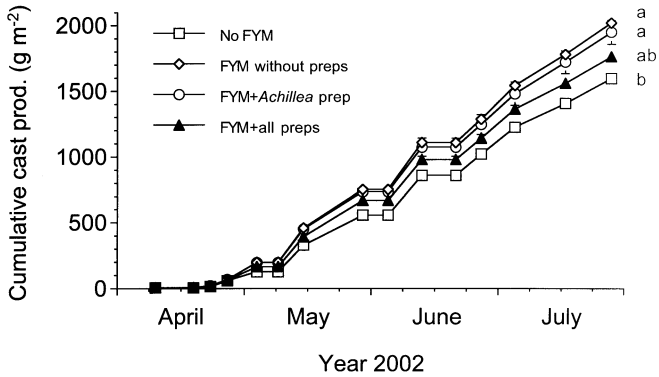

Fig. 4 Surface cast production (*prod.*) of earthworms in experimental spring wheat plots maintained since 1993 either with differently prepared biodynamic FYM (FYM+*Achillea*, FYM+all preps), FYM without preps or no FYM application. Means±SE, n=6. Small error bars are not depicted. *Different letters* indicate statistical significant differences at P<0.05 (Tukey-Kramer LSD test). For other abbreviations and terms, see Fig. 1

Root length density under grass-clover was unaffected by FYM application or biodynamic preparations and averaged across treatments was 23±2 cm cm^{-3} in 0–10 cm and 26±4 cm cm^{-3} in 10–20 cm soil depths (treatment effect P=0.221, depth effect P=0.041; no treatment×depth interaction occurred for root length density). Decomposition of cotton strips (Fig. 3) was marginally significantly different between treatments after 62 days (treatment effect P=0.056) and highly significantly different after 100 days (treatment effect P<0.001). While decomposition was similar in both soil layers after 62 days (depth effect P=0.264) it was significantly faster in upper soil layers than in deeper soil layers after 100 days (depth effect P=0.038). Biodynamic preparation of FYM did not influence decomposition during the first 62 days. However, after 100 days decomposition in the 0–10 cm depth was significantly faster in plots which received totally prepared FYM than in plots receiving no FYM, FYM without preparations or FYM with the *Achillea* preparation (Fig. 3). In the deeper soil layers, decomposition in plots receiving FYM without preparations was similar to in non-fertilised plots, whereas it was significantly faster in plots receiving FYM with *Achillea* and FYM with the total biodynamic preparation than in plots receiving no FYM (Fig. 3).

Cumulative surface cast production of earthworms in the experimental plots under spring wheat was significantly affected by FYM application (repeated measures ANOVA, treatment effect P<0.007; Fig. 4). Earthworms in plots which received no FYM produced 20% less surface casts than earthworms in plots receiving non-prepared FYM or FYM with the *Achillea* preparation. Species composition and size of earthworm communities was not affected by FYM applications (averaged across treatments 73±12 earthworms m^{-2}, P=0.175; 38±7 g m^{-2}, P=0.236). We found the following six species of earthworms across all treatments: epigeic species *Aporrectodea caliginosa* Sav., endogeic species *Aporrectodea limicola* Mich., intermediate species (anecic/endogeic, epigeic/endogeic) *Allolobophora chlorotica* Sav., *Aporrectodea rosea* Sav. and *Lumbricus rubellus* Hoffm., and anecic species *Lumbricus terrestris* L. The relative contribution of certain ecological groups to earthworm communities was sig-

Table 3 Crop yields relative to no FYM application on experimental plots maintained since 1993 with differently prepared FYM applications. No data are available for 1994. Means±SE, n=6. No significant differences at P<0.05 were determined on relative yields within years. For abbreviations, see Table 1

Crop	Year	Relative yields (yields without FYM=100)		
		FYM without preps	FYM+*Achillea* prep	FYM+all preps
Spring wheat	1993	109 ± 4	106 ± 3	109 ± 4
Grass-clover	1995	90 ± 5	100 ± 5	103 ± 5
Potatoes	1996	110 ± 5	110 ± 2	109 ± 3
Winter wheat	1997	137 ± 8	132 ± 11	138 ± 8
Field beans	1998	103 ± 4	102 ± 3	95 ± 4
Spring wheat	1999	126 ± 6	118 ± 4	126 ± 5
Winter rye	2000	99 ± 3	98 ± 3	99 ± 3
Grass-clover	2001	112 ± 8	113 ± 7	118 ± 6
Spring wheat	2002	102 ± 3	101 ± 7	103 ± 5

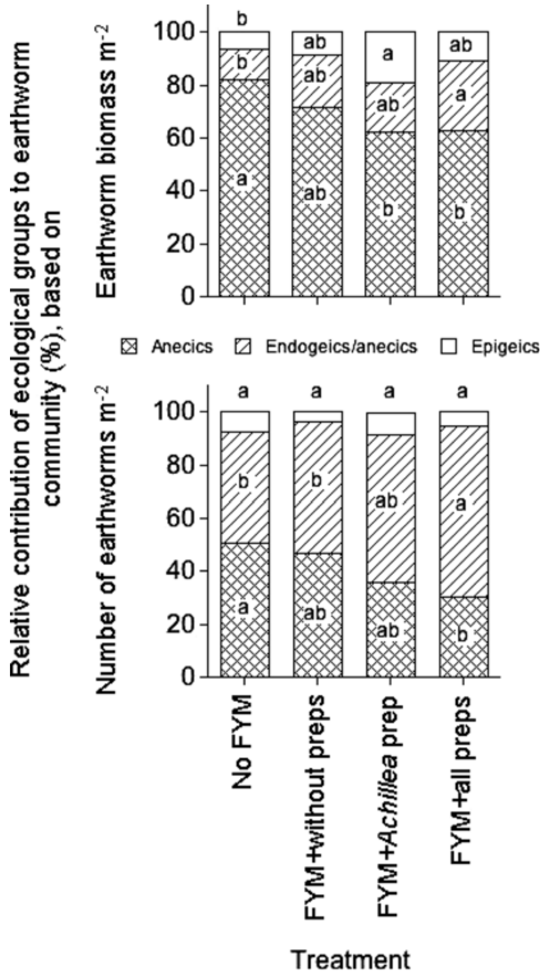

Fig. 5 Composition of earthworm communities in experimental spring wheat plots maintained since 1993 either with differently prepared biodynamic FYM (FYM+*Achillea*, FYM+all preps), FYM without preps or no FYM application (Sampling date: Autumn 2002). Means, n=6. *Different letters* indicate statistical significant differences at P<0.05 (Tukey-Kramer LSD test). For abbreviations and terms, see Fig. 1

nificantly affected by FYM application (treatment effects for relative contribution based on number of earthworms m^{-2}, epigeics P=0.597, endogeics P=0.420, endogeics/anecics P=0.010, anecics P=0.038; treatment effect for relative contribution based on earthworm biomass m^{-2}, epigeics P=0.092, endogeics P=0.419, endogeics/anecics P=0.052, anecics P=0.053; Fig. 5). Earthworms of the intermediate ecological group (endogeics/anecics) were marginally significantly more numerous (P=0.071) and had significantly more biomass (P=0.033) in plots treated with completely prepared FYM than in plots treated with not prepared FYM (Fig. 5). Anecic species were significantly less numerous in plots which received completely prepared FYM than in non-FYM plots (P=0.007; Fig. 5).

Crop yields on experimental plots were significantly affected by the FYM treatment applied (treatment effect P=0.003) and varied significantly between years (year effect P<0.001, treatment×year interactions P=0.508; Table 3). However, yields among plots which received FYM remained in all years unaffected by biodynamic preparations (Table 3).

Discussion

Generally, our results from this 9-year field experiment show various significant (P<0.05) alterations in measured soil parameters due to FYM application. This finding is not new and agrees with the results from several other experiments investigating the effects of composted manure application in organically managed field experiments (Reganold and Palmer 1995; Raupp 1995; Mäder et al. 1996; Fließbach et al. 2000; Willson et al. 2001; Whalen and Chang 2002). Plots which did not receive FYM over 9 years showed about 20% lower C_{mic}, 35% lower dehydrogenase activity, 20% lower earthworm activity, 10% lower yields, slightly lower decomposition rates, and similar earthworm population sizes than, plots receiving composted manure. These relatively slight decreases in soil biological activity and yields indirectly also reflect the success of organic farming strategies aiming at sustaining high soil biological quality and activity through a well-balanced crop rotation design.

More remarkably, however, are significant alterations in soil pH, basal respiration, metabolic quotient, C_{mic}/C_{org}, decomposition rate, and earthworm community composition due to the biodynamic preparation of applied FYM. Other long-term studies have also documented higher soil pH, total C and N concentrations (Alföldi et al. 1993), microbial biomass, dehydrogenase and saccharase activity in biodynamically managed field plots than in organically managed plots (Mäder et al. 1993). In contrast, other short-term studies, did not find differences in microbial parameters and earthworm populations between organically and biodynamically managed soils (Carpenter-Boggs et al. 2000a). To our knowledge, the current study is the first one investigating possible effects of specific biodynamic compost preparations on an extensive number of soil parameters in a long-term field experiment. How those very low-dose preparations can affect soil processes is still not clear; however, there is evidence that biodynamic preparations can already alter the composting process resulting in increased temperature within the compost piles, affecting the microbial community and phospholipid fatty acid concentration of dairy manure compost (Carpenter-Boggs et al. 2000b).

Soil basal respiration is considered to reflect the availability of C for microbial maintenance and is a measure of basic turnover rates in soil (Insam et al. 1991). In our study, plots which received FYM prepared with *Achillea* extract had higher respiration rates and thus higher turnover rates than plots which received completely prepared or non-prepared FYM. A significantly reduced metabolic quotient in the upper soil layers in plots which received completely prepared FYM compared to plots which received no FYM or *Achillea*-prepared FYM indicates a more efficient microbial turnover due to biodynamic FYM preparation (Insam and Domsch 1988; Insam and Haselwandter 1989). Thus, microbial communities in plots receiving completely prepared FYM seem to be able to use organic substances more for growth than for maintenance (Mäder et al. 2002) and that nutrient turnover is accomplished at low C costs (Insam et al. 1991). Differences in soil metabolic quotient are also often discussed as a reaction to environmental stress or different microbial community structure. In our study metabolic quotient in plots receiving completely prepared FYM was significantly lower than in other plots, indicating a less stressed soil environment and a more diverse microbial community structure (Fließbach and Mäder 1997), thus leading to higher metabolic efficiency of the soil microbes (Fließbach and Mäder 2000). The lower basal respiration and metabolic quotient could also reflect differences in compost quality indicating that FYM prepared with all six preparations is more mature with less available C and a greater proportion of humified material than the other FYM types tested. We also found significantly higher C_{mic}/C_{org} ratios in plots which received FYM prepared with *Achillea*. This is in line with findings of Fließbach and Mäder (2000) who also reported higher C_{mic}/C_{org} ratios from biodynamic systems in comparison to unmanured or conventional systems.

Plant materials have been shown to decay more completely in organic systems with increasing amounts of microbial biomass compared to conventional systems (Fließbach and Mäder 2000). In our study decomposition rates were additionally affected by biodynamic preparations indicating that the qualitative properties of biodynamic FYM also favours decomposer organisms in soils. Like other studies, we did not find any effect of biodynamic preparations on earthworm activity (Pfiffner et al. 1993) or earthworm community size (Carpenter-Boggs et al. 2000a). However, considering a 4-year data set, Pfiffner and Mäder (1997) found significantly fewer earthworm individuals in 1 year in biodynamic plots compared to other organic or unfertilised plots. In the current study we determined significant alterations in the composition of earthworm communities, resulting in a lower contribution of anecics and a higher contribution of endogeics/anecics in plots receiving completely biodynamically prepared FYM compared to plots where no or non-prepared FYM was applied. This indicates that differences in compost qualities due to the biodynamic preparations stimulated earthworms living in the soil more than those feeding on organic material from the soil surface. This may have wide ecological implications because earthworm communities in our plots are largely comprised of endogeic and/or anecic species which are known to be important in the establishment and maintenance of soil structure (Springett 1983; Scheu 1987). Pfiffner et al. 1993 found a lower contribution of endogeics in biodynamic plots compared to organic plots under beet roots. Different plant species with different nutrient contents and root systems have been shown to affect earthworm communities differently (Edwards and Bohlen 1996) and can thus be an explanation for these contrasting results.

In conclusion, our results show that: (1) organic farming systems using composted FYM as fertilisers can stimulate biological soil activity and thus support soil quality and fertility, and (2) the application of biodynamically prepared compost can significantly alter microbial turnover, decomposition rates and earthworm community composition in soils which may, however, not necessarily translate into effects on crop yields.

Acknowledgements We are very grateful to Christian Dahn, Frank Täufer, Henning Riebeling and Johannes Siebigteroth for maintaining field plots throughout the years. Thanks to Gerd Welp and Marina Anissimova for providing their laboratory facilities for microbial analyses and their advice on this. Thanks also to Dieter Zedow, Kim Schieve, Thomas Gerhardt, Marina Piatto, Harriet Leese, Birgit Stöcker and Sonja Reinhardt for conducting soil laboratory analyses and helping with field sampling. The Institute of Biodynamic Agriculture, Darmstadt, Germany provided the compost preparations.

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