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Research Article

Effects of two decades of organic and mineral fertilization of arable crops on earthworms and standardized litter decomposition

Auswirkungen von zwei Jahrzehnten organischer und mineralischer Düngung von Ackerkulturen auf Regenwurmaktivität und standardisierten Streuabbau

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Summary

Organic fertilization has been shown to benefit soil biota. A field experiment was established in 1991 at the AGES experimental research station Ritzlhof to investigate the effects of long-term fertilization on soil biota and crop yields. Experimental plots were cultivated using a crop rotation with maize, wheat, barley, and pea. Eight treatments consisted of compost application (urban organic waste, green waste, cattle manure, and sewage sludge compost). Composts were applied exclusively (organic) or amended with mineral nitrogen (N) fertilizers (80 kg N ha^{-1}, organic-mineral) and compared to 0 (control) and mineral (40, 80, and 120 kg N ha^{-1}) fertilization. Earthworm activity and biomass, litter decomposition, crop growth, and yield parameters were investigated under winter barley (*Hordeum vulgare* L.) in 2014 after uniform mineral fertilization and 1.5 years after the last compost application. Earthworm activity was significantly increased under long-term organic-mineral fertilization compared to the control, whereas earthworm biomass was unaffected by compost application. Litter decomposition rate was highest in the control. Only barley stem growth was affected by fertilization, whereas other barley parameters including yield were unaffected. The results showed that long-term fertilization affects soil biota even if compost is not applied every year.

Keywords: earthworm activity, compost, fertilizer, organic fertilizer, soil biota

Zusammenfassung

Organische Düngung fördert das Bodenleben. An der Versuchsstation Ritzlhof der AGES wurde 1991 ein Feldversuch angelegt, der die Auswirkungen unterschiedlicher Düngung auf das Bodenleben und Ernteerträge untersucht. Die Versuchsparzellen wurden mit der Fruchtfolge Körnermais, Weizen, Gerste und Erbse bestellt. Acht Bewirtschaftungsvarianten umfassten Kompostanwendung (Bioabfallkompost, Grünschnittkompost, Rinder-Stallmist und Klärschlammkompost). Die Komposte wurden allein („organisch") oder mit zusätzlicher mineralischer Stickstoffdüngung (80 kg N ha^{-1}, „organisch-mineralisch") aufgebracht und mit einer Nulldüngung (Kontrolle) und rein mineralischer Düngung (40, 80, 120 kg N ha^{-1} „mineralisch") verglichen. Die Regenwurmaktivität und -biomasse, die Zersetzung der organischen Substanz und Wachstum und Biomasseparameter von Wintergerste (*Hordeum vulgare* L.) wurden 2014 nach einheitlicher Mineraldüngung und eineinhalb Jahre nach der letzten Kompostaufbringung bestimmt. Die Regenwurmaktivität war nach langjähriger organisch-mineralischer Düngung signifikant höher als bei der Kontrolle, während die Regenwurmbiomasse durch Kompostanwendung nicht signifikant beeinflusst wurde. Die Zersetzungsrate war in der Kontrollvariante am höchsten. Nur die Länge der Gersten-Stängel war nach organisch-mineralischer Düngung signifikant höher als in der Kontrolle, alle anderen Parameter der Gerste (einschließlich der Biomasse-Erträge) zeigten keine Unterschiede. Die Ergebnisse zeigten, dass langjährige organisch-mineralische Düngung das Bodenleben beeinflusst, auch wenn Kompost nicht jedes Jahr angewendet wird.

Schlagworte: Regenwurmaktivität, Kompost, Düngung, organische Düngung, Bodenleben

1. Introduction

The use of compost in agriculture aims to conserve finite resources, such as phosphorus, while improving soil fertility. Positive effects of compost application on soils and crops are known from numerous studies (e.g., Hartl and Erhart, 2005; Ros et al., 2006a,b; Erhart and Hartl, 2010; Lehtinen et al., 2017). However, little is known about the effect of decade-long compost amendments on soil life and crop growth parameters. Agricultural by-products such as composts are reported to provide economic value (El-Haggar, 2007) by adding nutrients to the soils, which should be taken into account within fertilization schemes (Lehtinen et al., 2017). Furthermore, soil organic matter (SOM) steadily increases in systems that were treated with farmyard manure compost (Niggli and Fließbach, 2009). Thus, the application of organic material such as composts contributes to CO_2 binding in agricultural soils (Powlson et al., 2011) and may be one measure to achieve the 4permille goal raised at COP21 (UNFCCC 2015), the annual increase of soil organic carbon (SOC) by 0.4%. Besides enhancing SOC and plant available nutrients, long-term compost application increases other chemical, physical, and biological soil quality parameters (Lehtinen et al., 2017). Compost amendment may enhance water infiltration and water storage capacity and make the crop plants more resilient against extreme weather conditions (Mäder et al., 2002; Fließbach et al., 2008). Optimal mineral N fertilization may increase SOC compared to zero N (Dersch and Böhm, 2001), because of the higher crop and root residues. According to Thirukkumaran and Parkinson (2000), ammonium nitrate reduces microbial activities and litter decomposition.

Earthworms are well-known biological indicators for the effects of management practices on soil (Lavelle, 1988; Pfiffner and Luka, 2007; Suthar, 2009). Earthworms are among the most important detritivore animals in agroecosystems, improving soil aeration and mixing mineral soil with organic particles (Edwards and Bohlen, 1995). Usually, organic amendments are reported to benefit earthworms (Pfiffner and Mäder 1997; Suthar, 2009). Especially, earthworm activity, measured by their surface cast production, is a sensitive indicator of fertilization (Zaller and Köpke, 2004). Earthworms in plots that received no farmyard manure produced 20% less surface casts than earthworms in plots that were fertilized with composted farmyard manure for more than 9 years. Hong et al. (2011) reported an enrichment of SOM in earthworm casts; Zhang et al. (2013) elucidated the role of earthworms in stimulating C sequestration. Earthworms also affect soil microorganisms and alter litter decomposition (Hartwich, 2000; Zimmer et al., 2005). Litter decomposition is important in agricultural systems because it releases nutrients from the organic matter that can be used by the soil organisms and ultimately by plants (Coleman et al., 2004; Keuskamp et al., 2013). Increasing SOM by compost amendments may stimulate microbial activity and growth but do not necessarily affect decomposition rates (Hadas et al., 1996).

In this study, we investigated how different long-term organic and mineral fertilization affect the abundance and activity of earthworms, litter decomposition, and the growth and yield parameters. We examined long-term effects after 24 years of different organic and mineral fertilization; in the past 7 years, compost was applied regularly only every second year. The main objective of the study was to assess the effects of the fertilization classes (control, mineral, organic, organic-mineral) and whether long-term compost and/or mineral fertilizer applications show effects even when different compost fertilization was carried out only once in 2 years.

2. Materials and Methods

2.1 Site description and field experiment

The experiment was established in 1991 at Ritzlhof near Linz in Upper Austria (N 48°11'18.42; E 14°15'15.12; altitude 280 m a.s.l.) as described in Ros et al. (2006a, b), Tatzber et al. (2015), and Lehtinen et al. (2017). The soil is classified as a loamy silt Cambisol with 13.6% sand, 69% silt, and 17.4% clay. On an average, soils on this site have a pH ($CaCl_2$) of 6.9, 1.28% of organic C, and 0.14 % of total N in 0–25 cm (Tatzber et al., 2015). The climate is temperate with mean long-term annual temperature of 8.5°C and a mean long-term annual precipitation of 753 mm. Field plots (each 6 m × 5 m) included 12 fertilization treatments with 4 replicates, a detailed description of the experiment is given in Lehtinen et al. (2017) and Tables 1 and 2. The plots were cultivated according to good farming practice using a traditional crop rotation (Table 2). The treatments consisted of a control without nitrogen fertilization (0 kg N), treatments fertilized with mineral N (40 kg N ha^{-1} $year^{-1}$, 80 kg N ha^{-1} $year^{-1}$, and 120 kg N ha^{-1} $year^{-1}$ as calcium-ammonium-nitrate, CAN) and treatments with organic amendments—urban organic waste compost (OWC), green waste compost (GWC), cattle manure compost (MC), and municipality sewage sludge compost (SSC)—each treatment corresponding 175 kg N ha^{-1} $year^{-1}$. Further variants consisted of the four compost amendments plus 80 kg mineral N (CAN) ha^{-1} (Table 1). The average C inputs (1991–2011) with compost applications were 2,277 kg C ha^{-1} $year^{-1}$ with OWC, 2,190 kg C ha^{-1} $year^{-1}$ with GWC, 2,567 kg C ha^{-1} $year^{-1}$ with MC, and 4,081 kg C ha^{-1} $year^{-1}$ with SSC. Fertilization was applied annually with the exception of pea (no fertilization at all) and compost, no application took place for the cropping season 2004, 2008, 2010, 2012, and 2014 (Table 2). The study is of long term, and a set of parameters (abundance and activity of earthworms, litter decomposition and winter barley growth and yield) were obtained in 2014, while soil parameters were measured in 2012. In the cropping season 2014, all plots were ploughed (25 cm deep) with subsequent rotary harrow treatment 1 day before sowing. Winter barley (*Hordeum vulgare* L. variety Christelle) with a seeding rate of 270 kernels m^{-2} was sown using a Reform seed drill with 2.5 m sowing wide on September 9, 2013. A uniform N fertilization of all long-term treatments was applied but compost was not applied (the last compost was given in October 2012 before sowing of winter wheat, see Table 2). The mineral N fertilization was carried out on February 25, 2014, in the developmental stage BBCH 25 (Zadoks et al., 1974) using Linzer plus Volldünger resulting in 40 kg N ha^{-1} N, 16 kg P ha^{-1}, 16 kg K ha^{-1}, 6 kg MgO ha^{-1}, and 8 kg sulfur ha^{-1}. On April 9, 2014, at BBCH 35, the plots were treated with Linzer CAN 27% N at a rate of 49 kg N ha^{-1}.

2.2 Sampling and analyses of biological indicators

2.2.1 Activity, abundance, and biomass of earthworms

Activity of earthworms was assessed by counting the surface casts (Zaller and Arnone, 1997) on a randomly selected and permanently marked area of 50 cm × 50 cm in each of the experimental plots from April 27, 2014, to June 25, 2014. Four countings were taken in an interval of 1 week after the first measuring. For the cast counting, winter barley was cut at a height of about 5 cm in every plot to better see the casts. Casts were collected, filled in paper bags, and oven dried at 60°C for 1 week and weighed afterwards. Cast production was calculated as the dry matter production per square meter. To determine the number of earthworms (abundance), one randomly selected 40 cm × 40 cm × 30 cm (length × width × depth) hole per experimental plot was dug out using a spade, the excavated soil was put on a plastic foil and subsequently sieved (mesh size, 0.5 cm). All earthworms occurring in this soil sample were sorted out and stored in cold water. Earthworm numbers and fresh weight were determined after storing earthworms in plastic boxes with wet kitchen towel and no additional food supply for one night. This way they could empty their intestinal contents. All earthworm data were calculated on a square meter basis. Earthworm extraction took place from April 28, 2014, until May 24, 2014.

Table 1. Fertilization scheme at the Ritzlhof experiment
Tabelle 1. Düngungsschema am Versuch Ritzlhof

Treatment No.	Type of fertilization	Organic nitrogen fertilization (kg N ha^{-1})	Mineral nitrogen fertilization (kg N ha^{-1})	Fertilization class
1	No fertilization (control)	0	0	Control
2	Mineral N fertilization	0	40	Mineral fertilization
3	Mineral N fertilization	0	80	
4	Mineral N fertilization	0	120	
5	Urban organic waste compost	175	0	Organic fertilization
6	Green waste compost	175	0	
7	Cattle manure compost	175	0	
8	Sewage sludge compost	175	0	
9	Urban organic waste compost + mineral N	175	80	Organic-mineral fertilization
10	Green waste compost + mineral N	175	80	
11	Cattle manure compost + mineral N	175	80	
12	Sewage sludge compost + mineral N	175	80	

Table 2. Crop type and compost application at the Ritzlhof experiment from 1991 to 2014
Tabelle 2. Feldfrüchte und Anwendung von Komposten am Versuch Ritzlhof von 1991 bis 2014

Year	Crop type	Compost application (yes/no)	Further fertilization information
1991	Maize	Yes	
1992	Spring wheat	Yes	
1993	Winter barley	Yes	
1994	Maize	Yes	
1995	Spring wheat	Yes	
1996	Winter barley	Yes	
1997	Maize	Yes	
1998	Spring wheat	Yes	
1999	Winter barley	Yes	
2000	Maize	Yes	
2001	Spring wheat	Yes	
2002	Winter barley	Yes	
2003	Maize	Yes	
2004	Pea	No	No fertilization at all
2005	Winter wheat	Yes	
2006	Winter barley	Yes	
2007	Maize	Yes	
2008	Pea	No	No fertilization at all
2009	Winter wheat	Yes	
2010	Winter barley	No	Uniform mineral N-P-K fertilization on every plot
2011	Maize	Yes	
2012	Pea	No	No fertilization at all
2013	Winter wheat	Yes	
2014	Winter barley	No	Uniform mineral N-P-K fertilization on every plot

2.2.2 Litter decomposition (Tea Bag Index)

The decomposition rate (k) and the litter stabilization factor (S) were assessed using the Tea Bag Index (TBI) method (Keuskamp et al., 2013). To determine the litter decomposition, two commercial teabags containing green tea and two teabags containing rooibos tea (Lipton, Unilever) were buried pairwise in a depth of 8 cm. In total, 96 pairs of green tea and rooibos tea were buried in the 48 plots. Half of the teabag pairs were excavated after 28 days, cleaned from adhered soil particles, and dried for 1 week at 60°C before weighing. The second half of the teabag pairs was excavated after 56 days and also dried and weighed. Decomposition rate and stabilization factor were calculated according to the method of Keuskamp et al. (2013).

2.3 Soil sampling and analyses of chemical soil properties

The results of biological and yield parameters were complemented with earlier results of chemical soil parameters. Soil samples were taken in August 2012 in 0–25 cm soil depth. On each plot, 10 subsamples were taken with a single gouge auger (cores of 30 mm in diameter) that were mixed and stored in plastic bags. Before the analyses, the soil samples were air dried and sieved using <2 mm mesh. Soil pH ($CaCl_2$) was determined electrochemically (pH/mV Pocket Meter pH 340i, WTW, Weilheim, Germany) in 0.01 M $CaCl_2$ at a soil-to-solution ratio of 1:2.5 (ÖNORM L1083). Soil organic carbon was analyzed by dry combustion using a LECO RC-612 TruMac CN (LECO Corp., St. Joseph, MI, USA) at 650°C (ÖNORM L1080). Total nitrogen (N_t) was determined according to ÖNORM EN 16168 by elemental analysis using a CNS 2000 SGA-410-06 at 1,250°C. Nitrogen (N) mineralization potential on dried soils was measured by the anaerobic incubation method (Keeney, 1982), modified according to Kandeler (1993). Extractable P and K were determined with CAL (calcium acetate/lactate) according to Schüller (1969) and ÖNORM L1087 with spectral photometer (P, using molybdenum blue method) and flame photometer

(K), using a Segmented flow Analyzer SAN (Skalar)). Magnesium (Mg) was analyzed by 0.0125 M $CaCl_2$ (method SCHACHTSCHABEL, ÖNORM L1093) using a flame atomic absorption spectrometer, Thermo Fisher iCE 3500.

2.4 Winter barley growth and yield parameters

To determine the barley biomass production of all 48 plots, 1 m^2 was harvested 5 cm above the soil surface by hand using a pruning clipper. The barley was harvested on 1 July at BBCH 89. The stem-to-ear ratio was assessed on 20 randomly chosen plants from every plot that were cut close to the ground at harvest time. From every plant, the length of the ear and the length of the stem were measured. After weighing the biomass, the ears (spikes) were cut off with a pair of scissors and threshed by a manual threshing machine. One sample was taken from every plot to calculate the thousand kernel weight (TKG) at a humidity rate of 14% (Contador Pfeuffer machine, Pfeuffer GmbH, Germany, Kitzingen).

2.5 Statistical analyses

A two-way analysis of variance (ANOVA) was used to assess the influence of the factor fertilization class at four levels: no fertilization/control (n = 4), mineral fertilization (n = 12), organic fertilization (n = 16), and organic-mineral fertilization (n = 16). The dependent variables were earthworm activity (cumulative surface cast weight, average cast weight, cumulative number of surface casts, average cast number), abundance and biomass of earthworms, litter decomposition (decomposition rate and stabilization factor after 28 and 56 days), and barley growth and yield (biomass of 1 m^2, TKG, length of stem and ear, and stem-to-ear ratio). Mean values were computed; Tukey's post-hoc test was used for mean comparisons. Correlations between variables were calculated with the Spearman correlation coefficient. All statistical analyses were performed using SPSS (version 20, IBM SPSS Statistics, USA).

3. Results

3.1 Activity, abundance, and biomass of earthworms

Activity, abundance, and biomass of earthworms are shown in Table 3. The cumulative surface cast weight was significantly affected by the fertilization class. The highest cumulative cast weight was found under long-term organic-mineral fertilization, with significant differences compared to the control and only mineral fertilization. The average cast weight per sampling was also highest under combined mineral and organic fertilization, revealing significant differences only compared to mineral fertilization. The cumulative number of surface casts showed similar results. The highest amount of cumulative cast numbers occurred under organic-mineral fertilization, significantly lower ones under mineral fertilization. The average cast numbers were statistically higher under both organic and organic-mineral fertilization, compared to only mineral fertilization.

Total number of earthworms was not affected by the fertilization class. Organic-mineral fertilization resulted in the highest number of earthworms, the lowest number of earthworms occurred in the control. Earthworm biomass

Table 3. Activity, abundance, and biomass of earthworms (EW, n = 48); letters are only indicated if there are significant differences (Tukey's post-hoc test, p<0.05)

Tabelle 3. Regenwurmaktivitäten, -häufigkeiten und –biomasse (n = 48), Buchstaben werden nur bei statistisch signifikanten Unterschieden angezeigt (Tukey´s Post Hoc Test, p<0,05).

	Control (n = 4)	Mineral fertilization (n = 12)	Organic fertilization (n = 16)	Organic-mineral fertilization (n = 16)
EW cumulative surface cast weight in g m^{-2}	$2{,}093^{a}$	$2{,}012^{a}$	$2{,}552^{ab}$	$2{,}801^{b}$
EW average cast weight g m^{-2}	523^{ab}	503^{a}	638^{ab}	678^{b}
EW cumulative number of surface casts m^{-2}	78.0^{ab}	71.0^{a}	104.8^{ab}	105.3^{b}
EW average cast number m^{-2}	39.0^{ab}	35.5^{a}	53.5^{b}	52.6^{b}
Total number of EW m^{-2}	57.8	64.1	71.9	79.7
EW biomass in g m^{-2}	11.1	23.7	23.4	37.3
Average weight per EW g m^{-2}	1.67	2.62	2.54	4.44

was unaffected by fertilization: the control showed the lowest biomass and the organic-mineral fertilization showed the highest biomass. Average weight per earthworm was unaffected by treatments but tended to be highest under organic-mineral fertilization and lowest in the control.

3.2 Litter decomposition

Litter decomposition rate (k) and stabilization factor (S) after 28 and 56 days, respectively, are shown in Table 4. Litter decomposition rate (k) after 28 days was affected by the fertilization class. It was significantly higher in the control compared to the organic-mineral class and the mineral class. The decomposition rate in the organic fertilization class was not different from control treatments. Litter decomposition rate after 56 days was not affected by the fertilization class.

The stabilization factor (S) after 28 days was affected by the fertilization class. The stabilization factor in the control was significantly lower compared to the organically fertilized class and the organic-mineral fertilized treatment. The mineral fertilization class showed an intermediate stabilization factor. The stabilization factor (S) after 56 days did not reveal significant differences between the fertilization classes.

3.3 Chemical soil properties and correlative relationships

After long-term organic fertilization with composts and combined organic-mineral fertilization, the pH values, SOC, N_t contents, and the N mineralization potential, as well as plant available P-CAL and K-CAL, increased significantly compared with only mineral fertilization (Table 5). Earthworm activities (cumulative and average cast weights) showed highly significant ($p<0.01$) positive correlations with SOC, N_t, the N mineralization potential, and plant available P-CAL and K-CAL (Table 6). The cumulative and average cast numbers were positively influenced by soil pH, SOC, N_t, N mineralization potential, and P-CAL. The number of earthworms (living and total) was significantly positively affected by pH, SOC, N_t, and the P-CAL content. The same soil properties (except for N_t) had a stimulating influence on the total earthworm biomass. Furthermore, a positive correlation between SOC and P-CAL and the barley stem length was observed. Barley biomass increased with higher SOC and K-CAL and was positively influenced by N_t and the N mineralization potential. The litter decomposition rate (k) after 28 days correlated positively with pH and P-CAL and negatively with plant available soil Mg-Sch. The stabilization factor after 56 days correlated negatively with pH.

3.4 Barley growth and yield

The results of barley growth and yields are shown in Table 7. Neither barley biomass yields nor the TKG showed significant differences between the fertilization classes. Only the stem length was significantly higher with organic-mineral fertilization compared to the control. No significant differences occurred for the ear length and the stem-to-ear ratio.

4. Discussion

4.1 Activity, abundance, and biomass of earthworms

A combined long-term application of composts and mineral N fertilizers resulted in higher earthworm activity compared to solely mineral fertilization. In contrast, abundance and biomass of earthworms were unaffected by fertilization classes. However, in tendency, the highest values always occurred in the treatments with organic--mineral fertilization. This is in accordance with Estevez

Table 4. Litter decomposition, Tea Bag Index; letters are only indicated if there are significant differences (Tukey's post-hoc test, p<0.05)
Tabelle 4. Zersetzung, Teebeutel-Index; Buchstaben werden nur bei statistisch signifikanten Unterschieden angezeigt (Tukey´s Post Hoc Test, p<0,05).

	Control (n = 4)	Mineral fertilization (n = 12)	Organic fertilization (n = 16)	Organic-mineral fertilization (n = 16)
Litter decomposition rate (k) in g day^{-1} after 28 days	0.039^{b}	0.020^{a}	0.024^{ab}	0.022^{a}
Litter decomposition rate (k) in g day^{-1} after 56 days	0.025	0.017	0.020	0.020
Stabilization factor (S) after 28 days	0.283^{a}	0.335^{ab}	0.383^{b}	0.386^{b}
Stabilization factor (S) after 56 days	0.247	0.324	0.336	0.343

Table 5. Chemical soil properties (0-25 cm soil depth), mean values analysed in 2012. Letters are only indicated, if there are significant differences (Tukey´s post-hoc test, p<0.05)
Tabelle 5. Chemische Bodenparameter (0-25 cm Bodentiefe), Mittelwerte der Bodenuntersuchungen im Jahre 2012. Buchstaben werden nur bei statistisch signifikanten Unterschieden angezeigt (Tukey´s Post Hoc Test, p<0,05).

	Control (n = 4)	Mineral fertilization (n = 12)	Organic fertilization (n = 16)	Organic-mineral fertilization (n = 16)
pH_{CaCl2}	6.98^{ab}	6.85^{a}	7.12^{b}	7.12^{b}
SOC (%)	1.19^{a}	1.12^{a}	1.38^{b}	1.39^{b}
N_t (%)	0.14^{a}	0.14^{a}	0.16^{b}	0.16^{b}
C/N ratio	8.43	8.24	8.47	8.57
N mineralization potential (mg kg^{-1} 7 $days^{-1}$)	60.5^{a}	60.3^{a}	68.3^{b}	68.4^{b}
P-CAL (mg kg^{-1})	96.5^{a}	95.8^{a}	173.9^{b}	165.3^{b}
K-CAL (mg kg^{-1})	151.8^{ab}	128.7^{a}	189.1^{b}	183.4^{b}
Mg-Sch (mg kg^{-1})	119.3	114.2	110.0	107.8

et al. (1996) who claimed that solid cattle manure as an available food source can improve abundance of earthworms in soil. These authors also found that the effects of mineral fertilization on earthworms can vary. For example, Edwards (1983) observed that the application of mineral fertilizer on clay soils had no significant effect on the earthworm population. Edwards and Lofty (1982) reported that treatments receiving both inorganic and organic N had the largest populations of earthworms. The tendency of the increase in the abundance of earthworms in the treatments receiving organic amendments can be linked with the higher SOC contents in these treatments (Lehtinen et al., 2017). An addition of organic matter is believed to be one of the major management variables affecting abundance of earthworms (Leroy et al., 2008; Amossé et al., 2013). Our current results are in line with results of other long-term field experiments, showing that organic amendments increase both earthworm number and biomass compared to the sole use of mineral fertilizers (Jouquet and Doan, 2014; D´Hose et al., 2018). In another field experiment with spring wheat, which received no farmyard manure, earthworms produced 20% less surface casts than earthworms in treatments with amendments of farmyard manure for more than 9 years (Zaller and Köpke, 2004). In a long-term study from 1994 to 2004, Riley et al. (2008) stated that the incorporation of large amounts of organic matter and a longer ley period may explain the high density of earthworm channels in these systems. The improved development of earthworms with compost was also confirmed by the increased weight of earthworm casts in a study by Doan et al. (2013). In our study, compost plus inorganic fertilization had a significantly higher effect on earthworm activities than mineral N fertilization alone. Therefore, the addition of organic matter appears advisable in order to obtain maximum benefits from mineral fertilizers (Tiwari, 1993). The effects of compost application were still detectable in our study 18 months after the last application.

4.2 Litter decomposition

We studied decomposition and stabilization rate by the TBI method (Keuskamp et al., 2013) and found the highest decomposition after 28 days in the control and a significant lower decomposition under solely mineral and organic-mineral fertilization. This is in contrast to other findings showing increased decomposition in organic amendments with manure (Zaller and Köpke, 2004). Nitrogen fertilization could have reduced soil microbes (Thirukkumaran and Parkinson, 2000) by soil acidification and plant community changes (Zeng et al., 2016). In contrast, organic fertilization enhanced the microbial activity in the soil (Pokorná-Kozová and Novák, 1975). In the data that obtained after 56 days, no statistical differences were observed, which is partly in agreement with previous pot experiments (Zaller et al., 2016; Van Hoesel et al., 2017) in which litter decomposition in different agricultural management practices were compared. In a long-term field experiment, like in our case, the microorganisms might be well adapted to the different fertilization classes and thus decompose litter in a similar manner; however, we would have expected differences between the treatments.

Table 6. Spearman correlation coefficients between activity, abundance, and biomass of earthworms (EW); decomposition; and winter barley harvest parameters and soil properties (n = 48) in a soil depth of 0–25 cm
Tabelle 6. Spearman Korrelationskoeffizienten zwischen Regenwurmaktivitäten, -häufigkeiten und –biomasse, Zersetzung, Wintergerste-Ernteparameter und Bodenparameter (n = 48) in einer Bodentiefe von 0-25 cm

	pH	SOC	Nt	C/N	N mineralization potential mg kg^{-1} 7 $days^{-1}$	P-CAL	K-CAL	Mg-Sch
EW cumulative surface cast weight (g m^{-2})	0.119	0.428**	0.416**	0.084	0.417**	0.428**	0.447**	0.049
EW average cast weight (g m^{-2})	0.063	0.429**	0.420**	0.085	0.418**	0.381**	0.438**	0.065
EW cumulative number of surface casts (m^{-2})	0.420**	0.449**	0.437**	0.111	0.396**	0.460**	0.162	–0.186
EW average cast number (m^{-2})	0.413**	0.473**	0.466**	0.114	0.423**	0.468**	0.187	–0.162
Number of living EW (m^{-2})	0.364*	0.301*	0.324*	0.133	0.300*	0.435**	0.121	–0.153
EW biomass (g m^{-2})	0.320*	0.360*	0.268	0.414**	0.123	0.339*	0.072	–0.125
Total number of EW (m^{-2})	0.343*	0.316*	0.285*	0.239	0.267	0.379**	0.068	–0.194
Average weight of one EW in g)	0.212	0.177	0.063	0.381**	–0.074	0.197	0.001	–0.056
Barley stem length	0.110	0.290*	0.256	0.025	0.17	0.345*	0.147	–0.046
Barley ear length	–0.098	–0.002	0.099	–0.195	0.074	–0.109	0.074	0.206
Barley stem-to-ear ratio	0.214	0.25	0.16	0.206	0.112	0.369**	0.053	–0.234
Barley total biomass (kg m^{-2})	–0.059	0.351*	0.371**	0.021	0.444**	0.188	0.350*	0.059
S 28	0.207	0.211	0.151	0.231	0.038	0.277	–0.037	–0.02
k 28 (g day^{-1})	0.409**	0.228	0.208	0.103	0.272	0.329*	–0.186	–0.414**
S 56	–0.300*	–0.165	–0.152	–0.241	–0.185	–0.22	0.032	0.179
k 56 (g day^{-1})	0.06	0.086	0.024	0.065	–0.139	0.083	0.09	–0.067

Asterisks indicate significance at p<0.05 (*) and p<0.01 (**).

4.3 Chemical soil properties and correlation results

The increase in pH, SOC, and plant available nutrients such as P-CAL and K-CAL resulting in a better fertility status of compost fertilized soils was described in Lehtinen et al. (2017). Furthermore, the authors have already addressed the danger of applying P and K in excess with long-term compost amendments at allowed N rates (corresponding to 175 kg ha^{-1} $year^{-1}$) and the necessity of monitoring plant nutrients, which was visible in the actual evaluations as well. However, the increase in pH, SOC, and soil nutrients had, at least partly, a stimulating effect on activity, abundance, and biomass of earthworms. Our results confirm the improved prediction of biomass yields with the easily measurable biological soil indicator "N mineralization potential" (Dersch et al., 2003). Decomposition rates after 28 days were positively correlated with soil pH and plant available P-CAL, indicating better living conditions for soil microbes under these conditions. The role of soil pH is well known in the literature (e.g., Leifeld et al., 2008). The TBI method excludes the influence of soil meso- and macrofauna on decomposition and only allows soil microorganisms to enter the 0.25-mm mesh (Keuskamp et al., 2013). The stabilization factor after 56 days was negatively correlated with soil pH, also indicating the importance of soil pH in carbon cycling in soils (Leifeld et al., 2008).

4.4 Barley growth and yield

The significantly higher barley stem length under long-term organic-mineral fertilization reflected the effect of nitrogen as the most important nutrient for plants production. The reason why only significant differences in the stem length but not in the other investigated parameters (biomass yield, ear length, stem to ear ratio) were observed was probably the uniform cultivation in the experimental year 2014. Lehtinen et al. (2017) reported that yields of winter barley with solely compost application were comparable to 40 kg of mineral N fertilization and increased significantly with additional mineral fertilization. Sacco et al. (2015) argued that yield reductions after organic ferti-

Table 7. Growth and yield indices of winter barley. Letters are only indicated if there are significant differences (Tukey's post-hoc test, p<0.05).
Tabelle 7. Wachstums- und Ertragsindikatoren von Wintergerste. Buchstaben werden nur bei statistisch signifikanten Unterschieden angezeigt (Tukey's Post Hoc Test, p<0,05).

	Control (n = 4)	Mineral fertilization (n = 12)	Organic fertilization (n = 16)	Organic-mineral fertilization (n = 16)
Barley total biomass (kg m^{-2})	1.16	1.31	1.36	1.39
Thousand kernel weight (g)	42.1	42.3	42.6	40.6
Stem length (cm)	95.9[a]	96.6[ab]	101.9[ab]	103.8[b]
Ear length (cm)	6.36	6.42	6.86	6.25
Stem-to-ear ratio	15.7	15.5	16.0	17.0

lization are related to lower soil nutrient availability, because nutrients are provided mainly after mineralization. According to Bedada et al. (2014), the compost and mineral fertilizer treatments exceeded all the other treatments (compost, mineral fertilizer, control). The addition of either compost alone or in combination with NP fertilizers improved soil properties and crop productivity compared with the control and the treatments with mineral fertilizers. Therefore, compost addition can serve as a supplement to mineral fertilizer use and reduce the dependency on those fertilizers.

5. Conclusions

- Compost amendments, alone or in combination with mineral fertilization, benefit soil biota
- Higher earthworm activity (cumulative and average surface cast weight and cast number) occurred in the fields with long-term organic and organic-mineral fertilization compared to the control
- The highest decomposition rates after 28 days appeared in long-term zero fertilization, a significantly lower one with only mineral fertilization
- The stabilization factor was highest after the long-term organic-mineral and organic fertilization
- Productivity effects could be shown with higher barley stem length under long-term organic-mineral fertilization
- There appeared to be no necessity to apply compost every year in order to benefit soil biota

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