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Reduced tillage enhances earthworm abundance and biomass in organic farming: A meta-analysis

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Abstract

Organic farming aims to support and utilise ecosystem services such as bioturbation and the mixing of organic materials into the soil. These services are provided by earthworms. One possible way to support earthworm populations is to reduce tillage intensity.

The use of reduced tillage techniques has become more and more important in organic farming in recent years. While the positive effect of reduced soil tillage on earthworm population in conventional farming has been repeatedly described, there have been relatively few analyses focussed on organic farming systems. To address this gap in knowledge, we compiled and evaluated data on the influence of reduced tillage on earthworms in organic farming in temperate regions. Nineteen datasets on abundance from eight studies and 15 datasets on biomass from six studies were included in this analysis. Our analysis showed an overall significant positive effect of reduced tillage on earthworm abundance (+ 90 %) and earthworm biomass (+ 67 %). Reduced tillage includes shallow-inverting and non-inverting systems. The positive effects were only statistically significant for non-inverting systems. Reduced tillage used over several years resulted in a shift in earthworm communities to species characterised by higher mean individual biomass (*Lumbricus terrestris* (Linnaeus, 1758), *Aporrectodea longa* (Ude, 1885)).

Keywords: *review; temporal change; no-till; shallow inversion* tillage; *Lumbricidae*

Zusammenfassung

Reduzierte Bodenbearbeitung im ökologischen Landbau fördert die Abundanz und Biomasse von Regenwürmern: Eine Meta-Analyse

Im ökologischen Landbau wird die gezielte Förderung und Nutzung von Ökosystemdienstleistungen angestrebt. Bioturbation und die Einarbeitung von organischem Material in den Boden sind Ökosystemdienstleistungen, für die Regenwürmer von großer Bedeutung sind. Ein möglicher Ansatz Regenwürmer zu fördern, ist die Reduktion der Intensität bei der Bodenbearbeitung.

Obwohl reduzierte Bodenbearbeitung im ökologischen Landbau in den letzten Jahren an Bedeutung gewonnen hat, gibt es bis jetzt noch keine Meta-Analyse zu den Auswirkungen des Verfahrens auf Regenwürmer. In der vorliegenden Analyse wurden 19 Datensätze zur Abundanz von Regenwürmern aus 8 Studien und 15 Datensätze zur Biomasse aus 6 Studien berücksichtigt.

Insgesamt wirkt sich reduzierte Bodenbearbeitung im ökologischen Landbau positiv auf die Abundanz (+ 90 %) und Biomasse (+ 67 %) von Regenwürmern aus. Allerdings muss zwischen nicht-wendenden und flach-wendenden Verfahren unterschieden werden. Signifikant positive Effekte im Vergleich zu tief-wendenden Verfahren (Pflug) konnten nur für nicht-wendende Verfahren gezeigt werden. Wurde mehrere Jahre in Folge auf den Einsatz eines Pfluges verzichtet, kam es außerdem zu Verschiebungen in der Zusammensetzung von Regenwurmgemeinschaften. Es werden solche Arten gefördert, die ein höheres Individualgewicht haben (*Lumbricus terrestris*, (Linnaeus, 1758), *Aporrectodea longa* (Ude, 1885)).

Keywords: *Review; zeitliche Veränderungen; nicht-wendende Bodenbearbeitung; flach-wendende Bodenbearbeitung; Lumbricidae*

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1 Introduction

In organic farming, organic materials are of utmost importance for the nutrient supply of crops. Organic fertilizers as well as plant residues must be mixed into the soil and their decomposition must be maintained. In temperate regions, earthworms, especially deep burrowing anecic species such as *Lumbricus terrestris* (Linnaeus, 1758) and *Aporrectodea longa* (Ude, 1885), are very important for the incorporation and decomposition of plant residues in the soil (Blume et al., 2010).

In their recent meta-analysis, Briones and Schmidt (2017) showed that in general reducing tillage intensity promotes earthworm abundance and biomass confirming the results of previous reviews (Carr et al., 2013; Chan, 2001; van Capelle et al., 2012). However, some studies found results that contrast with these overall trends (Chan, 2001).

To our knowledge, there has been no attempt to systematically compile data on the influence of reduced tillage on earthworm abundance and biomass under organic farming. Examining the effect of reduced tillage on earthworm populations in organic farming is not straightforward as a wide range of management practices characteristic of organic farming such as the absence of agrochemicals, diversified crop rotations and the use of organic fertilizers may promote earthworms irrespective of the tillage methods used (Bertrand et al., 2015). In organic farming, farmyard manure, slurry, and plant residues are the main sources of organic amendments to the soil. While Leroy et al. (2008) could show that slurry and farmyard manure positively influenced earthworm communities under field conditions there is no reliable information on the influence of crop residues available (Bertrand et al., 2015). For wide organic crop rotations with consider-able proportions of ley, Riley et al. (2008) reported positive effects on earthworm communities. Besides biotic and abiotic factors interacting with the effect of tillage on earthworm communities, the way reduced tillage is conducted (shallow soil inversion tillage *vs* non-inversion tillage vs no-till) and the time elapsed since the last conventional mouldboard plough-based cultivation may influence the outcome (Briones and Schmidt, 2017).

Against this background we conducted a meta-analysis of data in peer-reviewed publications. Our main question was about the effect of reduced tillage in organic farming on earthworm abundance and biomass. Our study was guided by three hypotheses:

H_1: There is an overall positive effect of reduced tillage on earthworm abundance and biomass in organic farming.

H_2: In terms of reduced tillage techniques to support earthworm populations, non-inverting tillage is more beneficial than shallow-inverting soil tillage.

H_3: The positive effect of reduced tillage practices increases with the time elapsed since the last use of the conventional mouldboard plough.

2 Material & Methods

We conducted a literature search via Web of Science (www.webofknowledge.com) in October 2016 using the following combination of search terms:

Earthworm* AND Tillag* AND (Eco* OR Organic*) AND (Farm* OR Agricul*)

We identified 177 relevant publications. We screened abstracts and full texts to include only those studies in our meta-analysis that met the following requirements:

1. different ecological groups of earthworms (anecic, endogeic, epigeic) considered;
2. data on earthworm abundance and/or biomass included;
3. conducted under organic farming standards;
4. reduced tillage as treatment;
5. the use of mouldboard ploughing as control;
6. conducted in the temperate zone.

These requirements were met with eight studies providing 19 datasets on earthworm abundance and seven studies providing 17 datasets on earthworm biomass. When necessary we recalculated data of single studies to obtain abundance and biomass values per m^2. Where data were presented in figures only, we contacted the authors to obtain the original data. Since only so few studies could fulfil our requirements, the results of individual comparisons can have considerable influence on the overall result of the meta-analysis. Therefore, we sought to reduce variance within the response variable with a robust statistical approach to reject outliers using a "Tukey fence" with all values outside the interquartile range being considered as outliers (Cooper et al., 2016). The range was defined as $Q_1 - k*IQR$ to $Q_3 + k*IQR$. With Q_1 lower quartile point, Q_3 upper quartile point, $IQR = Q_3 - Q_1$ and $k = 1.5$. This process resulted in the inclusion of 19 datasets on abundance from eight studies and 15 datasets on biomass from six studies. It is obvious that some datasets are from the same study (Tables 1 and 2). We always checked that each dataset represented a unique comparison. In addition to mean abundance and biomass we collected information on soil type, duration of the study, and sampling procedure and compiled this information in Tables 1 and 2. We used relative change (RC) in earthworm abundance and biomass as response variables (Du et al., 2017). RC is defined as the change in abundance or biomass under reduced tillage relative to the abundance or biomass under conventional tillage and has been calculated as:

$$RC = (M_{RT} - M_{CT})/M_{CT}$$

where M_{RT} and M_{CT} are the mean abundance or biomass values under reduced (RT) and conventional (CT) tillage, respectively.

We followed the approach applied by Du et al. (2017) and checked for significant difference of means from zero by one-sample t-test or, in case of non-normality of the data, one-sample Wilcoxon signed rank test. Normality of data was checked using Shapiro-Wilk test. Like Cooper et al. (2016) we faced the problem that many studies did not give a measure of variance. Therefore, we followed the approach applied by these authors and Du et al. (2017) and conducted an unweighted meta-analysis. In terms of meta-analysis, weighting gives more influence to those datasets obtained from studies with higher numbers of replicates and/or lower variance. If unweighted analyses are conducted each dataset will influence the result in the same way. All statistical analysis were conducted using R 3.3.1 (R Development Core Team, 2016).

3 Results and discussion

Earthworm abundance was significantly higher (around 90 %) under reduced tillage when compared with mouldboard ploughing (Figure 1). From examination of specific reduced tillage systems, a doubling in the number of individuals (+ 99 %) is apparent where non-inverting soil tillage is conducted. Concerning earthworm biomass results are similar. There was an overall significant positive effect of reduced tillage (+ 67 %; Figure 1). However, while non-inversion tillage significantly enhanced biomass compared with mouldboard ploughing (+ 65 %), shallow-inversion tillage and mouldboard ploughing did not differ significantly. These results support our first hypothesis (H_1) that in organic farming, reduced tillage can promote earthworm abundance and biomass. Furthermore, with regard to hypothesis two (H_2), a positive effect of non-inversion tillage is evident, while the positive effect was not significant in case of shallow-inversion tillage. The results support the view that reducing tillage depth alone does not significantly promote earthworms (Metzke et al., 2007). All tillage systems that invert the soil impact negatively on anecic earthworms as their vertical burrows are destroyed and the animals can be injured or killed (Jeffery et al., 2010).

All studies considered mouldboard ploughing as control treatment, but there were differences in the mouldboard ploughing depth. Therefore, we examined the dataset in an additional analysis to use only those studies applying mouldboard ploughing to more than 25 cm depth as control. Results from this analysis did not differ from that shown in Figure 1 and we therefore do not further describe or discuss them.

Results of studies of changes in earthworm biomass due to reduced tillage as affected by the time elapsed since the last mouldboard ploughing are shown in Figure 2. While in the short term (5 to 32 months since last ploughing) the positive effect of reduced tillage was not significant, studies conducted 42 months or later after last ploughing showed a significant positive effect of reduced tillage on earthworm biomass. Earthworm abundance was influenced significantly positive in early (5 to 32 months) and medium (42 months) time period whereas later (78 to 114 months) no influence of reduced tillage could be revealed (Figure 2). Thus, our third hypothesis (H_3) could be confirmed for earthworm biomass only. We assume a cumulative effect over time for earthworm biomass as large and heavy anecic species are slowly

Table 1

Soil characteristics of the study sites and methods applied for earthworm sampling at the different study sites reported in the literature used. USDA TC: USDA texture classes according to Soil Survey Division Staff (1993).

Study	Study site	Soil					Earthworm sampling	
		USDA TC	Sand	Silt	Clay	Type of soil	Excavation depth [cm]	(Additional) extraction
Moos et al., 2016	Trenthorst/Wulmenau	Loamy	42	37	20	Stagnic Luvisols	0 - 15	Mustard solution
Crittenden et al., 2014	Lelystad	Light	66	12	23	Calcareous Marine Clay Loam	0 - 20	Formaldehyde solution
Kuntz et al., 2013	Frick	Heavy	22	33	45	Stagnic Eutric Cambisol	0 - 25	
De Oliveira et al., 2012	Favrieux	NA	NA	NA	NA	Haplic Luvisol	0 - 30	Mustard solution
De Oliveira et al., 2012	Villarceaux	NA	NA	NA	NA	Haplic Luvisol	0 - 30	Mustard solution
Peigne et al., 2009	Rhone Alpes	Light	58	27	15	Fluvisol		Formalin solution
Peigne et al., 2009	Brittany	Loamy	34	46	20	Cambisol		Formalin solution
Peigne et al., 2009	Pays de la Loire	Loamy	25	57	14	Cambisol		Formalin solution
Berner et al., 2008	Frick	Heavy	22	33	45	Stagnic Eutric Cambisol	0 - 20	Mustard solution
Metzke et al., 2007	Frankenhausen	Loamy	2	81	17	Luvisol	-	Formalin solution
Emmerling, 2001	Eichenhof	NA	NA	NA	NA	Cambisol	0 - 30	Mustard solution

Table 2

Earthworm abundance and biomass values used in the meta-analysis. RT: reduced tillage. RT_NI: Reduced tillage with techniques not inverting the soil. RT_SI: Reduced tillage with techniques inverting the soil, but shallower than CT. CT: conventional tillage. RC: Relative change. Group: A (5 to 32 months since last ploughing); B (42 months since last ploughing); C (78 to 114 months since last ploughing).

Study	Study site	Tillage system RT	Working depth RT [cm]	Time since last ploughing in RT Months	Group	Mean abundance RT (M_{RT}) [individuals m^{-2}]	Mean abundance CT (M_{CT}) [individuals m^{-2}]	Relative change in abundance (RC_A, $(M_{RT} - M_{CT})/M_{CT}$) %	Mean biomass RT (M_{RT}) [g m^{-2}]	Mean biomass CT (M_{CT}) [g m^{-2}]	Relative change in biomass (RC_A, $(M_{RT} - M_{CT})/M_{CT}$) %
Moos et al., 2016	Trenthorst/Wulmenau	RT_NI	15	24	A	406	97	319	-	-	-
Crittenden et al., 2014	Lelystad	RT_NI	8	42	B	557	543	3	74	35	111
Crittenden et al., 2014	Lelystad	RT_NI	8	42	B	446	543	-18	58	35	66
Kuntz et al., 2013	Frick	RT_SI	5	114	C	262	157	67	77.1	50.2	54
De Oliveira et al., 2012	Villarceaux	RT_NI	10	10	A	57	45	27	-	-	-
De Oliveira et al., 2012	Favrieux	RT_NI	10	5	A	314	145	117	-	-	-
Peigne te al., 2009	Rhone Alpes	RT_NI	0	42	B	5	2	150	-	-	-
Peigne te al., 2009	Rhone Alpes	RT_NI	15	42	B	6	2	200	2	1	100
Peigne te al., 2009	Rhone Alpes	RT_SI	20	42	B	6	2	200	3	1	200
Peigne te al., 2009	Pays de la Loire	RT_NI	0	30	A	37	13	185	37	23	61
Peigne te al., 2009	Pays de la Loire	RT_NI	15	30	A	16	13	23	27	23	17
Peigne te al., 2009	Pays de la Loire	RT_SI	20	30	A	31	13	138	26	23	13
Peigne te al., 2009	Brittany	RT_NI	0	78	C	61	92	-34	40	19	111
Peigne te al., 2009	Brittany	RT_NI	12	78	C	60	92	-35	40	19	111
Peigne te al., 2009	Brittany	RT_SI	15	78	C	76	92	-17	28	19	47
Berner et al., 2008	Frick	RT_NI	15	32	A	582	424	37	101	129	-22
Metzke et al., 2007	Frankenhausen	RT_SI	10	24	A	28.5	32.8	-13	38.1	27.0	41
Emmerling, 2001	Eichenhof	RT_SI	15	42	B	28	22	27	26.6	16.6	60
Emmerling, 2001	Eichenhof	RT_NI	30	42	B	98	22	345	23.5	16.6	42

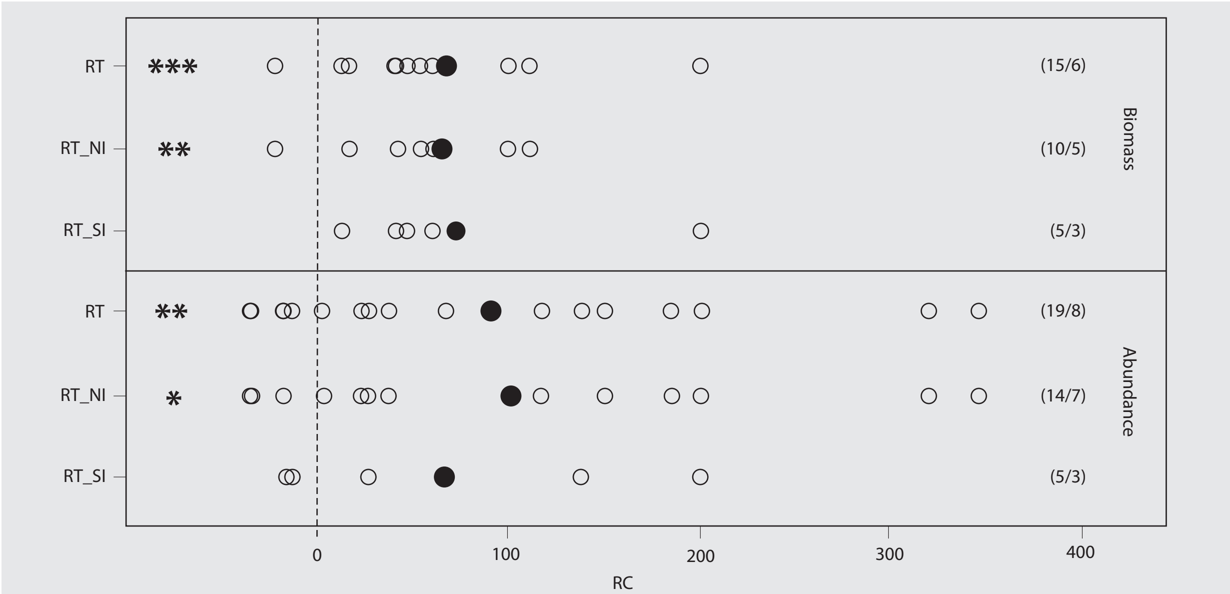

Figure 1

Influence of different types of reduced tillage on earthworm abundance (individuals m^{-2}) and biomass (g m^{-2}) in organic farming. The relative change (RC, %) under measures of reduced tillage when compared with measures of conventional tillage is presented. Filled circles indicate mean values. The number of comparisons / number of studies are given in brackets. RT: reduced tillage. RT_NI: reduced tillage, non-inversion tillage. RT_SI: reduced tillage, shallow inversion tillage. $RC = (M_{RT} - M_{CT})/M_{CT}$; with M_{RT}: mean under reduced tillage; M_{CT}: mean under conventional tillage. Asterisks indicate significant difference of means/medians from zero (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). P-values according to t-test or Wilcoxon-signed-rank test (when data were not normally distributed).

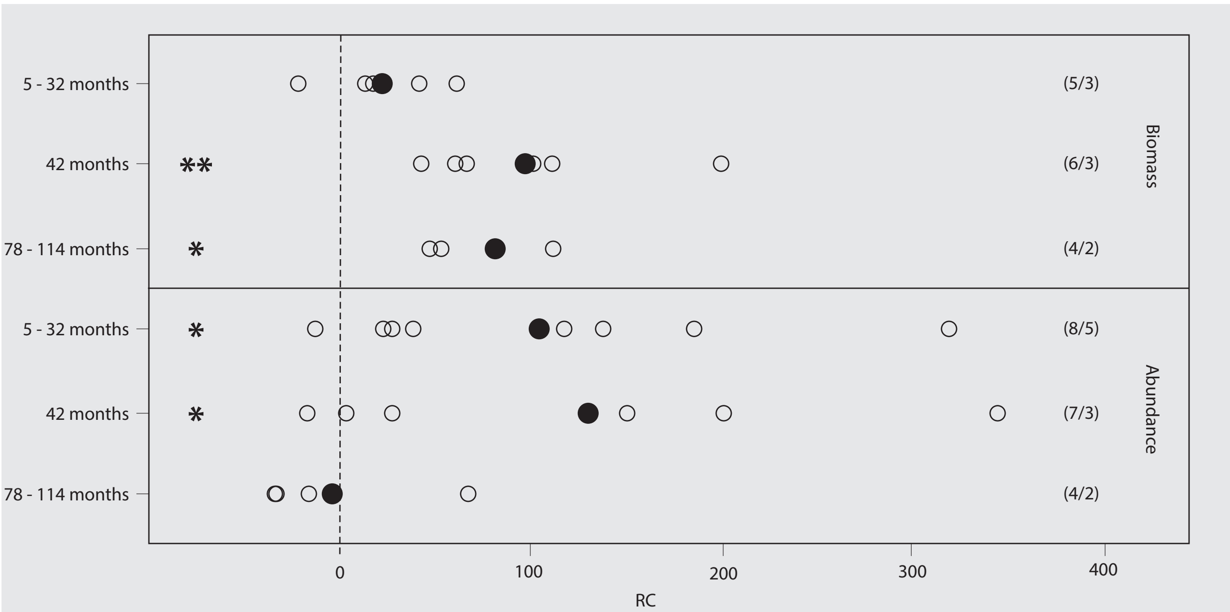

Figure 2

Influence of reduced tillage on earthworm abundance (individuals m^{-2}) and biomass (g m^{-2}) in organic farming in relation to the last use of a mouldboard plough. Given is the relative change (RC, %) under measures of reduced tillage when compared with measures of conventional tillage. Filled circles indicate mean values. In brackets: number of comparisons/ number of studies. $RC = (M_{RT}-M_{CT})/M_{CT}$; with M_{RT}: mean under reduced tillage; M_{CT}: mean under conventional tillage. Asterisks indicate significant difference of means/medians from zero (* $p < 0.05$, ** $p < 0.01$). P-values according to t-test or Wilcoxon-signed-rank test (when data were not normally distributed).

reproducing and developing (Jeffery et al., 2010). Therefore, overall earthworm biomass increases over time when these species find favourable habitat conditions. Differences in earthworm abundance between conventional and reduced tillage decreased and seem to disappear with time since last ploughing. This could be due to the positive effect of tillage/ploughing on some endogeic species like *Aporrectodea caliginosa* (Savigny, 1826). Boström (1995) and Crittenden et al. (2014) found interactions between tillage systems and organic matter management. Increased organic matter availability in the topsoil due to ploughing positively affected endogeic species and here in particular *A. caliginosa*. Besides the increased availability of organic matter in the topsoil reduced competition of anecic earthworms due to mouldboard ploughing can be favourable for endogeic species (Eriksen-Hamel and Whalen, 2007). We assume a shift in earthworm assemblage under long-term reduced tillage from endogeic to anecic species dominating the communities. This is expressed by increasing biomass along with stable abundance values.

Conclusions

Overall, there are few peer-reviewed publications on the influence of reduced tillage on abundance and biomass of earthworms in organic farming. Nevertheless, the available data show a positive effect of reduced tillage compared with mouldboard ploughing in the short-term. This result point to an opportunity to conduct a wide-ranging survey of earthworm communities under the preconditions described and to accompany this survey with an evaluation of ecosystem services provided by earthworms in these fields.

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References

Berner A, Hildermann I, Fliessbach A, Pfiffner L, Niggli U, Mader P (2008) Crop yield and soil fertility response to reduced tillage under organic management. Soil Till Res 101(1-2):89-96

Bertrand M, Barot S, Blouin M, Whalen J, Oliveira Td, Roger-Estrade J (2015) Earthworm services for cropping systems : a review. Agron Sustain Dev 35:553-567

Blume H-P, Brümmer GW, Horn R, Kandeler E, Kögel-Knabner I, Kretschmar R, Stahr K, Wilke B-M (2010) Lehrbuch der Bodenkunde. Heidelberg : Spektrum, 569 p

Boström U (1995) Earthworm populations (*Lumbricidae*) in ploughed and undisturbed leys. Soil Till Res 35(3):125-133

Briones MJI, Schmidt O (2017) Conventional tillage decreases the abundance and biomass of earthworms and alters their community structure in a global meta-analysis. Global Change Biol 23:4396-4419

Carr P, Gramig G, Liebig M (2013) Impacts of organic zero tillage systems on crops, weeds, and soil quality. Sustain 5(7):3172-3201

Chan KY (2001) An overview of some tillage impacts on earthworm population abundance and diversity : implications for functioning in soils. Soil Till Res 57(4):179-191

Cooper J, Baranski M, Stewart G, Lange MN, Bàrberi P, Fließbach A, Peigné J, Berner A, Brock C, Casagrande M, Crowley O, David C, Vliegher AD, Döring TF, Dupont A, Entz M, Grosse M, Haase T, Halde C, Hammerl V, Huiting H, Leithold G, Messmer M, Schloter M, Sukkel W, Heijden MGAvd, Willekens K, Wittwer R, Mäder P (2016) Shallow non-inversion tillage in organic farming maintains crop yields and increases soil C stocks : a meta-analysis. Agron Sustain Dev 36(22):1-20

Crittenden SJ, Eswaramurthy T, de Goede RGM, Brussaard L, Pulleman MM (2014) Effect of tillage on earthworms over short- and medium-term in conventional and organic farming. Appl Soil Ecol 83(0):140-148

De Oliveira T, Bertrand M, Roger-Estrade J (2012) Short-term effects of ploughing on the abundance and dynamics of two endogeic earthworm species in organic cropping systems in northern France. Soil Till Res 119(0):76-84

Du Z, Angers DA, Ren T, Zhang Q, Li G (2017) The effect of no-till on organic C storage in Chinese soils should not be overemphasized : a meta-analysis. Agric Ecosyst Environ 236:1-11

Emmerling C (2001) Response of earthworm communities to different types of soil tillage. Appl Soil Ecol 17(1):91-96

Eriksen-Hamel NS, Whalen JK (2007) Competitive interactions affect the growth of *Aporrectodea caliginosa* and *Lumbricus terrestris* (*Oligochaeta: Lumbricidae*) in single- and mixed-species laboratory cultures. Eur J Soil Biol 43(3):142-150

Ernst G, Emmerling C (2009) Impact of five different tillage systems on soil organic carbon content and the density, biomass, and community composition of earthworms after a ten year period. Eur J Soil Biol 45(3):247-251

Jeffery S, Gardi C, Jones A, Montanarella L, Marmo L, Miko L, Ritz K, Peres G, Römbke J, Putten WHvd (eds) (2010) European atlas of soil biodiversity. Luxembourg : EC, Publ Off EU, 128 p

Kuntz M, Berner A, Gattinger A, Scholberg JM, Mader P, Pfiffner L (2013) Influence of reduced tillage on earthworm and microbial communities under organic arable farming. Pedobiologia 56(4-6):251-260

Leroy BLM, Schmidt O, Van den Bossche A, Reheul D, Moens M (2008) Earthworm population dynamics as influenced by the quality of exogenous organic matter. Pedobiologia 52(2):139-150

Metzke M, Potthoff M, Quintern M, Hess J, Joergensen RG (2007) Effect of reduced tillage systems on earthworm communities in a 6-year organic rotation. Eur J Soil Biol 43:S209-S215

Moos JH, Schrader S, Paulsen HM, Rahmann G (2016) Occasional reduced tillage in organic farming can promote earthworm performance and resource efficiency. Appl Soil Ecol 103:22-30

Peigné J, Cannavaciuolo M, Gautronneau Y, Aveline A, Giteau JL, Cluzeau D (2009) Earthworm populations under different tillage systems in organic farming. Soil Till Res 104(2):207-214

R Development Core Team (2016) R: a language and environment for statistical computing. Vienna : R Foundation Statistical Computing

Riley H, Pommeresche R, Eltun R, Hansen S, Korsaeth A (2008) Soil structure, organic matter and earthworm activity in a comparison of cropping systems with contrasting tillage, rotations, fertilizer levels and manure use. Agric Ecosyst Environ 124(3–4):275-284

Soil Survey Divison Staff (1993) Soil survey manual. Washington : U.S. Dept Agric, 437 p, US Dept Agric Handbook 18

van Capelle C, Schrader S, Brunotte J (2012) Tillage-induced changes in the functional diversity of soil biota : a review with a focus on German data. Eur J Soil Biol 50:165-181