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

Jan Hendrik Moos*, Stefan Schrader**, and Hans Marten Paulsen*

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.


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*
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) showed 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**<sub>1</sub>: There is an overall positive effect of reduced tillage on earthworm abundance and biomass in organic farming.

**H**<sub>2</sub>: In terms of reduced tillage techniques to support earthworm populations, non-inverting tillage is more beneficial than shallow-inverting soil tillage.

**H**<sub>3</sub>: 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<sup>2</sup>. Where data were presented in figures only, we contacted the authors to obtain the original data. Since only so few studies could fulfill 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 \( Q_1 - k \times IQR \) to \( Q_1 + k \times IQR \). With \( Q \), lower quartile point, \( Q_1 \), 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:

\[
RC = \frac{M_{RT} - M_{CT}}{M_{CT}}
\]

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 (H₁) that in organic farming, reduced tillage can promote earthworm abundance and biomass. Furthermore, with regard to hypothesis two (H₂), 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 (H₃) 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

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<table>
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<tr>
<th>Study</th>
<th>Study site</th>
<th>USDA TC</th>
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<th>Silt</th>
<th>Clay</th>
<th>Type of soil</th>
<th>Excavation depth (cm)</th>
<th>Earthworm sampling</th>
</tr>
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</tr>
<tr>
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<td>Cambisol</td>
<td>0 - 30</td>
<td>Mustard solution</td>
</tr>
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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).
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.

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<th>Tillage system</th>
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<th>Time since last ploughing in RT [months]</th>
<th>Mean abundance RT (MRT)</th>
<th>Mean abundance CT (MCT)</th>
<th>Relative change in abundance (RCA, (MRT - MCT)/MCT)</th>
<th>Mean biomass RT (MRT)</th>
<th>Mean biomass CT (MCT)</th>
<th>Relative change in biomass (RCA, (MRT - MCT)/MCT)</th>
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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. 

\[
RC = \frac{(M_{RT} - M_{CT})}{M_{CT}}; \quad \text{with} \quad M_{RT}: \text{mean under reduced tillage}; \quad M_{CT}: \text{mean under conventional tillage.}
\]

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. 

\[
RC = \frac{(M_{RT} - M_{CT})}{M_{CT}}; \quad \text{with} \quad M_{RT}: \text{mean under reduced tillage}; \quad M_{CT}: \text{mean under conventional tillage.}
\]

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 mould-board 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 mould-board 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 eco-system services provided by earthworms in these fields.

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References


J. H. Moos, S. Schrader, H. M. Paulsen · Landbauforsch · Appl Agric Forestry Res · 3/4 2017 (67)123-128