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Earthworms are little affected by reduced soil tillage methods in vineyards

Florian FABER[1], Elisabeth WACHTER[1], Johann G. ZALLER[2,*]

[1]*Education and Research Centre for Viticulture and Pomology Klosterneuburg, Klosterneuburg, Austria*
[2]*Institute of Zoology, University of Natural Resources and Life Sciences Vienna (BOKU), Vienna, Austria*
**Corresponding author: johann.zaller@boku.ac.at*

ABSTRACT

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Inter-rows in vineyards are commonly tilled in order to control weeds and/or to conserve water. While impacts of tillage on earthworms are well studied in arable systems, very little is known from vineyards. In an experimental vineyard, the impact of four reduced tillage methods on earthworms was examined: rotary hoeing, rotary harrowing, grubbing and no tillage. According to an erosion prevention programme, tillage was applied every other inter-row only while alternating rows retained vegetated. Earthworms were extracted from the treated inter-rows 10, 36, 162 and 188 days after tillage. Across dates, tillage methods had no effect on overall earthworm densities or biomass. Considering each sampling date separately, earthworm densities were affected only at day 36 after tillage leading to lower densities under rotary hoeing (150.7 ± 42.5 worms/m^2) and no tillage (117.3 ± 24.8 worms/m^2) than under rotary harrowing (340.0 ± 87.4 worms/m^2) and grubbing (242.7 ± 43.9 worms/m^2). Time since tillage significantly increased earthworm densities or biomass, and affected soil moisture and temperature. Across sampling dates, earthworm densities correlated positively with soil moisture and negatively with soil temperature; individual earthworm mass increased with increasing time since tillage. It was concluded that reduced tillage in vineyards has little impact on earthworms when applied in spring under dry soil conditions.

Keywords: agroecosystem; soil cultivation; soil disturbance; soil macrofauna; viticulture

Vineyard inter-row soil management is performed for weed control, water conservation, or to prevent erosion (Bauer et al. 2004). Tillage is often flexibly conducted in response to climatic conditions and/or physical characteristics of soil; however, it is usually performed at least once a year. Generally, tillage effects on soil organisms may be directly, through disturbance of an organisms' body, or indirectly, by exposing organisms to harmful conditions, by changing the distribution of organic matter in the soil or by changing soil moisture, temperature, aeration or compaction. Compared with arable systems, potential impacts of tillage on soil organisms in vineyards have rarely been investigated (Paoletti 1988, Coll et al. 2011, 2012, Vršič 2011, Virto et al. 2012). However, it can be expected that earthworms respond differently to tillage in vineyards than in arable land. The main reasons could be that vineyards are more intensively managed than arable fields including more pesticide applications, more soil compaction due to more frequent traffic and usually a lesser soil quality.

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In vineyards, as in many other agroecosystems, the role of earthworms in promoting soil fertility, aggregate formation and soil organic matter protection is important (Lavelle et al. 1997). Because earthworms belong to the biggest soil organisms, they are especially vulnerable to mechanical forces such as tillage. Thus, they were suggested as sensitive bioindicators for sustainable soil use (Cluzeau et al. 1987, Paoletti et al. 1998, Pérès et al. 2008). Earthworm activity has been shown to be associated with soil moisture (Zaller and Arnone 1999), affecting root growth (Arnone and Zaller 2014), plant production (van Groenigen et al. 2014), water infiltration and nutrient leaching (Spurgeon et al. 2013). Commonly, three ecological groups of earthworms can be distinguished in ecosystems. Epigeic species live in the top soil layer, anecic species live in the soil but come to the surface to collect plant material, and endogeic species that stay mainly in the soil (Bouché 1977). Research from arable fields show that conventional tillage, in general, reduces earthworm populations, while reduced tillage promotes it (Kladivko 2001). In vineyards, epigeics have been shown to be more affected by tillage than endogeic species (Paoletti et al. 1998).

The current study examined: (i) whether and to what extent reduced tillage methods in vineyard inter-rows affect the biomass and abundance of earthworms; (ii) to what extent different ecological groups of earthworms are affected, and (iii) whether earthworm populations recover from disturbance through tillage. It was hypothesized that tillage methods with rotating tools are more detrimental to earthworms than methods without rotating tools. Because epigeic and anecic earthworms are more mobile than endogeics, it was expected that they could better recover from soil disturbance than endogeics. Knowledge of the effect of different reduced tillage methods on earthworms would help to adopt sustainable soil management practices in vineyards.

MATERIAL AND METHODS

Study site. The study was conducted in a vineyard of the experimental winery Agneshof of the Education and Research Centre for Viticulture and Pomology of the Federal Ministry of Agriculture, Forestry, Environment and Water Management in Klosterneuburg, near Vienna, Austria (48°17'39.03''N, 16°19'26.18''E, 190 m a.s.l.). The vineyard (established in 1997) is south-facing, slightly inclined and cultivated with different red and white grape cultivars grown on a trellis (grapevine within-row distance: 1.0 m; row distance: 2.8 m). The vineyard was evenly treated with fungicides and fertilizers following good viticultural practice. Soils at the study site developed from alluvial soils of sandy, brown primary material and rounded pebble stones; additionally, chiselled Flysch marl stemmed from colluvial processes.

The study was conducted between April and October 2011. Precipitation was measured by a weather station and showed a maximum monthly rainfall in June (132 mm) and a minimum monthly rainfall in August (32 mm). Mean monthly temperature during the study period was lowest in April (13°C) and October (10°C) and highest in August 21°C. Rainfall in April and May was about 20% lower than long-term averages; mean temperature 8% higher than the long-term average for the period 1970–2000. Long-term mean annual air temperature at this location is 10°C, mean annual precipitation 620 mm (1970–2000, Central Institute of Meteorology and Geodynamics, Vienna).

Tillage treatments. Vineyard inter-rows were cultivated according to the Austrian soil erosion prevention programme allowing tillage of every second inter-row only, while leaving the other rows uncultivated and vegetated (ÖPUL 2007). Four different tillage methods were employed: rotary hoeing, rotary harrowing, grubbing and no tillage (control treatment). Each tillage method was conducted in a separate, randomly assigned vineyard inter-row and spatially replicated three times. Each inter-row was about 2.4 m wide and 20 m long. Rotary hoeing worked up to 100 mm soil depth with rotating shares at a horizontal axle (Figure 1). Rotary harrowing was performed to 100 mm depth with vertically rotating harrow discs and a front grubber to loosen up deeper soil depths (Figure 1). Grubbing was performed in a cultivation depth of 150 mm using a two-frame grubber with fixed shares (Figure 1). No tillage occurred in the control treatment. In order to be able to assess the impact of the time span since last tillage on earthworms, tillage was either conducted on 21 April or on 17 May 2011. Together there were 24 treated inter-rows: 4 tillage methods × 3 replicates × 2 dates.

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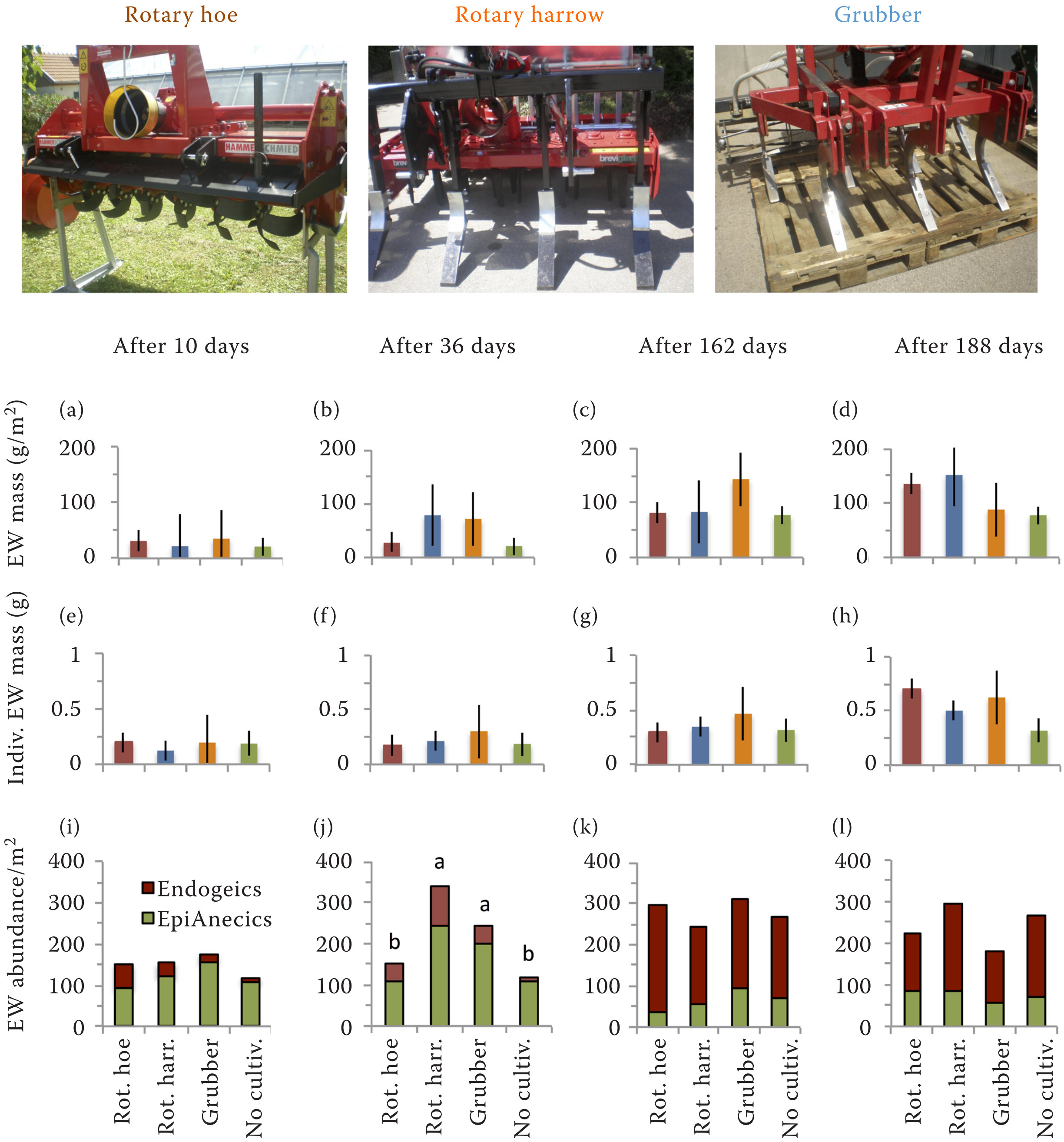

Figure 1. Impacts of tillage methods (rotary hoeing, rotary harrowing, grubber, no tillage) on earthworm (EW) biomass (a–d), specific EW mass (e–h) and EW density and abundance of different ecological groups of earthworms (anecics, endogeics, epigeics; (i–l) in vineyards 10, 36, 162 or 188 days after tillage. Different letters above bars denote significant differences between variants within a sampling date. Means ± standard deviation, $n = 3$

Sampling and measurements. Earthworms were assessed on 27 May and 26 October 2011 on one randomly selected area in the centre of the inter-row using a combined mustard extraction with subsequent hand sorting (Fründ and Jordan 2004). Therefore, a 50 × 50 cm metal frame was pressed about 50 mm into the soil and filled with 10-L mustard-water solution (60 g mustard powder; Eder Gewürze, Mattighofen, Austria). All earthworms appearing at the soil surface after 20 min were collected. After mustard extraction a central area of 0.25 × 0.25 m (0.25 m deep) within the metal

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frame was excavated using a spade and earthworms present in this soil cube collected. All earthworms collected with these two methods were collected, washed free of soil, weighed, counted and assigned to two ecological groups: epi-anecics (pigmented either along the complete length or in the anterior part) and endogeics (no pigmentation). The study distinguished only between these two groups as most of the collected earthworm specimens were juveniles impeding a reliable species identification.

During earthworm extraction, soil temperature was measured (0–100 mm depth) using a digital soil thermometer (Aquaterr T-300, Aquaterr Instruments and Automation, Costa Mesa, USA). Soil moisture was assessed gravimetrically by taking a soil sample with a metal cylinder (diameter 50 mm, depth 100 mm), packed in aluminium foil and weighed fresh and after drying at 105°C for 72 h.

Statistical analyses. First, parameters were tested for normality and variance homogeneity using P-P plots and Levene tests. Second, two-way analyses of variance (ANOVAs) with the factors tillage (4 levels) and time since cultivation (4 levels) on earthworm biomass, density, individual biomass, ecological groups of earthworms was performed. Third, for each sampling date, one-way ANOVAs were performed including the parameters mentioned above. When the main effects were significant, mean comparisons between tillage methods were conducted using the Tukey's tests. Relations between earthworm densities and soil moisture, soil temperature or days since tillage were tested using the Pearson correlations. Data were analysed using the software IBM SPSS Statistics (vers. 21, IBM Incorporation, Armonk, New York, USA).

RESULTS

Overall analysis showed that tillage affected soil temperature but not earthworm parameters; time since tillage affected nearly all measured parameters (Table 1). Soil temperature was also influenced by an interaction between tillage and time since tillage (Table 1). Analysing each sampling date separately, tillage affected earthworm density only at day 36 day after employing the tillage treatments, leading to lower densities under rotary hoeing (150.7 ± 42.5 worms/m; mean ± SD (standard deviation)) and no tillage (117.3 ± 24.8 worms/m^2) than under rotary harrowing (340.0 ± 87.4 worms/m^2) and grubbing (242.7 ± 43.9 worms/m^2; Figure 1j, Table 2). Earthworm biomass varied over time and tillage intensities but was at no sampling date significantly affected by tillage (mean earthworm fresh mass across dates: 71.8 ± 34.3 g/m^2; Figures 1a–d, Table 2). Only endogeic earthworms were affected by tillage only at day 36 after tillage (Figure 1i–l, Table 2). Tillage significantly affected soil temperature at day 10 and day 36; no data are available for day 162 and day 188 due to a sensor failure (Table 2).

Across dates, earthworm density was significantly positively correlated with soil moisture (Figure 2a) and negatively correlated with soil temperature (Figure 2b). Specific earthworm mass increased

Table 1. ANOVA results for the effects of vineyard inter-row soil cultivation (rotary hoeing, rotary harrowing, grubber, no cultivation) and time since cultivation (10, 36, 162 or 188 days) on earthworm (EW) parameters, soil moisture and temperature

Parameter	Soil cultivation (SC)		Time since cultiv. (TSC)		SC × TSC	
	F	*P*	*F*	*P*	*F*	*P*
EW biomass (g/m^2)	2.136	0.115	12.414	< **0.001**	1.372	0.242
EW density (no./m^2)	1.195	0.259	4.367	**0.011**	1.318	0.266
EW indiv. biomass (g/EW)	1.615	0.205	10.947	< **0.001**	0.749	0.624
Epianecics (no./m^2)	2.029	0.130	7.393	**0.001**	1.116	0.380
Endogeics (no./m^2)	0.829	0.487	31.342	< **0.001**	1.158	0.354
Soil moisture (%)	2.219	0.106	276.896	< **0.001**	1.528	0.182
Soil temperature (°C)	11.667	< **0.001**	6670.653	< **0.001**	6.333	< **0.001**

Significant effects are in **bold**

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Table 2. ANOVA results for the effects of vineyard inter-row soil tillage (rotary hoeing, rotary harrowing) on earthworms (EW), soil moisture and temperature

Variable	Soil tillage	
	F	*P*
After 10 days		
EW biomass (g/m²)	0.248	0.861
EW density (no./m²)	0.433	0.735
EW indiv. biomass (g/EW)	0.268	0.847
Epianecis (no./m²)	0.807	0.525
Endogeics (no./m²)	1.170	0.380
Soil moisture (%)	2.260	0.159
Soil temperature (°C)	6.222	**0.017**
After 36 days		
EW biomass (g/m²)	1.640	0.256
EW density (no./m²)	4.660	**0.036**
EW indiv. biomass (g/EW)	0.459	0.719
Epianecis (no./m²)	2.162	0.170
Endogeics (no./m²)	4.774	**0.034**
Soil moisture (%)	3.262	0.089
Soil temperature (°C)	12.000	**0.002**
After 162 days		
EW biomass (g/m²)	2.446	0.139
EW density (no./m²)	0.336	0.800
EW indiv. biomass (g/EW)	1.117	0.398
Epianecis (no./m²)	0.761	0.547
Endogeics (no./m²)	0.686	0.585
Soil moisture (%)	3.298	0.079
Soil temperature (°C)	–	–
After 188 days		
EW biomass (g/m²)	1.420	0.307
EW density (no./m²)	0.557	0.658
EW indiv. biomass (g/EW)	1.333	0.330
Epianecis (no./m²)	0.263	0.850
Endogeics (no./m²)	0.899	0.483
Soil moisture (%)	0.561	0.656
Soil temperature (°C)	–	–

– no data due to sensor failure. Significant effects are in **bold**

marginally significantly with increasing time from last tillage (Figure 2c).

DISCUSSION

Reduced tillage methods showed only subtle effects on earthworm densities or biomass in the study vineyard. This was surprising as tillage methods were compared with rotating versus fixed tools. This was attributed to the following reasons: First, tillage in vineyards is usually performed during a dry spring period when earthworms are in deeper soil horizons and not affected by tillage tools. Second, population sizes in spring are small consisting of small, less susceptible specimens that were not at peak activity. Third, disturbed inter-rows could have been re-populated from neighbouring undisturbed inter-rows. Field experiments where earthworm densities were manipulated showed that earthworms can quickly respond to different population densities (Zaller and Arnone 1999). However, whether this could also happen in vineyards would need to be verified using earthworm tracking methods (Butt and Lowe 2007).

The current study confirms another study investigating tillage impacts on earthworms in vineyards finding that the majority of earthworms were not affected in periodically tilled vineyard soils (Vršič 2011). In the current study, low earthworm densities under uncultivated inter-rows were similar to the tilled ones which is perhaps a consequence of higher soil compaction in uncultivated inter-rows due to frequent traffic for vineyard management (Coll et al. 2011).

While numerous studies conducted in arable fields showed a trend towards detrimental tillage effects on earthworms (Emmerling 2001, Singh et al. 2015), there are also studies reporting little or even stimulating impacts of tillage on earthworms. Earthworm abundance was similar between reduced tillage and mouldboard ploughing (Crittenden et al. 2014). Others showed that biomass of endogeic earthworms was 53% lower but abundance 70% higher under reduced tillage (Berner et al. 2008). In another study, reduced tillage increased anecic earthworms but did not affect overall earthworm abundance (Capowiez et al. 2009). Tillage intensity also decreased the functional diversity of the earthworm community but did not affect species numbers or abundance (Pelosi et al. 2014). Taken together, these contrasting findings suggest that the effects of tillage on earthworms depend on a variety of factors such as tillage method, time of tillage, soil texture or

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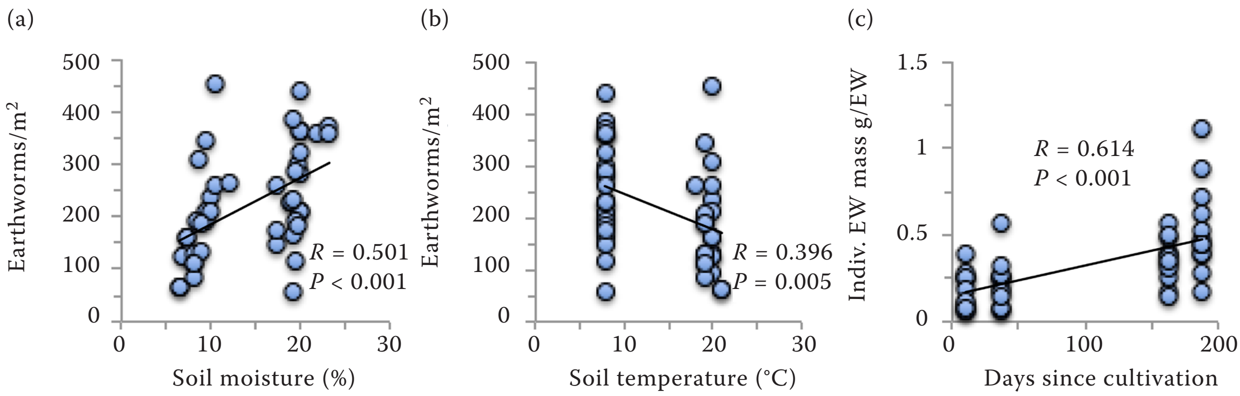

Figure 2. Relationship between (a) earthworm density and soil moisture or (b) soil temperature and specific earthworm mass and (c) days since different tillage methods were applied in vineyards. R – Pearson correlation index; P – significance of this relationship

earthworm species assemblages (Roger-Estrade et al. 2010, van Capelle et al. 2012). A possible detrimental effect of pesticides on earthworms (Gaupp-Berghausen et al. 2015) as the paramount factor can be excluded as the same pesticides were applied for all tillage treatments.

The current finding that abundances of epi-anecic earthworms were little influenced by tillage are in contrast to findings that epigeics were particularly sensitive to tillage (Paoletti et al. 1998). This could be explained by the rather dry weather during the course of the experiment that might have reduced the activity and susceptibility of both epigeics and anecics. The susceptibility to tillage of endogeics at a certain sampling date could be interpreted with seasonal variations in their activity (Zaller and Arnone 1997) and their lower ability to escape from disturbance as compared to epigeics or anecics. However, these aspects are little studied in earthworm ecology.

Earthworm densities in the study vineyard, regardless of tillage, correlated positively with soil moisture and negatively with soil temperature confirming published findings (Crittenden et al. 2014). Although bulk density was not assessed in the current experiment, it was observed that control treatments without tillage were more compacted leading to reduced earthworm populations (Bilalis et al. 2009, Crittenden et al. 2014).

Taken collectively, our results suggest that disturbance of earthworms by tillage is probably less detrimental in vineyards than in arable fields. However, there is also the possibility that alternating tillage of vineyards where only every second inter-row is disturbed might have enabled a repopulation of disturbed inter-rows from neighbouring vegetated inter-rows. More long-term studies conducted in vineyards with various soil types are needed to verify whether the current findings are of more general nature.

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REFERENCES

Arnone J.A., Zaller J.G. (2014): Earthworm effects on native grassland root system dynamics under natural and increased rainfall. Frontiers in Plant Science, 5: 152

Bauer K., Fox R., Ziegler B. (2004): Modern Soil Management in Viticulture. 1st Ed. (Moderne Bodenpflege im Weinbau). Austria and Stuttgart, Österreichischer Agrarverlag und Eugen Ulmer Verlag, Leopoldsdorf.

Berner A., Hildermann I., Fliessbach A., Pfiffner L., Niggli U., Mäder P. (2008): Crop yield and soil fertility response to reduced tillage under organic management. Soil and Tillage Research, 101: 89–96.

Bilalis D., Sidiras N., Vavoulidou E., Konstantas A. (2009): Earthworm populations as affected by crop practices on clay loam soil in a Mediterranean climate. Acta Agriculturae Scandinavica, Section B – Soil and Plant Science, 59: 440–446.

doi: 10.17221/160/2017-PSE

Bouché M.B. (1977): Strategies lombriciennes. In: Lohm U., Persson T. (eds): Soil Organisms as Components of Ecosystems. Uppsala, Swedish Natural Science Research Council, 122–133.

Butt K.R., Lowe C.N. (2007): A viable technique for tagging earthworms using visible implant elastomer. Applied Soil Ecology, 35: 454–457.

Capowiez Y., Cadoux S., Bouchant P., Ruy S., Roger-Estrade J., Richard G., Boizard H. (2009): The effect of tillage type and cropping system on earthworm communities, macroporosity and water infiltration. Soil and Tillage Research, 105: 209–216.

Cluzeau D., Lebouvier M., Trahen P., Bouché M.B., Badour C., Perraud A. (1987): Relations between earthworms and agricultural practices in the vineyards of Champagne. Preliminary results. In: Bonvicini Pagliai A.M., Omodeo P. (eds): On Earthworms. Modena, Mucchi, 465–484.

Coll P., Le Cadre E., Blanchart E., Hinsinger P., Villenave C. (2011): Organic viticulture and soil quality: A long-term study in Southern France. Applied Soil Ecology, 50: 37–44.

Coll P., Le Cadre E., Villenave C. (2012): How are nematode communities affected during a conversion from conventional to organic farming in southern French vineyards? Nematology, 14: 665–676.

Crittenden S.J., Eswaramurthy T., de Goede R.G.M., Brussaard L., Pulleman M.M. (2014): Effect of tillage on earthworms over short- and medium-term in conventional and organic farming. Applied Soil Ecology, 83: 140–148.

Emmerling C. (2001): Response of earthworm communities to different types of soil tillage. Applied Soil Ecology, 17: 91–96.

Fründ H.-C., Jordan B. (2004): Eignung verschiedener Senfzubereitungen als Alternative zu Formalin für die Austreibung von Regenwürmern. Mitteilungen der Deutschen Bodenkundlichen Gesellschaft, 103: 25–26.

Gaupp-Berghausen M., Hofer M., Rewald B., Zaller J.G. (2015): Glyphosate-based herbicides reduce the activity and reproduction of earthworms and lead to increased soil nutrient concentrations. Scientific Reports, 5: 12886.

Kladivko E.J. (2001): Tillage systems and soil ecology. Soil and Tillage Research, 61: 61–76.

Lavelle P., Bignell D., Lepage M., Wolters V., Roger P., Ineson P., Heal O.W., Dhillion S. (1997): Soil function in a changing world: The role of invertebrate ecosystem engineers. European Journal of Soil Biology, 33: 159–193.

ÖPUL (2007): Erosionsschutzprogramm. Available at: http://www.ama.at/Portal.Node/public?gentics.rm=PCP&gentics.pm=gti_full&p.contentid=10008.47310&MEBERW.pdf

Paoletti M.G. (1988): Soil invertebrates in cultivated and uncultivated soils in Northeastern Italy. Redia, 71: 501–563.

Paoletti M.G., Sommaggio D., Favretto M.R., Petruzzelli G., Pezzarossa B., Barbafieri M. (1998): Earthworms as useful bioindicators of agroecosystem sustainability in orchards and vineyards with different inputs. Applied Soil Ecology, 10: 137–150.

Pelosi C., Pey B., Hedde M., Caro G., Capowiez Y., Guernion M., Peigné J., Piron D., Bertrand M., Cluzeau D. (2014): Reducing tillage in cultivated fields increases earthworm functional diversity. Applied Soil Ecology, 83: 79–87.

Pérès G., Piron D., Bellido A., Goater C., Cluzeau D. (2008): Earthworms used as indicators of agricultural managements. Fresenius Environmental Bulletin, 17: 1181–1189.

Roger-Estrade J., Anger C., Bertrand M., Richard G. (2010): Tillage and soil ecology: Partners for sustainable agriculture. Soil and Tillage Research, 111: 33–40.

Singh P., Heikkinen J., Ketoja E., Nuutinen V., Palojärvi A., Sheehy J., Esala M., Mitra S., Alakukku L., Regina K. (2015): Tillage and crop residue management methods had minor effects on the stock and stabilization of topsoil carbon in a 30-year field experiment. The Science of the Total Environment, 518–519: 337–344.

Spurgeon D.J., Keith A.M., Schmidt O., Lammertsma D.R., Faber J.H. (2013): Land-use and land-management change: Relationships with earthworm and fungi communities and soil structural properties. BMC Ecology, 13: 46.

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. European Journal of Soil Biology, 50: 165–181.

van Groenigen J.W., Lubbers I.M., Vos H.M.J., Brown G.G., De Deyn G.B., van Groenigen K.J. (2014): Earthworms increase plant production: A meta-analysis. Scientific Reports, 4: 6365.

Virto I., Imaz M.J., Fernández-Ugalde O., Urrutia I., Enrique A., Bescansa P. (2012): Soil quality evaluation following the implementation of permanent cover crops in semi-arid vineyards. Organic matter, physical and biological soil properties. Spanish Journal of Agricultural Research, 10: 1121–1132.

Vršič S. (2011): Soil erosion and earthworm population responses to soil management systems in steep-slope vineyards. Plant, Soil and Environment, 57: 258–263.

Zaller J.G., Arnone J.A. (1997): Activity of surface-casting earthworms in a calcareous grassland under elevated atmospheric CO_2. Oecologia, 111: 249–254.

Zaller J.G., Arnone J.A. (1999): Earthworm and soil moisture effects on the productivity and structure of grassland communities. Soil Biology and Biochemistry, 31: 517–523.

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