



ELSEVIER

Contents lists available at ScienceDirect

Data in brief

journal homepage: www.elsevier.com/locate/dib



Data Article

A dataset for the effect of earthworm abundance and functional group diversity on plant litter decay and soil organic carbon level



Wei Huang^{a, b}, Grizelle González^c, Xiaoming Zou^{a, b, *}

^a College of Biology and the Environment, Nanjing Forestry University, 159 Longpan Road, Nanjing 210037, Jiangsu, China

^b Department of Environmental Sciences, College of Natural Sciences, University of Puerto Rico, P.O. Box 70377, San Juan, PR 00936-8377, USA

^c International Institute of Tropical Forestry, USDA Forest Service, Jardín Botánico Sur, 1201 Calle Ceiba, Río Piedras, PR 00926-1119, USA

ARTICLE INFO

Article history:

Received 5 January 2020

Received in revised form 1 February 2020

Accepted 3 February 2020

Available online 8 February 2020

Keywords:

Anecic worms

Endogeic worms

Epigeic worms

Forest floor mass

Litter decomposition

Soil carbon

ABSTRACT

This paper describes data of earthworm abundance and functional group diversity regulate plant litter decay and soil organic carbon (SOC) level in global terrestrial ecosystems. The data also describes the potential effect of vegetation types, litter quality, litterbag mesh size, soil C/N, soil aggregate size, experimental types and length of experimental time on earthworm induced plant litter and SOC decay. The data were collected from 69 studies published between 1985 and 2018, covering 340 observations. This data article is related to the paper "Earthworm Abundance and Functional Group Diversity Regulate Plant Litter Decay and Soil Organic Carbon Level: A Global Meta-analysis" [1].

© 2020 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

DOI of original article: <https://doi.org/10.1016/j.apsoil.2019.103473>.

* Corresponding author. College of Biology and the Environment, Nanjing Forestry University, 159 Longpan Road, Nanjing 210037, Jiangsu, China.

E-mail address: Xiaoming.zou@upr.edu (X. Zou).

<https://doi.org/10.1016/j.dib.2020.105263>

2352-3409/© 2020 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

Specifications Table

Subject	Ecology, Soil Science
Specific subject area	Earthworm ecology, litter decomposition, soil carbon
Type of data	Table
How data were acquired	Systematic review of the literature
Data format	Raw
Parameters for data collection	We used three different combinations of keywords: earthworm and litter decomposition; earthworm and forest floor; earthworm and soil carbon.
Description of data collection	Data were collected from the ISI-Web of Science and Google Scholar.
Data source location	18 countries over five continents
Data accessibility	With the article
Related research article	Wei Huang, Grizelle Gonzalez, Xiaoming Zou, Earthworm Abundance and Functional Group Diversity Regulate Plant Litter Decay and Soil Organic Carbon Level: A Global Meta-analysis, Applied Soil Ecology, in press, https://doi.org/10.1016/j.apsoil.2019.103473 . [1]

Value of the Data

- To date, no dataset has provided a comprehensive synthesis of existing experimental data about the effect of earthworms on litter decomposition and soil organic carbon (SOC) levels at global scale.
- Data can be used to quantify the effect of earthworms on litter decomposition and SOC levels at global scale.
- Data can be used to identify effects of earthworm functional group diversity, vegetation types, litter quality, litterbag mesh size, soil C/N, soil aggregate size, experiment types and length of experimental time on earthworm induced plant litter and SOC decay.

1. Data description

Data were extracted from peer-reviewed journal papers published between 1985 and 2018. Totally 340 observations from 69 studies were included. Detailed data are listed in Tables 1–5, giving the following information: location, ecosystem, earthworm density, annual litter decomposition rate, earthworm function group, the response ratio (R), mean annual temperature, mean annual precipitation, experimental type, experimental duration, litter quality, forest floor mass thickness and carbon stock, soil carbon concentration, soil C/N, soil aggregate size, and literature reference.

2. Experimental design, materials, and methods

A data set was compiled using literature search of peer-reviewed publications about the effects of earthworms on litter decomposition or SOC from the ISI-Web of Science and Google Scholar research database. We used three different combinations of keywords: earthworm and litter decomposition; earthworm and forest floor; earthworm and soil carbon. A total of 69 studies published between 1985 and 2018 were found (Tables 1–5). An Engauge Digitizer (Free Software Foundation, Inc., Boston, MA, United States of America) was used to extract numerical values from figures in selected articles in which data were graphically presented.

For Table 1, we included studies that reported earthworm density and litter decomposition/decay rate; 40 observations from 13 studies were found. For Table 3, we included studies that reported earthworm density and forest floor thickness or carbon stock; 32 observations from 12 studies were found. For Table 4, we included studies that reported earthworm density and soil carbon content (% g C/kg soil or mg C/g soil); 70 observations from 12 studies were found. For Tables 1, 3 and 4, we included studies that reflected earthworm density under field conditions (i.e. earthworms were not reduced or added), and plant litter from the vegetation currently under the experimental sites so that these observations can reflect the balance between earthworm density and turnover of plant litter, SOC under field conditions.

Table 1

Location, earthworm density, plant litter decomposition rate, and earthworm functional group in crop fields, tree plantations and forests worldwide for curve estimation.

Location	Ecosystem	Earthworm density (no./m ²)	Annual litter decomposition rate (y ⁻¹)	Earthworm function group	Reference
Georgia, USA	Crop				
	Soy bean	176	1.67	Mixture	[3]
	Rye	176	1.45	Mixture	
Queensland, Australia	Sugarcane Plantation	199	1.88	Endogeic	[4]
Dublin, Ireland	Salix	189	1.69	Mixture	[5]
Carlshead, UK	Short Rotation Forestry	152	0.91	Mixture	[6]
	Natural forest				
Puerto Rico, USA	Tabonuco (Upland)	45	1.47	Mixture	[7]
	Tabonuco (Riparian)	16	0.94	Mixture	
Anduze, France	Chestnut	86	1.50	Mixture	[8,9]
		86	0.55	Mixture	
		86	1.10	Mixture	
		86	0.64	Mixture	
		4	0.71	Anecic	
		4	0.56	Anecic	
		4	0.50	Anecic	
		4	0.37	Anecic	
		28	0.52	Mixture	
		28	0.52	Mixture	
		28	0.48	Mixture	
		28	0.25	Mixture	
		28	0.25	Mixture	
Skane, Sweden	Beech	2.5	0.33	Epigeic	[10]
		39.8	0.60	Mixture	
		219.7	2.15	Mixture	
Hawaii, USA	Metrosiderus	21	0.37	Mixture	[11,12]
Puerto Rico, USA	Tabonuco (Control)	168.8	1.12	Mixture	
	Tabonuco (Fertilization)	29.33	0.84	Endogeic	[13]
	Subtropical lower montane rain forest (Control)	12	0.7	mixture	
	Subtropical lower montane rain forest (Fertilization)	19	1.49	Mixture	
Ontario, Canada	Sugar maple and American beech	67.675	0.39	Mixture	[14]
	Aspen Forest	44.44	0.36	Mixture	
Colorado, USA	Pine Forest	44.44	0.31	Mixture	[15]
		0.77	0.29	Epigeic	
		0.77	0.25	Epigeic	
		0.77	0.25	Epigeic	
New York State, USA	Sugar maple	79.6	1.05	Mixture	[16]
		26.5	0.51	Mixture	
		99.4	1.27	Mixture	
	Oak	26.1	0.6	Mixture	
		81.6	0.96	Mixture	
		26.4	0.53	Mixture	
		92.6	1.16	Mixture	
		21.5	0.63	Mixture	

Table 2

The location, biome, mean annual temperature (MAT), mean annual precipitation (MAP), experimental type, experimental duration, earthworm functional group, earthworm numbers, litter quality for observations about the effects of earthworm on litter decomposition in the meta-analysis.

Location	Ecosystems	MAT (°C)	MAP (mm)	Experimental type	Experimental period (days)	Earthworm functional group	Litter type	Litter C/N	Litter bag mesh size (mm)	Effect size	References			
Puerto Rico, USA	Pasture	22–26	3500	Field	365	Endogeic	Leaf	26	1	2.62	[17]			
	Pasture	22–26	3500	Field	365	Endogeic	Root	101	1	1.10				
	Forest	20.8–24.5	3456	Field	365	Mixture	Leaf	32	1	1.22				
	Forest	20.8–24.5	3456	Field	365	Mixture	Root	101	1	1.12				
Maryland, USA	Forest (Tulip poplar Association-mature)			Field	240	Mixture	Leaf		10	2.29	[18]			
				Field	240	Mixture	Leaf		1	1.12				
Anduze, France	Forest	11.9	1212	Field	760	Mixture	Leaf		5	2.33	[8]			
				Field	760	Mixture	Leaf		5	1.75		[9]		
				Field	760	Mixture	Leaf		5	2.42				
				Field	760	Mixture	Leaf		5	1.492				
Chicago, USA	Forest (Buckthorn)			Field	365		Leaf		4	33.76	[19]			
				Field	365		Leaf		4	2.32				
				Field	365		Leaf		4	1.95				
				Field	365		Leaf		4	1.64				
	Forest (mesic)			Field	365		Leaf		4	9.81				
				Field	365		Leaf		4	3.73				
				Field	365		Leaf		4	2.33				
				Field	365		Leaf		4	2.56				
	Forest (maple)			Field	365		Leaf		4	2.79				
				Field	365		Leaf		4	0.77				
				Field	365		Leaf		4	1.73				
				Field	365		Leaf		4	0.94				
				Ibadan, Nigeria	Crop	Lab	56	Epigeic	Leaf	10.1			2.53	[20]
						Field	56	Epigeic	Leaf	10.1			1.98	
New York, USA	Forest (Oak)	1000		Field	190	Mixture	Leaf		10	0.98	[21]			
				Field	190	Mixture	Leaf		10	1.077				
	Forest (Sugar maple)			Field	190	Mixture	Leaf		10	1.027				
				Field	190	Mixture	Leaf		10	1.11				
	Forest (Oak)			Field	340	Mixture	Leaf		10	1.35				
				Field	340	Mixture	Leaf		10	1.51				
	Forest (Sugar maple)			Field	340	Mixture	Leaf		10	2.58				
				Field	340	Mixture	Leaf		10	1.53				
	Forest (Oak)			Field	540	Mixture	Leaf		10	1.68				
				Field	540	Mixture	Leaf		10	2.41				
Forest (Sugar maple)	Field	540	Mixture	Leaf		10	1.56							
	Field	540	Mixture	Leaf		10	2.59							

Guangdong, China		Lab	126	Endogeic	Leaf	0.93	[22]
		Lab	126	Anecic	Leaf	1.42	
Baden Wurttemberg, Germany	14–22	Lab	63	Anecic	Leaf 17.3	1	[23]
	14–22	Lab	63	Anecic	Leaf 17.3	1.91	
	14–22	Lab	63	Anecic	Leaf 17.3	2.37	
Amazonas, Brazil	24–31	Lab	97	Endogeic	Leaf 27	0.95	[24]
		Lab	97	Endogeic	Leaf 32	1.03	
		Lab	97	Endogeic	Leaf 34	1.07	
		Lab	97	Endogeic	Leaf 42	1.04	
		Lab	97	Endogeic	Leaf 27	0.78	
		Lab	97	Endogeic	Leaf 32	0.89	
		Lab	97	Endogeic	Leaf 34	1.00	
		Lab	97	Endogeic	Leaf 42	0.98	
Tyrol, Austria	15 - 20	Lab	84	Endogeic	Leaf 34.7	0.96	[25]
		Lab	84	Epigeic	Leaf 34.7	1.00	
		Lab	84	Epigeic	Leaf 34.7	1.43	
		Lab	84	Mixture	Leaf 34.7	1.02	
		Lab	84	Mixture	Leaf 34.7	1.09	
		Lab	84	Epigeic	Leaf 34.7	1.12	
		Lab	84	Epigeic	Leaf 34.7	1.32	
		Lab	84	Endogeic	Leaf 34.7	1.11	
		Lab	84	Endogeic	Leaf 27.2	0.95	
		Lab	84	Epigeic	Leaf 27.2	1.04	
		Lab	84	Epigeic	Leaf 27.2	1.97	
		Lab	84	Mixture	Leaf 27.2	1.02	
		Lab	84	Mixture	Leaf 27.2	1.31	
		Lab	84	Epigeic	Leaf 27.2	1.25	
		Lab	84	Epigeic	Leaf 27.2	2.05	
		Lab	84	Endogeic	Leaf 27.2	1.56	
Wisconsin, USA	Forest	Field	123	Anecic	Leaf	4.62	[26]
Minnesota, USA	Temperate deciduous forest	Lab	42	Anecic	Leaf	1.50	[27]
		Lab	42	Epigeic	Leaf	2.35	
		Lab	42	Mixture	Leaf	2.80	
		Field	82	Anecic	Leaf	1.06	
		Field	82	Epigeic	Leaf	1.47	
		Field	82	Mixture	Leaf	1.37	
Tyrol, Austria	15	Lab	28	Epigeic	Leaf	1.07	[28]
	15	Lab	28	Epigeic	Leaf	1.11	
	15	Lab	28	Epigeic	Leaf	1.17	
	15	Lab	28	Epigeic	Leaf	1.21	

(continued on next page)

Table 2 (continued)

Location	Ecosystems	MAT (°C)	MAP (mm)	Experimental type	Experimental period (days)	Earthworm functional group	Litter type	Litter C/N	Litter bag mesh size (mm)	Effect size	References
Bechstetdt, Germany		15–20		Lab	56	Anecic	Leaf			2.12	[29]
				Lab	56	Anecic	Leaf			2.68	
				Lab	56	Anecic	Leaf			3.15	
				Lab	56	Anecic	Leaf			3.26	
				Lab	56	Anecic	Leaf			2.67	
				Lab	56	Anecic	Leaf			4.00	
				Lab	56	Anecic	Leaf			13.28	
				Lab	56	Anecic	Leaf			6.28	
				Lab	56	Anecic	Leaf			1.34	
				Lab	56	Anecic	Leaf			1.06	
				Lab	56	Anecic	Leaf			35.85	
				Lab	56	Anecic	Leaf			2.15	
				Lab	56	Anecic	Leaf			5.95	
				Lab	56	Anecic	Leaf			1.33	
				Lab	56	Anecic	Leaf			2.18	
				Lab	56	Anecic	Leaf			4.72	
				Lab	56	Anecic	Leaf			9.63	
				Lab	56	Anecic	Leaf			1.16	
				Lab	56	Anecic	Leaf			1.20	
				Lab	56	Anecic	Leaf			1.56	
				Lab	56	Anecic	Leaf			1.80	
				Lab	56	Anecic	Leaf			3.34	
				Lab	56	Anecic	Leaf			11.36	
				Lab	56	Anecic	Leaf			6.97	
				Lab	56	Anecic	Leaf			12.36	
Puerto Rico, USA	Short rotation forestry	11.2	630	Lab	22	Mixture	Leaf			2.10	[30]
Hampshire, UK				Field	365	Mixture	Leaf	32.5		2.26	[31]
Carlshead, UK	Short rotation forestry	9	1000	Field	365	Mixture	Leaf	39.5		1.51	[6]
				Field	365	Mixture	Leaf	39.5	5	5.28	
				Field	365	Mixture	Leaf	52	5	8.15	
				Field	365	Mixture	Leaf	33	5	12.44	
				Field	365	Mixture	Leaf	32.5	5	10.41	
Kaserstattalm, Austria		9–17		Field	261	Mixture	Leaf	18.2	5	17.56	[32]
				Lab	120	Epigeic	Leaf			1.35	
				Lab	120	Epigeic	Leaf			1.07	
Gottingen, Germany		18		Lab	120	Epigeic	Leaf			2.50	[33]
				Lab	90	Epigeic	Leaf			1.24	

Table 3

Location, earthworm density, and forest floormass thickness and carbon stock in forests worldwide for curve estimation.

Location	Earthworm density (no./m ²)	Forest floormass		References
		Thickness (cm)	Carbon stock (g/m ²)	
Minnesota, USA	592.00	0.60		[34]
Minnesota, USA	821.47	1.14		[35]
Ontario, Canada	99.50	2.70		[36]
Alberta, Canada	622.72	4.19		[37]
	181.59	3.66		
	108.14	3.57		
	136.42	3.49		
	162.75	2.64		
	214.18	1.01		
	196.08	0.97		
	623.02	0.20		
	458.67	0.12		
	661.73	0.04		
Maryland, USA	212.00	1.00	116.00	[38]
Maryland, USA	38.00	6.25		[39]
Michigan, USA	9.10		895.60	[40]
	247.80		316.20	
New York State, USA	106.30		211.20	[41]
	76.83		70.40	
New York State, USA	150.00		196.34	[42]
	89.20		295.39	
Puerto Rico, USA	32.67		785.10	[43]
	56.00		406.40	
	8.76		563.90	
Jilin, China	780	1.0		[44]
	336	2.5		
	153	2.0		
	52	1.5		
Yunan, China	28.5	1.5		[45]
	12.35	0.5		
	7.5	1		

To be included in the meta-analysis, the paper had to report the means, standard deviation (SDs) and replicate numbers of litter percent mass loss or SOC for the control treatment (C, with no earthworms or reduced earthworm number) and the experimental treatment (E, with earthworms or earthworm number do not reduce). For studies that did not report SD or standard error (SE), we conservatively estimated SD values as 150% of the average variance across the dataset [2]. To evaluate the significance of the earthworm-induced effect on litter decomposition, 113 observations from 20 studies were found (Table 2). For the magnitude of the earthworm-induced effect on SOC content, 120 observations from 22 studies were found (Table 5). Because most of the studies do not report soil bulk density, we therefore converted SOC stocks with known bulk density (20 observations) to SOC concentrations. Besides earthworm functional groups, other details of experimental conditions were also specified in our analyses. We included studies that reported climate, vegetation types (naturally-grown forest, plantation, pastureland and crop), litter quality (litter C/N ratio and leaf versus root litter), litterbag mesh size, time length of experiment, soil depth, soil aggregate size, soil C/N ratio and experimental types (field versus laboratory). These parameters were the controlling factors that we considered for the earthworm effect on litter decay and SOC. The magnitude of the earthworm-induced effect on litter decay and SOC were calculated as the response ratio (R), $R = E/C$, where E and C are the means of experimental and control treatments, respectively.

Table 4

Location, earthworm density, and mineral soil carbon concentration in 12 sites of crop fields, pasture, and forests worldwide used for curve estimation.

Location	Ecosystems	Earthworm density (no./m ²)	Soil depth (cm)	Soil organic C concentration (%)	Earthworm functional group	References	
Ohio, USA	Crop Corn-soybean	17.9	0–10	16.1	Mixture	[46]	
			10–20	12.4			
			20–30	12.3			
			30–40	8.8			
Jiangsu, China	Rice–wheat	30	0–20	8.04	Anecic	[47]	
Timiș, Romania	Wheat-soybean-maize-barley	9.33		2.26		[48]	
		14.76		2.16			
		9.33		2.16			
		13.33		2.10			
		26.67		2.53			
Tennessee, USA	Rotation	46.05	0–15	1.2	Mixture	[49]	
	Corn						
	-soybean						
	Continuous Soybean						1.4
	Continuous Corn						1.0
	Bio-cover						
	Fallow						1.1
	Hair vetch						1.1
	Poultry litter						1.3
Hawaii, USA	Wheat	36.75	0–25	1.1	Mixture	[50]	
	Eucalypt	12		7.55			
		151		8.52			
		154		8.80			
		398		9.86			
Eifel, Germany	Four crop rotation (rape, winter wheat, winter barley, and spring barley)	119.3	0–10	1.56	Mixture	[51]	
		113.3	10–20	1.52			
			20–30	0.87			
			0–10	1.79			
			10–20	1.22			
		160	20–30	0.75	Mixture		
			0–10	1.94			
			10–20	1.23			
			20–30	0.74			
		132.7	0–10	1.71	Mixture		
			10–20	1.14			
			20–30	0.68			
			157.3	0–10			1.75
		10–20	1.15				
		20–30	0.67				

Karnataka, India	Agricultural fields (rice, nuts, and banana)	485.14	0–30	4.94	Mixture	[52]
KwaZuluNatal midlands, South Africa	Ryegrass	158.82	0–10	3.74	Mixture	[53]
	Maize	49.27		3.12	Mixture	
	Sugarcane	25.74		2.56	Epigeic	
	Ryegrass	76.53		3.21	Mixture	
	Maize	45.79		2.68	Mixture	
	Sugarcane	164.69		3.06	Epigeic	
Victoria, Australia	Crop	21.00	0–7.5	0.93		[54]
		46.00		0.94		
		50.00		0.96		
New Zealand	Pasture	637	0–5	3.98	Mixture	[55]
			5–10	4.10		
			10–18	3.30		
			18–26	3.20		
KwaZuluNatal midlands, South Africa	Kikuyu grass	236.03	0–10	7.58	Mixture	[53]
	Native grassland	6.08		5.79		
	Kikuyu grass	303.34		8.07		
New York, USA	Forest	106	0–5	5.75	Mixture	[39,40]
			5–10	2.63		
			10–15	1.65		
			15–20	1.43		
			0–5	6.97		
			5–10	4.12		
			10–15	1.93		
Honduras	Forest	37.89	15–20	1.71		[56]
			0–15	3.59		
			0–30	5.24		
Karnataka, India	Forest	561.06	0–10	5.24	Mixture	[52]
	Gum forest	60.29		3.53	Endogeic	[53]
	Pine forest	18.38		4.45	Mixture	
	Gum forest	60.97		5.62	Endogeic	
	Pine forest	19.91		5.51	Mixture	
Hawaii, USA	Eucalypt	173	0–25	8.90	Mixture	[50]
		147		9.43	Mixture	

The location, biome, MAT, MAP, experimental type, earthworm functional group, earthworm number, soil depth, soil C/N and soil aggregate size for observations about the effects of earthworm on soil organic carbon levels in the meta-analysis.

W. Huang et al. / Data in brief 29 (2020) 105263

Jiangsu, China	Rice–wheat	16	1106	Field	Anecic	0 - 20	2555	8.30	1.02	[47]
							2555		1.02	
Quebec, Canada	Hardwood	6.2	1058	Field		0–10		14.00	1.56	[60]
	forest					10–20		13.30	1.50	
Xishuangbanna	Rubber	21.8	1493	Field	Endogeic	0–5	600	11.80	0.94	[61]
, China	plantation					5–15	600	11.80	1.05	
						0–5	600	11.80	0.72	
						5–15	600	11.80	1.45	
Congo, Brail	Savanna				Endogeic	0–10			0.67	[62]
						10–20			1.31	
						20–30			1.00	
Georgia, USA				Lab	Endogeic		20	>2000	3.42	[63]
							20	250–2000	0.52	
Georgia, USA				Lab	Endogeic		20	>2000	3.12	[64]
							20	250–2000	0.78	
							20	53–250	0.71	
							20	<53	0.61	
Great Smoky		18		Lab	Epigeic		23		0.92	[65]
Mountains							23		0.89	
National							23	>2000	10.25	
Park, USA							23	>2000	5.32	
							23	250–2000	0.59	
							23	250–2000	0.80	
							23	53–250	0.08	
							23	53–250	0.66	
Trier, Germany		15		Lab	Mixture		42	14.88	1.01	[66]
							42	14.31	1.06	
							42	15.25	0.99	
							42	15.25	1.03	
Georgia, USA				Lab	Endogeic	0–3.5	37		1.03	[67]
					Epigeic	3.5–7	37		1.09	
					Endogeic	0–3.5	37		0.98	
					Epigeic	3.5–7	37		1.08	
Alberta, Canada				Lab	Epigeic	1–4	28		1.03	[68]
						1–4	56		0.89	
						1–4	84		0.96	
						1–4	28		0.73	
						1–4	56		0.89	
						1–4	84		0.70	
						4–7	28		0.94	
						4–7	56		0.90	
						4–7	84		1.00	
						4–7	28		0.79	
						4–7	56		1.00	

(continued on next page)

Table 5 (continued)

Location	Ecosystems	MAT (°C)	MAP (mm)	Experimental type	Earthworm functional group	Soil depth (cm)	Experimental period	Soil C/N	Soil aggregate size	Effect size of soil organic carbon	References
Jilin, China	18	Lab				4–7	84			0.68	[69]
						>7	28			1.16	
						>7	56			1.29	
						>7	84			1.04	
						>7	28			1.60	
						>7	56			1.23	
						>7	84			1.94	
						0–2.5	30			0.95	
						0–2.5	30			1.12	
						0–2.5	30			0.94	
						0–2.5	30			1.18	
						2.5–5	30			1.03	
						2.5–5	30			0.77	
						2.5–5	30			0.95	
Hubei, China	25±2	Lab		Anecic		2.5–5	30			1.14	[70]
							40			0.96	
							40			0.77	
							40			1.10	
							40		<250	0.79	
							40		250–1000	1.21	
Jinlin, China	20	Lab		compost			40	13.04	1000–2000	1.19	[71]
							18		>2000	1.04	
							18			1.15	
							18			1.04	
							35			1.12	
							35			1.10	
Puerto Rico, USA		Lab		Anecic			35	14.09		1.08	[30]
							22			0.98	
							22			1.01	
							22			0.94	
							22			0.99	
							22			0.97	
Hanoi, Vietnam	15–25	Lab		Mixture			22			0.97	[72]
							22			0.97	
							365			1.02	
							365			0.82	
							365			0.81	

Acknowledgments

This work was financially supported by a cooperative agreement between the USDA-Forest Service International Institute of Tropical Forestry and the University of Puerto Rico [14-JV-11120101-018, 2015]. Grizelle González was supported by the Luquillo Critical Zone Observatory [EAR-1331841] and the Luquillo Long-Term Ecological Research Site [DEB-1239764].

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] W. Huang, G. González, X. Zou, Earthworm abundance and functional group diversity regulate plant litter decay and soil organic carbon level: a global meta-analysis, *Appl. Soil Ecol.* (2019), <https://doi.org/10.1016/j.apsoil.2019.103473>.
- [2] I.M. Lubbers, K.J. van Groenigen, S.J. Fonte, J. Six, L. Brussaard, et al., Greenhouse-gas emissions from soils increased by earthworms, *Nat. Clim. Change* 3 (2013) 187–194.
- [3] R. Parmelee, M. Beare, W. Cheng, P. Hendrix, S. Rider, et al., Earthworms and enchytraeids in conventional and no-tillage agroecosystems: a biocide approach to assess their role in organic matter breakdown, *Biol. Fertil. Soils* 10 (1990) 1–10.
- [4] A. Spain, M. Hodgen, Changes in the composition of sugarcane harvest residues during decomposition as a surface mulch, *Biol. Fert. soils* 17 (1994) 225–231.
- [5] J. Curry, M. Kelly, T. Bolger, Role of invertebrates in the decomposition of *Salix* litter in reclaimed cutover peat, in: A.H. Fitter (Ed.), *Ecological Interactions in the Soil Special Publication Number 4 of the British Ecological Society*, Blackwell Scientifica Publications, London, 1985, pp. 393–397.
- [6] N. Rajapaksha, K.R. Butt, E. Vanguelova, A. Moffat, Effects of short rotation forestry on earthworm community development in the UK, *For. Ecol. Manag.* 309 (2013) 96–104.
- [7] J. Dechaine, H. Ruan, L.Y. Sanchez-de, X. Zou, Correlation between earthworms and plant litter decomposition in a tropical wet forest of Puerto Rico, *Pedobiologia* 49 (2005) 601–607.
- [8] J. Cortez, M. Bouché, Field decomposition of leaf litters: earthworm–microorganism interactions—the ploughing-in effect, *Soil Biol. Biochem.* 30 (1998) 795–804.
- [9] J. Cortez, Field decomposition of leaf litters: relationships between decomposition rates and soil moisture, soil temperature and earthworm activity, *Soil Biol. Biochem.* 30 (1998) 783–793.
- [10] H. Staaf, Foliage litter turnover and earthworm populations in three beech forests of contrasting soil and vegetation types, *Oecologia* 72 (1987) 58–64.
- [11] G. Aplet, Alteration of earthworm community biomass by the alien *Myrica faya* in Hawai'i, *Oecologia* 82 (1990) 414–416.
- [12] P.M. Vitousek, D.R. Turner, W.J. Parton, R.L. Sanford, Litter decomposition on the Mauna Loa environmental matrix, Hawai'i: patterns, mechanisms, and models, *Ecology* 75 (1994) 418–429.
- [13] X. Yang, M. Warren, X. Zou, Fertilization responses of soil litter fauna and litter quantity, quality, and turnover in low and high elevation forests of Puerto Rico, *Appl. Soil Ecol.* 37 (2007) 63–71.
- [14] B.W. Jennings, S.A. Watmough, The impact of invasive earthworms on soil respiration and soil carbon within temperate hardwood forests, *Ecosystems* 19 (2016) 942–954.
- [15] G. González, T.R. Seastedt, Z. Donato, Earthworms, arthropods and plant litter decomposition in aspen (*Populus tremuloides*) and lodgepole pine (*Pinus contorta*) forests in Colorado, USA, *Pedobiologia* 47 (2003) 863–869.
- [16] E.R. Suárez, T.J. Fahey, J.B. Yavitt, P.M. Groffman, P.J. Bohlen, Patterns of litter disappearance in a northern hardwood forest invaded by exotic earthworms, *Ecol. Appl.* 16 (2006) 154–165.
- [17] Z. Liu, X. Zou, Exotic earthworms accelerate plant litter decomposition in a Puerto Rican pasture and a wet forest, *Ecol. Appl.* 12 (2002) 1406–1417.
- [18] K. Szlavecz, M. McCormick, L. Xia, J. Saunders, T. Morcol, et al., Ecosystem effects of non-native earthworms in Mid-Atlantic deciduous forests, *Biol. Invasions* 13 (2011) 1165–1182.
- [19] L. Heneghan, J. Steffen, K. Fagen, Interactions of an introduced shrub and introduced earthworms in an Illinois urban woodland: impact on leaf litter decomposition, *Pedobiologia* 50 (2007) 543–551.
- [20] C.O. Adejuyigbe, G. Tian, G.O. Adeoye, Microcosmic study of soil microarthropod and earthworm interaction in litter decomposition and nutrient turnover, *Nutrient Cycl. Agroecosyst.* 75 (2006) 47–55.
- [21] P.J. Bohlen, P.M. Groffman, T.J. Fahey, M.C. Fisk, E. Suárez, et al., Ecosystem consequences of exotic earthworm invasion of north temperate forests, *Ecosystems* 7 (2004) 1–12.
- [22] J. Wu, H. Li, W. Zhang, F. Li, J. Huang, et al., Contrasting impacts of two subtropical earthworm species on leaf litter carbon sequestration into soil aggregates, *J. Soils Sediments* 17 (2017) 1672–1681.
- [23] N. Eisenhauer, S. Marhan, S. Scheu, Assessment of anecic behavior in selected earthworm species: effects on wheat seed burial, seedling establishment, wheat growth and litter incorporation, *Appl. Soil Ecol.* 38 (2008) 79–82.
- [24] Y. Araújo, F.J. Luizão, E. Barros, Effect of earthworm addition on soil nitrogen availability, microbial biomass and litter decomposition in mesocosms, *Biol. Fertil. Soils* 39 (2004) 146–152.
- [25] J. Seeber, S. Scheu, E. Meyer, Effects of macro-decomposers on litter decomposition and soil properties in alpine pastureland: a mesocosm experiment, *Appl. Soil Ecol.* 34 (2006) 168–175.
- [26] J. Qiu, M.G. Turner, Effects of non-native Asian earthworm invasion on temperate forest and prairie soils in the Mid-western US, *Biol. Invasions* 19 (2016) 73–88.

- [27] H.G. Greiner, D.R. Kashian, S.D. Tiegs, Impacts of invasive Asian (*Amyntas hilgendorfi*) and European (*Lumbricus rubellus*) earthworms in a North American temperate deciduous forest, *Biol. Invasions* 14 (2012) 2017–2027.
- [28] F. Kitz, M. Steinwandter, M. Traugott, J. Seeber, Increased decomposer diversity accelerates and potentially stabilises litter decomposition, *Soil Biol. Biochem.* 83 (2015) 138–141.
- [29] G. Patoine, M.P. Thakur, J. Friese, C. Nock, L. Honig, et al., Plant litter functional diversity effects on litter mass loss depend on the macro-detritivore community, *Pedobiologia* 65 (2017) 29–42.
- [30] C. Huang, G. González, P.F. Hendrix, Resource utilization by native and invasive earthworms and their effects on soil carbon and nitrogen dynamics in Puerto Rican soils, *Forests* 7 (2016) 277.
- [31] N.S.S. Rajapaksha, K.R. Butt, E.I. Vangelova, A.J. Moffat, Short rotation forestry – earthworm interactions: a field based mesocosm experiment, *Appl. Soil Ecol.* 76 (2014) 52–59.
- [32] J. Seeber, G. Seeber, R. Langel, S. Scheu, E. Meyer, The effect of macro-invertebrates and plant litter of different quality on the release of N from litter to plant on alpine pastureland, *Biol. Fertil. Soils* 44 (2008) 783–790.
- [33] D. Grubert, O. Butenschon, M. Maraun, S. Scheu, Understanding earthworm – Collembola interactions and their importance for ecosystem processes needs consideration of species identity, *Eur. J. Soil Biol.* 77 (2016) 60–67.
- [34] D.H. Alban, E.C. Berry, Effects of earthworm invasion on morphology, carbon, and nitrogen of a forest soil, *Appl. Soil Ecol.* 1 (1994) 243–249.
- [35] C.M. Hale, L.E. Frelich, P.B. Reich, J. Pastor, Exotic earthworm effects on hardwood forest floor, nutrient availability and native plants: a mesocosm study, *Oecologia* 155 (2008) 509–518.
- [36] T.E. Sackett, S.M. Smith, N. Basiliko, Indirect and direct effects of exotic earthworms on soil nutrient and carbon pools in North American temperate forests, *Soil Biol. Biochem.* 57 (2013) 459–467.
- [37] N. Eisenhauer, S. Partsch, D. Parkinson, S. Scheu, Invasion of a deciduous forest by earthworms: Changes in soil chemistry, microflora, microarthropods and vegetation, *Soil Biol. Biochem.* 39 (2007) 1099–1110.
- [38] K. Szilávecz, C. Csuzdi, Land use change affects earthworm communities in Eastern Maryland, USA, *Eur. J. Soil Biol.* 43 (2007) S79–S85.
- [39] Y. Ma, T.R. Filley, C.T. Johnston, S.E. Crow, K. Szilávecz, et al., The combined controls of land use legacy and earthworm activity on soil organic matter chemistry and particle association during afforestation, *Org. Geochem.* 58 (2013) 56–68.
- [40] K.J. McFarlane, M.S. Torn, P.J. Hanson, R.C. Porras, C.W. Swanston, et al., Comparison of soil organic matter dynamics at five temperate deciduous forests with physical fractionation and radiocarbon measurements, *Biogeochemistry* 112 (2013) 457–476.
- [41] T.J. Fahey, J.B. Yavitt, R.E. Sherman, J.C. Maerz, P.M. Groffman, et al., Earthworm effects on the incorporation of litter C and N into soil organic matter in a sugar maple forest, *Ecol. Appl.* 23 (2013) 1185–1201.
- [42] P.J. Bohlen, D.M. Pelletier, P.M. Groffman, T.J. Fahey, M.C. Fisk, Influence of earthworm invasion on redistribution and retention of soil carbon and nitrogen in northern temperate forests, *Ecosystems* 7 (2004) 13–27.
- [43] M.W. Warren, X. Zou, Soil macrofauna and litter nutrients in three tropical tree plantations on a disturbed site in Puerto Rico, *For. Ecol. Manag.* 170 (2002) 161–171.
- [44] Y. Xiu, Q. Li, Y. Ling, S. Bo, The relation and difference of nutritional elements in forest litter-macrofaunas-soil system, *Chinese Geo. Res.* 25 (2006) 320–326.
- [45] S. Wang, H. Wang, W. Li, Effect of different land use types on spatial-temporal distribution of earthworm density and biomass, *Chinese J. Ecol.* 36 (2017) 118–123.
- [46] W.D. Shuster, S. Subler, E. McCoy, Deep-burrowing earthworm additions changed the distribution of soil organic carbon in a chisel-tilled soil, *Soil Biol. Biochem.* 33 (2001) 983–996.
- [47] J. Zhang, F. Hu, H. Li, Q. Gao, X. Song, et al., Effects of earthworm activity on humus composition and humic acid characteristics of soil in a maize residue amended rice–wheat rotation agroecosystem, *Appl. Soil Ecol.* 51 (2011) 1–8.
- [48] M. Iordache, I. Borza, Relation between chemical indices of soil and earthworm abundance under chemical fertilization, *Plant Soil Environ.* 56 (2010) 401–407.
- [49] A.J. Ashworth, F.L. Allen, D.D. Tyler, D.H. Pote, M.J. Shipitalo, Earthworm populations are affected from long-term crop sequences and bio-covers under no-tillage, *Pedobiologia* 60 (2017) 27–33.
- [50] X. Zou, M. Bashkin, Soil carbon accretion and earthworm recovery following revegetation in abandoned sugarcane fields, *Soil Biol. Biochem.* 30 (1998) 825–830.
- [51] G. Ernst, C. Emmerling, 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 (2009) 247–251.
- [52] T.S.H. Kumar, M. Siddaraju, C.H.K. Bhat, K.S. Sreepada, Seasonal distribution and abundance of earthworms (Annelida: Oligochaeta) in relation to the edaphic factors around Udupi Power Corporation Limited (UPCL), Udupi District, south-western coast of India, *J. Threat. Taxa* 10 (2018) 11432.
- [53] R.J. Haynes, C.S. Dominy, M.H. Graham, Effect of agricultural land use on soil organic matter status and the composition of earthworm communities in KwaZulu-Natal, South Africa, *Agric. Ecosyst. Environ.* 95 (2003) 453–464.
- [54] P. Haines, N. Uren, Effects of conservation tillage farming on soil microbial biomass, organic matter and earthworm populations, in north-eastern Victoria, *Aust. J. Exp. Agric.* 30 (1990) 365–371.
- [55] N.L. Schon, A.D. Mackay, R.A. Gray, M.B. Dodd, The action of an anecic earthworm (*Aporrectodea longa*) on vertical soil carbon distribution in New Zealand pastures several decades after their introduction, *Eur. J. Soil Biol.* 62 (2014) 101–104.
- [56] S.J. Fonte, E. Barrios, J. Six, Earthworms, soil fertility and aggregate-associated soil organic matter dynamics in the Quesungual agroforestry system, *Geoderma* 155 (2010) 320–328.
- [57] T.J. Fahey, J.B. Yavitt, R.E. Sherman, J.C. Maerz, P.M. Groffman, et al., Earthworms, litter and soil carbon in a northern hardwood forest, *Biogeochemistry* 114 (2012) 269–280.
- [58] L. Cole, R.D. Bardgett, P. Ineson, Enchytraeid worms (Oligochaeta) enhance mineralization of carbon in organic upland soils, *Eur. J. Soil Sci.* 51 (2000) 185–192.
- [59] L.Y. Sánchez-de, J. Lugo-Pérez, D.H. Wise, J.D. Jastrow, M.A. González-Meler, Aggregate formation and carbon sequestration by earthworms in soil from a temperate forest exposed to elevated atmospheric CO₂: a microcosm experiment, *Soil Biol. Biochem.* 68 (2014) 223–230.
- [60] M. Wironen, T.R. Moore, Exotic earthworm invasion increases soil carbon and nitrogen in an old-growth forest in southern Quebec, *Can. J. For. Res.* 36 (2006) 845–854.

- [61] M. Zhang, X. Zou, D.A. Schaefer, Alteration of soil labile organic carbon by invasive earthworms (*Pontoscolex corethrurus*) in tropical rubber plantations, *Eur. J. Soil Biol.* 46 (2010) 74–79.
- [62] P. Lavelle, A. Martin, Small-scale and large-scale effects of endogeic earthworms on soil organic matter dynamics in soils of the humid tropics, *Soil Biol. Biochem.* 24 (1992) 1491–1498.
- [63] H. Bossuyt, J. Six, P. Hendrix, Rapid incorporation of carbon from fresh residues into newly formed stable microaggregates within earthworm casts, *Eur. J. Soil Sci.* 55 (2004) 393–399.
- [64] H. Bossuyt, J. Six, P.F. Hendrix, Protection of soil carbon by microaggregates within earthworm casts, *Soil Biol. Biochem.* 37 (2005) 251–258.
- [65] W. Zhang, P.F. Hendrix, L.E. Dame, R.A. Burke, J. Wu, et al., Earthworms facilitate carbon sequestration through unequal amplification of carbon stabilization compared with mineralization, *Nat. Commun.* 4 (2013) 2576.
- [66] G. Ernst, I. Henseler, D. Felten, C. Emmerling, Decomposition and mineralization of energy crop residues governed by earthworms, *Soil Biol. Biochem.* 41 (2009) 1548–1554.
- [67] Q. Zhang, P.F. Hendrix, Earthworm (*Lumbricus rubellus* and *Aporrectodea caliginosa*) effects on carbon flux in soil, *Soil Sci. Soc. Am. J.* 59 (1995) 816–823.
- [68] S. Scheu, D. Parkinson, Effects of earthworms on nutrient dynamics, carbon turnover and microorganisms in soils from cool temperate forests of the Canadian Rocky Mountains — laboratory studies, *Appl. Soil Ecol.* 1 (1994) 113–125.
- [69] Y. Guo, A. Liang, Y. Zhang, S. Zhang, X. Chen, et al., Evaluating the contributions of earthworms to soil organic carbon decomposition under different tillage practices combined with straw additions, *Ecol. Indic.* 109 (2018) 516–524.
- [70] Y. Wu, M. Shaaban, Q.A. Peng, A. Zhou, R. Hu, Impacts of earthworm activity on the fate of straw carbon in soil: a microcosm experiment, *Environ. Sci. Pollut. Res. Int.* 25 (2018) 11054–11062.
- [71] X. Zhu, L. Chang, J. Li, J. Liu, L. Feng, et al., Interactions between earthworms and mesofauna affect CO₂ and N₂O emissions from soils under long-term conservation tillage, *Geoderma* 332 (2017) 153–160.
- [72] P.T. Ngo, C. Rumpel, T.T. Doan, P. Jouquet, The effect of earthworms on carbon storage and soil organic matter composition in tropical soil amended with compost and vermicompost, *Soil Biol. Biochem.* 50 (2012) 214–220.