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► **To cite this version:**

Vincent Ducasse, Vincent Tolon, Apolline Auclerc, Line Capowiez, Joséphine Peigné, et al.. The use of vermicompost from urban organic waste leads to a sustainable increase of earthworm abundance: a three-year study in a crop field converting to organic farming. *European Journal of Soil Biology*, 2025, 127, pp.103789. <10.1016/j.ejsobi.2025.103789>. <hal-05393304>

HAL Id: hal-05393304

<https://isara.hal.science/hal-05393304v1>

Submitted on 25 Mar 2026

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1 **The use of vermicompost from urban organic waste leads to a sustainable**
2 **increase of earthworm abundance: a three-year study in a crop field**
3 **converting to organic farming**

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12
13 **Keywords:** Agroecology - Soil quality - Compost – Digestate – Recycling

14
15 **Abbreviations:**

16 GLMM: Generalized Linear Mixed Models

17 LMM: Linear Mixed Models

18 OFMSW: Organic Fraction of Municipal Solid Waste

19 OM: Organic matter

20
21
22 **Highlights:**

- 23 • We studied the effect of different municipal solid waste on earthworms
24 • Compost had no effect on the abundance of adult earthworms after 3 years
25 • Digestate led to a large but transient increase in adult earthworm biomass
26 • Vermicompost steadily increased adult earthworm abundance and biomass

27 **1. Introduction**

28 Although historically linked to the development of agriculture, organic waste had little interest
29 for farmers at the beginning of the 20th century because of the intensification of agriculture and
30 the development of the chemical industry [1]. As soon as urban organic residues were no longer
31 reused, they became waste. Moreover, the standardization of practices such as the use of N-P-
32 K fertilizers in agriculture [2] and farm specialization led to a breakdown of activities by sector
33 and region (dairy farming in mountains and cereal in plains). But since the second part of the
34 20th century, with the development of circular economy concepts and the emergence of new
35 agricultural currents like organic farming, this organic fraction of municipal solid waste
36 (OFMSW) has shown renewed interest as a resource for soil fertility in agriculture. To develop
37 and promote long-term sustainable agriculture [3], the management of organic waste (from
38 farms and cities) remains a major challenge in the 21st century [4]. We observed a paradox
39 about organic matter (OM), which is insufficiently present in farms (and therefore compensated
40 by chemical fertilizers) [5], while cities have developed unsustainable management of their
41 OFMSW (mostly incinerated or landfilled). Nevertheless, it is possible to restore this OM cycle
42 thanks to circular economy principles while reducing our impact on the environment [6].

43

44 In a review concerning OFMSW, Lohri et al. [7] listed the different valorization processes in
45 four groups: (i) direct use (direct spreading, direct feed, or direct combustion), (ii) biological
46 treatment (composting, vermicomposting, black soldier fly larvae treatment, anaerobic
47 digestion (AD), fermentation), (iii) physicochemical treatment (transesterification,
48 densification) and (iv) thermochemical treatment (pyrolysis, liquefaction, gasification). For
49 agriculture, composting and anaerobic digestion are the most treatments used in Europe. Even
50 if far less studied, vermicompost from OFMSW can be an excellent opportunity for agriculture
51 [8]. Vermicomposting is a controlled process of OM degradation with the specificity of
52 earthworm addition before the decomposition to accelerate the stabilization process for
53 increasing biological, physical, and chemical quality of the product [9–11]. The earthworm
54 species used are usually epigeics since they live in the litter or wastes, they reproduce quickly,
55 and consume a large amount of OM [12,13]. This process, realized under mesophilic conditions,
56 permits a degradation and stabilization of OM by the interaction of earthworms, associated
57 microorganisms, and other decomposers [14]. Composting is a degradation of OM in
58 thermophilic and aerobic conditions which leads to a succession of microbial communities
59 transforming waste into a soil amendment: compost [15]. AD is a biochemical process that can

60 convert OM into biogas (essentially CH₄ and CO₂) and digestate (slurry), the latter can be used
61 as such or separated into solid and liquid phases [16,17].

62

63 The need for OM is particularly crucial for organic farming since the fundamental aim of this
64 system is to maintain soil fertility to sustainably supply essential nutrients to crops [18].
65 However, it is difficult to assess and forecast soil OM changes due to the variability of soils
66 and the diversity of OM applied [19]. Organic farmers typically rely on OM resources to sustain
67 their production. Indeed, without chemicals for pests, weeds, and pathogen management,
68 organic farming is generally dependent on tillage [20], which can result in biodiversity loss
69 [21]. To address these issues, adapted farming practices have been developed, such as crop
70 rotation (lengthening and diversifying cycles) [22] or “soil conservation” techniques with no or
71 limited tillage practices [20]. The current challenge for organic farming is to reduce its impacts
72 on soil and maintain yields. [23].

73

74 Soil biodiversity, which is composed of all organisms that perform at least one active stage of
75 their life cycle in the soil (bacteria, fungi, vertebrates, invertebrates) [24], provides many
76 services for ecosystems by actively participating in the regulation of soil physico-chemical
77 processes [25]. Biological components are quantitatively and qualitatively measurable and can
78 be used as diagnostic tools of soil quality. [26]. Earthworms, as soil engineers, have a major
79 role in modifying soil structure [27] and influencing many other ecosystem services such as
80 pedogenesis, water regulation, nutrient cycling, primary production, climate regulation,
81 pollution control, and cultural services [12]. In organic production, they are considered useful
82 actors for the transformation of OM and the supply of nutrients to plants [22]. Moreover,
83 earthworms are potential bio-indicators of crop system quality [28] because they are very
84 reactive to changes in practices within agroecosystems [29]. D’Hose et al. [30] showed, in a
85 European multi-year field experiment, that input of OM increases earthworm abundance
86 between 63 to 151% and their biomass between 66 and 196% (using compost, farmyard manure
87 or animal slurry). However, no studies were carried out to compare the impact of different OM
88 from OFMSW on earthworm communities in the field, whereas it is well known that earthworm
89 populations are influenced by the quality of OM [31]. For example, digestate generally
90 increases earthworm abundance after a few months, even if it sometimes causes surface toxicity
91 [32]. Composts can also increase the earthworm population [33]. However, the impact of
92 vermicompost from OFMSW (and any other type of waste) on earthworm communities in field
93 conditions has never been studied to our knowledge. Depending on the applied products

94 (different compositions and textures, i.e., solid or liquid), earthworms are expected to respond
95 differently because they select food according to its palatability [34]. Moreover, anecic species
96 select carbon-derived foods such as crop residues [35], epigeics generally prefer fresh or semi-
97 decomposed OM, and endogeics prefer soil-integrated OM, whether fresh or decomposed [36].

98

99 We set out to evaluate the impact of OFMSW products on the earthworm in a commercial field
100 in transition from conventional to organic, with the concomitant adoption of reduced tillage.
101 For this, we set up a 3-year field trial with yearly inputs of compost, digestate, and
102 vermicompost. A previous study had characterized in depth the potential amending effect of
103 their products and showed that compost and vermicompost were those with the higher
104 amending potential (for the medium/long term and very long term respectively) compared to
105 digestate characterized by a lower amending potential (more close to a fertilizer) [37]. Within
106 the current study, we hypothesized that products from OFMSW could increase the abundance
107 and biomass of earthworms. We predict that compost and vermicompost would have a greater
108 effect than digestate, which is more a fertilizer than an amendment, and that additionally can
109 be toxic for earthworms foraging at the soil surface.

110

111 **2. Materials and methods**

112 *2.1. Study site, soil characteristics, and climate data*

113 The experimental site is located in the town of Civrieux in the southeast of France (45°54'45"N,
114 4°53'40"E). This crop field was converted to organic farming (OF) at the beginning of our three-
115 year trial in 2020. The farmer also stopped tillage at the beginning of our experiment
116 (agronomic practices are presented in Table S1). Table 1 presents the main characteristics of
117 this typic Luvisol (redoxic) soil typical of the northern Lyon field crops [38]. The field is
118 characterized by a low OM content (1.5%), a silty sandy clay texture, a slightly acidic pH (6.3),
119 and a balanced C/N (8.9). The average temperature (°C) and cumulative precipitation (mm)
120 from the French station Lyon-Bron (45°43'17"N, 4°56'57"E) during the time of
121 experimentation, with the values month by month and the deviation from normal calculated
122 from 1981 to 2010, are given in Table S2.

123

124 **Table 1.** Mean, minimum, and maximum values for the physico-chemical analyses of the soil from the
 125 experimental plot of Civrieux at the beginning of the experiment. Means are from 24 samples (1 per
 126 subplot) except for the soil bulk density, where the samples were taken between the plots ($n=16$).

| Measurements | Units | Mean | Min. | Max. | Standard or method |
|---|---------------------|-------|-------|-------|----------------------------|
| Clay | g.kg ⁻¹ | 106 | 89 | 133 | NF X 31-107 |
| Fine silt | g.kg ⁻¹ | 211 | 175 | 241 | NF X 31-107 |
| Coarse silt | g.kg ⁻¹ | 441 | 410 | 464 | NF X 31-107 |
| Fine sand | g.kg ⁻¹ | 236 | 174 | 274 | NF X 31-107 |
| Coarse sand | g.kg ⁻¹ | 7 | 4 | 13 | NF X 31-107 |
| Total limestone (CaCO ₃) total | g.kg ⁻¹ | <1 | <1 | <1 | NF EN ISO 10693 |
| pH | - | 6.30 | 5.90 | 6.90 | NF ISO 10390 |
| Organic Carbon (OC) | g.kg ⁻¹ | 8.90 | 7.50 | 9.90 | NF ISO 14 235 |
| Organic Matter (OM) (1.72 x OC) | g.kg ⁻¹ | 15.31 | 12.90 | 17.03 | Calculation |
| Total Nitrogen (TN) Kjeldahl | g.kg ⁻¹ | 0.98 | 0.87 | 1.22 | Colorimetric determination |
| C/N | - | 9.19 | 7.10 | 11.30 | Calculation |
| Potassium (K ₂ O) exchangeable | g.kg ⁻¹ | 0.15 | 0.10 | 0.21 | NF X31-108 |
| Calcium (CaO) exchangeable | g.kg ⁻¹ | 1.68 | 1.48 | 1.91 | NF X31-108 |
| Magnesium (MgO) exchangeable | g.kg ⁻¹ | 0.09 | 0.06 | 0.13 | NF X31-108 |
| Phosphorus (P ₂ O ₅) assimilable (P Olsen) | g.kg ⁻¹ | 0.07 | 0.06 | 0.08 | NF ISO 11263 |
| Copper (Cu) | mg.kg ⁻¹ | 13.09 | 11.70 | 14.30 | NF X-31-147 |
| Zinc (Zn) | mg.kg ⁻¹ | 42.15 | 36.60 | 48.20 | NF X-31-147 |
| Cadmium (Cd) | mg.kg ⁻¹ | 0.14 | <0.1 | 0.93 | NF X-31-147 |
| Chromium (Cr) | mg.kg ⁻¹ | 38.65 | 35.40 | 42.10 | NF X-31-147 |
| Mercury (Hg) | mg.kg ⁻¹ | 0.025 | 0.021 | 0.032 | Elemental analyzer |
| Nickel (Ni) | mg.kg ⁻¹ | 16.82 | 14.40 | 21.10 | NF X-31-147 |
| Lead (Pb) | mg.kg ⁻¹ | 16.90 | 14.80 | 19.10 | NF X-31-147 |

127

128 2.2. Experimental design of the field experiment

129 In this 3-year experiment (2 applications and 3 years of survey), we applied the products
 130 (compost, digestate, and vermicompost) on the basis of equivalent total nitrogen but with two
 131 doses (recommended dose and twice this dose). We used this approach (total N equivalent) to
 132 follow the practices generally applied in the organic farms of the region (SE France) and
 133 because the products from the biowaste are generally rich in N. To avoid groundwater pollution,
 134 especially for digestate, which is easily leachable, we did not test the high dose for this product.
 135 Our experiment therefore had 6 treatments: low-dose of compost (Cx1), high-dose of compost
 136 (Cx2), low-dose of digestate (Dx1), low-dose of vermicompost (Vx1), high-dose of
 137 vermicompost (Vx2), and a control without OM application. The treatments were randomly
 138 assigned in 4 blocks. All subplots of 90 m² (15 x 6 m) were separated by a border of one meter
 139 between each other. Each year, we adapted the doses of products to the nutritional needs of the
 140 crop. The computed doses of inputs took into account the results of the analysis of products
 141 each year (Table 2). The chemical quality of products applied in 2020 and 2021 is presented in
 142 Tables S3 and S4, respectively, and a detailed analysis of products applied in 2020 was

143 presented by Ducasse et al. (2023). For each product, three samples of approximately 20 to 40
 144 liters were taken randomly for these analyses. These were obtained by mixing about twenty
 145 samples at different depths of the pile for compost and vermicompost and at different levels in
 146 the tank for the digestate. For barley cultivation in the first year (2020), we applied product
 147 doses of 60 and 120 kg.N.ha⁻¹ (Total N), and for wheat in the second year (2021) we applied
 148 doses of 80 and 160 kg.N.ha⁻¹ (Total N). The final year was a cover crop (end of 2022) followed
 149 by a nitrogen-fixing crop (lentil and oat mix in 2023), thus no product was applied.
 150

151 **Table 2.** *Inputs of products carried out on the experimental site of Civrieux calculated from the analysis*
 152 *of raw products according to the years of application.*

| Year (crop) | Inputs doses | Products | Equivalent N (kg.ha ⁻¹) | Equivalent C (t.ha ⁻¹) | Real quantity (t.ha ⁻¹) |
|------------------|-----------------------------------|--------------|--|---------------------------------------|--|
| 2020 (Barley) | Dose 60 kg.N.ha ⁻¹ | Compost | 46 | 0.49 | 2.22 |
| | | Digestate | 54.36 | 0.32 | 11.44 |
| | | Vermicompost | 55.07 | 0.55 | 6.67 |
| | Dose 120 kg.N.ha ⁻¹ | Compost | 94.31 | 1.00 | 4.56 |
| | | Vermicompost | 111.05 | 1.10 | 13.44 |
| | | | | | |
| 2021 (Wheat) | Dose 80 kg.N.ha ⁻¹ | Compost | 88.32 | 1.11 | 5.44 |
| | | Digestate | 75.52 | 0.35 | 14.78 |
| | | Vermicompost | 83.06 | 0.90 | 9.33 |
| | Dose 160 kg.N.ha ⁻¹ | Compost | 176.28 | 2.21 | 10.78 |
| | | Vermicompost | 165.15 | 1.79 | 18.56 |
| | | | | | |

153
 154

155 2.3. Origins of products from Organic Fraction of Municipal Solid Waste (OFMSW)

156 The three studied products were derived from organic waste from the city of Lyon (France) and
 157 were (i) compost from the selective collection of professional food waste, (ii) a digestate from
 158 an agricultural anaerobic digestion made with a mix of OFMSW and (iii) a vermicompost from
 159 a mixture of 4 different collective vermicomposters made with citizen food waste. The compost
 160 was made using an electromechanical composter (Tidy Planet A900) mixed with food waste
 161 and shredded wood as the bulking agent (50/50 in volume). The waste remained in the
 162 composter for an average of 12–14 days at 50–70°C before the compost matured in bins for
 163 three months and was sieved at 20 mm and then stored in “Bigbags” (1m³). The digestate was
 164 produced by AD without phase separation in the form of sludge. At the time of digestate
 165 collection for the first application in 2020, the daily mixture consisted of 23 tons of slurry, four
 166 tons of cattle manure, three tons of horse manure, four tons of paper sludge, one and a half tons
 167 of caramel process residues, seven tons of biowaste (in the form of soup) and nine tons of
 168 slaughterhouse grease. In total, there was a mixture of 30 tons of agricultural residues (~60 %)
 169 and 21.5 tons of waste from the food and paper industry (~40 %). The daily mix between

170 agricultural waste and food and paper industry waste for the second spreading in 2021 was also
171 60 and 40%. The mixture of vermicompost came from collective vermicomposters in the same
172 district of the city of Lyon and was collected at maturity (stage ready for standardization and
173 sale by producers). The vermicompost was made by citizens from biowaste and cardboard as
174 the bulking agent and managed by an association and site referents (person trained in
175 vermicomposting which is responsible of installation). The transformation process involved 4
176 to 5 months of degradation (60% biowaste and 40% cardboard by volume, which was
177 occasionally supplemented with white wood chips) and an average of 1 month of maturation.
178 After collected, the vermicompost was sieved at 50 mm.

179

180 *2.4. Evaluation of earthworm communities*

181 Earthworm monitoring was carried out every 6 months in spring and autumn from T0 (October
182 2020) to T5 (February 2023). Earthworms were sampled by manual sorting of blocks of soil 40
183 x 40 cm and 30 cm deep.". The extracted earthworms were identified, separated into juveniles
184 and adults, and weighed in the laboratory.. For the first samples (T0 – October 2020 and T1 –
185 February 2021), we sampled only one replication per plot and then 2 for the next 3 dates (T2 –
186 October 2021, T3 – March 2022 and T4 – October 2022) and lastly 3 for the final date (T5 –
187 February 2023).

188

189 *2.5. Soil bulk density*

190 Soil bulk density was measured by extracting soil cylinders (100 cm³) at 0-10 cm depth. We
191 computed bulk density based on the difference between the weight of wet and dry soil (after 2
192 days at 105°C) and the volume of the cylinder. Bulk density was measured at the beginning, in
193 the middle, and at the end of the experiment (2020/10/13, 2021/03/05, and 2022/03/09,
194 respectively). At each date, one cylinder was sampled per plot.

195

196 *2.6. Data analysis*

197 All results were analyzed with R software version 4.2.2 [39] and all the graphs were made
198 using the package ‘ggplot2’ version 3.4.1 [40].

199 To analyze earthworm biomasses, the exponential response was modeled with a log
200 transformation and linear mixed effect models (LMM). To avoid problems with $\log(0)$
201 computation and arbitrary choice of the constant c in the $\log(x+c)$ transformation that strongly
202 modifies variable distribution and estimates, we used the quartile method of Stahel [41]. This

203 transformation produces low bias in estimates and was performed with the formula
204 $\log(x+Q_{1x}^2/Q_{3x})$ with Q_{1x} and Q_{3x} first and third quartiles of the x variable. We were able to
205 apply this transformation because the occurrence of biomass equal to zero was less than 25%
206 in our data.

207

208 For the earthworm abundances, GLMM with a negative binominal error link was realized using
209 the package ‘lme4’ version 1.1-31 with the functions `glmer.nb` [42]. Following each model fit,
210 its dispersion was measured using the square root of the penalized residual sum of squares
211 divided by the number of observations (`dispersion_glmer` function, ‘blmeco’ package).
212 According to the recommendations, the model was accepted if the parameter was between 0.75
213 and 1.4 [42].

214

215 We modeled the variation of the four response variables (abundance and biomass both for adults
216 and juveniles) with the treatments (one factor with 6 modalities), the time (days since 1st
217 sampling), an additional the quadratic effect of time to account for possible non-linear temporal
218 trends and interactions of treatments with time and its quadratic effect. These models, therefore,
219 make it possible to give a trajectory of the variable (increase and/or decrease, stabilization) as
220 a function of time for the different treatments studied. We added to each model a random block
221 effect on the intercept to account for uncontrolled local differences in earthworm abundance
222 and biomass. The significance of fixed factors and their interaction was determined by a
223 likelihood ratio test (LRT) using the `add1` and `drop1` functions of the ‘stats’ package.

224

225 As a complement to this analysis, Tukey multiple comparison tests were performed on the
226 treatment effect within models using the package ‘multcomp’ version 1.4-20 [43].

227

228 To analyze variation in the composition of the earthworm communities, a principal component
229 analysis (PCA) was performed without the undetermined juvenile endogeic. We used the ‘ade4’
230 package [44].

231

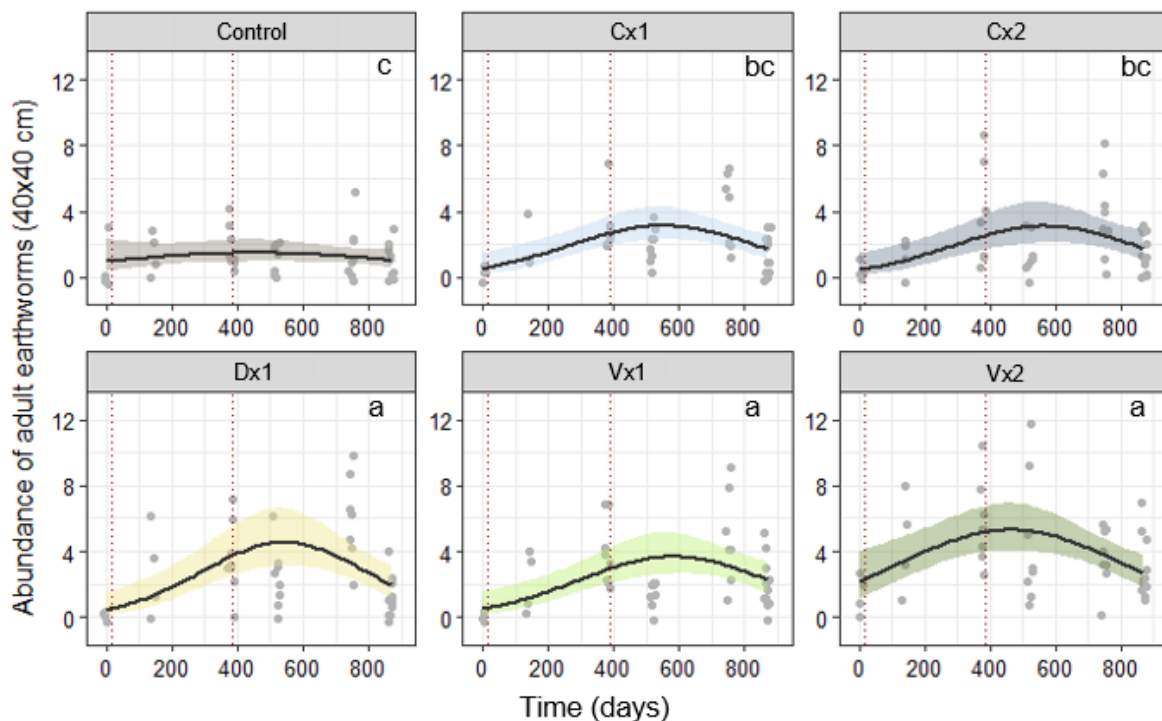
232 For the changes of density over time, we performed 3 LMM with fixed-effects blocks with (1)
233 time alone, (2) the treatment factor alone, and (3) time and treatments with or without
234 interactions.

235

236 **3. Results**

237 3.1. Earthworm abundance

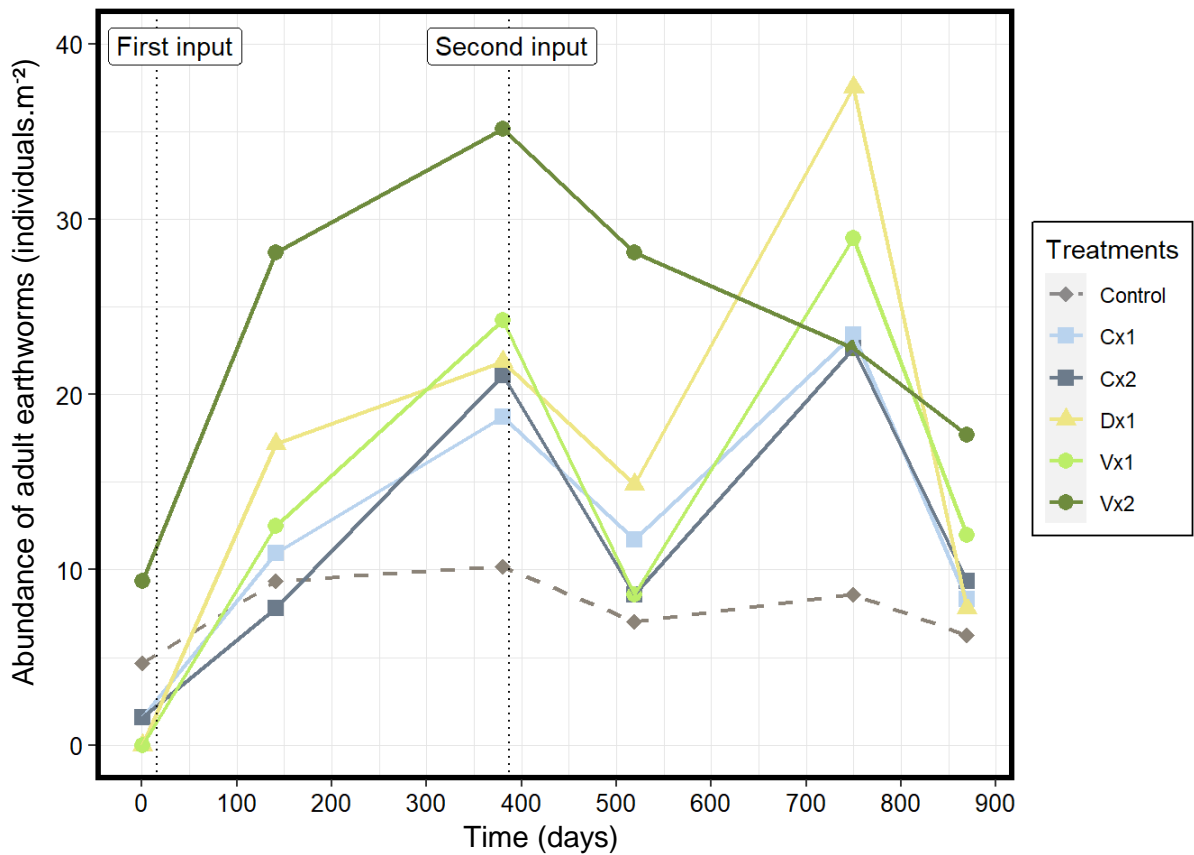
238 We found 6 species *Lumbricus terrestris* (Linnaeus, 1758), *Aporrectodea nocturna* (Evans,
 239 1946), *Aporrectodea caliginosa* (Savigny, 1826), *Aporrectodea cupulifera* (Tetry, 1937),
 240 *Allolobophora chlorotica* (Savigny, 1826) and *Aporrectodea icterica* (Savigny, 1826). Since
 241 present in low abundances, all epigeics (mainly *Lumbricus castaneus*) were considered
 242 together. Too small endogeics (< 0.1 g) could not be accurately assigned to a species and were
 243 classified as undetermined juvenile endogeics. Regarding adult abundance, we observed a
 244 significant effect of treatments ($p < 0.001$), a non-significant linear time effect ($p = 0.45$) but a
 245 significant non-linear time effect ($p < 0.001$). None of the interactions between these factors
 246 were significant (all $p > 0.28$; Fig. 1). Vx2 was characterized by a significantly higher abundance
 247 of adults than Cx1, Cx2, and control. The abundance for Vx2 was, however, not significantly
 248 different from the Vx1 and Dx1 treatments. These two latter treatments were different from the
 249 control. At our last sampling date, the abundance of adult earthworms drastically decreased,
 250 but this decrease was the lowest for Vx2 compared to all the other amended plots (Fig. 2). At
 251 this date, we observed an average (\pm SE) of 18 adults per m^2 (\pm 12) for Vx2 and 12 adults per
 252 m^2 (\pm 9) for Vx1 followed by Cx2 with 9 adults per m^2 (\pm 8) and Cx1 and Dx1 with 8 adults
 253 per m^2 (\pm 7 for both treatments) and finally 6 adults per m^2 (\pm 7) for control (Fig. 2).



254

255 **Fig. 1.** Abundance of adult earthworms per sampling point for each treatment for the 3 years of the
 256 experiment. C: compost; D: digestate; V: vermicompost; x1: low dose and x2: high dose. The grey dots
 257 represent values for subplots, and the red dashed lines represent the dates of OM inputs. The black line
 258 represents the GLMM model with a negative binomial error link, and the colored envelope corresponds

259 to a trend line with a 95% confidence interval of our negative binomial model. Letters are used to show
 260 the differences between treatments (treatments sharing a letter are not significantly different).
 261
 262



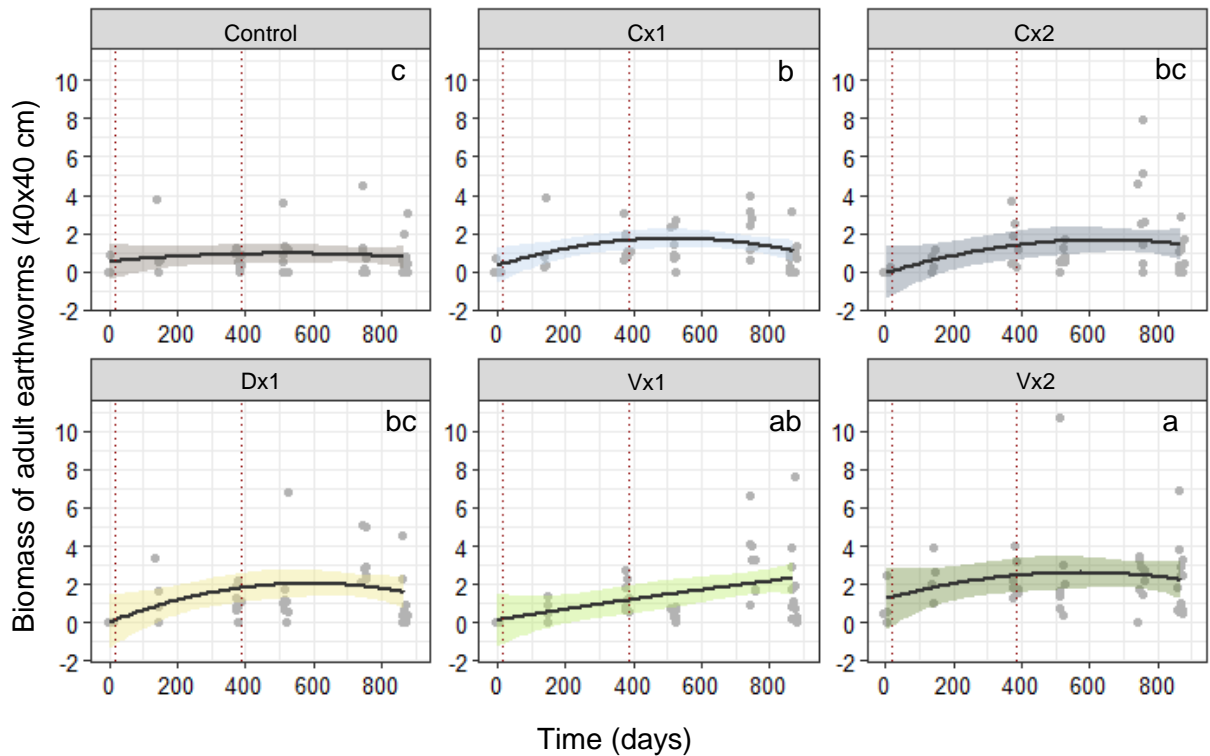
263
 264
 265 **Fig. 2.** Mean abundances of adult earthworms converted to individuals.m⁻² for the three years with C:
 266 compost; D: digestate; V: vermicompost; x1: low dose and x2: high dose. Dotted lines are the dates of
 267 organic matter inputs.
 268

269 Regarding the abundance of juveniles, we observed a marginal effect of treatments ($p=0.052$)
 270 and significant linear ($p<0.001$) and quadratic time effects ($p<0.001$). None of the interactions
 271 were significant (all $p>0.32$). The abundance of juvenile earthworms showed a large and
 272 continuous decrease from an average of about 300 individuals at T0 to 11 individuals at T6
 273 when all treatments were combined (Fig. S5).
 274

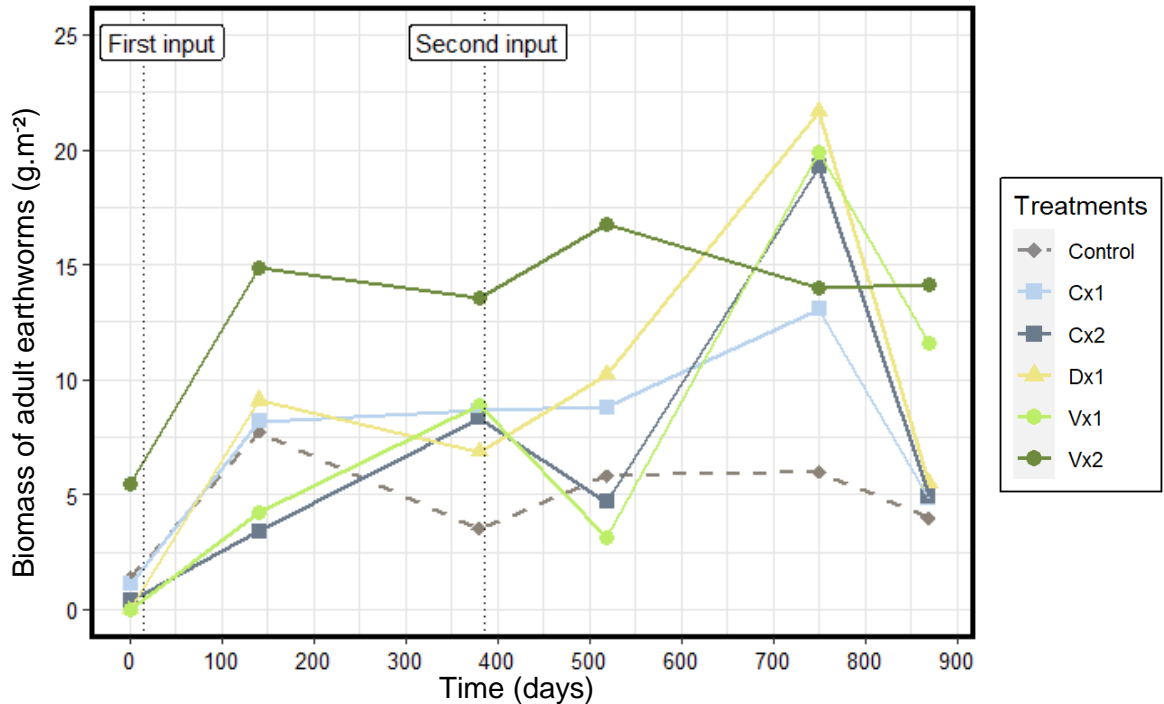
275 3.2. Earthworm biomass

276 Regarding the biomass of adults, a significant effect was observed for treatments ($p<0.001$) and
 277 for the nonlinear effect of time ($p=0.56$ and $p<0.001$ for linear and quadratic time, respectively).
 278 We observed no significant effect for the interaction between time and treatments ($p>0.097$).
 279 Biomasses for Vx2, Vx1, and Cx1 were higher than for the control (Fig. 3). Vx1 was not
 280 significantly different from other treatments (Dx1, Cx1, and Cx2). Cx2 and Dx1 were not
 281 different from the control. At the last sampling, the highest biomass of adults were observed is

282 Vx2 with 14 g.m⁻² (± 12) followed by Vx1 with 12 g.m⁻² (± 14), Dx1 with 5 g.m⁻² (± 8), Cx2
 283 and Cx1 with 5 g.m⁻² (± 5 and 8 respectively) and finally 4 g.m⁻² (± 6) for the control (Fig. 4).
 284 Once again, a large decrease was observed after 750 days excepted for Vx2 and control.



285
 286
 287 **Fig. 3.** Biomass of adult earthworms per sampling point for each treatment for the 3 years of the
 288 experiment. Lines are the result of the LMM with quadratic effect of polynomial 2 on time applied to
 289 data transformed by the Stahel method (2008). The letters indicate the statistical differences between
 290 treatments and C: compost; D: digestate; V: vermicompost; x1: low dose and x2: high dose. The black
 291 line represents the GLMM model with a negative binomial error link, and the colored envelope
 292 corresponds to a trend line with a 95% confidence interval of our negative binomial model. Letters are
 293 used to show the differences between treatments (treatments sharing a letter are not significantly
 294 different).
 295



297
298
299
300
301
302

Fig. 4. Average biomasses of adult earthworms converted to g.m^{-2} for the three years with C: compost; D: digestate; V: vermicompost; x1: low dose and x2: high dose. Dotted lines are the dates of organic matter inputs.

303 For the biomass of juveniles, there was no treatment difference ($p=0.24$) but a marked non-
304 linear time effect ($p < 0.001$ for linear and quadratic time effect) was observed. The abundance
305 showed a continuous decrease from, on average, 60 to 5 g.m^{-2} in the last sampling for all the
306 treatments (Fig. S6).

307

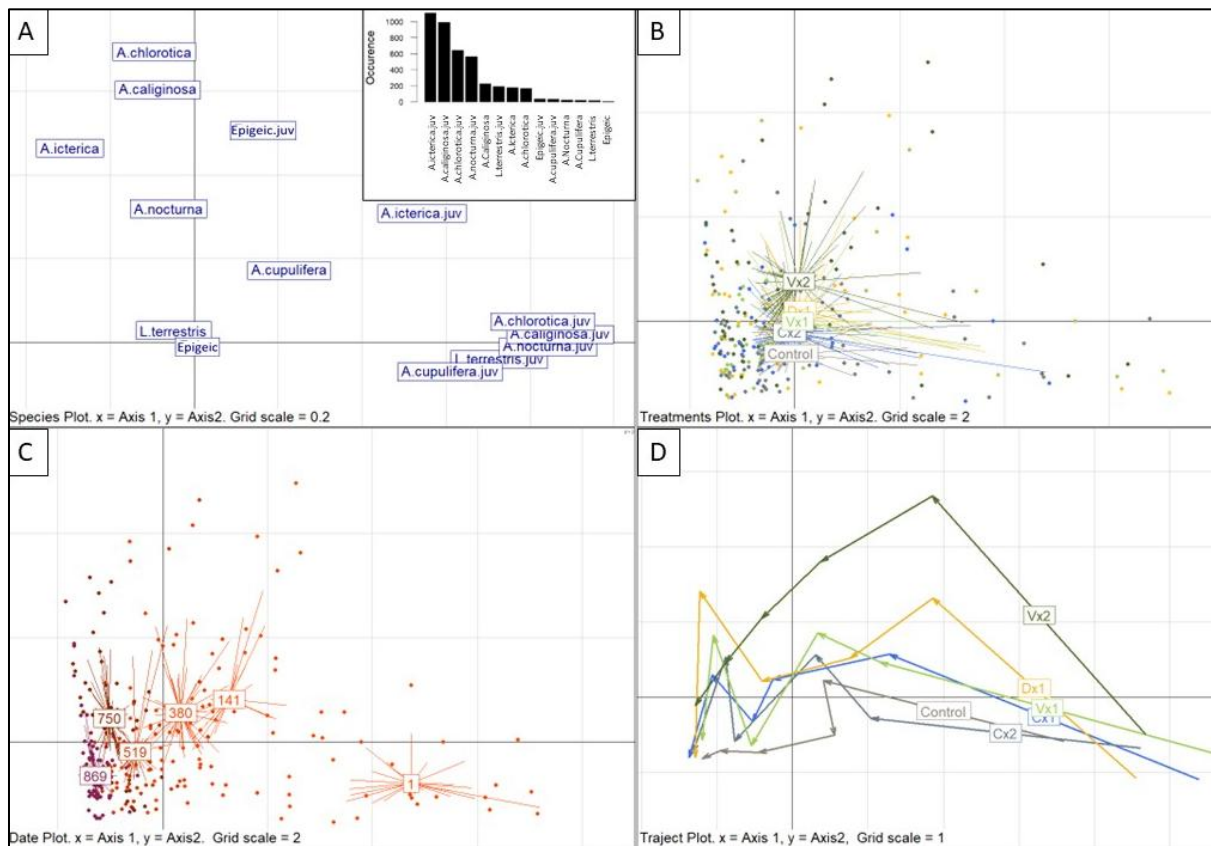
308 3.3. Effects on species

309 The earthworm communities were dominated by endogeic species, representing 80% of those
310 sampled earthworms. This proportion remained stable with time. Juveniles of *A. caliginosa* and
311 *A. icterica* showed the highest total abundances summed over all the sampling dates (about a
312 thousand individuals), followed by juveniles of *A. chlorotica* and *A. nocturna* (around 600
313 individuals). Adults of *A. caliginosa*, *A. icterica*, and *A. chlorotica* displayed, as did juveniles
314 *L. terrestris*, moderate abundances (around 200 individuals), whereas individuals of the other
315 species or age classes were low (less than 40) for every date of the experiment (Fig. S7). The
316 first two axes of the principal component analysis explained 36.3% of the total inertia (Fig. 5).
317 The first axis opposed most juveniles to adults (Figure 5.A) and corresponds to a global time
318 effect (Figure 5.C) illustrating the great decrease of juveniles along time. The second axis

319 opposed adults of *A. chlorotica* and *A. caliginosa* on one side to adults of *L. terrestris* and
 320 epigeics on the other side. This axis also opposed control plots to Vx2 plots (Fig. 5.B).

321
 322 The treatment trajectories in time (Fig. 5.D) showed similar trends for all the treatments. Over
 323 time, we observed a global shift from communities dominated by juveniles (i.e., on the right
 324 side of the PCA) to communities dominated by adults (on the left side of the PCA). All
 325 treatments, except Vx2, showed limited variation with time on the second axis, indicating only
 326 small variations in community species composition.

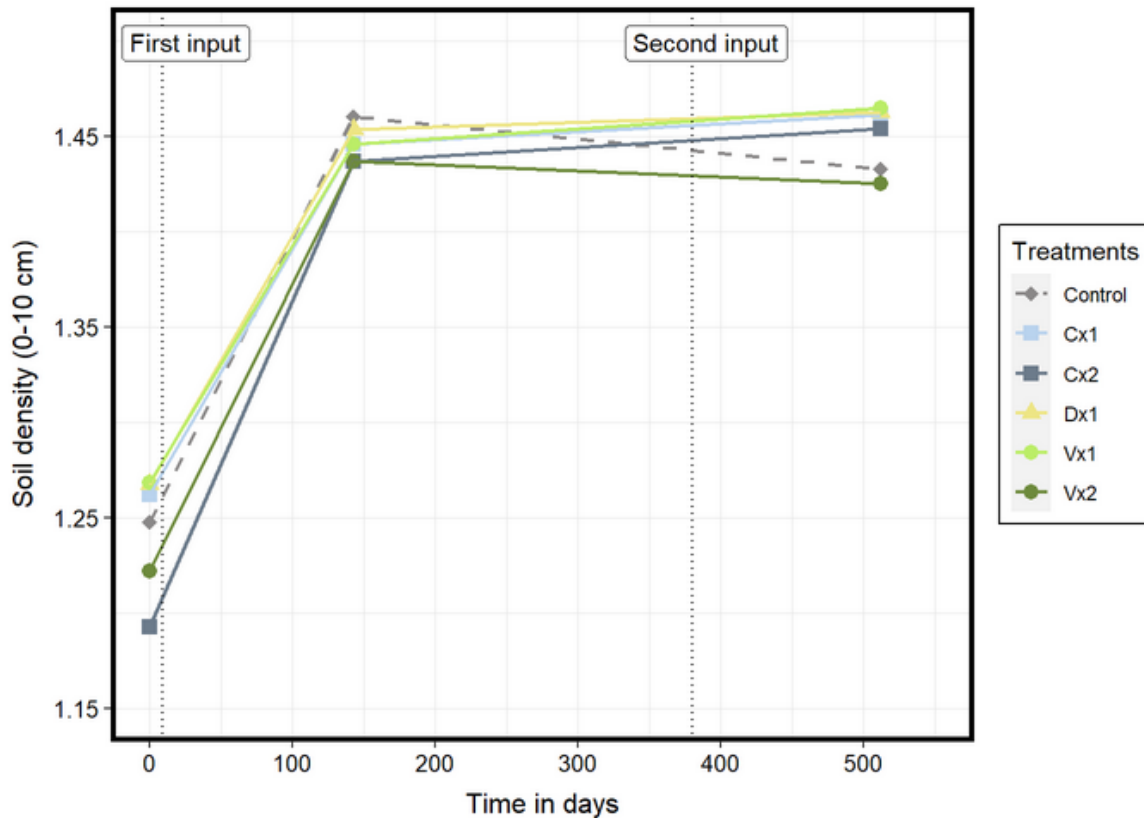
327
 328 When we looked at each species separately, we observed that the differences between
 329 treatments for adults (amended plots vs control) are mainly due to the increase of endogeics
 330 earthworm species (*A. caliginosa*, *A. chlorotica*, and *A. icterica*) almost regardless of the type
 331 of OM applied (Fig. S8). Compost, whatever the dose, did not lead to an increase in the
 332 abundances of *A. chlorotica* compared with vermicompost. Interestingly, the peak for *A.*
 333 *icterica* always occurred after the second input, whereas the peak for *A. caliginosa* was always
 334 higher after the first input.



335
 336 **Fig. 5.** PCA in non-scaled data of earthworm abundances with results (A) by species, (B) by treatments,
 337 (C) by dates (converted to days of experiment) and (D) with the treatments trajectories along the time
 338 (vector) with C: compost; D: digestate; V: vermicompost; x1: low dose and x2: high dose.
 339

340 3.4. Soil bulk density

341 LMM applied on soil bulk density development did not show an interaction between time and
342 treatments ($p=0.9$), no effect of treatments ($p=0.7$), but an effect of time ($p<0.001$). The last
343 density measurement showed lower values for control and Vx2 (1.43), 1.45 for Cx2 and 1.46
344 for Cx1, Vx1 and Dx1 (Fig. 6).



345 **Figure 6.** Soil bulk density of soil samples taken in the 0-10 cm layer for the three years with
346 C: compost; D: digestate; V: vermicompost; x1: low dose and x2: high dose.
347
348

349 **4. Discussion**

350 First of all, it is important to keep in mind that the waste inputs for the OFMSW are not identical
351 across the studied processes. Indeed, it was not possible to carry out vermicomposting and
352 anaerobic digestion with the same inputs since the processes are too different (for example,
353 regarding required volumes). Despite this, comparing products with similar amounts of
354 biowaste for each process allowed to study the systemic effects of the digestate, the compost,
355 and the vermicompost when applied to the soil.

356
357 **4.1. Global response of earthworm populations with time in this field under transition**

358 The dynamics of adult abundance follow a same logic for all the treatments with an increase of
359 population following organic product application and a marked decrease at the last date in

360 February 2023, except for the control, which remains stable throughout the experiment. On the
361 contrary, juveniles showed a drastic decrease in abundance in all treatments (including the
362 control). This is in contradiction with the results of Barrera et al. [45] who observed a large
363 increase in earthworm abundance, especially for juveniles, after sewage sludge application.
364 Moreover, the observed abundances in our study were rather low compared to the results of the
365 RMQS-Biodiv monitoring program at the national scale, with an average total abundance of
366 195.3 individuals per m² (28.3 anecics and 167.0 endogeics) in crop plots in France [46]. In
367 fact, at the end of our experiment, earthworm abundance only ranged between 8 and 17
368 individuals per m². This is also at odds with the work of D'Hose et al. [30] based on a set of
369 long term trials of crops in Europe. These authors showed an increase in earthworm abundance
370 and biomass following the application of compost (+63% and +66%, respectively), slurry
371 (+103% and +96%, respectively) and manure (+151% and +165%, respectively) compared to
372 mineral fertilizers. The increase of adults in amended plots compared to the control was mainly
373 related, in our study, by the increase of the three most abundant endogeic species (*A. caliginosa*,
374 *A. chlorotica* and *A. icterica*) with, however, a difference for the latter species whose largest
375 increases were only observed after the second input, whereas the peak of *A. caliginosa* was
376 observed after the first input in the amended plots. This difference may be linked to the fact that
377 different behaviors can be observed within the endogiec ecological category. Indeed, *A. icterica*
378 is believed to be more geophagous and to live deeper than other endogeic earthworms [47]. In
379 contrast, the abundance of the anecic species remained stable and low in all of the plots. Since
380 the products were mixed with the first soil layer (up to 5-8 cm) by a disc harrow, it is not so
381 surprising that endogeic adult earthworms better benefited from the amendments.

382

383 These low abundances could be linked to the rapid and important increase in the soil bulk
384 density in the field. This increase, cessation of tillage, has impacted the earthworm populations
385 which were mainly composed of juveniles at T0 (> 99%). Indeed, juveniles are more sensitive
386 to compaction because of lower muscle capacity than adults [48]. Soil compaction is known to
387 affect earthworm abundance and biomass [49] and negatively influence the earthworm
388 burrowing activity [50,51]. In addition, the climatic conditions of 2022 (drought, Table S2)
389 were not very suitable for the earthworm populations. A minor but complementary hypothesis
390 could also explain the diminution of the earthworm populations: with the conversion to organic
391 farming, the potential yield losses could have led to a decrease in the quantity of crop residues,
392 which is an important food source for earthworms [35].

393

394 *4.2. Response of earthworms to the different products*

395 *4.2.1. Compost*

396 Compost at low and high doses did not increase adult earthworm abundance in our experiment.
397 However, Cx1 showed an increase in adult biomass compared to the control. The lack of effect
398 after compost application was also observed in the study of Valdez et al. [52] after 19 years of
399 application of sewage sludge compost at doses similar to ours: 88 and 174 kg.N.ha⁻¹ (4.4 and
400 8.7 t.ha⁻¹). Our result may be explained by a very low cumulative input over 3 years, with a
401 total of 7.66 for Cx1 and 15.36 t.ha⁻¹. Leroy et al. [33] showed an increase in earthworm
402 abundance after a cumulative input of 67.59 t.ha⁻¹ of compost (biowaste and garden waste) in
403 two years. With 5 times higher inputs, earthworm abundance was higher than the control with
404 400 to 500 versus 150 individuals per m² (an average increase of 167 to 233%). Thus, in our
405 study, compost inputs (based on the N crop requirements) were realistic but too limited to lead
406 to an increase in earthworm abundances.

407

408 *4.2.2. Digestate*

409 Contrary to compost, digestate increased earthworm adult abundance. The response was strong
410 and rapid just after the application. However, when product was no longer applied, the
411 earthworm population declined drastically. Unlike compost, no increase in biomass of adults
412 was observed. We did not see a negative effect on earthworm abundance after digestate
413 application, as sometimes observed [31]. This may be explained by the date of sampling (i.e.,
414 4 months after application), while mortality generally occurred a few days or weeks after the
415 application. However, Rollett et al. [53] observed a decrease in earthworm abundance 6 months
416 after application of a high dose of biowaste digestate (220 kg.N.ha⁻¹) in grasslands but not in
417 crops. According to these authors, the decrease in earthworm abundance in grassland could be
418 linked to direct contact with digestate when earthworms forage at the soil surface. Thus, the
419 decrease observed by Rollett et al. [53] was likely due to the higher proportion of anecics in
420 grasslands, as these earthworms are known to feed on the surface and thus may be directly
421 exposed to fresh digestate.

422

423 *4.2.3. Vermicompost*

424 Contrary to the two other products, vermicompost at both doses increased adult earthworm
425 abundance and biomass compared to the control. This effect lasted longer for Vx2 with a
426 smaller final decrease compared to other treatments at the last sampling date. In February 2023,
427 Vx2 plots had 3 times more adult earthworms than control plots, with, on average, 18 against 6

428 adults per m². This response is assumed to be long-lasting and not transient since linked to adult
429 earthworms [45]. The impact of vermicompost on earthworm communities in the field has
430 never been studied so far to our knowledge, but it seems promising to sustain earthworm
431 populations in field crops.

432 **5. Conclusions**

433

434 In this 3-year study focusing on the application of OFMSW in a recently converted organic
435 farming crop, we found neutral to positive effects on the earthworm communities despite a
436 general context of an important decrease in the abundance of juveniles, likely due to a marked
437 increase of the soil bulk density when tillage was stopped. All products initially increased the
438 abundance and in some cases, biomass of adult earthworms after an OM input. However, with
439 our realistic (from an agronomical perspective) but low inputs (compared to the literature), we
440 did not observe long-lasting effects and the populations decreased rapidly or remained stable
441 one year after the last input. Contrary to compost and digestate, vermicompost was the only
442 product that led to a significant and lasting increase of both earthworm biomass and abundance
443 compared to the control. This study confirms that this process can lead to a sustainable recycling
444 of urban organic waste into a useful product for agriculture. Therefore, vermicomposting can
445 be considered as an alternative process adapted to the recycling of OFMSW for agriculture.

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- 605

7. Supplementary

Supplementary Table S1. Farmer interventions on the experimental field (non-irrigated system).

| Date | Interventions | Product - Depth | Quantity per ha |
|------------|---|-----------------|---------------------------|
| 14/05/2019 | Last chemical intervention (fungicides) | | |
| 11/07/2019 | Harvest (last before organic farming) | | |
| 22/07/2019 | Disc harrow | 5 to 8 cm | |
| 20/08/2019 | Sowing: Chlorofiltre mix | | 10.48 kg |
| | Sowing: <i>Sorgho piper</i> | | 9.52 kg |
| 06/01/2020 | Tillage | 25 cm | |
| 18/03/2020 | Seedbed cultivator | 10 cm | |
| 04/04/2020 | Seedbed cultivator | 5 cm | |
| 08/05/2020 | Weeder harrow | 3 to 4 cm | |
| 18/05/2020 | Seedbed cultivator | 5 cm | |
| 20/05/2020 | Seeding: Soybean | | 650 000 grains |
| | Biological inoculum | RESID HC | 1.513 kg |
| | | INOCULUM | 0.931 kg |
| | | FORCE 48 | |
| | | INOCULUM | 0.698 kg |
| 21/05/2020 | Mechanical weed control | 2 cm | |
| 28/05/2020 | Mechanical weed control | 4 cm | |
| 01/06/2020 | Mechanical weed control | 4 cm | |
| 16/06/2020 | Hoeing | 5 to 8 cm | |
| 03/07/2020 | Hoeing | 5 to 8 cm | |
| 16/09/2020 | Harvest (Soybean) | | 15.45 Quintals |
| 30/09/2020 | Disc harrow | 5 to 8 cm | |
| 22/10/2020 | Input of products and weeder harrow | 4 to 5 cm | |
| 29/10/2020 | Scalper | 5 à 12 cm | |
| 07/11/2020 | Sowing: Barley | AMISTAR (C) | 6.40 doses |
| | | HIMALAYA (C) | 1.60 doses |
| | | | 400 grains.m ² |
| 24/02/2021 | Mechanical weed control | | |
| 02/07/2021 | Harvest: Barley | | 44.37 Quintals |
| 07/2021 | Sowing Buckwheat | | |
| 09/2021 | Harvest: Buckwheat | | 5 Quintals |
| 23/10/2021 | Disc harrow | 5 to 8 cm | |
| 28/10/2021 | Input of products | | |
| 20/11/2021 | Disc harrow (burial of products) | 5 to 8 cm | |
| 20/11/2021 | Sowing: Winter wheat | ALESSIO BIO (F) | 400 grains.m ² |
| 15/12/2021 | Contribution of the rest of the compost | | |
| 24/02/2022 | Mechanical weed control | 2 cm | |
| 18/03/2022 | Mechanical weed control | 4 cm | |
| 12/04/2022 | Mechanical weed control | 4 cm | |
| 09/07/2022 | Harvest: Winter wheat | | 17.32 Quintals |
| 15/08/2022 | Disc harrow | 5 to 8 cm | |
| 13/10/2022 | Sowing: triticale cover crop | | 180 kg |
| 25/01/2023 | Tillage | | |
| 24/03/2023 | Mechanical weed control | | |
| 29/03/2023 | Sowing: lentil and oat | | 10 kg oats |
| | | | 85 kg lentils |
| 25/07/2023 | Harvest: lentil and oat | | 4 Quintals (lentils) |

Supplementary Table S2. Climate data with average temperature (°C) and cumulative precipitation (mm) from the French station Lyon-Bron (45°43'17"N, 4°56'57"E) during the time of experimentation with the value month by month and the deviation from normal calculated from 1981 to 2010.

| Climate data | Type of value | Jan. | Feb. | Mars | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total | | | |
|--------------|-------------------------------|-----------------------|------|------|------|-------|-------|-------|------|-------|-------|------|------|-------|------|------|-------|
| 2020 | Average | | | | | | | | | | | 20.1 | 13.1 | 9.6 | 6.3 | 14.6 | |
| | Temperature (°C) | Deviation from normal | | | | | | | | | | +2.5 | -0.3 | +2.1 | +2.0 | +2.1 | |
| | Cumulative precipitation (mm) | Annual value | | | | | | | | | | | 67.6 | 128.0 | 18.2 | 97.9 | 658.5 |
| | | Deviation from normal | | | | | | | | | | | -23% | +30% | -78% | +77% | -21% |
| 2021 | Average | 3.7 | 8.7 | 8.8 | 11.0 | 14.5 | 22.0 | 21.6 | 20.9 | 20.1 | 13.2 | 6.9 | 5.1 | 13.0 | | | |
| | Temperature (°C) | Deviation from normal | | | | | | | | | | | | | | | |
| | Cumulative | 67.1 | 32.6 | 30.2 | 50.8 | 178.7 | 37.8 | 177.1 | 51.7 | 61.1 | 146.9 | 36.8 | 91.8 | 962.6 | | | |
| | precipitation (mm) | Deviation from normal | | | | | | | | | | | | | | | |
| 2022 | Average | 2.5 | 7.2 | 9.7 | 11.8 | 19.2 | 23.1 | 24.3 | 24.7 | 18.5 | 17.4 | 10.3 | 6.1 | 14.6 | | | |
| | Temperature (°C) | Deviation from normal | | | | | | | | | | | | | | | |
| | Cumulative | 24.2 | 31.6 | 24.1 | 18.4 | 16.0 | 130.9 | 0.6 | 71.8 | 81.0 | 41.4 | 85.6 | 81.6 | 607.2 | | | |
| | precipitation (mm) | Deviation from normal | | | | | | | | | | | | | | | |
| 2023 | Average | 5.5 | 5.9 | 9.9 | 11.2 | 16.5 | 22.2 | 23.9 | 24.3 | 21.8 | 16.8 | 9.2 | | | | | |
| | Temperature (°C) | Deviation from normal | | | | | | | | | | | | | | | |
| | Cumulative | 36.9 | 3.0 | 64.3 | 54.0 | 33.2 | 96.2 | 33.6 | 50.7 | 58.6 | 150 | 81 | | | | | |
| | precipitation (mm) | Deviation from normal | | | | | | | | | | | | | | | |

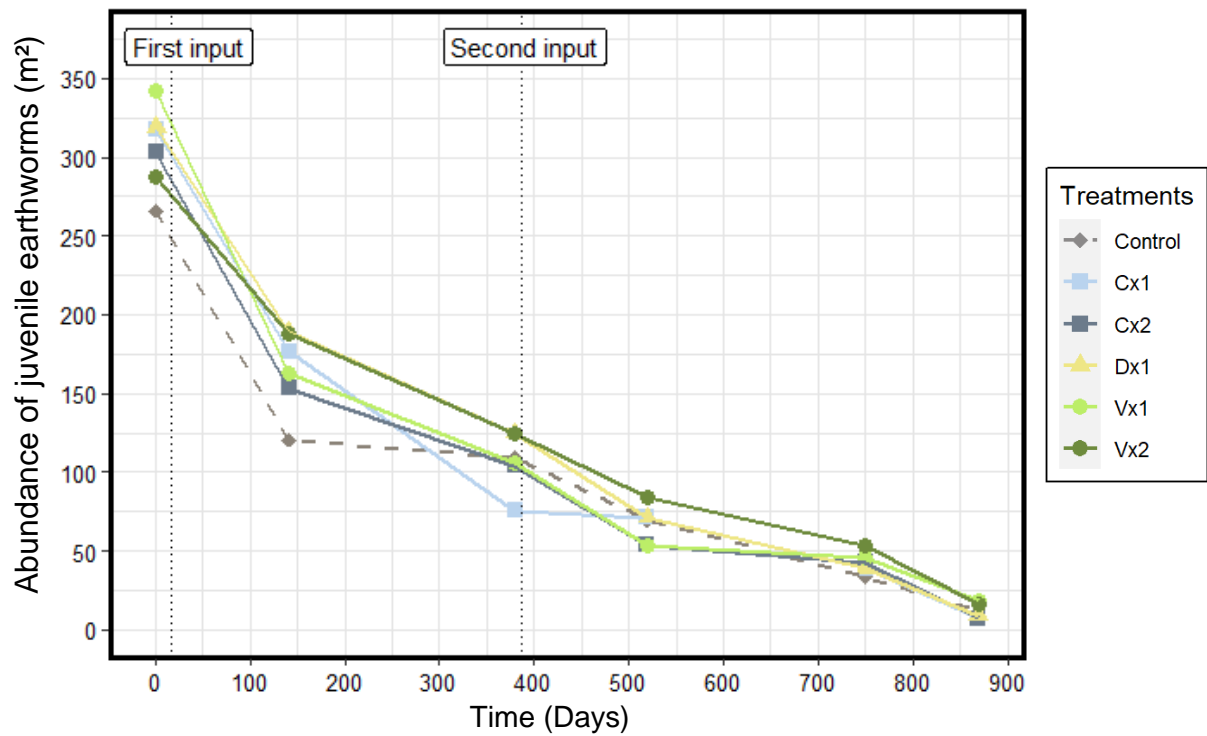
Supplementary Table S3. Averages (standard deviation) of physicochemical analyses (dry weights) according to standard NF U44-051 of the products used in Civrieux in October 2020 (C: compost; D: digestate; V: vermicompost; nd: not determined; abs: absence).

| | Density kg.l ⁻¹ | Dry weight % | pH | Total N | N-NH ₄ ⁺ | N-NO ₃ ⁻ | Organic N | OM | Organic C |
|---|---------------------------------|---|--------------|----------------------|--------------------------------|--------------------------------|-----------------|--------------------------|--------------------|
| | g.kg ⁻¹ | | | | | | | | |
| C | 0.37 (0.03) | 51.93 (7.14) | 9.40 (0.10) | 39.80 (1.42) | 0.18 (0.03) | 0,47 (0,40) | 39,20 (1,45) | 760,33 (18,58) | 424,33 (8,39) |
| D | nd | 7.31 (0.33) | 7.97 (0.25) | 65 (3.40) | 23.73 (0.42) | 0,05 (0,01) | 41,21 (2,99) | 672 (2) | 378,33 (1,53) |
| V | 0.59 (0.01) | 37.40 (2.2) | 8.67 (0.75) | 22.13 (1.34) | <0.05 (0) | 1,09 (0,94) | 21 (2,10) | 417,33 (44,52) | 219 (25,36) |
| | C/N | P | K | Ca | Mg | Helminth and Salmonella | Fluoranthene | Benzo(b) fluoranthene | Benzo(a) pyrene |
| | g kg-1 | | | | | mg.kg ⁻¹ | | | |
| C | 10 (0) | 17.07 (1.40) | 30.57 (3.62) | 75.53 (2.15) | 5.25 (0.19) | abs | <0,05 (0) | <0,05 (0) | <0,05 (0) |
| D | 5.83 (0.30) | 26.57 (1.52) | 50.73 (0.60) | 50.87 (0.60) | 10.11 (0.69) | abs | <0,05 (0) | <0,05 (0) | <0,05 (0) |
| V | 9.67 (0.42) | 13.37 (0.35) | 23.37 (6.12) | 165.67 (22.03) | 7.93 (0.39) | abs | 0,08 (0,05) | <0,05 (0) | <0,05 (0) |
| | As | Cd | Cr | Cu | Hg | Ni | Pb | Se | Zn |
| | mg.kg ⁻¹ | | | | | | | | |
| C | 0.85 (0.12) | 0.27 (0.02) | 6.17 (0.56) | 25.57 (0.68) | <0.02 (0) | 4,58 (0,32) | 9,34 (2,30) | <1,50 (0) | 113,33 (7,02) |
| D | nd | 0.25 (0) | 18.77 (1.81) | 47.07 (1.18) | <0.02 (0) | 7,56 (0,50) | 2,62 (0,21) | <1,50 (0) | 240,33 (5,51) |
| V | 3.62 (1.40) | 0.32 (0.03) | 20.63 (6.85) | 45.70 (1.22) | <0.02 (0) | 12,84 (3,90) | 50,60 (37,42) | nd | 203,67 (61,26) |
| | Pebbles and limestone > 2 mm | Plastic films and expanded polystyrene | | Hard plastics > 2 mm | Glass and metals > 2 mm | | Sharps elements | | |
| | % | | | | | | | | |
| C | 1.51 (0.46) | 0 | | 0 | 0.003 (0.006) | | abs | | |
| D | 0.13 (0.22) | 0 | | 0 | 0 | | abs | | |
| V | 27.17 (0.91) | 0.02 (0.02) | | 0.02 (0.03) | 0.07 (0.03) | | abs | | |

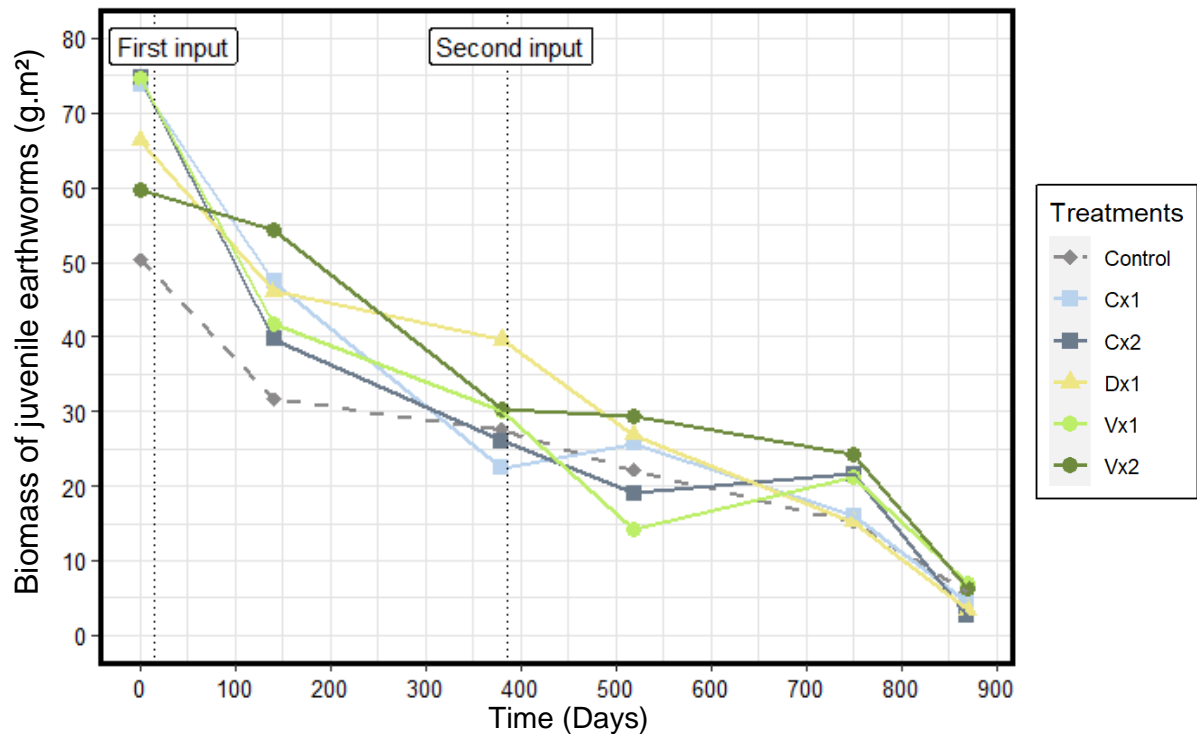
Supplementary Table S4. Averages (standard deviation) of physicochemical analyses (dry weights) according to standard NF U44-051 of the products used in Civrieux in October 2021 (C: compost; D: digestate; V: vermicompost; nd: not determined; abs: absence). Sup C. represents the compost analyses made in December 2021 to adjust the N dose which was too low with the first compost intake.

| | Density kg.l ⁻¹ | Dry weight % | pH | Total N | N-NH ₄ ⁺ | N-NO ₃ ⁻ | Organic N g.kg ⁻¹ | OM | Organic C |
|--------|---------------------------------|---|----------------------|----------------|--------------------------------|--------------------------------|---------------------------------|---|--------------------|
| C | 0.37 (0.01) | 42.33 (5.14) | 7.67 (0.23) | 34.97 (0.45) | 0.09 (0.03) | 0,95 (0,47) | 30,60 (5,11) | 742,67 (12,50) | 419,33 (9,50) |
| C sup. | 0.32 | 54.10 | 7.30 | 34.10 | 0.18 | <0,01 | nd | 809 | 445 |
| D | nd | 6.19 (0.03) | 8.53 (0.06) | 82.50 (1.81) | 36.33 (0.85) | 0,17 (0,02) | 46 (1,61) | 675,33 (2,08) | 387 (2,65) |
| VC | 0.57 (0.01) | 44.60 (1.57) | 7.73 (0.40) | 19.97 (1.37) | 0.06 (0.02) | 0,67 (0,09) | 19,20 (1,35) | 395 (20,95) | 216,67 (5,13) |
| | C/N | P | K | Ca | Mg | Helminth and Salmonella | Fluoranthene | Benzo(b) fluoranthene mg.kg ⁻¹ | Benzo(a) pyrene |
| | g kg-1 | | | | | | | | |
| C | 11.33 (0.58) | 9.72 (0.62) | 24.13 (1.03) | 77.77 (1.37) | 4.87 (0.47) | abs | <0,05 (0) | <0,05 (0) | <0,05 (0) |
| C sup. | 13 | 9.73 | 19.90 | 59 | 3.73 | nd | nd | nd | nd |
| D | 4.70 (0.10) | 26.23 (0.68) | 60.17 (1.88) | 43.37 (0.64) | 8.04 (0.30) | abs | <0,05 (0) | <0,05 (0) | <0,05 (0) |
| VC | 10.33 (0.58) | 11.47 (0.76) | 9.21 (0.56) | 177.33 (25.70) | 7.14 (0.30) | abs | <0,05 (0) | <0,05 (0) | <0,05 (0) |
| | As | Cd | Cr | Cu | Hg | Ni | Pb | Se | Zn |
| | mg.kg ⁻¹ | | | | | | | | |
| C | 0.77 (0.23) | 0.16 (0.01) | 4.10 (0.79) | 24.40 (2.03) | <0.02 (0) | 3,38 (0,20) | 4,30 (0,46) | <1,50 (0) | 114,37 (48,60) |
| C sup. | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| D | 1.94 (0.11) | 0.28 (0.03) | 13.20 (1.73) | 46.50 (0.78) | <0.02 (0) | 6,77 (0,62) | 2,78 (0,13) | nd | 237,33 (4,04) |
| VC | 2.85 (0.21) | 0.26 (0.02) | 9.52 (0.76) | 37 (3.77) | <0.02 (0) | 5,79 (0,39) | 45,03 (16,41) | <1,50 (0) | 175,33 (11,85) |
| | Pebbles and limestone > 2 mm | Plastic films and expanded polystyrene | Hard plastics > 2 mm | | Glass and metals > 2 mm | | Sharps elements | | |
| | % | | | | | | | | |
| C | 2.14 (1.58) | 0 | 0 | | 0.003 (0.006) | | abs | | |
| C sup. | nd | nd | nd | | nd | | nd | | |
| D | 0.06 (0.11) | 0.01 (0.01) | 0 | | 0 | | abs | | |
| VC | 25.50 (0.92) | 0.01 (0.01) | 0 | | 0 | | abs | | |

Supplementary Fig. S5: Average abundance of juvenile earthworms per m² during the time of the experiment with C: compost; D: digestate; V: vermicompost; x1: low dose and x2: high dose.



Supplementary Fig. S6: Average biomass of juvenile earthworms per m² during the time of the experiment with C: compost; D: digestate; V: vermicompost; x1: low dose and x2: high dose.



Supplementary Table S7: Abundance of earthworms by species and state (adult or juvenile) for each sampling date for all treatments.

| Species | State | 2020/10/06 | 2021/02/23 | 2021/10/20 | 2022/03/08 | 2022/10/25 | 2023/02/21 |
|----------------------|-------|------------|------------|------------|------------|------------|------------|
| <i>L. terrestris</i> | Adult | 1 | 1 | 0 | 2 | 5 | 4 |
| <i>L. terrestris</i> | Juv. | 82 | 25 | 39 | 20 | 21 | 5 |
| <i>A. nocturna</i> | Adult | 0 | 5 | 0 | 3 | 9 | 9 |
| <i>A. nocturna</i> | Juv. | 197 | 80 | 123 | 60 | 68 | 34 |
| Epigeic | Adult | 0 | 1 | 3 | 3 | 0 | 0 |
| Epigeic | Juv. | 0 | 19 | 12 | 5 | 0 | 0 |
| <i>A. caliginosa</i> | Adult | 1 | 20 | 85 | 35 | 39 | 46 |
| <i>A. caliginosa</i> | Juv. | 372 | 185 | 225 | 133 | 33 | 44 |
| <i>A. chlorotica</i> | Adult | 1 | 21 | 46 | 17 | 53 | 29 |
| <i>A. chlorotica</i> | Juv. | 270 | 109 | 178 | 43 | 33 | 8 |
| <i>A. icterica</i> | Adult | 2 | 7 | 25 | 38 | 75 | 30 |
| <i>A. icterica</i> | Juv. | 229 | 212 | 209 | 251 | 170 | 40 |
| <i>A. cupulifera</i> | Adult | 6 | 0 | 9 | 2 | 3 | 0 |
| <i>A. cupulifera</i> | Juv. | 21 | 3 | 5 | 1 | 0 | 1 |

Supplementary Fig. S8: Abundance of earthworms per m^2 during the time of the experiment with C: compost; D: digestate; V: vermicompost; x1: low dose, x2: high dose; L.terr: *Lumbricus terrestris*, A.noct: *Aporrectodea nocturna*, A.cali: *Aporrectodea caliginosa*, A.chloro: *Allolobophora chlorotica*, A.ict: *Allolobophora icterica* and A.cupu: *Aporrectodea cupulifera*.

