




Article

# Properties of Vermicomposts Derived from Cameroon Sheep Dung

Mariola Garczyńska <sup>1,\*</sup>, Joanna Kostecka <sup>1</sup>, Grzegorz Pączka <sup>1</sup>, Edmund Hajduk <sup>2</sup>,  
Anna Mazur-Pączka <sup>1</sup> and Kevin Richard Butt <sup>3</sup>

<sup>1</sup> Department of the Basis of Agriculture and Waste Management, Institute of Agricultural Sciences, Land Management and Environmental Protection, College of Natural Sciences, University of Rzeszow, Cwiklinskiej 2, 35-601 Rzeszow, Poland; jkosteck@ur.edu.pl (J.K.); grzegp@ur.edu.pl (G.P.); anamazur@ur.edu.pl (A.M.-P.)

<sup>2</sup> Department of Soil Science, Chemistry of Environment and Hydrology, Institute of Agricultural Sciences, Land Management and Environmental Protection, College of Natural Sciences, University of Rzeszow, Cwiklinskiej 2, 35-601 Rzeszow, Poland; ehajduk@ur.edu.pl

<sup>3</sup> School of Natural Sciences, University of Central Lancashire, Preston PR 1 2HE, UK; krbutt@uclan.ac.uk

\* Correspondence: mgar@ur.edu.pl; Tel.: +48-17-872-1649

Received: 29 June 2020; Accepted: 20 July 2020; Published: 22 July 2020



**Abstract:** Due to a need for sustainability in agriculture, waste products ought to be utilized in the most appropriate way. A study was undertaken relating to the vermicomposting of Cameroon sheep dung (CSD) by the earthworm *Dendrobaena veneta*. Processing of this waste was investigated using unadulterated CSD and in a 1:1 mixture with unpalatable (waste) hay (CSDH). Results demonstrated that these materials were actively processed by *D. veneta* with vermicomposts obtained which can be characterized by a higher amount of total nitrogen, phosphorus and potassium (average, respectively, 17.0, 10.5, 13.2 g kg<sup>-1</sup> d.m.), as well as lower total carbon and magnesium content (respectively, 340 and 3.2 g kg<sup>-1</sup> d.m.), compared with the initial waste material. No significant differences were found between CSD and CSDH vermicomposts with respect to chemistry. Levels of selected trace elements (average: Cu 17.5–18.8, Cr 5.7–5.8, Pb 13.5–14.4, Ni < 3, Cd < 0.4 mg kg<sup>-1</sup> d.m.) in both vermicomposts did not exclude their application to agricultural soil as a fertilizer.

**Keywords:** Cameroon sheep dung; earthworms; *Dendrobaena veneta*; hay; macroelements; trace elements; vermicomposting

## 1. Introduction

A sustainable agriculture strategy demands the implementation of multidirectional actions that combine productive aims of agriculture with environmental protection requirements. Soil protection is one of the significant objectives within this area. European Union countries are obliged to maintain appropriate soil functioning and take essential steps to avoid major processes that degrade the soil environment, stop their intensification and determine regions where degradation occurs [1]. A decrease in organic matter content and depletion of nutrients are the major threats to the natural functioning of soils. Loss of organic matter causes disturbances of chemical, physical and biological processes and alters the biogeochemical cycle of many elements which leads to the deterioration of quality and productivity of soils [2–5]. Analyzing the problems of soil ecosystems, The International Decade of Soils (2015–2024) was announced by The International Union of Soil Sciences (IUSS) at a Soil Conference in Vienna (5 December, 2015) [6].

One of the many factors causing such a situation is the use of mineral fertilizers. In Poland, an average of 133 kg ha<sup>-1</sup> is used on agricultural land [7]. In 2017, 11.6 million tons of nitrogen fertilizer

was used in EU agriculture—an increase of 8% since 2007 [8]. The use of mineral fertilization is inherent in additional costs, especially the purchase of nitrogen and phosphorus fertilizers is relatively expensive. In addition, some of them (mainly P or Ca) can be a source of soil pollution with heavy metals [9,10]. Analysis of soil organic matter content and other fertility parameters suggest it would be more valuable to apply organic fertilizer or a mixture of organic and mineral fertilization [11,12].

An increase in *Homo sapiens* population, urbanization, industrialization and agriculture has increased the production of wastes, including those that are biodegradable. Of the latter, animal dung, may constitute a high-quality resource, serving for the production of composts and vermicomposts [13,14]. Among these resources are manures from horses, cattle, pigs, poultry and other animals [15–20]. Manure used as a fertilizer can be a source of many nutrients for plants [21–24]. For example, the analysis of the chemical composition of various types of manure in Poland showed on average 1 kg of dry matter: 4.8 g N, 3.1 g P<sub>2</sub>O<sub>5</sub>, 6.7 g K<sub>2</sub>O, 4.3 g CaO, 1.6 g MgO, 21.5 mg B, 23 mg Cu, 194 mg Zn, 1.63 mg Mo, 345 mg Mn, 2449 mg Fe [24]. The application of manure-derived vermicomposts has an effect on soil fertility and crop quality [18,25–27]. This is particularly important in light soils, in which the water–air relationships cause naturally lower organic matter content compared to heavy soils [5].

In recent years, an interest in alternative stock of farmyard species has systematically grown in Poland [28]. This includes hair sheep, for example, Cameroon sheep or Somali sheep. Hair sheep originate from Africa but have acclimatized well to Polish conditions. Properly managed excrement, or vermicompost produced from hair sheep, could be an additional benefit for a sheep farmer. This farm-produced organic fertilizer can be used for plant growth and improvement of soil quality. Although there is literature on vermicompost from general sheep dung [29–31], no characteristics have been produced for the vermicomposting of Cameroon sheep droppings.

In addition, it is worth noting as an issue, that under South Eastern Poland's conditions, agri-environmental programs are very popular [32]. Farmers covered by these programs, postpone mowing of meadows until mid-July or even after 1st August, to allow ground-nesting birds to successfully raise young. Such action, however, reduces the fodder value of the hay collected thereafter, which is only reluctantly eaten by stock. Such hay can be used as bedding, stored for natural biodegradation or burnt in biomass boilers. Nevertheless, one limitation in the production of pellets or biomass from hay is the physico-chemical composition as it contains numerous difficult-to-degrade substances (suberin or cutin). A viable alternative could be utilization in a vermicomposting process, following recommendations of the General Directorate for Environmental Protection (2015) [33] and the Ministry of Agriculture and Rural Development (2019) [34].

Interest in sheep dung is a result of subsidized sheep breeding, supported by the Rural Development Programme for the period 2015–2020, which opens up the characterization of this manure as another reason for the study. Fertilizers are defined by Polish law in the Fertilizers and Fertilization Act of 7 June, 2018 [35] as products intended for providing plants with nutrients or increasing soil fertility, which are mineral fertilizers, natural fertilizers, organic fertilizers and organic-mineral fertilizers. This Act [35] indicates the process of vermicomposting as an appropriate method for the production of valuable organic fertilizers (chapter 1, article 2.1 item 5). Characteristics that support the use of vermicompost are high water capacity, high porosity and gradual, slow release of nutrients to the soil [36–38]. The content of macroelements in composted manure is usually higher than fresh animal manure. Composting of animal manure also encourages soil microbial activity, which promotes the soil's trace mineral supply, improving plant nutrition [39]. If compared with unprocessed manure, it helps with the stabilization of the soil profile, prevents erosion, improves soil structure, is favorable to retaining moisture and can reduce problems with drainage in damp areas. Additionally, manure may contain pathogenic organisms and constitute a potential source of zoonoses, and therefore it may be the main risk for spreading diseases among animals and people [40]. Numerous studies highlight the effectiveness of vermicomposting manure of different origins to reduce pathogenic microorganisms. A reduction in pathogens occurs by passage through the intestines of an earthworm, which obviates

the need to raise the temperature. The final product, with regard to microbiological quality, can then be considered as class A compost [41–44].

In addition, vermicomposts have been shown to provide a favorable influence on growth, development, flowering, fructification and plant health. They also limit the expansion of fungal diseases, such as *Pythium*, *Rhizoctonia*, *Plectosporium* and *Verticillium*; the presence of numerous pests, nematodes in field cultivation of tomatoes, peppers, strawberries and grapes, as well as *Myzus persicae* aphid, which is a transmitter of many viruses; and *Pseudococcus* and *Pieris brassicae* caterpillars in the cultivations of tomatoes, peppers and cabbages. Such positive impacts of vermicomposts, in field experiments and greenhouse cultivation, has been shown by many authors [30,45–56]. By applying vermicompost, soil can be enriched with organic matter and mineral compounds, to be absorbed by plants. Besides this, vermicompost fertilizer also causes an increase in biological activity in the soil and improves structure [30]. Determination of the main macro-elements (nitrogen, carbon, potassium, phosphorus, calcium, magnesium) of the soil is one of the most important criteria of the assessment of soil richness [57].

The major aim of the current research was to determine the feasibility to vermicompost Cameroon sheep dung, in a pure form and mixed with marginal value hay from agri-environmental programs. A further aim was to determine the properties of vermicomposts obtained from these droppings. Finally, the effects of these substrates on growth of the populations of the vermicomposting species *Dendrobaena veneta* were also to be examined.

## 2. Materials and Methods

### 2.1. The Source of the Vermicomposted Substrate—Cameroon Sheep Dung

Cameroon sheep dung was collected from an agritourism farm in Krosno. It consisted of waste from these animals and cereal straw litter. The feces were dried at a temperature of 105 °C ready for use. This was to reduce the ammonium levels known to be detrimental to some earthworms.

### 2.2. Vermicomposting

The experiment was conducted at the University of Rzeszów in 2016–2017 and ran for a period of six months in each year.

Earthworms used in the experiment (*Dendrobaena veneta* Rosa, 1886) came from our own multi-annual breeding line. Before starting the experiment, the earthworms were selected from breeding beds and placed into containers filled with garden soil and manure for 14 days, so that they would become acclimatized to experimental conditions, in accordance with the methodology used by Kostecka et al. [15].

The experiment was carried out in containers: 18 × 18 × 8 cm. Each was filled with garden soil (2 dm<sup>3</sup>) of known physico-chemical characteristics (Kronen universal soil: pH in H<sub>2</sub>O 6.0–6.5; salinity 1.0–2.0 (mg·dm<sup>-3</sup>); N 355 ± 57 (mg·dm<sup>-3</sup>); P<sub>2</sub>O<sub>5</sub> 300 ± 36 (mg·dm<sup>-3</sup>); K<sub>2</sub>O 400 ± 59 (mg·dm<sup>-3</sup>) solid, loose form, fraction 0–20 mm) and properly balanced food. Holes in the containers were made to allow for air flow. Waste biomass was contained in traps made of lathing mesh.

Eight containers were divided between two treatments: Cameroon sheep dung (CSD) and CSD mixed in a 1:1 ratio with unpalatable (waste) hay (CSDH) as outlined below:

- CSD (10 mature *D. veneta* with known and balanced biomass were placed within each container—(0.550 ± 0.016 g) + garden soil + 400 g of Cameroon sheep dung;
- CSDH (10 mature *D. veneta* with known and balanced biomass within each container—(0.553 ± 0.011 g) + garden soil + 400 g of Cameroon sheep dung mixed with dampened hay (in 1:1 ratio).

To maintain appropriate waste humidity, containers were dampened every 7 days with the same volume (100 mL) of tap water (pH—7.5, conductivity—486 μS·cm<sup>-1</sup>, nitrates V—8.5 mg·dm<sup>-3</sup>, nitrates III—0.01 mg·dm<sup>-3</sup>, Mg—14.2 mg·dm<sup>-3</sup>, hardness water—231 CaCO<sub>3</sub> mg·dm<sup>-3</sup>).

The containers were placed in an air-conditioned chamber (temperature  $20 \pm 0.5$  °C, humidity 70%). Macroelement (N, P, K, Ca, Mg) content was determined both in the waste material and in vermicompost, in accordance with the methodology used by the Ministry of Agriculture, Fisheries and Food [58]. All measurements were performed in three replications. Moreover, some trace elements (Ni, Pb, Cr, Cd, Cu) were also determined in the vermicompost.

Organic carbon was determined by use of an elemental analyzer Vario EL Cube (Thermo Fisher Sci); N—by Kjeldahl's method, pH in H<sub>2</sub>O—by potentiometric method, salinity (NaCl g·dm<sup>-3</sup>) and conductivity (mS)—by conductometric method, phosphorus—by vanadium-molybdenum method, potassium and calcium—by flame photometry method (FES), magnesium—by atomic absorption spectrophotometry method (AAS). The C:N ratio was calculated (in mass/mass ratios).

Cd, Cr, Cu, Pb and Ni were determined in soil extracts with aqua regia—using flame and electrothermal absorption spectrophotometry [59]. In the research pursued, the total content of trace elements was determined. The uncertainty for the total analytical procedure (including sample preparation) was below the level of 15%. The accuracy was checked using reference materials SRM 2709a (San Joaquin Soil) and the recovery (87%–102%) was acceptable for determined heavy metals.

The dynamics of the populations of *D. veneta* during vermicomposting (CSD and CSDH) were assessed 5 times per month, using manual sorting [60]. Earthworms found were counted and had biomasses determined.

The results were developed and presented as the mean  $\pm$  SD. Statistical analysis at a confidence level of 0.05 was performed with the use of a Student's t-test using Statistica software v.10.1.

### 3. Results and Discussion

Vermicomposts produced from CSD and CSDH were rich in nutrients (Table 1), but none of these analyzed characteristics were statistically different ( $p > 0.05$ ). Characteristic comparisons of Cameroon sheep dung (initial material) with the vermicomposts obtained, showed differences in salinity, total C, N as well as P, K and Mg ( $p < 0.05$ ).

**Table 1.** Selected features and total macroelement content in base material and in vermicompost.

Features Units	Characterized Substrates	CSD	CSDH
pH in H <sub>2</sub> O	Initial material	7.4–8.4	7.2–7.8
	Final	6.7–6.8	6.7–6.8
conductivity (mS)	Initial material	2.9 $\pm$ 0.3 <sup>a</sup>	3.1 $\pm$ 0.4 <sup>a</sup>
	Final	3.75 $\pm$ 0.05 <sup>a</sup>	3.9 $\pm$ 0.1 <sup>a</sup>
salinity (NaCl g·dm <sup>-3</sup> )	Initial material	4.9 $\pm$ 0.3 <sup>a</sup>	4.8 $\pm$ 0.3 <sup>a</sup>
	Final	1.2 $\pm$ 0.3 <sup>b</sup>	1.1 $\pm$ 0.1 <sup>b</sup>
C	Initial material	480.6 $\pm$ 6 <sup>a</sup>	480.7 $\pm$ 5 <sup>a</sup>
	Final	340 $\pm$ 10 <sup>b</sup>	365 $\pm$ 14 <sup>b</sup>
N	Initial material	14.0 $\pm$ 2 <sup>a</sup>	14.5 $\pm$ 3 <sup>a</sup>
	Final	17 $\pm$ 1 <sup>b</sup>	18 $\pm$ 2 <sup>b</sup>
P	Initial material	8.0 $\pm$ 0.5 <sup>a</sup>	8.0 $\pm$ 0.4 <sup>a</sup>
	Final	10.5 $\pm$ 0.7 <sup>b</sup>	9.6 $\pm$ 0.2 <sup>b</sup>
K	Initial material	10.0 $\pm$ 0.6 <sup>a</sup>	10.4 $\pm$ 0.5 <sup>a</sup>
	Final	13.2 $\pm$ 0.4 <sup>b</sup>	13.6 $\pm$ 0.4 <sup>b</sup>
Ca	Initial material	15.5 $\pm$ 0.2 <sup>a</sup>	15.7 $\pm$ 0.3 <sup>a</sup>
	Final	16.2 $\pm$ 0.3 <sup>a</sup>	16.6 $\pm$ 0.3 <sup>a</sup>
Mg	Initial material	5.5 $\pm$ 0.5 <sup>a</sup>	5.5 $\pm$ 0.6 <sup>a</sup>
	Final	3.2 $\pm$ 0.3 <sup>b</sup>	3.0 $\pm$ 0.3 <sup>b</sup>
C/N	Initial material	34.7 $\pm$ 0.4 <sup>a</sup>	35.1 $\pm$ 0.3 <sup>a</sup>
	Final	20.0 $\pm$ 0.6 <sup>b</sup>	20.0 $\pm$ 1.0 <sup>b</sup>

CSD—final-vermicompost from Cameroon sheep dung (initial material—Cameroon sheep dung); CSDH—final-vermicompost from Cameroon sheep dung with mixed dampened hay in 1:1 ratio (initial material—Cameroon sheep dung with hay). aa, bb—no statistically significant differences, ab—statistically significant differences.

### 3.1. Humus

Organic matter changes in the composting process promote the formation of humus compounds. Humus is formed from the remaining part of detritus during the process of humification. This process has a comprehensive influence on soil, resulting in the improvement of its properties. The addition of composts or vermicomposts (especially to a sandy soil) causes a gradual increase in organic matter content, which in turn improves soil aeration, ensures soil protection against erosion and increases the availability of nutrients [38,61,62]. Humus soil content is different, dependent on the agronomic category of the soil and climatic-soil condition. In Poland, in terms of humus content, mineral soils are divided into low humus soils (below 1%), medium humus soils (1.01%–2%), humus soils (2.01%–3%) and high humus soils (over 3%). It is estimated that up to 2030, on average, 0.8% of organic matter in Poland will be degraded [63]. About 45% of soils in Europe have low or very low organic matter content (0%–2% organic carbon) [8].

The main factors decreasing the amount of humus are intensification of agriculture, unsustainable mineral fertilization and simplified crop rotation. Plants that contribute the most to the depletion of soil organic matter resources are root crops and corn, whereas leguminous plants and their mixtures with grasses enrich the soil the most with organic matter.

### 3.2. Changes in pH

Cameroon sheep dung and vermicomposts produced in our experiment did not differ in pH value ( $p > 0.05$ ). According to Jahanbakhshi and Kheiralipour [30], vermicompost has a more neutral pH compared to sheep dung, and the use of a high amount has no detrimental effects on soil and plants.

Importantly, both manure and the vermicomposts produced had an appropriate pH at which most of the macroelements contained in the soil were available to plants (pH range 6.5–8.5). In addition, the pH of vermicomposts may allow the availability of most micronutrients (e.g., Zn or Cu).

The exposure of ecosystems to acidification in the EU-28 (critical loads from 43% in 1980 to 7% in 2010) and EEA member countries (to 7%) has been decreasing since the 1980s, although in some areas, reduction targets, defined as interim objectives in the EU's National Emission Ceilings Directive, have not been met [64]. The prolonged use of mineral (NPK) fertilization decreases pH value, especially in light soils, therefore organic fertilization may be a better alternative to mineral fertilization [65].

### 3.3. Changes in Salinity

The salinity of vermicomposts, which was significantly lower compared to initial material dung, is a significant factor affecting soil properties as well as the growth and development of plants ( $p < 0.05$ ). Similarly, Aali et al. [29], Jahanbakhshi and Kheiralipour [30] and Alikhani et al. [66] have recorded lower salinity in the vermicompost made in comparison to sheep dung. The reason for this finding might be attributed to the easier leaching in vermicompost and to a lesser degree, by the consumption and accumulation of ions in the earthworm biomass.

If the salinity is too high, it may lead to disturbances in the plant uptake of such macro-elements as P, Mg and N [11,38,67]. Soil salinization is projected to increase in future climate change scenarios due to sea level rise and impact on coastal areas, and the rise in temperature will inevitably lead to increased evaporation and further salinization. Soil salinity is dynamic and spreading globally in over 100 countries [68].

### 3.4. Macronutrient Content

Both the dung and the vermicomposts produced had a high Ca content. This macro-element (Ca) is important for soils and crops. According to the Institute of Soil Science and Plant Cultivation (IUNG) [63], approximately 49.7% of the examined soil samples required liming (including Małopolska Province 77.5%, Podkarpackie Province 73.4% and Kujawy-Pomorze Province 26.5%). In Poland, approximately 60% of arable soils require liming and approximately 20% of soils exhibit Mg, Zn, Mn

and Cu deficiencies [4]. The application of lime depends on the agronomic category of soil (very light, light, medium or heavy).

Deficiency of P in the soil restricts plant growth and development. Vermicomposting increased the content of P for plants in vermicomposts compared to the base material ( $p < 0.05$ ). According to Alidadi et al. [69], during the process of vermicomposting in the gastrointestinal tract of earthworms, the P content increases with the participation of alkaline bacteria. Earthworms change insoluble P to a soluble form via the phosphatase enzyme present in their gut [19]. The increase in available forms of P in vermicompost increase the content of P in the soil at a pH close to neutral. In the case of pH values outside of 5–7, there will most probably be retrograde motion (that is reversible) of easily assimilate forms of P [70].

Coulibaly et al. [18] noticed that vermicompost (generated from manure) caused better assimilation of P by the plant *Lagenaria siceraria* in comparison to crops without fertilization and with cattle manure fertilization. Similar results were obtained by Mahmud et al. [38] in pineapple cultivation where, after six months, he noticed that the P from the vermicompost was the most assimilable.

The content of the total forms of macro-elements, such as K, in vermicomposts significantly increased compared to the base dung ( $p < 0.05$ ). An increased K level in vermicompost indicates the increased rate of mineralization of organic compounds containing K [71]. This is beneficial because light soils, frequently acidified, are very poor in available K. This is also interesting, in the process of vermicomposting, despite the increase in the content of K and a more or less constant level of Ca, the salinity decreased. Salinity was determined on the basis of the specific conductivity of vermicompost suspension in water, so the value of this parameter (and its estimated salinity) is influenced by various ions, including those not tested and not specified in the work. Maybe the primary substrates used for composting were different from K<sup>+</sup> and Ca<sup>2+</sup> charge carriers—acids or salts, for example in the form of organic compounds—that have been mineralized. This could be an interesting starting point for further studies.

In vermicomposts, compared to the dung, the content of total P increased ( $p < 0.05$ ), whereas Mg content decreased ( $p < 0.05$ ).

The vermicompost derived from Cameroon sheep dung, in comparison to cattle manure-based vermicomposts, contained more N, P and Mg, and less Ca [72], more N, P and K [73], more C, N and P, and less P and Mg [74].

### 3.5. Changes in C:N Ratio

Total carbon content did not differ in both vermicomposts produced (CSD: CSDH) ( $p > 0.05$ ), but it was significantly lower compared to the initial material ( $p < 0.05$ ). A decrease in the organic carbon content is associated with the process of mineralization, which is the transformation of organic carbon into CO<sub>2</sub> through the respiration of organisms [19,25].

As a result of the vermicomposting process, a statistically significant increase in nitrogen content in the obtained fertilizers was observed (CSD: from 14.0 to 17.0 g kg<sup>-1</sup> d.m.; CSDH: from 14.5 to 18.0 g kg<sup>-1</sup> d.m.). This resulted in a significant reduction in the C:N ratio (respectively, from 34.7 and 35.1 to 20.0 in both vermicomposts). Al-Delfi and Abdulkareem [75], studying the composting of poultry manure with or without plant residues, also observed that at the end of the composting process, the total organic carbon decreased, while the total nitrogen increased in contrast with initial values.

The basis of rational nutrient management with the use of composts or vermicomposts in agriculture is to determine C:N ratio and the general forms of mineral ingredients. The C:N ratio in vermicomposts indicates their maturity, so it is commonly used for the assessment of quality of organic fertilizers [20,76–79]. The C:N ratio depends on many factors: e.g., on vermicomposting technology and type of baseline waste. In the vermicomposts produced, C:N ratios ranged from 19 to 22, which indicated the appropriate level of substrate maturity. Coulibaly et al. [18] suggested that vermicompost produced from cattle manure was characterized by a C:N ratio of 27.86; whereas raw manure—of 89.37. In turn, Sharma and Garg [19] processed other types of waste mixtures (composed of cattle

manure, rice straw and paper) and obtained a broader range of C:N ratios (from 12.23 to 38.85), thus demonstrating a varying degree of vermicompost maturity. The results indicated that C:N ratio is more appropriate in vermicompost (12.8) compared to sheep manure (28) [30]. Thus, using vermicompost as a fertilizer would provide better and more facilitative conditions for plants to absorb nitrogen.

### 3.6. Trace Elements

Another important factor determining the usefulness of fertilizers, particularly those that are produced based on organic waste, is heavy metal content [80,81]. The Regulation of the Minister of Agriculture and Rural Development [82] precisely determined the maximum content of nickel, cadmium, chromium, lead, mercury and copper in organic fertilizers. Analyses of the fertilizers produced from Cameroon sheep dung showed a low content of these unwanted chemical elements (Table 2).

**Table 2.** Total content of trace elements in vermicomposts.

Properties Units	Features of Vermicomposts	
	CSD	CSDH
Cu	17.5 ± 1.9 <sup>a</sup>	18.8 ± 1.8 <sup>a</sup>
Cr	5.8 ± 0.6 <sup>a</sup>	5.7 ± 1.6 <sup>a</sup>
Ni	<3 <sup>*</sup>	<3 <sup>*</sup>
Cd	<0.40 <sup>*</sup>	<0.40 <sup>*</sup>
Pb	14.4 ± 2.3 <sup>a</sup>	13.5 ± 1.8 <sup>a</sup>

CSD and CSDH as in Table 1, \* result below the lower range limit of the method [59], aa—no statistically significant differences.

The content of harmful substances, including trace elements (TE), is low over most agricultural areas. Therefore, TE do not have a negative impact on soil functions. However, identification of the areas where there are contaminated soils makes it possible to adopt the environmental risk analysis, remediation measures and mitigation practices. It is an innovative approach, which allows additional ecotoxicological tests and the analysis of the bioavailable contents and the mobile form of pollution to be conducted [83].

The vermicomposting process may affect the reduction in content of trace elements in vermicomposts, which might be the result of bioaccumulation of the elements by earthworms [84,85]. During waste disposal, it comes from the transformation of fractions of trace elements from accessible to inaccessible forms.

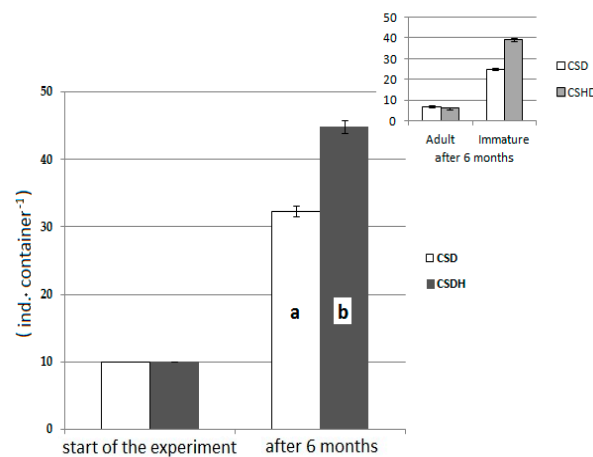
During the digestion of organic wastes, the mobile fractions of metals are either accumulated in cutaneous tissues or are bound to low-molecular weight, cysteine-rich metal binding proteins such as metallothioneins (MTs) possessing a high affinity for metals such as Hg, Zn, Ni, Co, Cu and Cd. Most organic acids in vermicompost are also organic chelating agents that absorb micronutrients such as Fe, Zn, Cu and Mn [86].

The increase in assimilable forms of microelements has been noticed—for instance, Bityudskii and Kaidun [87] indicated an increase in the number of assimilable forms of Fe and Mn in earthworm casting, and Devliegher and Verstraete [88] observed that the accessibility of such microelements as Fe, Mn and Cu for plants had increased in the soil in the presence of earthworms (respectively by 6%, 12%, 6%). The best results concerning vermicomposting technology on the solubility of some microelements (Fe, Mn, Cu and Zn) as well as heavy metals (Pb, Cd and Cr) in different combinations of fly ash and organic substances revealed that the introduction of the earthworm *Eisenia fetida*, to different combinations of fly ash and cow dung, resulted in the transformation of a significant number of microelements into bioavailable forms, but the solubility of heavy metals was generally reduced, probably through forming organometallic complexes [89].

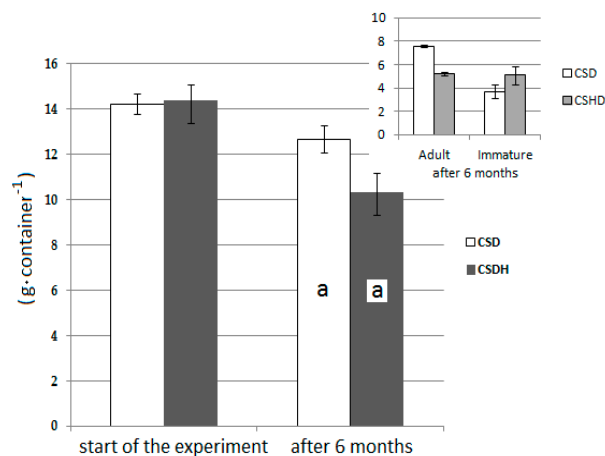
Sizmur and Richardson [90] performed an extensive analysis of the bioavailability of potentially toxic elements in vermicomposts and noticed that endogeic and epigeic earthworms increase the mobility of them in the bulk soil, and earthworms from all ecological groups mobilize potentially toxic elements during the passage of soil through the earthworm gut. They also observed an increase in the concentration and uptake of potentially toxic elements by plants growing on soils inhabited by epigeic (mostly *Eisenia fetida*) earthworms. On the other hand, it can alleviate micronutrient deficiencies in degraded soils.

### 3.7. Characteristics of the Earthworm Population

Earthworms are the key organisms that break down organic matter and process nutrients. Dominguez and Edwards [91] described vermicomposting as the process of decomposition composed of interactions between earthworms and microorganisms. These organisms are responsible for the biochemical degradation of organic products, and earthworms are key factors in this process, causing fragmentation and conditioning of the substrate, thus increasing the biological activity of waste [77]. The populations of *Dendrobaena veneta* vermicomposting Cameroon sheep dung (CSD and CSDH) developed well, as shown in Figures 1 and 2.



**Figure 1.** The mean number of *D. veneta* earthworms depending on the applied waste ( $p < 0.05$ ). ab—statistically significant differences.



**Figure 2.** The mean biomass of *D. veneta* earthworms depending on the applied waste ( $p > 0.05$ ). aa—no statistically significant differences.



In the experiment, for accelerating the adaptation of sheep dung to the nutritional requirements of earthworms, it had been heated to 105 degrees C, but at the production scale it was achieved by aging dung before vermicomposting [71].

The addition of hay to Cameroon sheep dung (CSDH), as an alternative version to CSD, had a positive impact on the earthworm population of *D. veneta* ( $p < 0.05$ ). Although the two populations did not differ in biomass ( $p > 0.05$ ), the addition of hay significantly enhanced the number of earthworms ( $p < 0.05$ ). This will ensure an obvious profit to the vermicomposter, which is through the possibility to process more material through a greater population of *D. veneta* and/or by the potential sale of these excess earthworms.

#### 4. Conclusions and Future Directions

1. Cameroon sheep dung, in a pure form and mixed 1:1 with marginal value hay, can be vermicomposted into a material that has a physico-chemical structure and quality, making it suitable for use as an agricultural fertilizer. As a result of the vermicomposting of organic compounds in them, the “thickening” of mineral components and narrowing of the C:N ratio (carbon loss) took place.
2. The scaling-up of this vermicomposting process to utilize the dung from Cameroon sheep and other ovine stock (in Poland and further afield) could help to consolidate a more circular economy. Further research in this area may prove valuable by linking with small and medium sized farms seeking diversification (post 2020 support from the Rural Development Programme in Poland to be investigated).
3. One major consideration when moving to a farm scale operation is the economics of the process. Before “scaling-up”, a comprehensive economic evaluation is required. This should naturally include the removal of dung, production of a more premium quality fertilizer and production of earthworms (potential protein).

**Author Contributions:** Conceptualization, M.G.; data curation, J.K., G.P. and A.M.-P.; investigation, M.G., J.K., G.P., E.H., A.M.-P., K.R.B.; methodology, M.G.; writing—original draft, M.G.; writing—review and editing, M.G., E.H., J.K. and K.R.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** The project was financed under the program of the Minister of Science and Higher Education under the name “Regional Initiative of Excellence” in the years 2019–2022: project number 026/RID/2018/19, funding amount PLN 9 542 500.00.

**Conflicts of Interest:** The authors declare no conflicts of interest.

#### References

1. Thematic Strategy on Soil Protection (COM (2006) 231). Available online: <https://www.eea.europa.eu/policy-documents/soil-thematic-strategy-com-2006-231> (accessed on 20 February 2020).
2. Tan, K.H. Humic matter in soil and environment. In *Principles and Controversies*; CRC Press, Taylor and Francis Group: Boca Raton, FL, USA, 2014; pp. 79–104.
3. Gonet, S.; Smal, H.; Chojnicki, J. Chemical properties of soils. *Soil Sci.* **2015**, 189–231. (In Polish)
4. Lexicon of fertilization. 2017. Available online: <https://nawozy.eu/wiedza/leksykon-nawozenia.html> (accessed on 25 February 2020).
5. Ukalska-Jaruga, A.; Smreczak, B.; Strzelecka, J. The influence of organic matter on the quality of agricultural soils. *Studia Rap. IUNG-PIB* **2017**, 54, 25–39. (In Polish). Available online: [http://iung.pl/index.php?option=com\\_content&view=article&id=123&Itemid](http://iung.pl/index.php?option=com_content&view=article&id=123&Itemid) (accessed on 20 February 2020).
6. European Soil Database. Available online: <http://esdac.jrc.ec.europa.eu/resource-type/european-soil-databasesoil-properties> (accessed on 26 February 2020).
7. Statistical Yearbook of Agriculture. Warszawa: Cental St65. 2017. Available online: <http://stat.gov.pl/obszary-tematyczne/roczniki-statystyczne/roczniki-statystyczne/rocznik-statystycznyrolnictwa-2014,6,8.html> (accessed on 13 March 2020).

8. Eurostat, Statistics Explained. Agri-Environmental Indicator—Tillage Practices. 2017. Available online: [http://epp.eurostat.ec.europa.eu/statistics\\_explained/index.php/Agri-environmental\\_indicator\\_-\\_tillage\\_practices](http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Agri-environmental_indicator_-_tillage_practices) (accessed on 10 March 2020).
9. Gambuś, F.; Wieczorek, J. Pollution of fertilizers with heavy metals. *Ecol. Chem. Eng. A* **2012**, *19*, 353–360. [[CrossRef](#)]
10. Czarnecki, S.; Düring, R.-A. Influence of long-term mineral fertilization on metal contents and properties of soil samples taken from different locations in Hesse, Germany. *Soil* **2015**, *1*, 23–33. [[CrossRef](#)]
11. Jankowski, K.; Jodełka, J.; Sosnowski, J. The influence of nitrogen fertilization applied in different doses on fodder quality of meadow sward. *J. Ecol. Eng.* **2013**, *14*, 59–62. [[CrossRef](#)]
12. Ciesielczuk, T.; Rosik-Dulewska, C.; Poluszyńska, J.; Polis, K. Natural adhesives of fertiliser cuber as an element of sustainable plant cultivation. *Proc. ECOpole* **2016**, *10*, 112–119, (In Polish with English Summary).
13. Gbenou, B.; Adjolahoun, S.; Ahoton, L.; Sadou, A.; Houinato, M.; Sisin, A.A. Animal dung availability and their fertilizer values in a context of low soil fertility conditions for forage seed and crops production in Benin. *Am. J. Agric. Res.* **2017**, *2*, 1–16. [[CrossRef](#)]
14. Kostecka, J.; Garczyńska, M.; Podolak, A.; Pączka, G.; Kaniuczak, J. Kitchen organic wastes as material for vermiculture and source of nutrients for plants. *J. Ecol. Eng.* **2018**, *19*, 267–274. [[CrossRef](#)]
15. Kostecka, J. Investigation into vermicomposting of organic wastes. *Sci. Pap. Agric. Univ. Crac.* **2000**, *268*, 88. (In Polish, with English Summary)
16. Garg, V.K.; Chand, S.; Chhillar, A.; Yadav, A. Growth and reproduction of *Eisenia foetida* in various animal wastes during vermicomposting. *Appl. Ecol. Environ. Res.* **2005**, *3*, 51–59. [[CrossRef](#)]
17. Vodounnou, D.S.J.V.; Kpogue, D.N.S.; Tossavi, C.E.; Mennsah, G.A.; Fiogbe, E.D. Effect of animal waste and vegetable compost on production and growth of earthworm (*Eisenia fetida*) during vermiculture. *Int. J. Recycl. Org. Waste Agric.* **2016**, *5*, 87–92. [[CrossRef](#)]
18. Coulibaly, S.S.; Edoukou, F.E.; Kouassi, K.I.; Barsan, N.; Nedeff, V.; Bizoro, I.A. Vermicompost utilization: A way to food security in rural area. *Heliyon* **2018**, *4*, 1–24. [[CrossRef](#)] [[PubMed](#)]
19. Sharma, K.; Garg, V.K. Comparative analysis of vermicompost quality produced from rice straw and paper waste employing earthworm *Eisenia fetida* (Sav.). *Bioresour. Technol.* **2018**, *250*, 708–715. [[CrossRef](#)] [[PubMed](#)]
20. Sharma, K.; Garg, V.K. Vermicomposting: A Green technology for organic waste management. In *Waste to Health*; Singhania, R.R., Agawal, R.A., Eds.; Springer: Midtown Manhattan, NY, USA, 2018; pp. 199–235. Available online: <https://www.springerprofessional.de/en/vermicomposting-a-green-technology-for-organic-waste-management/15288396> (accessed on 22 May 2020).
21. Jalali, M. Phosphorus Availability as Influenced by Organic Residues in Five Calcareous Soils. *Compost Sci. Util.* **2009**, *17*, 241–246. [[CrossRef](#)]
22. Cardoso, C.; López, F.M.; Orden, L.; Rodríguez, R.; Díaz, J. Phosphorus availability of seven organic manures in a sandy soil. *Acta Hort.* **2016**, *1146*, 149–156. [[CrossRef](#)]
23. Lal, B.; Sharma, S.C.; Meena, R.L.; Sarkar, S.; Sahoo, A.; Balai, R.C.; Guatam, P.; Meena, B.P. Utilization of byproducts of sheep farming as organic fertilizer for improving soil health and productivity of barley forage. *J. Environ. Manag.* **2020**, *269*, 110765. [[CrossRef](#)]
24. Maćkowiak, C.; Żebrowski, J. Chemical composition of manure in Poland. *Fertil. Fert.* **2000**, *4*, 119–130. Available online: [http://nawferti.iung.pulawy.pl/zeszyty/pelne/5%20%202000%20\(4\).pdf](http://nawferti.iung.pulawy.pl/zeszyty/pelne/5%20%202000%20(4).pdf) (accessed on 12 July 2020). (In Polish).
25. Belliturk, K.; Hinish, N.; Adiloglu, A. The effect of vermicompost sheep manure and cow manure on nutrition content of curly lettuce (*Lactuca sativa* var.). *Fresenius Environ. Bull.* **2017**, *26*, 1116–1120.
26. Zaremanesh, H.; Nasiri, B.; Amiri, A. The effect of vermicompost biological fertilizer on corn yield. *J. Mater. Environ. Sci.* **2017**, *8*, 154–159. Available online: [https://6-JMES-2408-Zaremanesh\(1\).pdf](https://6-JMES-2408-Zaremanesh(1).pdf) (accessed on 19 May 2020).
27. Adiloglu, S.; Acikgoz, F.E.; Solmaz, Y.; Caktii, E.; Adiloglu, E. Effect of vermicompost on the growth and yield of lettuce plant (*Lactuca sativa* l. var. *crispa*). *Int. J. Plant Soil Sci.* **2018**, *21*, 1–5. [[CrossRef](#)]
28. Fałowska, A.; Migdał, W. Characteristics of Cameroonian sheep and other broad breeds. *Breed. Rev.* **2018**, *2*, 15–16. (In Polish)
29. Aali, R.; Jafarpour, M.; Kazemi, E.; Pessarakli, M. Effects of raw materials on vermicompost qualities. *J. Plant Nutr.* **2017**, *40*, 1635–1643. [[CrossRef](#)]

30. Jahanbakhshi, A.; Kheiralipour, K. Influence of vermicompost and sheep manure on mechanical properties of tomato fruit. *Food Sci. Nutr.* **2019**, *1*, 1172–1178. [[CrossRef](#)] [[PubMed](#)]
31. Gašior, J.; Kaniuczak, J.; Kostecka, J. Chemical composition of vermicompost varieties produced from manure of cattle, sheep and pigs. *Zesz. Nauk. Akad. Rol. Im H Kołłątaja Krakowie* **1998**, *334*, 143–148, (In Polish, with English Summary).
32. Mroczek, J.R.; Kostecka, J.; Korczyńska, M. The assessment of the role of agri-environmental program in the perception by farmers selected aspects of environmental issues. *Ecol. Eng.* **2013**, *34*, 189–197, (In Polish, with English Summary). [[CrossRef](#)]
33. General Directorate for Environmental Protection. *Possibility of Using Late-Cut Hay, Coming from the Protection of Selected Habitats in Natura 2000 Areas, to Reduce the Cost of Heating Public Facilities. Case Study*; Generalna Dyrekcja Ochrony Środowiska: Warsaw, Poland, 2015. Available online: [https://www.gdos.gov.pl/files/aktualnosci/49107/Poradnik\\_wersja\\_elektroniczna.pdfWojewodztwoDolnoślaskie](https://www.gdos.gov.pl/files/aktualnosci/49107/Poradnik_wersja_elektroniczna.pdfWojewodztwoDolnoślaskie) (accessed on 26 February 2020).
34. Ministry of Agriculture and Rural Development. Methodology for Preparing Habitat Documentation for Packages 4 and 5 “Agri-Environment-Climate Measures” under RDP 2014–2020. 2019, p. 59. Available online: [https://www.downloads.Program\\_Rozwoju\\_Obszarow\\_Wiejskich\\_na\\_lata\\_2014-2020.pdf](https://www.downloads.Program_Rozwoju_Obszarow_Wiejskich_na_lata_2014-2020.pdf) (accessed on 24 February 2020).
35. The Fertilisers and Fertilisation Act (Journal of Laws of the Republic of Poland, 28 June 2018, item 1259) (Dz. U. 2018 Nr 147, poz. 1259). Available online: <https://www.infor.pl/akt-prawny/DZU.2018.124.0001259,ustawa-o-nawo-zach-i-nawozeniu.html> (accessed on 20 January 2020).
36. Rajiv, K.S.; Sunita, A.; Krunal, C.; Dalsukh, V. The wonders of earthworms & its vermicompost in farm production: Charles Darwin’s ‘friends of farmers’, with potential to replace destructive chemical fertilizers from agriculture. *Agric. Sci.* **2010**, *1*, 76–94. [[CrossRef](#)]
37. Ali, U.; Sajad, N.; Khalid, L.; Riaz, L.; Rabbani, M.M.; Syed, J.H.; Malik, R.N. A review on vermicomposting of organic wastes. *Environ. Prog. Sustain. Energy* **2015**, *34*, 1050–1062. [[CrossRef](#)]
38. Mahmud, M.; Adbullah, R.; Syafawati Yaacob, J. Effect of vermicompost amended on nutritional status of sandy loam soil, growth performance and yield of pineapple (*Ananas comosus* var. MD2) under field condition. *Agronomy* **2018**, *8*, 183. [[CrossRef](#)]
39. Faridullah, P.A.; Hafeez, S.; Alam, A.; Ma, J.; Shah, S.H.; Waseem, A. Evaluating nutrient elements and heavy metals in fresh and composted manure of different livestock. *Fresenius Environ. Bull.* **2014**, *23*, 1773–1777. Available online: [https://www.prt-parlar.de/download\\_feb\\_2014/](https://www.prt-parlar.de/download_feb_2014/) (accessed on 24 May 2020).
40. Albihn, A.; Vinneras, B. Biosecurity and arable use of manure and biowaste—Treatment alternatives. *Livest. Sci.* **2007**, *112*, 232–239. [[CrossRef](#)]
41. Eastman, B.R.; Kane, P.N.; Edwards, C.A.; Trytek, L.; Guandi, B.; Stermer, A.L.; Mobley, J.R. The effectiveness of vermiculture in human pathogen reduction for USEPA biosolids stabilization. *Compost Sci. Util.* **2001**, *9*, 38–49. [[CrossRef](#)]
42. Contreras-Ramos, S.M.; Escamilla-Silva, E.M.; Dendooven, L. Vermicomposting of biosolids with cow manure and oat straw. *Biol. Fert. Soils* **2015**, *41*, 190–198. [[CrossRef](#)]
43. Kumar, R.; Shweta, A. Removal of pathogens during vermistabilization. *Environ. Sci. Technol.* **2011**, *4*, 621–629. [[CrossRef](#)]
44. Karimi, H.; Mokhtari, M.; Salehi, F.; Sojoudi, S.; Ebrahimi, A. Changes in microbial pathogen dynamics during vermicomposting mixture of cow manure–organic solid waste and cow manure–sewage sludge. *Int. J. Recycl. Org. Waste Agric.* **2017**, *6*, 57–61. [[CrossRef](#)]
45. Kostecka, J.; Błażej, J. Growing plants on vermicompost as a way a produce high quality foods. *Bull. Pol. Acad. Biol. Sci.* **2000**, *48*, 1–10. Available online: <https://repozytorium.ur.edu.pl/handle/item/3113> (accessed on 27 January 2020).
46. Acevedo, I.C.; Pire, R. Effects of vermicompost as substrate amendment on the growth of papaya (*Carica papaya* L.). *Interciencia* **2004**, *29*, 274–279.
47. Edwards, C.A.; Domínguez, J.; Arancon, N.Q. The influence of vermicomposts on plant growth and pest incidence. In *Soil Zoology for Sustainable Development in the 21st Century*; Hanna, S., Mikhail, W.Z.A., Eds.; Self-Publisher: Cairo, Egypt, 2004; pp. 397–420.

48. Arancon, N.Q.; Edwards, C.A.; Bierman, P.; Metzger, J.D.; Lucht, C. Effects of vermicomposts produced from cattle manure, food waste and paper waste on the growth and yield of peppers in the field. *Pedobiologia* **2005**, *49*, 297–306. [CrossRef]
49. Yardim, E.N.; Arancon, N.A.; Edwards, C.A.; Oliver, T.J.; Byrne, R.J. Suppression of tomato hornworm (*Manduca quinquemaculata*) and cucumber beetles (*Acalymma vittatum* and *Diabotrica undecimpunctata*) populations and damage by vermicomposts. *Pedobiologia* **2006**, *50*, 23–29. [CrossRef]
50. Zaller, J.G. Vermicompost as a substitute for peat in potting media: Effects on germination, biomass allocation, yields and fruit quality of three tomato varieties. *Sci. Hortic.* **2007**, *112*, 191–199. [CrossRef]
51. Arancon, N.Q.; Edwards, C.A.; Babenko, A.; Cannon, J.; Galvis, P.; Metzger, J.D. Influences of vermicomposts, produced by earthworms and microorganisms from cattle manure, food waste and paper waste, on the germination, growth and flowering of petunias in the greenhouse. *Appl. Soil Ecol.* **2008**, *39*, 91–99. [CrossRef]
52. Azarmi, R.; Giglou, M.T.; Taleshmikail, R.D. Influence of vermicompost on soil chemical and physical properties in tomato (*Lycopersicum esculentum*) field. *Afr. J. Biotechnol.* **2008**, *7*, 2397–2401. Available online: <https://www.ajol.info/index.php/ajb/article/view/59004> (accessed on 14 May 2020).
53. Padmavathiamma, P.; Li, L.Y.; Kumari, U.R. An experimental study of vermi-biowaste composting for agricultural soil improvement. *Bioresour. Technol.* **2008**, *99*, 1672–1681. [CrossRef] [PubMed]
54. Singh, R.; Sharma, R.R.; Kumar, S.; Gupta, R.K.; Patil, R.T. Vermicompost substitution influences growth, physiological disorders, fruit yield and quality of strawberry (*Fragaria x ananassa* Duch.). *Bioresour. Technol.* **2008**, *99*, 8507–8511. [CrossRef] [PubMed]
55. Suthar, S. Vermicomposting of vegetable-market solid waste using *Eisenia fetida*: Impact of bulking material on earthworm growth and decomposition rate. *Ecol. Eng.* **2009**, *35*, 914–920. [CrossRef]
56. Zhao, H.-T.; Li, T.-P.; Zhang, Y.; Hu, J.; Bai, Y.-C.; Shan, Y.-H.; Ke, F. Effects of vermicompost amendment as a basal fertilizer on soil properties and cucumber yield and quality under continuous cropping conditions in a greenhouse. *J. Soil Sediment.* **2017**, *17*, 2718–2730. [CrossRef]
57. Handzel, A.; Królczyk, J.B.; Latawiec, A.E.; Pluta, K.; Malina, D.; Sobczak-Kupiec, A. Determination of element content and physicochemical properties of selected soils. *Infrastruct. Ecol. Rural Areas* **2017**, *1*, 287–295, (In Polish, with English Summary).
58. Ministry of Agriculture, Fisheries and Food (MAFF). The analysis of agricultural materials 2nd edn. In *A Manual of the Analytical Methods Used by the Agricultural Development and Advisory Service (ADAS)*; HMSO: London, UK, 1981.
59. PN-ISO 11047: Soil Quality—Determination of Cadmium, Chromium, Cobalt, Copper, Lead, Manganese, Nickel and Zinc in the Soil Extracts with Royal Water—Methods of Flame and Electrothermal Absorption Spectrometric Methods. 2001. Available online: <https://www.iso.org/standard/24010.html> (accessed on 14 May 2020).
60. Pelosi, C.; Bertrand, M.; Capowiez, Y.; Boizard, H.; Roger-Estrade, J. Earthworm collection from agricultural fields: Comparisons of selected expellants in presence/absence of hand-sorting. *Eur. J. Soil Biol.* **2009**, *45*, 176–183. [CrossRef]
61. Baligar, V.; Fageria, N.; He, Z. Nutrient use efficiency in plants. *Commun. Soil Sci. Plant* **2001**, *32*, 921–950. [CrossRef]
62. Roy, R.; Finck, A.; Blair, G.; Tandon, H. *Plant Nutrition for Food Security a Guide for Integrated Nutrient Management*; FAO Fertilizer and Plant Nutrition Bulletin; FAO: Rome, Italy, 2006; Volume 16, p. 368.
63. The Institute of Soil Science and Plant Cultivation-National Research Institute (IUNG-PIB Report). Environmental Aspects of Soil Acidification in Poland. 2017. (In Polish). Available online: [http://www.izbarolnicza.lodz.pl/sites/default/files/IUNG%20ekspertyza%20\\_wapnowanie\\_17.10.2017r.pdf](http://www.izbarolnicza.lodz.pl/sites/default/files/IUNG%20ekspertyza%20_wapnowanie_17.10.2017r.pdf) (accessed on 20 January 2020).
64. European Environment Agency (EEA). Exposure of Ecosystems to Acidification, Eutrophication and Ozone (CSI 005). 2019. Available online: <http://www.eea.europa.eu/data-and-maps/indicators/exposure-of-ecosystems-to-acidification-2/exposure-of-ecosystems-to-acidification> (accessed on 28 January 2020).
65. Han, S.H.; An, J.Y.; Hwang, J.; Kim, S.B.; Park, B.B. The effects of organic manure and chemical fertilizer on the growth and nutrient concentrations of yellow poplar (*Liriodendron tulipifera* Lin.) in a nursery system. *Forest Sci. Technol.* **2016**, *12*, 137–143. [CrossRef]
66. Alikhani, F.; Yakhchali, B.; Mohammadi, L. Comparing physicochemical properties of common compost and vermicompost. *Iran. J. Biol.* **2011**, *24*, 925–934.

67. Ciesielczuk, T.; Rosik-Dulewska, C.; Wiśniewska, E. Possibilities of coffee spent ground use as a slow action organo-mineral fertilizer. *Annu. Set Environ. Prot.* **2015**, *17*, 422–437.
68. Shahid, S.A.; Zamad, M.; Heng, L. Soil Salinity: Historical Perspective and a World Overview of the Problem. In *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques*; Springer, Cham: Midtown Manhattan, NY, USA, 2018; pp. 45–53. [[CrossRef](#)]
69. Alidadi, H.; Hosseinzadeh, A.; Najafpoor, A.A.; Esmaili, H.; Zangeneh, J.; Takabi, M.D.; Piranloo, F.G. Waste recycling by vermicomposting: Maturity and quality assessment via dehydrogenase enzyme activity, lignin, water soluble carbon, nitrogen, phosphorous and other indicators. *J. Environ. Manag.* **2016**, *182*, 134–140. [[CrossRef](#)] [[PubMed](#)]
70. Guimarães, R.N.; Damin, V.; Fernandes, P.M.; Leandro, W.M.; Campos de Melo, A.P.; Santana Rosa, J.Q. Production of phosphate biofertilizer through composting and vermicomposting process. *Comun. Sci.* **2017**, *8*, 32–443. [[CrossRef](#)]
71. Garg, P.; Gupta, A.; Satya, S. Vermicomposting of different type of waste using *Eisenia foetida*: A comparative study. *Bioresour. Technol.* **2006**, *97*, 391–395. [[CrossRef](#)]
72. Wang, X.-X.; Zhao, F.; Zhang, G.; Zhang, Y.; Yang, L. Vermicompost improves tomato yield and quality and the biochemical properties of soils with different tomato planting history in a greenhouse study. *Front. Plant Sci.* **2017**, *8*, 1–11. [[CrossRef](#)]
73. Chaulagain, A.; Maharjan, B.; Pathak, R.; Piya, S.; Chimoriya, S.; Sherstha, I.; Gauchan, D.P.; Lamichhane, J.J. Effect of Feeding Materials on Yield, Quality of Vermicompost, Multiplication and Reproduction of *Eisenia foetida*. *Sci. Engine Technol.* **2018**, *13*, 15–25. [[CrossRef](#)]
74. Kist, S.G.P.; Joseila, M.; Matados de, M.R.; Witt, S.C.; Luiz, M.E.; Bemfica, S.R.; Dias, O.F.B. The vermicompost anticipates flowering and increases tomato productivity. *Agrocienc. Urug.* **2019**, *23*, 1–7. [[CrossRef](#)]
75. Al-Delfi, H.F.; Abdulkareem, M.A. Characterization of composted poultry manure with or without plant residues. *Plant Arch.* **2020**, *20*, 1303–1310. Available online: [http://plantarchives.org/20-1/1303-1310%20\(5427\).pdf](http://plantarchives.org/20-1/1303-1310%20(5427).pdf) (accessed on 11 May 2020).
76. Kończak-Konarkowska, B. The Principles of Fertilizer Recommendations in Horticulture. In *Manual for Horticulture Laboratories in Chemical and Agricultural Research Laboratories*; National Chemical and Agricultural Research Laboratory: Warsaw, Poland; Regional Chemical and Agricultural Research Laboratory: Gorzów Wielkopolski, Poland, 2009; p. 69. (In Polish)
77. Edwards, C.A.; Subler, S.; Arancon, N.Q. Quality criteria for vermicomposts. In *Earthworms, Organic Wastes and Environmental Management*; Edwards, C.A., Arancon, N.Q., Sherman, R., Eds.; CRC Press: Boca Raton, FL, USA, 2011; pp. 287–301.
78. Garczyńska, M.; Pączka, G.; Wirkus, K.; Podolak, A.; Mazur-Pączka, A.; Bartkowska, I.; Kostecka, J. Vermicomposting of post-Harvest maize waste. *Annu. Set Environ. Protect.* **2018**, *20*, 358–374.
79. Pączka, G.; Garczyńska, M.; Mazur-Pączka, A.; Podolak, A.; Szura, R.; Skoczko, I.; Kostecka, J. Vermicomposting of sugar beet pulp using *Eisenia fetida* (Sav.) earthworms. *Annu. Set Environ. Protect.* **2018**, *20*, 588–601.
80. Fekri, M.; Kaveh, S. Heavy metal accumulation in soil after application of organic wastes. *Arab. J. Geosci.* **2013**, *6*, 463–467. [[CrossRef](#)]
81. Wang, Y.; Han, W.; Wang, X.; Chen, H.; Zhu, F.; Wang, X.; Lei, Ch. Speciation of heavy metals and bacteria in cow dung after vermicomposting by the earthworm *Eisenia fetida*. *Bioresour. Technol.* **2017**, *24*, 411–418. [[CrossRef](#)] [[PubMed](#)]
82. The Regulation of the Minister of Agriculture and Rural Development on the method of assessing the pollution of the earth's surface (21 September 2016) (Dz.U.2016 poz. 1395). Available online: <http://isap.sejm.gov.pl/DetailsServletid.WDU20160001395>. (accessed on 11 June 2020).
83. Smreczak, B.; Siebielec, G.; Ukalska-Jaruga, A.; Klimkowicz-Pawlas, A. Ocena zawartości kadmu, cynku i ołowiu oraz benzo(a)pirenu w glebach użytkowanych rolniczo—Dwadzieścia lat monitoringu chemizmu gleb ornych Polski. *Studia I Rap. IUNG-PIB* **2018**, *58*, 81–95.
84. Wang, L.M.; Zhang, Y.M.; Lian, J.J.; Chao, J.Y.; Gao, Y.X.; Yang, F.; Zhang, L.Y. Impact of fly ash and phosphatic rock on metal stabilization and bioavailability during sewage sludge vermicomposting. *Bioresour. Technol.* **2013**, *136*, 281–287. [[CrossRef](#)] [[PubMed](#)]

85. Gong, X.; Li, S.; Sun, X.; Wang, L.; Cai, L.; Zhang, J.; Wei, L. Green waste compost and vermicompost as peat substitutes in growing media for geranium (*Pelargonium zonale* L.) and calendula (*Calendula officinalis* L.). *Sci. Hortic.* **2018**, *236*, 186–191. [[CrossRef](#)]
86. Dominguez, J.; Edwards, C.A. Relationships between composting and vermicomposting. *Vermiculture Earthworms. Org. Wastes Environ. Manag.* **2010**, *1*, 11–26.
87. Bityutskii, N.P.; Kaidun, P.I. The influence of earthworms on the mobility of microelements in soil and their availability for plants. *Eurasian Soil Sci.* **2008**, *41*, 1306–1313. [[CrossRef](#)]
88. Devliegher, W.; Verstraete, W. The effect of *Lumbricus terrestris* on soil in relation to plant growth: Effects of nutrient-enrichment processes (NEP) and gut-associated processes (GAP). *Soil Biol. Biochem.* **1997**, *29*, 341–346. [[CrossRef](#)]
89. Bhattacharya, S.S.; Chattopadhyay, G.N. Effect of Vermicomposting on the Transformation of Some Trace Elements in Fly Ash. *Nutr. Cycl. Agroecosyst.* **2006**, *75*, 223–231. Available online: <https://link.springer.com/article/10.1007%2Fs10705-006-9029-7> (accessed on 12 May 2020). [[CrossRef](#)]
90. Sizmur, T.; Richardson, J. Earthworms accelerate the biogeochemical cycling of potentially toxic elements: Results of a meta-analysis. *Soil Biol. Biochem.* **2020**, *148*, 107865. [[CrossRef](#)]
91. Dominguez, J.; Edwards, C.A. Vermicomposting organic wastes: A review. In *Soil Zoology for Sustainable Development in the 21st Century*; Hanna, S., Mikhall, W.Z.A., Eds.; Self-Publisher: Cairo, Egypt, 2004; pp. 369–395.



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