Effects of vermicompost on plant and soil characteristics – a literature overview

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Summary: Vermicomposts are earthworm faeces after processing of different organic wastes. The composition is variable and dependent on the nature of the substrate. Several characteristics make vermicomposts interesting for agriculture (plant growth/health, soil health) such as their macronutrient content (N, P, K, organic matter) and specific components (humic acids, phytohormones, enzymes). This literature overview describes multiple researches on the effects of vermicompost in agriculture with a focus on macronutrient content and plant growth.

Keywords: vermicompost, plant growth, plant health, soil health, humic acids, plant hormones, enzymes

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Preface

In the Netherlands, there are surpluses of manure and digestates/biogas slurries (digested manure and residual flows), which represent a negative value. At the same time, these residual flows contain valuable ingredients for the production of biomass (as raw material for food and feed products), for improving soil quality and for energy production. The number of feasible business cases in which the residual flow is upgraded has so far been limited. This is due both to the efficiency of the technologies used and the legislation and regulations related to the residual flows.

Recent information from research, scientific literature and companies provides new starting points for a biobased valorisation of manure/digestate streams and improving the efficiency of anaerobic digestion. The innovative aspect of our research is the cultivation of new types of biomass on the residual flows and the use of the conversion products to improve anaerobic digestion. This involves the use of separated manure and digestate products for the cultivation of mushrooms/fungi, worms, insects, specific bacteria and aquatic biomass. The resulting biomass can be further refined and marketed as food, feed and bio-based feedstock. There are also processed manure and digestate products that are valuable as fertilizer products for soil and plant growth, as substrate for improvement of anaerobic digestion or for export/use besides in agriculture. This gives a new interpretation to obligatory manure processing.

The aim of this project is to further explore and substantiate/test these ideas on lab and practical scale, leading to a proof of principles for new bio-based upgrading methods for manure and digestate that can be used in conjunction to better close cycles and/or sell outside regular agriculture. Bottlenecks in legislation and regulations are explored and put on the agenda. Key figures are also calculated that are necessary for assessing sustainability (e.g. costs, environmental effects) and for supporting legislation (e.g. minerals, food safety).

The livestock sector gains insight into the possibilities of biobased valorisation and better marketing of their most important residual flows. For the SMEs involved, this research provides proof of principle for their technology and input in their business cases. The combined effects of the technologies provide new knowledge, methods and research directions for science. In a social context, the use and upgrading of manure and digestates in other ways also contributes to the transition to a circular bio-economy with an efficient and sustainable agri-food sector.

More information:

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Summary

Vermicomposts are earthworm faeces after processing of different organic wastes. The composition is variable and dependent on the nature of the substrate. The worms degrade organic matter and release small organic compounds and/or mineral nutrients through their metabolic products. The availability of several nutrients and pH increases while organic matter is stabilized. Several characteristics thus make vermicomposts interesting for agriculture (plant growth/health, soil health) such as their macronutrient content (N, P, K, organic matter) and specific compounds (humic acids, phytohormones, enzymes). This literature overview describes multiple researches on the effects of vermicompost in agriculture with a focus on macronutrient content and plant growth. It has been found by several authors that the presence of earthworms in agricultural ecosystems with low soil N availability can lead up to more than 20 % a increases in crop yield and aboveground biomass, due to N releases from the organic matter they process. Vermicomposting leads to changes in the microbial (functional) diversity of the substrates. In general, vermicompost composition adheres to standards for organic amendments.
Vermicomposts from organic waste streams have potential as an organic fertilizer for several agricultural applications and this application increases circularity in the agrifood sector.

1 Introduction

1.1 Outline of the report

One of the focus organisms of this PPP project is the earthworm, which is known to affect plant growth/health and soil quality. The goal of this research was to create an overview of the main scientific results for these effects. There are however numerous scientific publications in this field and therefore it was decided to describe in Chapter 2 the main effects: effects on pathogens/pests, interesting components in the vermicompost and integral effects on the soil. Chapter 3 consists of a table with multiple researches on the composition of vermicompost and its effects. This table can be used as a starting point for further (literature) research.
This overview focuses on the composition and application of vermicomposts for plant growth/health and soil health only, not on worm tea, worm mucus or the gut bacteria present in the worms. Also, micronutrients and pollutants (e.g. heavy metals) in vermicomposts were not evaluated for this overview.

1.2 General information on earthworms and vermicompost

A large variety of organic waste streams (e.g. manures, agricultural residues, garden wastes, weeds, industrial/food wastes) can be converted by different types of earthworms into worm casts (vermicompost, worm humus) while the worms grow and reproduce during the process. Lim et al. (2016) show an overview of the different types of waste that can be converted. This process is called vermicomposting. A typical mass balance for the processing of dairy manure by earthworms is shown in Figure 1 (Nova Pinedo et al., 2019).

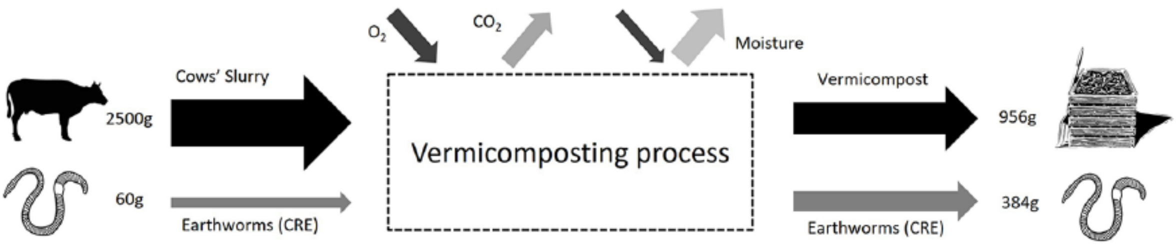

Figure 1 *Overview of manure bioconversion by earthworms (Figure from: (Nova Pinedo et al., 2019)).*

Different worm species can be used for vermicomposting, the most common ones being: *Eisenia fetida*, *Dendrobaena veneta* and *Eisenia andrei*. Blouin et al. (2013) review the ecological function of earthworms and their role in nutrient cycling. Earthworms degrade organic matter and release small organic compounds and/or mineral nutrients through their metabolic products (casts, urine, mucus which contain NH_4^+, urea, allantoin and uric acid) and also from dead worm tissues. The nutrients (especially N) are then re-used by plants. In addition to the release of nitrogen, phosphorus is solubilized by the action of earthworms (Ros et al., 2017). Their results suggested that an increase in pH and enhanced interaction of dissolved organic matter with the reactive surface of metal (hydr)oxides is likely the major cause of increased PO_4 release via competitive adsorption/desorption. This leads to higher concentrations of dissolved inorganic P in earthworm casts, increased soil fertility and plant yield. Lv et al. (2014) used fluorescence excitation–emission matrix (EEM) combined with parallel factor analysis to find out that during vermicomposting of sewage sludge and cattle manure dissolved organic carbon (DOC), the ratio between dissolved organic carbon and dissolved organic

nitrogen (DOC/DON), protein-like compounds and ammonia decreased, while nitrate and humic acid-like compounds increased.
In addition to the worms producing vermicompost, they grow and reproduce on the substrates, when of sufficient nutritional value. Worm biomass, if grown on safe substrates can be applied as a protein-rich feed source, for example for poultry or fish (e.g. Velasquez et al., 1991; Khan et al., 2016).

1.2.1 Effects of vermicompost and worms

Based on the type of substrate, the composition of the vermicompost varies. In addition, earthworms can bioaccumulate pollutants such as heavy metals or micropollutants (e.g. Hirano & Tamae, 2011; van der Wal et al., 2004). From many researches it is concluded that application of vermicomposts has beneficial effects on plant growth/health and soil health.
Van Groenigen et al. (2014) did an extensive literature meta-analysis on the effects of earthworms on plant growth. They concluded that the presence of earthworms in agroecosystems lead to a 25 % increase in crop yield and a 23 % increase in aboveground biomass, dependent on the presence of crop residues, earthworm densities and fertilization type and rate. When soil N availability is high, the positive effects disappear, which confirms that earthworms mainly stimulate plant growth by releasing N (nitrate) from residues and organic matter. Bertrand et al. (2015) wrote a review on the benefits of earthworms for crops, and they present techniques to increase earthworm abundance. Earthworms influence soil organic matter and cycling of nutrients by stabilizing the organic matter in their casts and by altering physical protection within aggregates and enhancing microbial activity. In addition, they induce the production of hormone-like substances that improve plant growth/health. Hussain & Abbasi (2018) also wrote an extensive review on the effects of vermicomposts from different substrates on plant growth. In general they found that vermicompost is beneficial for plant germination, growth and yield and improves physical and chemical soil properties as well as agricultural productivity, regardless of the substrate. However, they also found that maximum concentration limits apply.
Blouin et al. (2019) did a meta-analysis of the effects of vermicompost on plant growth. Application of vermicompost led to increases in commercial yield, shoot, root and total biomass and maximum effects were found at concentrations of 30-50 % of the soil volume. Producers usually recommend concentrations of 20 % and more. They concluded that dairy manure is the best substrate for increasing plant shoot and root biomass. For the best effect of vermicompost no fertilizer should be added, as this has the same main effect as vermicompost: adding N. The most responsive plant families (largest biomass increase) were herbs (especially Cucurbitaceae and Asteraceae) and legumes. According to Vuković et al. (2021), who review vermicomposting in general and effects of vermicompost on plant growth and yield, the main knowledge gaps to be addressed are microbial community composition, application rates, heavy metal concentrations, plant pathogens and diseases and selection of organic wastes.
Van Groenigen et al. (2019) did another extensive literature meta-analysis on the fertility of earthworms casts compared to bulk soil. In the casts, concentrations of TOC, P_{total} and N_{total} were 40-48 % higher as a result of preferential feeding or concentration processes. Also the availability of nutrients, mineral N and available P, increased by 241 % and 84 % respectively. This availability results to a large extent from (bio)chemical transformation processes in earthworm guts. In addition, there were significant increases in pH (0.5 units), cation exchange capacity (40 %), and base saturation (27 %). All in all, their results showed that earthworms casts are much more fertile than bulk soil for almost all analysed parameters. The found variability in the results for cast fertility could depend on the presence of plants and interactions between earthworm species traits and specific soil properties.

1.2.2 Compost and manure in the Netherlands

In the Netherlands, two main types of compost are produced: VFG compost and green compost. The composition of composts is variable, but there can be differences in organic matter and VFG compost contains more minerals (Jonkheer, 2010). Two quality marks (Keurcompost, two classes I and II (Beoordelingsrichtlijn Keurcompost, 2021) or RAG certificate) exist for compost in the Netherlands.

Table 1 shows the average composition of the two compost types and the most common animal manures. Also, the average composition of a wide range of different vermicomposts is shown, based on the international literature data gathered in table 2. The composition of vermicompost shows a very large range of values. Averages for vermicomposts could not be provided as some of the source articles mention averages and others mention individual data. Characteristics of the vermicomposts are dependent on the feed substrate for the worms.

Table 1 *Average composition of different common livestock manures, composts and ranges for vermicompost*

Parameter (g/kg DM unless stated otherwise)	Pig slurry	Cow slurry	Poultry manure	Green compost	VFG compost	Vermicompost
Dry matter (g/kg product)	107	92	562	600	700	184-965
Organic matter	738	772	740	300	240-340	108-944
N_{total} (N)	65	43	51	5-8	13	0.1-45
Phosphate (P_2O_5)	36	16	41	2-4	5	1.2-103.5
Potassium (K_2O)	44	59	34	7		0.3-189.6
C/N ratio*	11.9	16.8	8.0	18.7		5.5-28.5

Sources: Smits, 2011; Handboek Bodem en Bemesting, online, Table 1 (this report). C/N ratio calculated as (0.5*OM)/N_{org}

Based on these ranges for vermicompost it is hard to draw conclusions on resemblances to other composts or animal manures.

1.2.3 Legislation

Bernal et al. (2017) discuss European legislation for composts. Regulations vary per country dependent on soil policies and composts are sometimes considered waste, sometimes fertilizer. Usually the agronomic value (C/N ratio, OM (organic matter), C, N_{total} etc), heavy metals and inert materials content are well defined in the national regulations, but pathogen and phytotoxicity standards are not uniform.
There are no standards for vermicompost. Ducasse et al. (2022) wrote an extensive review on vermicomposting of municipal solid waste and referred to standards for organic amendments. Standard NF U44-051 mentions minimal values for C/N ratio of 8, dry matter of 30 %, organic matter 20 % (= organic carbon 10 %) and maximum values for P, K and N of 3 %. For vermicomposts from food waste vs. green waste the authors mention values of C_{org}, N, P and K of 19 vs. 25 %, 1.6 vs. 1.9 %, 1.2 vs. 0.7 % and 2.3 vs. 1.3 %. Green waste thus leads to vermicomposts higher in C and N, but lower in P and K. Even though the ranges for vermicompost summarized in table 1 are very broad, on average its composition adheres to these standards for organic amendments.

2 Literature data on applications, specific components in and effects of vermicompost

2.1 Effects on pathogens/pests

Messelink et al. (2013) found that when 20 % of peat was replaced by worm compost, populations of red peach aphids on pepper plants increased with 35 % compared to on plants grown with peat alone. The mechanism behind this was unclear, possibly the phloem sap composition was affected but this is difficult to measure.
Renčo & Kováčik (2015) tested vermicompost from municipal green wastes (30 % leaves, 70 % grass) for its nematicidal potential and compared it to aqueous solutions of vermicompost with or without urea. Numbers of cysts, eggs and juveniles of *Globodera rostochiensis* (pathotype Ro1) and *G. pallida* (pathotype Pa2) decreased with all materials and this was correlated to dosage but the aqueous solutions were more effective. In addition, stem height and weight were positively influenced by all materials. They also describe the effect of vermicomposts on other plant parasites (e.g. arthropods, nematodes).
Gudeta et al. (2022) wrote a review on the application of vermicompost (and its derivatives) against several fungal pathogens, e.g. *Rhizoctonia solani*, *Alternaria solani*, *Aspergillus niger*, *A. flavus*, *Fusarium oxysporum*, and *F. graminearum*. This effect may be due to for example antibodies in the coelomic fluid of earthworms.
Basco et al. (2017) studied the addition of biological control agents (*Trichoderma harzianum*, *Pseudomonas fluorescens* and *Bacillus subtilis*) to vermicompost against tomato wilt (*Fusarium oxysporum* f. sp. *lycopersici*). They found significant variations in disease reduction, improved plant growth & yield and higher stimulation of antioxidants in tomato plants treated with biofortified vermicompost as compared to the control, with the best results for added *T. harzianum*.

2.2 Peat replacement and growing media

Mota et al. (2007) investigated whether it was possible to (partially) replace peat with vermicompost. They concluded that inclusion levels should not exceed 50 % of the original peat content. Ma et al. (2022) wrote a review on how vermicompost influences the composition of growing media and plant growth. Vermicompost increases available N and P and water-holding porosity of growing media, as well as seed germination rate, seedling index, shoot, root and total biomass. Pore space was slightly reduced. They concluded that vermicompost from dairy manure was most suitable for growing mediums and that the inclusion percentage should be 40-60 % for optimum plant growth.

2.3 Substances in vermicompost

2.3.1 Plant hormones and enzymes

Vermicompost can contain plant hormones such as cytokinins, gibberellins (e.g. GA_3) and auxins (e.g. IAA) and enzymes (alkaline phosphatase, cellulase, urease) (Ruangjanda et al., 2022). Urease is involved in the decomposition of carbamide resulting in the formation of carbonic acid and ammonia, while cellulase is involved in hydrolyzing cellulose to glucose. Concentrations of these compounds in vermicompost are dependent on substrate type. Plant hormones/growth regulators can be released from the organic substrates or produced during biomass transformation and are affected by composting parameters. Aremu et al. (2015) analyzed vermicompost leachate produced from garden

waste for phytohormones and phenolic acids and quantified (varying concentrations of) cytokinins, indole-3-acetic acid (IAA), 18 gibberellins (GAs) and 6 brassinosteroids (BRs). These substances may be responsible for favourable physiological plant responses after application of vermicomposts, for example increased growth and yield as well as improved stress responses to several (a)biotic stressors. Busato et al. (2016) studied concentrations of phosphatase during vermicomposting and its relation with other chemical constituents. Phosphatase is needed to hydrolyze P before plant uptake and high concentrations typically are measured during vermicomposting. Phosphatase activities in two different vermicomposts were positively correlated to TOC (total organic carbon), pH and water-soluble P (WSP) and negatively correlated to humic acid (HA) concentrations. Ros (2019) describes that soil organisms and plants can produce enzymes (phosphatases and phytases) that improve solubilisation and hydrolysis of organic P components and that earthworm faeces contain both phosphatases and increased plant-available P concentrations. However, they cite one research that found lower phosphatase concentrations in earthworms faeces as compared to the soil.
Adhikary (2012) describe that vermicompost contains beneficial soil microbes (nitrogen-fixing, phosphate solubilizing bacteria, actinomycetes) and growth hormones auxins, gibberellins & cytokinins.

2.3.2 Humic acids

Aguiar et al. (2013) isolated humic acids from subsequent vermicompost maturation stages of different substrates. Humic acid content (organic residue humification) increased with maturation of the vermicompost. All isolated HAs promoted lateral root emergence of maize seedlings, acidification of the aqueous growth medium and induction of proton pumps without changes in apparent molecular weight but with increases in hydrophobic domains.
Atiyeh et al. (2002) isolated humic acids from different vermicomposts and grew tomato and cucumber seedlings with them. The growth of both crops (plant height, leaf area, shoot/root dry weight) increased with humic acids, but plant growth decreased when humic acid concentrations exceeded a certain threshold, possibly as a result of plant growth hormones adsorbed onto the humic acids.
Albanell et al. (1988) found that during vermicomposting of two substrates total humic acid concentrations increased (as did CEC and mineral nutrients) while pH, soluble salts, organic matter and N decreased. This confirmed that earthworms increase the transformation of organic substances to stable humic compounds.
Muscolo et al. (1999) isolated a humic substance of low molecular weight (HEf) from faeces of two earthworm species and concluded they had similar effects as auxin derivatives (2,4-D=2,4-dichlorophenoxyacetic acid and IAA=indole-3-acetic acid) in suspensions of *Daucus carota* (carrot) cells. The humics can influence plant growth via physiological effects and are synthesized by microorganisms (e.g. actinomycetes) in the earthworm guts.
Martinez-Balmori et al. (2014) evaluated bioactivity of isolated humic acids from different vermicomposts and found more than 200 different molecules. The humic acids had the ability to induce lateral root emergence in maize seedlings due to the strong hydrophobic character of the extracts and the preservation of altered lignin derivatives. They concluded that humics isolated from vermicompost can be used as plant growth promotors.
Canellas et al. (2015) wrote a review on humic and fulvic acids in general as biostimulants in horticulture. They compiled an extensive database on the effects of humic acids (sometimes isolated from vermicomposts) on vegetables, fruit crops and ornamental plants. They also mention that some authors have doubts on the effects of humic acids, since positive effects on plant growth can also be attributed to extra nutrients present in the extracts.
In an earlier research Canellas et al. (2002) found that humic acids isolated from vermicompost induced the proliferation of sites of lateral root emergence in maize roots (enhanced root elongation, lateral root emergence and plasma membrane H^+-ATPase activity).
Hernandez et al. (2015) isolated humic acids from vermicompost and applied them to lettuce leaves. The effects were a shortened production cycle and increased number of leaves per plant. A combination of decreased total carbohydrate content, increased total protein content in leaves, and induction of nitrate reductase and phenylalanine ammonia lyase activity seemed to have caused these effects.

Cultivations under sub optimal conditions or with low nutrient inputs might be markets for humic acids (for instance organic farmers) (Gollenbeek and van der Weide, 2020).

2.4 Other (effects on bacterial communities, pesticide degradation)

Munoz-Ucros et al. (2020) described use of vermicompost extracts for application in the rhizosphere of tomato plants. The effects of vermicompost on rhizosphere microbiome are a complex interaction of the rhizosphere medium and bacteria from the vermicompost itself and from the rhizosphere.
Sanchez-Hernandez & Domínguez (2017) describe the role of vermicompost in pesticide degradation. They produced vermicompost on spent coffee grounds and found several enzymes involved in C, N, P and S cycling: protease, urease, laccase and carboxylesterases (CbEs). The earthworms substrate influenced the enzyme levels. Results of their research suggest a bioscavenging role (bioscavengers being proteins/ enzymes that prevent intoxication by inactivating/binding toxins) of the CbEs in reaction to chlorpyrifos contamination.
Domínguez et al. (2019) describe the development of the bacterial community during vermicomposting of Scotch broom (*Cytisus scoparius*) with *Eisenia andrei*. Taxonomic diversity increased, as well as functional diversity of the community, for example concerning metabolic capacity, streptomycin and salicylic acid synthesis, and nitrification. These developments may be an explanation for the reported beneficial effects of vermicompost on plants/soils.

3 Macro composition of different vermicompost types with a short description of the effects on plants and soil

Table 2 *Macro composition of different vermicomposts and reported effects from literature. Experimental results were adopted from the references, but the experimental setups were not checked. For experimental details the original articles should thus always be consulted.*

Reference	Substrate	N_{total} g/kg DM	P g/kg DM	K g/kg DM	OM g/kg DM	C/N	pH	EC µs/cm	DM %	Effects/crop/worm species
Adhikary, 2012	Unknown	15-22	18-22	10-15		20.9	8.09 ± 0.09	180 ± 20	46.5 ± 0.3	e.g. *L. terrestris* and *Dendrobaena veneta*
Afriyie et al., 2013	Dry fermented digestate from domestic municipal organic waste	19.3	0.5	1.3	444	13.3	8.0			VC led to soil improvement in terms of soil N, K and CEC, compared to other fertilizers
Aguiar et al., 2013	Cattle manure, sugar cane bagasse, sunflower cake					12-16				*Eisenia fetida,* humic acids from VC led to improved plant characteristics of maize seedlings
Albanell et al., 1988	Sheep manure alone and mixed with flock cotton residues	17.1-17.6	43.1-43.7	9.6-10.2	401-470	8.9-9.1	7.2-7.7	800-1110	43.7-50.5	*Eisenia fetida.* VC had higher nutritional values and humification degree, thus good agronomic qualities
Allardice et al., 2015	Chicken manure	11	9.5	1.5			6.5			*Eisenia fetida, Lupinus angustifolius*. Increased biomass production after addition of VC with rhizobia and stimulation of bacterial N fixation as well as nematode numbers and diversity. Effects changed with concentration
Aremu et al., 2015	Garden-waste (for example, vegetables)	22.6	9.9	6.4			7.8			*Eisenia fetida* VC extracts contained a rich diversity of plant growth hormones and phytochemicals
Atiyeh et al., 1999	Pig manure	23.6	45	4		12	5.3	11800		Tomato plants. Plant growth was promoted with vermicompost in terms of plant height and root/shoot biomass for example
Atiyeh et al., 2002	Separated pig solids or food (fruit and vegetable) waste									Tomato and cucumber plants. *Eisenia fetida.* Humic acids from two types of vermicompost increased the growth of the plants significantly, in terms of plant height, leaf area, shoot and root dry weight, with a maximum response at certain concentrations

Ávila-Juárez et al., 2015	Mushroom waste (based on barley stubble, corn, and organic peat), leaf-cutting ant waste and cow compost	1.5-1.9	0.5-2.8	7.4-16.0	473-513	14.4-20	6.3-7.3	3500-7900	40.6-88.6	Tomato (*Solanum lycopersicum* cv. Rafaello). *Eisenia fetida.* All VC extracts had a positive effect on the production of lycopene and decreased the presence of ions phytotoxic to plants and improved soil structure but had no effect on the physiological variables
Basco et al., 2017										Tomato. VC biofortified with selected biological control agents (BCAs) i.e. *Trichoderma harzianum*, *Pseudomonas fluorescens* and *Bacillus subtilis.* VC application led to reduction of disease incidence, enhancement in plant growth/ yield and stimulation of antioxidants
Busato et al., 2012	Composted cattle manure and sunflower cake after oil extraction at a 3:1 ratio (w:w) with extra bacteria	22-24	~11			~13	6.6-6.8			*Eisenia fetida*. Addition of extra bacteria led to increased N and P components concentrations and higher acid phosphatase activity
Busato et al., 2016	Sugar cane filter cake and cattle manure	9.3-30.6				~10-11	6.0-6.2			*Eisenia fetida.* Phosphatase activities correlated positively with TOC, pH and water-solube P and negatively with humic acid content in two vermicomposts.
Campos-Mota and Blok, 2008	Paper mill sludge and vegetable wastes, mainly apple waste and pulps from vegetable juice production		0.06-0.87 mmol	2.2-11.2 mmol	470-750		6.9-7.2	600-3700		VC can be useful as a component in potting media by adding nutrients and microbial activity
Canellas et al., 2002	Plant residues from *Panicum maximun* Jacq. and cattle manure 5:1 (v/v)	13.3				10	6.2			*Eisenia fetida.* Maize (*Zea mays*) seedlings. Humic acids from VC enhanced root growth in conjunction with a marked proliferation of sites of lateral root emergence and stimulated plasma membrane H^+-ATPase activity
Carricondo-Martínez et al., 2022	Tomato crop vegetal residue	13.5			302		8.3	3390		Tomato. In most treatments with VC the yield was comparable to that with mineral fertilizers but there was no clear correlation with sap analysis. VC also led to higher microorganism presence in the soil
Das et al., 2022	Cow manure	18.6	15.4	17.8	591	18.5	7.1		96.5	*Eisenia fetida.* Indian spinach (*Basella alba* L.). VC had marked impacts on plant growth and shoot N, P, and K contents up to the third plant cycle

Das & Deka, 2021	Potato plant biomass, cow dung	15.7-18.2	7.4-8.4	0.26-0.28	108-147	~6-10	6.6-6.9	3100-3300		*Eisenia fetida*. VC products are enriched with plant available macro and micronutrients. Neutral pH and C/N ratios are beneficial for horticultural purposes
Domínguez et al., 2018	Scotch broom	36.4	3.1	6.0	795	12.9	6.6	200	18.4	*Eisenia andrei.* VC contained high nutrient concentrations and toxic plant components had been significantly degraded
Ducasse et al., 2022	Biodegradable urban organic waste	15.4 ± 6.5	5.6 ± 3.7	12.6 ± 8		15.05 ± 5.46	7.59 ± 0.71			A comparison with regular compost from the same types of waste suggested that VC is slightly more suitable for crop production with significantly lower C/N and pH and higher N and P. VC was found to have a better effect on plant growth than compost
Dume et al., 2022	Hydrolysed chicken feather residue and dried pelletized wheat straw	~3.8-5.0	2.0-3.0	14.5-19.8		~5.8-6.0	4.1-4.5	3000-4400		*Eisenia andrei.* Acid phosphatase, arylsulphatase, alanine aminopeptidase and leucine aminopeptidase were more active in the treatments with earthworms and positively correlated with P and C/N ratio
Esteves et al., 2020	Cattle manure	14	28	15		15	8.6		88.6	Maize (*Zea mays* L.), millet (*Pennisetum glaucum* L.) and sorghum (*Sorghum bicolor*). VC improved plant growth in pots containing iron mine tailings. This was probably due to the growth of thick plant roots
Flores-Solórzano et al., 2022	Press palm fiber, coffee pulp and food waste	35.4			815	13		770		*Eisenia fetida,* tomato seeds (*Solanum lycopersicum* L.). Composting worked better than vermicomposting for tomato seed germination
García et al., 2016	Cattle manure									Humic acids from VC slightly increased the ROS (reactive oxygen species) production in roots, the induction of genes responsive to the redox regulatory metabolism and the activity of the primary antioxidant enzyme involved in the regulation and modulation of ROS metabolism
Gómez-Brandón et al., 2021	White grape marc (*Vitis vinifera* L. cv. Albari˜no) and red grape marc (*Vitis vinifera* L. cv. Mencía)	5.5-8.9	0.8-1.4	4.4-6.5 g	896-921	26.4-28.5	7.6-8.5	224-365	27-30	*Eisenia andrei*. VC from two types of grape wastes had optimum levels of moisture, pH and EC for application in soil
Gong et al., 2019	Garden wastes mixed with cattle manure and/or spent mushroom substrate (SMS)	17.3-32.3	4.2-9.7	6.8-16.5			7.6-8.1	2510-3850		*Eisenia fetida.* Seed germination index (GI) of Chinese cabbage (*Brassica parachinensis*) and tomato (*Lycopersicon esculentum* L.). Heavy metal concentrations were increased in the final vermicomposts compared to the initial materials, but none of them exceeded the permissible limits. The substrate combinations of the different VC types influenced the germination indexes

Kalantari et al., 2011	Farmyard manure	35	7.1	1.0		5.5	7.7	6880		Corn. VC was suitable as pot mixture at a mixing rate of 3 % and performed better than compost
Koskey et al., 2022	Wheat straw (20%) and horse manure (80%)	0.09-0.1					5-6	2600-3100	0.4-0.5 (liquid extract)	*Eisenia fetida* and *Eisenia andrei.* Berseem clover, lentil, and sunflower. Liquid VC had diverse groups of bacteria and a few fungal taxa and enhanced mycorrhizal properties and selected growth- and yield-related variables in in the tested crops
Lloyd et al., 2016	85–90% dairy manure and 10–15% rice hulls, composted	24				17				Strawberries. Microbial activity was high in VC, and fungi and bacteria were abundant, but little stimulation of the microbial community was evident in VC amended soil, possibly due to its local application
Majlessi et al., 2012	Restaurant food waste	11				14.3	7.5	4900		*Eisenia fetida.* Cress. From the germination index (GI) it was concluded that VC was moderate phytotoxic which seemed to be related to EC values. However, the C/N value showed that the vermicompost was stable
Martinez-Balmori et al., 2014	Cattle manure, sugar cane bagasse, sunflower cake from seed oil extraction, or filter cake from a sugar cane factory									*Eisenia fetida.* Maize seedlings. Humic substances from different VCs retained a chemical composition strongly related to the composition of the substrates. The large hydrophobic character of humic extracts and the preservation of altered lignin derivatives conferred to humic acids the ability to induce lateral root emergence in maize seedlings
Rehman et al., 2022	Leaves of *Conocarpus erectus* and farmyard manure	15.6-18.6	0.6-1.5	2.9-4.1		9-14.9	6.5-6.7	6300-7500		*Eisenia fetida.* Mung beans *(Vigna radiata* L*)*. Toxic components in *C. erectus* leaves were reduced by vermicomposting and the VC was beneficial for growth and yield parameters of the crop
Ruangjanda et al., 2022	*Azolla microphylla* (Azolla) biomass, eggshells, fruit peels, cassava pulp, spent mushroom substrate	5.8-9.3	5.7-11.3	3.5-6.2		8.5-19.7	8.6-9.4	495-1161		*Eudrilus eugenia*
Sanchez-Hernandez & Domínguez, 2017	Spent coffee grounds	45.4±2.8	3.01±0.32	6.52±0.37	944±113	10.3±0.46	6.94±0.06	118±7.5	21.3±1.13	*Eisenia andrei*
Schröder et al., 2021	Canteen kitchen waste (mainly coffee and fruit) with coir/coconut fiber or paperboard and soil	10.3-16.2	1.0-1.7	6.3-14.7	420-813	21.9-26.9	6.1-7.2	276-773	26.3-44.7	Lettuce (*Lactuca sativa* var. capitata), *Eisenia fetida.* The lettuce yield and total uptake of P, K, Ca, and Mg were highest in plants grown in VC. All composts required additional N for lettuce growth

Tesfamichael & Stoknes, 2017	Dewatered food waste digestate				733		7.4	1900	57.7	*Eisenia fetida* and *Eisenia andrei*. Lettuce and head cabbage plants. Reducing the proportion of peat in a potting medium to 25 % by substituting it with VC was feasible. The VC was stable, grain structured, very high in nitrate and comparatively lower in soluble phosphate
Uzinger et al., 2021	Digested municipal sewage sludge	31.3	24.1	1.7		7			34.8	Perennial ryegrass (*Lolium perenne*). *Eisenia fetida.* The agronomic efficiencies of compost and VC from digested sewage sludge were lower than that of the substrate. In the short term, the substrate proved to be the best fertiliser, while compost made from it was the best for organic matter replenishment. The efficiency of the compost was the same as that of the VC
Wako & Muleta, 2023	Different plants with cow dung	15-18	13-16	8-158		14.1-19.5				Tomato (*Solanum lycopersicum* L.).
Wang et al., 2021	Dairy manure	9.7	45.2	7.6	299		7.1	157		Cucumber (*Cucumis sativus* L.). *Pheretima* earthworms. Single and combined application of biochar and vermicompost generally improved soil properties and increased crop yield and quality. The treatment also significantly improved the fruit quality
Wu et al., 2013	Cattle dung	15.6	14.8	28.8	389				52.2	*Eisenia fetida. Lolium perenne* L. or *Medicago sativa* L. Compared with chemical fertilizer, VC led to higher levels of soil microbial biomass, nematode abundance, and mite abundance in saline alkali soils. This could be attributed to the increased level of soil organic matter, although no significant effect was observed on plant cultivation
Xue et al., 2022	Septic tank waste or dairy shed solids (mainly cow manure) with horticultural factory wastes (tomato prunings and palm fibre as bulking agents)	16-20	3.4-3.6			16.8-19.9	5.2-6.7	8000-9400		*Eisenia fetida* One exotic tree species (radiata pine, *Pinus radiata* D. Don) and two native tree species (mānuka, *Leptospermum scoparium* and tōtara, *Podocarpus totara*). VC significantly improved soil chemical properties and enzymatic activities, increased total seedling dry weight and shoot concentrations of N and P. VCs were comparable to chemical fertilizers for growth of the native species. Increased growth was mainly related to improved N and P nutrition associated with enhanced root growth and soil enzymatic activities
Yadav et al., 2014	Cow dung	8.2-14.7	1.2-2.8	2.4-4.9		9.4-13.1				*Lumbricus castaneus*, *Aporrectodea caliginosa*, *Eisenia fetida* and *Aporrectodea longa* and mixes
Yang et al., 2015	Dairy manure	15.7	9.9	5.2	553	10.9	7.8	500	88.7	Biochar was made from VC

Yatoo et al., 2022	Macrophytes (floating, i.e., A*zolla*, *Lemna*, and *Salvinia*), cow manure. Banana peel, bone meal, eggshell, and tea waste	23.1-28.7	7.3-8.6	31.3-37.4		12.9-17.1	7.7-8.0	3400-3900		*Eisenia fetida.* Fenugreek seeds (Methi). Seed germination index was high with all three VC types

4 Conclusions and recommendations

There is ample literature on the composition of different vermicomposts and their effects on plant growth/health and soil health. For scientific details on the researches presented in this overview, the original articles should be consulted. Vermicomposting increases the breakdown of organic matter and increases plant-available nutrient concentrations (N, P, K). Vermicomposting increases stable humic and fulvic acids content. Vermicompost composition is highly variable and dependent on substrate type and can thus not easily be compared to other composts or different animal manures. Several components of interest for plant growth and health in vermicomposts are humic acids, plant hormones, enzymes (e.g. for solubilizing P) and beneficial soil microbes. Some authors report beneficial effects of VC against fungal pathogens and nematodes, but also sometimes adverse effects, such as an increase in aphids. In general, many references report plant growth promoting effects of vermicomposts. Also, some authors mention that vermicompost can partially replace peat or function as a main ingredient of growing media.
Vermicomposts from organic waste streams have potential as an organic fertilizer for several agricultural applications and this application increases circularity in the agrifood sector.

For further integration/comparison of research details it is recommended to work with standard vermicompost parameters, i.e. through a set of clear units based on dry matter content. Care should be taken not to confuse the effects of different vermicompost compounds, for example nutrients and plant growth hormones. Also pre- or posttreatment (e.g. pre-composting, air drying) steps for vermicomposts should be mentioned clearly.

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