© by PSP Volume 32– No. 02/2023 pages 831-840 Fresenius Environmental Bulletin

EFFECT OF VERMICOMPOST AND *Lumbricus Terrestris* ON SOIL PARAMETERS AND MAIZE GROWTH

Jakub Neupauer[1,*], Peter Kovacik[1], Jan Gazo[1], Sylwester Smolen[2]

[1]Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 01 Nitra, Slovakia
[2]University of Agriculture in Krakow, Al. Mickiewicza 21, 31-120 Kraków, Poland

ABSTRACT

There is a great deal of research showing the effect of earthworms and vermicompost on soil parameters and phytomass production of cultivated crops. However, the specific effects of *Lumbricus terrestris* on soil properties under different soil conditions are unknown. The aim of this work was to investigate A) the effect of soil and soil mixed with vermicompost in ratios 9:1 and 4:1; B) the effect of earthworms (*Lumbricus terrestris* L.) on physico-chemical parameters of substrates and total above-ground biomass of maize (*Zea mays* L.).The pot experiment was located in a vegetation cage on the campus of the Slovak University of Agriculture in Nitra (Slovak Republic). 12 individuals of *Lumbricus terrestris* were added to the prepared substrates. Soil samples were taken at the end of the vegetation period. Three sample were done during the vegetation period to detect maize growth.

The highest vermicompost content was shown to increase the available phosphorus, potassium and sulphur content and increase the substrate's electrical conductivity. We also saw an increase on pH, total sorption capacity and a decrease in calcium content in comparison with pure soil. In terms of physical properties, a significant decrease in bulk density and increase in porosity was observed with a 20% vermicompost content. Earthworm activity increased content of the available phosphorus, potassium and calcium, but decreased the total sorption capacity and electrical conductivity of substrates. Earthworms were shown to increase porosity and actual air content in the control variant. Increasing vermicompost content caused an increase in total biomass due to the increasing content of available nutrients in the vermicompost. Based on the obtained results, there is a suggestion that a combination of vermicompost and earthworms improves soil properties and promotes plant growth. This finding supports the importance of soil macro fauna and organic matter in agricultural soils.

KEYWORDS:
Earthworm, nutrients, phytomass, slime, soil, physical properties

INTRODUCTION

Waste management is considered an integral part within a sustainable society, but this requires the diversion of biodegradable parts of municipal waste from landfills to alternative processes for their recycling, such as vermicomposting [1]. Vermicomposting is a combined process of conversion of plant residues by the action of earthworms and microorganisms [2]. The beginning of the process is characterised by high earthworm activity. The ingestion and fragmentation of organic substrate by earthworms occurs, which is associated with a reduction in the volume of organic material [3]. In the process, the total number of bacteria and their species diversity increases, with an increase in the number of bacteria capable of fixing nitrogen and suppressing plant diseases [4]. In the vermicompost maturation phase, microorganisms play a dominant role as they continue to transform organic matter digested by earthworms [5]. Vermicomposting increases the content of total nitrogen, phosphorus, and potassium in the final product [6]. However, the relative abundance of heavy metals such as iron, manganese, zinc, copper, chromium and nickel also increases [7].

The product obtained in the vermicomposting process is called vermicompost. Its effect on soil and crops has been addressed by several authors [8-9]. Vermicompost increases stem and root length, number and length of leaves [10], dry weight of plants, roots and leaves [11], increases total fruit yield and average fruit weight [12]. Vermicompost also has an effect on increasing the chlorophyll content [13] thereby increasing the rate of net photosynthesis [12]. In medicinal plants, it increases the number of flowers and the essential oil content [14]. In addition, vermicompost also increases the soluble sugars and vitamin C content and improves enzyme activity [12], but it may have a negative effect on increasing nitrate content in vegetables [13].

The product obtained after vermicomposting has a positive effect on the soil's physical parameters such as aeration and soil porosity [15]. Vermicompost affects the degree of soil aggregation and reduces bulk density [16]. Among the agrochemical properties, it increases the content of nitrogen, phosphorus (P_2O_5), potassium (K_2O), soil carbon [17], calcium, zinc, and manganese [18]. It also has beneficial effects on soil microbial and enzymatic activity, cation sorption capacity [12] and soil oxidation potential [16].

The earthworm (*Lumbricus terrestris* L.) is a native species in western Europe but is now found across the globe. It is an anecdotal species [19] and can form long vertical tunnels up to 3 m deep [20]. Earthworms feed on organic material from the soil surface, which they retract into their tunnels and consume only at various stages of decomposition. They coat withdrawn food with secretions that contain bacteria that aid the food's better decomposition [20]. Earthworms have been shown to have a positive effect on the increase of available nutrients in the soil [21], influence the change of pH [22] or the overall soil's sorption capacity [23]. They mainly affect porosity within the soil's physical properties [24], which in turn affects the soil's hydrophysical properties [25]. Earthworm activity promotes plant photosynthesis [26] and increases chlorophyll and carotenoid content [27]. All the above-mentioned positive properties regarding earthworms affect higher total biomass of the grown crops [28]. Nowadays, the important role of slime producing earthworms is increasingly discussed. The slime influences the soil's agrochemical, microbiological and phytophysical properties [29].

MATERIALS AND METHODS

The pot experiment was carried out in a vegetation cage on the Slovak University of Agriculture campus in Nitra (Slovak Republic). The vegetation cage consisted of a metal structure to protect the experiment from birds.

The experiment evaluated the effect of two factors: a) content of vermicompost, b) the presence of earthworms (*Lumbricus terrestris* L.) on the soil's physical and agrochemical parameters, and total phytomass yield of maize. There was a total number of six treatments. The experiment variants are shown in Table 1. Medium heavy soil of chernozem type (Haplic Chernozems) was obtained from the Dolné Krškany (Slovak Republic) site from a 0.00 - 0.30 m soil layer, which was homogenised and sieved through a size sieve 3x3 cm. The vermicompost was obtained from VermiVital Záhorce s.r.o. Earthworms were hand collected from agricultural land and followed by species identification. Soil and vermicompost were analysed for basic agrochemical parameters before establishing the experiment (Table 2).

The experiment was performed using the randomised block method in 3 repetitions. Before filling the containers with soil and vermicompost, a net was placed underneath each container to prevent the earthworms escaping. The containers were a cylindrical shape with a 35 cm diameter and a height of 35 cm. On March 20th, the soil and vermicompost were mixed according to Table 1 to produce soil substrates. Subsequently, 12 pieces of *Lumbricus terrestris* were added to treatments 2, 4 and 6. The average weight of earthworms was 6.1 grams. The containers, together with the substrate and earthworms, were placed on saucers that could hold 1000 ml of the escaped soil solution, which was returned to the containers when required.

TABLE 1
Variants of experiment

Variant	Substrate	*Lumbricus terrestris*	Mark
1	Soil 20 kg	0 pcs	S
2		12 pcs	S+EW
3	soil 18 kg + 2 kg vermicompost (10% VC)	0 pcs	S+VC10
4		12 pcs	S+VC10+EW
5	soil 16 kg + 4 kg vermicompost (20% VC)	0 pcs	S+VC20
6		12 pcs	S+VC20+EW

EW – earthworm, VC – vermicompost, S – soil

TABLE 2
Agrochemical properties of the soil and vermicompost used in the experiment

Substrate		N_{an}	P	K	Ca	S	CEC	EC	pH_{KCl}	C_{ox}
Description	Mark	mg.kg^{-1}					mmol. kg^{-1}	µS		%
Soil	S	10.5	7	185	8,150	2.5	496.4	0.14	6.8	1.2
Vermicompost	Vc	974.5	5,150	27,250	6,975	1,250	208.6	10.4	7.6	24.5

CEC – Cation exchange capacity, EC – electrical conductivity

The model crop was maize (*Zea mays* L.) variety P9241 from Pioneer. Sowing was carried out on April 27th to a depth of 3 cm and the substrate was subsequently irrigated at 75% field water capacity. During vegetation, the pots were irrigated with irrigation water, with negligible nutrient content. One week after emergence, the number of germinated plants was standardized to the same number in all pots (6 individuals per pot). At the first sampling (June 7th, 2021) 2 individual plants were analysed. At the second sampling (July 6th, 2021) one individual was taken from each container. The harvest took place on September 9th, 2021 and 3 individuals were measured.

Analysis of the weight of aboveground phytomass. The weight of plants in fresh and dried condition was measured on a total of 3 occasions according to the growth phase: BBCH 14-15 (June 7th, 2021), BBCH 31-32 (July 6th, 2021) and at technical maturity, at growth stage BBCH 89 (September 9th, 2021). After sampling, the plants were taken to the laboratory where they were weighed for fresh weight. They were then placed in a drying oven at 105°C and dried to a constant weight. After drying, the plants were weighed.

Soil properties analysis. A soil substrates analysis for physical properties was carried out after harvesting the crop, using a ring kit. According to the methodological procedures presented by [30], the substrate's following physical parameters were determined: bulk density ($g.cm^3$), porosity, instantaneous soil moisture and instantaneous air content (%). Soil samples for agrochemical analysis were collected from the entire soil profile using a soil auger. The following analytical methods were used to analyse individual parameters: N-NH4+ colourimetrically using Nessler's agent, N-NO3- colourimetrically using phenol 2,4-disulfonic acid. Inorganic nitrogen (Nan) was calculated as the sum of $N\text{-}NH_4^+$ + $N\text{-}NO_3^-$ (Nan = $N\text{-}NH_4^+ + NO_3^-$). The contents of accessible P, K, and Ca were determined after substrate extraction in Mehlich III solution, with P detected colourimetrically, K on a flame spectrometer, and Ca spectrophotometri-cally [31], sulphur spectrophotometrically; Cox spectrophotometrically after oxidation [32], and pH potentiometrically [33]. Total sorption capacity T=H+S; H - hydrolytic acidity was determined titrationally with 0.1 M NaOH [33] and sum of exchangeable base cations (S) - titrationally in 0.1 M HCl according to the methodology of [34]. The electrical conductivity value was determined using a conductivity meter.

Statistical processing. The results obtained were statistically processed by single and multivariate analysis of variance methods. The differences between the variants were assessed using the LSD test at a 0.05 level of significance. Statistical processing of single and multifactorial analysis of variance was performed using Statgraphic ver. 5.1. Soil properties were assessed by the method of principal component analysis in Statistica ver. 10.

RESULTS AND DISCUSSION

Effect of variants on agrochemical properties of substrates. The application of vermicompost resulted in an increase in the available forms of phosphorus, potassium and sulphur in the substrates (Table 3), which correlates with the findings of [6] and [35]. We did not find a statistically significant effect of addition of 10% vermicompost on available calcium and sulphur contents. The overall higher nutrient availability is related to decomposition of organic matter, reduction in its volume and mineralisation of nutrients [36]. The joint action of earthworms and microorganisms in the vermicomposting process, especially the genus *Glomeromycota*, can release protons to mobilise insoluble soil phosphate [37] and phosphatase enzymes. This leads to the solubilisation of organically phosphorus to its accessible forms [6].

In our study, we used vermicompost with alkaline pH, which also had an effect on the change in pH at the end of the growing season (Table 3). In the process for decomposition of organic matter, the increase in pH value can be caused by alkaline humates [17], precipitation of calcium carbonate [38] and formation and accumulation of ammonia (NH_3) [39]. Naturally, as the substrate's calcium content increases, the soil's pH also increases. Increased pH also had a direct effect on increasing the electrical conductivity value, which correlates with the findings of [38].

The highest CEC and EC values were significantly increased in the soil with the highest vermicompost ratio of 20% (Table 3), which correlates with the findings [16]. CEC values are commonly used as an indicator of compost maturity and nutrient retention capacity [38]. Organic fertilisers increase the electrical conductivity in the soil due to higher stability of vermicompost particles [8] by the formation of salts, ammonium and inorganic ions that occur in the degradation process of raw materials [6]. Electrical conductivity was shown to increase with increasing soil water content, which correlates with the findings of [40]. Plants take nutrients from the soil solution and therefore, any substance that increases the soil's water retention capacity helps to take nutrients from the soil [41].

TABLE 3
Influence of factors on agrochemical parameters of soil substrates

Factor		pH	P	K	Ca	S	CEC	EC
			mg.kg^{-1}				mmol.kg^{-1}	µS
Vermi-compost	0%	6.71^{a} (0.20)	8.5^{a} (1.7)	171.6^{a} (7.0)	6,725.0^{b} (64.5)	2.5^{a} (0.4)	495.7^{a} (8.4)	168.7^{a} (3.1)
	10%	7.02^{b} (0.02)	158.1^{b} (29.9)	652.8^{b} (44.4)	6,512.5^{ab} (275.0)	10.6^{a} (3.8)	505.5^{b} (3.8)	232.0^{b} (4.1)
	20%	7.07^{b} (0.04)	367.5^{c} (24.7)	1,460.9^{c} (96.1)	6,350.0^{a} (177.9)	32.5^{b} (10.3)	507.5^{b} (5.4)	303.2^{c} (5.4)
	$LSD_{0.05}$	0.15	27.6	64.8	230.0	8.8	4.068	4.73
Lumbricus terrestris	without	6.86^{a} (0.25)	164.4^{a} (156.5)	719.8^{a} (549.0)	6,408.3^{a} (249.8)	12.0^{a} (10.9)	507.8^{b} (4.6)	237.5^{b} (61.8)
	with	7.00^{b} (0.11)	191.7^{b} (167.3)	803.7^{b} (616.6)	6,650.0^{b} (161.2)	18.4^{a} (17.7)	497.9^{a} (7.2)	231.8^{a} (58.6)
	$LSD_{0.05}$	0.12	22.6	52.9	187.8	7.2	3.3	3.87

CEC – Cation exchange capacity, EC – electrical conductivity. Different letters describe statistically significant differences between treatments, p <0.05. Standards deviations are in the parenthesis.

In our experiment, earthworms significantly increased the available nutrient content more in the vermicompost treatments than in the control. Earthworms increased the K content in unfertilised variant by 0.7%, calcium by 0.7% and sulphur by 21%, while they increased K, Ca and S contents by 12%, 4% and 60%, respectively, in the highest vermicompost treatments (Table 4). This was probably due to the low food supply for earthworms in the unfertilised variant [21] and the increased burial of organic matter in their burrows in the variants with vermicompost addition [28]. The increase in the content of accessible forms of nutrients by earthworms is also due to microbial communities inside the earthworm gut.

These decompose organic matter inside the earthworm gut by hydrolysis [38]. Earthworms, through their excretions, supply the soil with bacterial species found only in their guts [42] and promote the mineralisation of organic matter [38]. Through their activity, they alter the soil's biological activity, providing nitrogenous leachates, enzymes, slime and body fluids, thereby increasing the soil's available nitrogen and phosphorus content [39].

Earthworms were shown to increase soil pH in the control without vermicompost and with content of vermicompost 20%. Earthworms release acceptable potassium from silicate minerals [43] and increase the Ca^{2+} and Mg^{2+} content thereby displacing other cations from the soil colloidal complex, which may affect the change in soil pH [22]. [44] reports that epidermal mucus produced by earthworms on their body surface may also cause pH change.

Earthworms can increase soluble salts because they increase the number of soluble cations and anions in their excretions [38]. In our experiment was observed a negative effect on electrical conductivity in substrates (Table 3). The decrease in electrical conductivity by earthworms was caused by increased substrate permeability due to the formation of worm tracks by earthworms and subsequent loss

TABLE 4
Influence of variants on agrochemical parameters of soil substrates

Variant		pH	P	K	Ca	S	CEC	EC
substrate	earthworms		mg.kg^{-1}				mmol.kg^{-1}	µS
soil	0	6.54^{a} (0.01)	7.0^{a} (0.0)	165.7^{a} (2.1)	6,700^{b} (70.7)	2.3^{a} (0.0)	502.8^{b} (3.6)	169.5^{a} (4.0)
	12	6.58^{b} (0.04)	10.0^{a} (0.0)	177.5^{a} (1.8)	6,750^{b} (70.7)	2.8^{a} (0.4)	488.7^{a} (0.1)	167.9^{a} (3.1)
soil + 10% VC	0	7.01^{c} (0.03)	133.8^{b} (1.8)	614.5^{b} (4.7)	6,300^{a} (212.1)	8.8^{a} (5.4)	508.6^{c} (1.1)	235.5^{c} (0.7)
	12	7.02^{c} (0.00)	182.5^{c} (17.7)	691.1^{c} (1.7)	6,725^{a} (35.3)	12.5^{a} (0.0)	502.3^{b} (1.9)	228.5^{b} (0.7)
soil + 20% VC	0	7.04^{c} (0.03)	352.5^{d} (17.7)	1,379.3^{d} (30.7)	6,225^{b} (35.5)	25.0^{b} (3.5)	512.1^{c} (1.0)	307.45^{e} (3.6)
	12	7.11^{d} (0.02)	382.5^{d} (24.7)	1,542.5^{e} (11.6)	6,475^{ab} (176.8)	40.0^{c} (8.8)	502.8^{b} (0.1)	298.85^{d} (0.2)
	$LSD_{0.05}$	0.06	35.2	33.3	297.6	10.9	4.3	6.4

CEC – Cation exchange capacity, EC – electrical conductivity. Different letters describe statistically significant differences between treatments, p <0.05. Standards deviations are in the parenthesis.

of leachate, which may contain inorganic ions [42]. Earthworm application also caused a statistically demonstrable reduction in CEC in each fertilisation variant (Table 4), which correlates with the findings of [23].

Effect of variants on a substrate's physical properties. The use of vermicompost decreased bulk density and increased porosity, instantaneous moisture content and instantaneous air content, however, statistical significance was observed between the variants without vermicompost and with 20% vermicompost content. The 10% VC volume showed no statistically significant difference between the variant without fertilisation but also with higher vermicompost content, except for porosity (Table 5). The bulk density decreased with increasing vermicompost content, which correlates with the findings of [45]. [46] indicated that vermicompost increase water retention capacity more significantly than conventional compost, thereby improving the efficiency of water and nutrient use by plants. The substrate's increased water content is also due to the higher organic matter content, which contains micropores [25]. Increased porosity may be due to aggregation of soil particles by the action of microorganisms in the vermicompost, producing polysaccharides that help to aggregate soil particles [16]. Increased porosity is also influenced by the pore size range, with an increase in the number of pores in the size range of 30-50 µm and 50-500 µm, while decreasing the number of pores that are larger than 500 µm [47].

Earthworms had no statistically significant effect on a substrate's physical parameters. There was a slight decrease in bulk density of soils, and an increase in porosity, moisture content of substrates and instantaneous air content. However, statistical significance was not demonstrated among the studied parameters (Table 5).

The results show different behaviour by earthworms in substrates with pure soil (var. S) and with addition vermicompost on a substrate's physical parameters (var. S+VC10 and S+VC20) (Table 6). Earthworm activity in the variant without vermicompost reduced the bulk density and instantaneous moisture content of the substrates. Organic fertiliser in combination with earthworms caused a slight increase in bulk density and instantaneous moisture content, but a decrease in the substrate's porosity and instantaneous air content (Table 6). The slight decrease in porosity in the variants with the addition of vermicompost may be due to earthworm movement [24].

Earthworms increased the substrate's total porosity without vermicompost. Earthworms create burrows by ingesting and removing soil mainly in compacted soils, with drier soils allowing them to create longer burrows with higher macropore contents that do not bind water [48], but these pores are important in gas exchange [49].

The slime produced by earthworms also has a great influence on the soil's hydrophysical and agrochemical properties. Slime facilitates their movement in the soil and protects them from being enveloped by soil particles [29], while attaching to burrows of earthworms [49]. The earthworm has been shown to develop a system of permanent tunnels, with a layer of slime sticking to the burrow walls at each passage [50]. These slime-lined corridors contribute to increased water infiltration from the soil and preferential waterflow to deeper parts of the soil [51] as water preferentially flows through the large openings created by earthworms [25].

The increased soil moisture and reduced air content in the organic fertiliser treatments may be explained by the higher water retention capacity of earthworm slime, which also creates suitable terms for microorganisms [52]. Consumption and the mixing of organic matter by earthworms in variants with vermicompost lead to the formation of more hydrophilic coatings on inorganic soil components [25]. Different earthworm species have different behaviour on soil physical parameters. The activity of the earthworm *M. posthuma* can lead to a reduction in porosity because it produces low-stability water-resistant exudate [21]. The *P. corethrurus* species produces exudates that coalesce and clog most pores near the soil surface [53].

TABLE 5
Influence of factors on physic parameters of soil substrates

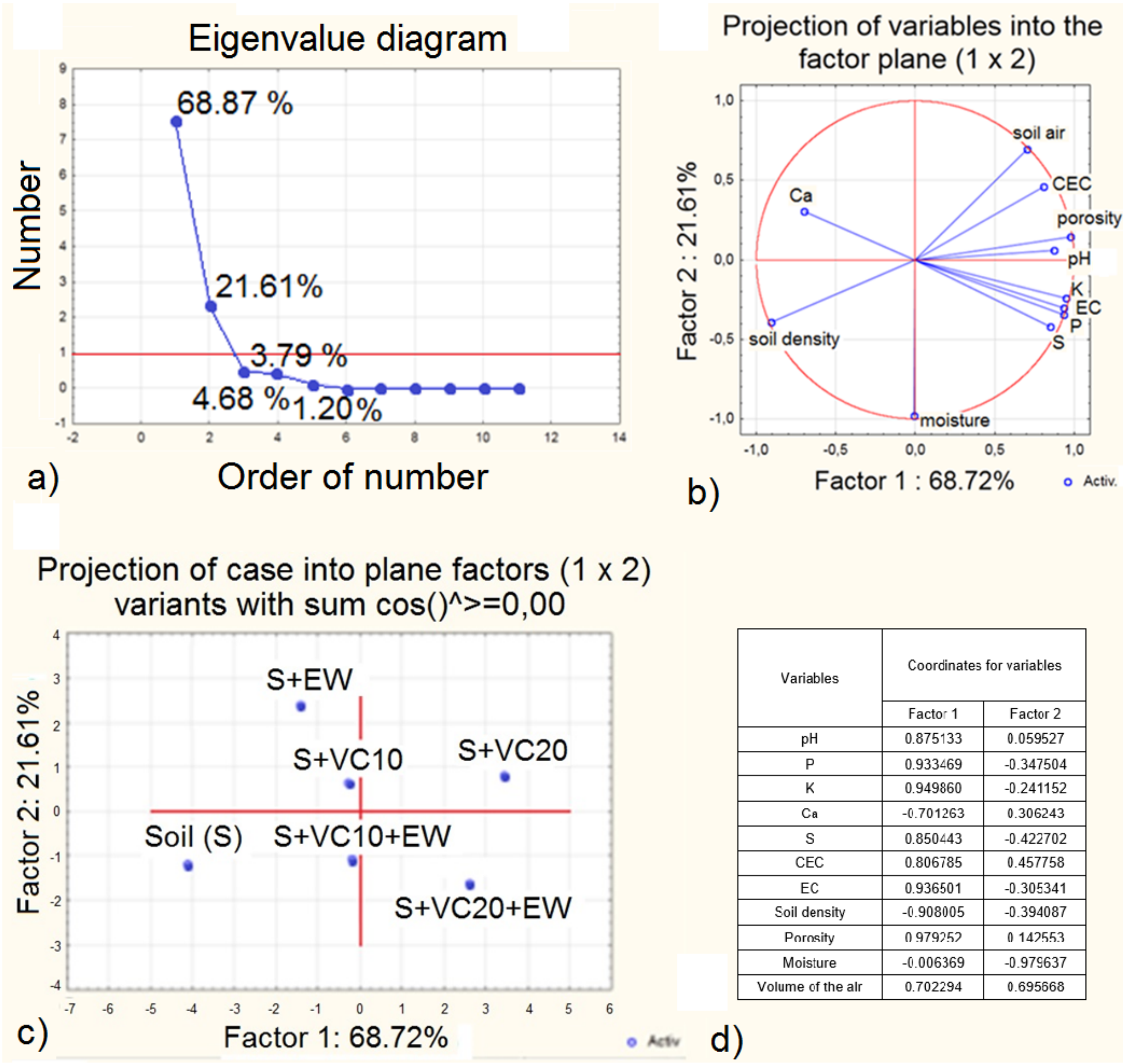
Factor		Bulk density (g.cm^3)	Porosity	Moisture	Volume of the air
				%	
Vermi-compost	0%	1.60^b (0.14)	50.6^a (3.7)	35.8^a (5.0)	14.8^a (8.7)
	10%	1.56^{ab} (0.4)	53.5^a (1.0)	38.7^a (2.8)	14.8^a (3.4)
	20%	1.40^a (0.6)	59.3^b (1.6)	38.2^a (7.0)	21.1^a (6.4)
	$LSD_{0.05}$	0.15	3.88	9.08	11.2
Lumbricus terrestris	0 ks	1.54^a (0.16)	53.7^a (5.6)	37.1^a (5.3)	16.6^a (8.7)
	12 ks	1.50^a (0.07)	55.2^a (3.0)	38.0^a (5.0)	17.2^a (4.6)
	$LSD_{0.05}$	0.13	3.17	7.4	9.18

Different letters describe statistically significant differences between treatments, p <0.05. Standards deviations are in the parenthesis.

TABLE 6
Influence of variants on physic parameters of soil substrates

Variant		Bulk density	Porosity	Moisture	Volume of the air
substrate	Earthworms	(g.cm^3)		%	
Soil	0	1.72^c (0.03)	47.50^a (0.4)	39.68^a (2.1)	7.82^a (2.5)
	12	1.49^{bc} (0.08)	53.76^b (1.4)	31.87^a (3.1)	21.87^{bc} (4.6)
Soil + 10% VC	0	1.54^{bc} (0.05)	53.95^b (0.6)	37.05^a (3.4)	16.90^{abc} (4.0)
	12	1.58^c (0.02)	53.00^b (1.4)	40.40^a (1.0)	12.61^{ab} (0.4)
Soil + 20% VC	0	1.36^a (0.04)	59.72^c (2.4)	34.61^a (10.0)	25.11^c (7.6)
	12	1.45^{ab} (0.01)	58.85^c (0.7)	41.71^a (0.5)	17.14^{abc} (0.2)
	$LSD_{0.05}$	0.11	3.3	11.3	10.1

Different letters describe statistically significant differences between treatments, $p < 0.05$. Standards deviations are in the parenthesis.



Variables	Coordinates for variables	
	Factor 1	Factor 2
pH	0.875133	0.059527
P	0.933469	-0.347504
K	0.949860	-0.241152
Ca	-0.701263	0.306243
S	0.850443	-0.422702
CEC	0.806785	0.457758
EC	0.936501	-0.305341
Soil density	-0.908005	-0.394087
Porosity	0.979252	0.142553
Moisture	-0.006369	-0.979637
Volume of the alr	0.702294	0.695668

FIGURE 1
Principal components analysis (PCA) of soil chemical and physical proporties after ona year application of mineral (control) and vermicompost (VC) fertilizer with (EW) or without *Lumbricus terrestris*.
a) Eigenvalue diagram; b) Projection of variables into the F1-F2 plane. Variables are: pH, available P, K, Ca and S, CEC – Cation exchange capacity, EC – electrical conductivity, soil density, porosity, moisture and volume of air; c) Projection of variants into the F1-F2 plane; d) table of faktors variables

Factor 2 includes 21.61% of all variability, and thus the graph shows 90.33% of all data used. The S+VC20+EW variant is characterised by high content of sulphur, potassium, phosphorus and EC.

The results of the principal component analysis of soil properties at the end of vegetation in the substrates are shown in Figure 1 (detailed values are given in Tables 4 and 6). There are 2 factors that have a value greater than 1. Factor one, which includes 68.72% of all variability, divided the variants based on vermicompost content. Factor 1 did not include instantaneous moisture content data. Clean soil was characterised by higher calcium content and higher bulk density.

Effect of variants on aboveground biomass. Figure 2 shows the evolution of aboveground biomass during the growing season. There was a positive effect of vermicompost application on both fresh and dried biomass at each sampling date. The positive effect of vermicompost on total fresh and dry aboveground biomass was demonstrated in different crops such as: maize [8], tomatoes [10], basil [11], strawberries [12], onion [35] or buckwheat [41]. The increase in biomass is mainly related to the availability of essential nutrients for their sufficient uptake and plant development [8]. [54] reported that the growth of main roots and the promotion of secondary root formation in maize are enhanced by plant growth hormones in vermicompost, especially auxins [10], but also cytokinins and gibberellins [39]. Not all current studies report a positive impact of vermicompost. [9] planted two species of ornamental flowers in a greenhouse and found that at content of vermicompost 25% in the substrate, reduced total plant biomass, total number of flowers and their weight, and mortality of individuals was also recorded. They motivated this negative phenomenon by high level of toxic ions, high salinity and change in physical properties of substrates caused by addition of vermicompost. They also add that individual plant species may differ in their tolerance to high soil salinity.

In the first sampling, the variants without earthworms had a higher weight of both fresh and dried biomass, but in the next two samplings we see a positive effect of earthworms on aboveground biomass. (Figure 2), which correlates with the findings of [28]. Earthworm excretions become coated with slime, producing more water-resistant aggregates than are found in the surrounding soil [29]. These aggregates cause better aeration, water retention and better aerobic conditions in the soil, which is of great importance for proper root development and nutrient availability to plants [16]. The increase in total biomass by earthworms is due to the improvement in N mineralisation and improvement in photosynthesis of plants, through the increase in RUBISCO enzyme and synthesis of ATP [23].

Organic fertilisers can replace up to 50% of the fertiliser dose from industrial fertilisers, while the combination with mineral fertilisers is cost-effective and maintains soil health and ensures better plant growth [35].

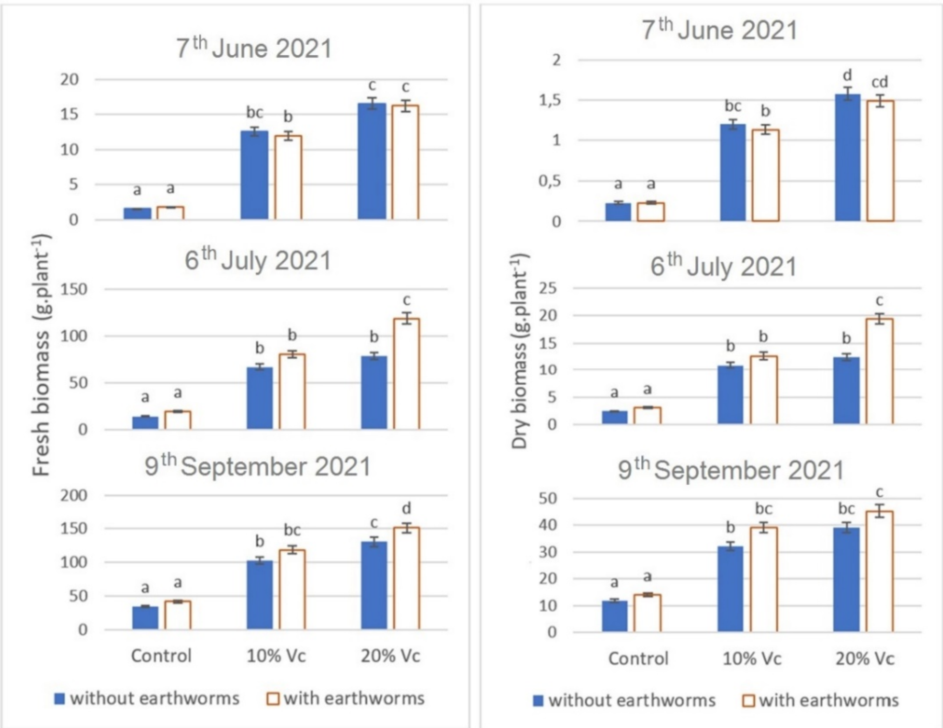


FIGURE 2
Influence of variants on fresh and dry biomass

CONCLUSION

Based on the evidence from our experiment, we conclude that increasing the vermicompost content in the substrate had a positive effect on the soil's physicochemical parameters and the development of the crop grown. There was no effect of 20% vermicompost content compared to 10% rate on pH, CEC, soil bulk density, instantaneous air and water content of the substrate. The earthworm was found to be an important representative of soil fauna, which increased the soil's available P, K, Ca content by its activity, thereby increasing the crop's total phytomass. Differences in earthworm behaviour in clean soil and substrates with addition of vermicompost on soil's physical parameters were noted. The produced earthworm slime has a great role on the change of soil properties. However, further research is needed on the importance of earthworms and the mechanism of the slime's action on the parameters of soil and crop growth.

ACKNOWLEDGEMENTS

This research was supported by the project VEGA no. 1/0378/20

REFERENCES

[1] Adhikary, S. (2012) Vermicompost, the story of organic gold: A review. Agricultural Sciences. 3, 905-917.

[2] Gupta R., Garg, V.K. (2011) Potential and possibilities of vermicomposting in sustainable solid waste management: a review. Int. J. Environ. Waste Manage. 7(3–4), 210-234.

[3] Domínguez, J., Sanchez-Hernandez, J.C., Lores, M. (2017) Vermicomposting of winemaking by-products, in: Galanakis, C.M., (Ed.), Handbook of grape processing by-products. Academic Press, London. 55-78.

[4] Brandon, M.R., Aira, M., Kolbe, A.R., de Andrade, N., Pérez-Losada, M., Domínguez, J. (2019) Rapid Bacterial Community Changes during Vermicomposting of Grape Marc Derived from Red Winemaking. Microorganisms. 7(10), 473.

[5] Brandon, M.R., Aira, M., Santana, N., Pérez-Losada, M., Domínguez, J. (2020) Temporal Dynamics of Bacterial Communities in a Pilot-Scale Vermireactor Fed with Distilled Grape Marc. Microorganisms. 8(5), 642.

[6] Mago, M., Gupta, R., Yadav, A., Garg, V.K. (2022) Sustainable treatment and nutrient recovery from leafy waste through vermicomposting. Bioresource Technology. 347, 1-9.

[7] Ahmed, R., Deka, H. (2022) Vermicomposting of patchouli bagasse—A byproduct of essential oil industries employing Eisenia fetida. Environmental Technology & Innovation. 25, 1-13.

[8] Raza, S.T., Wu, J., Rene, E.R., Ali, Z., Chen, Z. (2022) Application of wetland plant-based vermicomposts as an organic amendment with high nutritious value. Process Safety and Environmental Protection. 165, 941-949.

[9] Lazcano, C., Dominguez, J. (2010) Effects of vermicompost as a potting amendment of two commercially-grown ornamental plant species. Spanish Journal of Agricultural Research. 8(4), 1260-1270.

[10] Zuhair, R., Moustafa, Y.T.A., Mustafa, N.S.A., El-Dahshouri, M.F., Zhang, L., Ageba, M.F. (2022) Efficacy of amended vermicompost for bio-control of root knot nematode (RKN) Meloidogyne incognita infesting tomato in Egypt. Environmental Technology & Innovation. 27, 1-9.

[11] Celikcan, F., Kocak, M.Z., Kulak, M. (2021) Vermicompost applications on growth, nutrition uptake and secondary metabolites of Ocimumbasilicum L. under water stress: A comprehensive analysis. Industrial Crops and Products. 171, 1-12.

[12] Zuo, Y., Zhang, J., Zhao, R., Dai, H., Zhang, Z. (2018) Application of vermicompost improves strawberry growth and quality through increased photosynthesis rate, free radical scavenging and soil enzymatic activity. Scientia Horticulturae. 233, 132-140.

[13] Kováčik, P., Olšovská, K., Smoleń, S., Ledwożyw-Smoleń, I. (2021) Parameters of radish phytomass (Raphanus sativus L.) determined by vermicompost and earthworms (Eisenia fetida). Folia Hort. 33(1), 217-233.

[14] Sharafabad, Z.H., Abdipour, M., Hosseinifarahi, M., Kelidari, A., Rashidi, L. (2022) Integrated humic acid and vermicomposting changes essential oil quantity, and quality in field-grown Lavandula angustifolia L. intercropped with Brassica nigra L. Industrial Crops and Products. 178, 1-15.

[15] Arancon, N.Q., Edwards, C.A., Babenko, A., Cannon, J., Galvis, P., Metzger, J.D. (2008) 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. 39. 91–99.

[16] Manivannan, S., Balamurugan, M., Parthasarathi, K., Gunasekaran, G., Ranganathan, L.S. (2009) Effect of vermicompost on soil fertility and crop productivity of beans (Phaseolus vulgaris). J. Environ. Biol. 30, 275–281.

[17] Rajkhowa, D.J., Sarma, A.K., Mahanta, K., Ssaikia, U.S., Krishnappa, R. (2016) Effect of vermicompost on greengram productivity and soil health under hilly ecosystem of North East India. Journal of Environmental Biology. 38, 15-19.

[18] Azarmi, R., Giglou, M.T., Taleshmikail, R.D. (2008) Influence of vermicompost on soil chemical and physical properties in tomato (Lycopersicum esculentum) field. Afr. J. Biotechnol. 7(14), 2397–2401.

[19] Bouché, M. B., Gardner, R. H . (1984) Earthworm functions: population estimation techniques. Revue d'Ecologie et de Biologie du Sol. 21, 37– 63.

[20] Tobiášová, E., Zaujec, A. (2004) Biology of soil. Slovak University in Nitra, Nitra, 1-113 (in Slovak).

[21] Bottinelli, N., Henry-des-Tureaux, T., Hallaire, V., Mathieu, J., Benard, Y., Duc Tran, T., Jouquet, P. (2010) Earthworms accelerate soil porosity turnover under watering conditions. Geoderma. 156(1-2), 43-47.

[22] Li, Y., Wang, J., Shao, M. (2021) Effects of earthworm casts on water and salt movement in typical Loess Plateau soils under brackish water irrigation. Agricultural Water Management. 252, 1-9.

[23] Medina-Sauza, R., Álvarez-Jiménez, M., Ortíz-Huerta, Y., Ruiz-Sayago, E., Blouin, M., Villain, L., Guevara, R., Sangabriel, W., Reverchon, F., Barois, I. (2022) Bulk and rhizosphere soil properties under two Coffea species influenced by the earthworm Pontoscolexcorethrurus. Rhizospere. 21, 1-14.

[24] Bodner, G., Leitner, D., Kaul, H.-P. (2014) Coarse and fine root plants affect pore size distributions differently. Plant and Soil. 380, 133-151.

[25] Hallam, J., Holden, J., Robinson, D.A., Hudson, M.E. (2021) Effects of winter wheat and endogeic earthworms on soil physical and hydraulic properties. Geoderma. 400, 1-12.

[26] Ratsiatosika, O., Blanchart, E., Razafimbelo, T., Razafindrakoto, M., vom Brocke, K., Cao-Hamadou, T.V., Andriamarosata, J.-M.R., Ramanantsoanirina, A., Trap, J. (2021) Does rice breeding affect the ability of plants to interact with earthworms in nutrient-depleted Ferralsols?. Applied Soil Ecology. 163, 1-8.

[27] Kaur, P., Bali, S., Sharma, A., Vig, A.P., Bhardwaj, R. (2017) Effect of earthworms on growth, photosynthetic efficiency and metal uptake in Brassica juncea L. plants grown in cadmium-polluted soils. Environ. Sci. Pallut. Res. 24, 13452-13465.

[28] Bertrand, M., Blouin, M., Barot, S., Charlier, A., Marchand, D., Roger-Estrade, J. (2015) Biocontrol of eyespot disease on two winter wheat cultivars by on anecic earthworm (*Lumbricus terrestris*). Applied Soil Ecology. 96, 33-41.

[29] Guhra T., Stolze, K., Schweizer, S., Totsche, K.U. (2020) Earthworm mucus contributes to the formation of organo-mineral associations in soil. Soil Biology and Biochemistry. 145, 1-10.

[30] Hrivňáková, K. (2011) Uniform working procedures for soil analysis, VUPOP, Bratislava. 23-26 (in Slovak).

[31] Mehlich, A. (1984) Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Soil Sci. Plant Anal. 1(5), 1049–1416.

[32] Tyurin, I. V. (1966) Soil genesis and fertility issues. Nauka, Moskva, 42–47 (in Russian).

[33] Fiala, K. (1999) Binding methods for soil analysis, VUPOP, Bratislava. 85-88 (in Slovak).

[34] Hanes, J., Chlpík, J., Mucha, V., Sisák, P., Zaujec, A. (1995) Pedology, Slovak University of Agriculture, Nitra, 30-43, (in Slovak).

[35] Ramos, R.F., Santana, N.A., de Andrade, N., Romagna, I.S., Tirloni, B., de Oliveira Silveira, A., Domínguez, J., Jacques, R.J.S. (2022) Vermicomposting of cow manure: Effect of time on earthworm biomass and chemical, physical, and biological properties of vermicompost. Bioresource Technology. 345, 1-8.

[36] Srivastava, P.K., Gupta, M., Upadhyay, R.K., Sharma, S., Shika, Singh, N., Tewari, S.K., Singh, B. (2012) Effects of combined application of vermicompost and mineral fertilizer on the growth of Allium cepa L. and soil fertility. J. Plant Nutr. Soil Sci. 175, 101-107.

[37] Liu, M., Wang, Ch., Wang, F., Xie, Y. (2019) Maize (*Zea mays*) growth and nutrient uptake following integrated improvement of vermicompost and humic acid fertilizer on coastal saline soil. Applied Soil Ecology. 142, 147-154.

[38] Cai, L., Cong, X., Ding, H., Li, S., Hao, D., Yu, K., Ma, Q., Sun, X., Muneer, M.A. (2022) Vermicomposting with food processing waste mixtures of soybean meal and sugarcane bagasse. Environmental Technology & Innovation. 28, 1-11.

[39] Ruangjanda, S., Iwai, Ch.B., Greff, B., Chang, S.W., Ravindran, B. (2022) Valorization of spent mushroom substrate in combination with agro-residues to improve the nutrient and phytohormone contents of vermicompost. Environmental Research. 214, 1-8.

[40] Bai, W., Kong, L., Guo, A. (2013) Effects of physical properties on electrical conductivity of compacted lateritic soil. Journal of Rock Mechanics and Geotechnical Engineering. 5(5), 406-411.

[41] Mohammadi, E,. Fattahi, M., Barin, M., Ashrafi-Saeidlou, S. (2022) Arbuscular mycorrhiza and vermicompost alleviate drought stress and enhance yield, total flavonoid concentration, rutin content, and antioxidant activity of buckwheat (Fagopyrum esculentum Moench). South Africa Journal of Botany. 148, 588-600.
[42] Huang, K., Li, F., Wei, Y., Fu, X., Chen, X. (2014) Effects of earthworms in physicochemical properties and microbial profiles during vermicomposting of fresh fruit and vegetable wastes. Bioresource Technology. 170, 45-52.
[43] Basker, A. – Macgregor, A.N. – Kirkman, J.H. (1992) Influence of soil ingestion by earthworms on the availability of potassium in soil: An incubation experiment. Biology and Fertility of Soils. 14, 300-303.
[44] Schrader, S. (1994) Influence of earthworms on the pH conditions of their environment by cutaneous mucus secretion. Zoologischer Anzeiger. 233, 211-219.
[45] Doan, T.T., Henry-des-Tureaux, T., Rumpel, C., Janeau, J-J., Jouquet, P. (2015) Impact of compost, vermicompost and biochar on soil fertility, maize yield and soil erosion in Northern Viernam: A three year mesocosm experiment. Science of the Total Environment. 514, 147-154.
[46] Kováčik, P., Kmeťová, M. (2017) Impact of vermicompost on phytomass of maize, Slovak University of Nitra, Nitra, 50-80 (in Slovak).
[47] Pagliai, M., Guidi, G., La Marca, M. (1980) Macro and micro morphometric investigation on soil–dextran interactions. J. Soil Sci. 31(3), 493–504.
[48] Perreault, J.M., Whalen, J.K. (2006) Earthworm burrowing in laboratory microcosms as influenced by soil temperature and moisture. Pedobiologia. 50, 397-403.
[49] Brown, G.G., Barois, I., Lavelle, P. (2000) Regulation of soil organic matter dynamics and microbial activityin the drilosphere and the role of interactionswith other edaphic functional domains. European Journal of Soil Biology. 36(3-4), 177-198.
[50] Jégou, D., Schrader, S., Diestel, H., Cluzeau, D. (2001) Morphological, physical and biochemical characteristics of burrow walls formed by earthworms. Applied Soil Ecology. 17(2), 165-174.
[51] Emmerling, Ch., Rassier, K.M., Schneider, R. (2015) A simple and effective method for linking field investigations of earthworms and water infiltration rate into soil at pedon-scale. Journal of Plant Nutrition and Soil Science. 178(6), 841-847.
[52] Zheng, W., Ma, Y., Wang, X., Wang, X., Li, J., Tian, Y., Zhang, X. (2022) Producing high-quality cultivation substrates for cucumber production by in-situ composting of corn straw blocks amended with biochar and earthworm casts. Waste Management. 139, 179-189.
[53] Hallaire, V., Curmi, P., Duboisset, A., Lavelle, P., Pashanasi, B. (2000) Soil structure changes induces by the tropical earthworm Pontoscolex-corethrurus and organic inputs in a Peruvian ultisol. European Journal of Soil Biology. 36(1), 35-44.
[54] Canellas, L.P., Olivares, F.L., Okorokova-Façanha, A.L., Façanha, A.R. (2002) Humic acids isolated from earthworm compost enhance root elongation, lateral root emergence, and plasma membrane H+-ATPase activity in maize roots. Plant Physiol. 130(4), 1951-1957.

Received: **30.09.2022**
Accepted: **02.11.2022**

CORRESPONDING AUTHOR

Jakub Neupauer
Faculty Agrobiology and Food Resources
Slovak University of Agriculture in Nitre
Nitra 94911 – Slovak Republic

e-mail: xneupauer@uniag.sk