Parameters of radish phytomass (*Raphanus sativus* L.) determined by vermicompost and earthworms (*Eisenia fetida*)

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ABSTRACT

In 2-year outdoor pots experiment, which was realised in the vegetation cage situated in the campus of Slovak University of Agriculture in Nitra, both the impact of different doses of vermicompost (Vc) (0%, 10%, 20%, 25% and 50%) and the number of earthworms (EW) (0, 10 and 20 individuals/pot) in the soil substrate were studied on the quantitative and qualitative parameters of radish yield. The achieved results show that along with the increasing quantity of Vc, the total chlorophyll content also increased proportionally. The content of vitamin C declined and the content of nitrates increased in both the aboveground and underground biomass. The weight of the roots and leaves of radish increased until the content of Vc in the substrate did not exceed 20%. Vermicompost abundance >20% led to the decline of root and leaf biomass formation. The root yield and leaf biomass were higher in the presence of 50% Vc content in the substrate, compared with the control. The EW had mostly a negative impact on radish phytomass formation, particularly both weight and root diameter. The highest percentage of roots weight decline cultivated in the treatment with EW were obtained with the least dose of Vc (10%), thereby the least quantity of fodder for the EW. The impact of EW on the total chlorophyll, vitamin C and nitrates contents in roots and leaves was non-significant. The number of EW did not influence the root diameter and content of vitamin C; however, it affected the root weight.

Keywords: earthworms, nitrates, root weight, total chlorophyll content, vermicompost, vitamin C

INTRODUCTION

The worldwide deterioration of the environment activates both professionals and the lay public to protect nature. Nowadays, different ecological movements are working at different knowledge levels. Representatives of these movements with a lower level of professionalism in soil chemistry and soil life sciences have caused nutrition of agricultural

crops to be done through organic fertilisers; this has been perceived uncritically positively by numerous groups of people. While it is a well-known fact that not only application of commercial fertilisers but also organic fertilisers could negatively affect the quality of groundwater and increase the quantity of greenhouse gases in the atmosphere (Akiyama and

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Tsuruta, 2003; Deng et al., 2017). In countries with low doses of commercial fertilisers applied in the conventional agriculture, the use of organic fertilisers negatively influences the environment more often than the application of commercial ones. To avoid the possible negative impacts of organic fertilisers on the environment, the European Commission (1991, 1999) limits the maximum annual incorporation of organic fertilisers to an amount equivalent to $170 \text{ kg N} \cdot \text{ha}^{-1}$ (Manojlovič et al., 2017).

The European (unscientific) population has accepted the view that fertilisation by organic fertilisers compared with mineral fertilisers results always in a higher quality of cultivated crops. However, the effect of application is given by the parameters of organic fertilisers and the rationality of their utilisation. Therefore, it is evident that the impact of organic fertilisers on the yield quantity and quality of cultivated crops could be positive and neutral, but also negative (León et al., 2012; Kmeťová et al., 2013; Zayed et al., 2013; Chakraborty et al., 2016; Gholami et al., 2018a, 2018b; Najjari and Ghasemi, 2018). Similarly, their effect on the soil parameters and the environment is determined by the quality, dose and date of their application and could be positive or negative (Kong et al., 2014; Wu et al., 2019).

Nowadays, in many countries worldwide, the usage of commercial fertilisers is highly professional. It is based on complying with the information about several soil parameters (nutrients content, pH, bulk density, etc.), with changes in plant requirements for nutrients during their growth (Vaněk et al., 2013). As a result, crop growers, who take into consideration the latest trends in plant nutrition, apply commercial fertilisers in doses and periods, which allow an assumption of their maximal use for yield formation.

In the practical use of organic fertilisers, the same effort has been enforced related to their economic, and, consequently ecological impact, as in the commercial fertilisers use. The fact that a great part of nutrients from organic fertilisers are fixed in organic compounds requires their application for a longer time before the period of increased nutrient uptake by plants starts, in comparison to commercial fertilisers. This time is necessary for a release of nutrients from organic bonds and mineralisation of organic compounds (Schulten and Schnitzer, 1998) as well. As so far, agronomists cannot model weather development, the time required for mineralisation of nutrients generates the opportunity for nutrient losses caused by their depletion, evaporation and erosion. This is one of the reasons why organic fertilisers (manure, liquid manure and composts) used in Slovakia contribute more to the total washed-away nitrogen in comparison with commercial fertilisers (Bielek and Kudejarov, 1991).

With the increasing percentage of nutrient use from fertilisers (industrial and organic) for yield formation of cultivated crops, the risk of their leakage into ground or surface water, as well as the risk of environmental pollution decreases. Therefore, it could be stated that,

if plant nutrition is realised rationally, i.e. economically effectively, it could also be ecological.

Another myth, which has been assumed by the not non-significant part of the European population, says that the more earthworms (EW) are in the soil, the higher yield and quality of cultivated crops are achieved. However, EWs influence both the quantity and quality of cultivated crops not only positively, but also in a negative manner. The positive impact of the EW alone (different genera) and the EW in a vermicompost (Vc) was recorded on the aboveground biomass formation of cultivated crops by Brown et al. (2004), Van Groenigen et al. (2014) and Nweke (2017). The ambiguous, positive and negative effects of EW (*Pontoscolex corethrurus*) on the total phytomass and tradable cabbage phytomass was presented by Nurhidayati et al. (2016). Similarly, the positive and negative influences of EW (*Eisenia fetida*) on the underground plant phytomass were published by Kováčik et al. (2018a). In their experiments, the EW had a negative impact on the weight of radish roots and a positive effect on the weight of carrot roots. The recorded opposite effect of the EW on radish roots in comparison with carrot roots was explained by the different effect of the EW on crops of shorter (radish) and longer (carrot) growing season. A shorter growing season did not allow the plants to regenerate sufficiently after the attack of the EW on root hairs. Statistically non-significant, positive and negative reactions of plants to the presence of EW were presented by Doan et al. (2013) and Elmer (2016). Based on meta-analyses, Van Groenigen et al. (2014) claimed that in different ecosystems the EW increase crop yields on average by 25%, formation of aboveground phytomass by 23% and underground phytomass by 20%.

Different attention has been paid in different countries to the research focused on the impact of individual EW number on the height and quality of yields of specific plant species. In conditions of Central Europe, but also worldwide, it is still not known how many pieces of EW of a particularly species are beneficial for cultivation of specific plants, and how many are harmful. The utility and harmfulness of EW should be evaluated not only from the aspect of yield quantity, but also from the yield quality and impact on the environment. The well-known fact is that EW activity increases the mobility of a majority of nutrients in the soil. As a positive phenomenon, improved bio-availability of nitrogen (Tripathi and Bhardwaj, 2004), phosphorus and potassium (Garg et al., 2006) leads to the increased yield and content of nutrients in cultivated crops, respectively. Nevertheless, EW also increases the mobility of metals in the soil, resulting in their increased uptake by plants and consequently, increased concentration in plants (Sizmur et al., 2011; Du et al., 2014). This is, of course, an undesirable phenomenon. An increase of heavy metal contents in plants as affected by the EW activity in soils could be many-fold (Ruiz et al., 2011). It is evident that the measure of utility and harmfulness of the increased bioavailability of nutrients in soils as a result of the EW

activity depends significantly on the soil parameters. EW generally help to form soil aggregates (Wright and Upadhyay, 1998), which improve the water retention in nature and improve several physical, chemical and biological soil parameters (Sharma et al., 2005; Russell et al., 2016). The aim of this paper was to answer the question on how different doses of Vc (I) and the *E. fetida* (II) EW added to soil substrate affect both the quantity and quality of radish yield.

MATERIALS AND METHODS

Experimental design and field management

The 2-year pots experiment (2017 and 2018) was conducted in the vegetation cage (a fenced space on full sun with 10 × 15 m size. On cage sides and ceiling there was a metal mesh of size 15 mm × 15 mm, which protected the experiment against birds of the Slovak University of Agriculture in Nitra, situated in the university campus (48°18'N, 18°05'E) to study the impact of two factors (I – quantity of Vc, and II – number of EW) on formation of radish phytomass. The total number of treatments was 13. Treatment 1 was a control treatment (soil without Vc); Treatments 2–5 were targeted to determine the effect of 10%, 20%, 25% and 50% proportion of Vc on the total weight of soil substrate; Treatments 6–13 were established to detect the influence of 10 and 20 EW in the growing medium, as tested in Treatments 2–5.

In the experiment, five different growing substrates were mixed to fill the pots, while each pot was cylindrically shaped with 35 cm height and 35 cm diameter holding 20 kg of the substrate. In Treatment 1, the substrate was composed only from the soil, while the substrate in Treatments 2–5 was represented by four types of mixtures consisting of 18, 16, 15 and 10 kg of soil and 2, 4, 5 and 10 kg of Vc, respectively. The basic chemical parameters of both used soil (S) and Vc are indicated in Table 1.

The soil-to-Vc phytomass weight ratio in the created mixtures was as follows: 9:1, 4:1, 3:1 and 1:1. In Treatments 6–13, the same growing media were used like in Treatments 2–5, whereby EW (*E. fetida*, red worms) were added to the growing substrate. The EW used in the experiment was supplied by VermiVital Ltd. The following pairs of treatments, such as 6 and 7, 8 and 9, 10 and 11, 12 and 13 contained the identical substrate like Treatments 2–5. Ten red worms were added in the treatments with even numbers (8, 10, 12), and 20 red worms in the treatments with odd numbers (9, 11, 13) (Tables 2–8).

In the experiment, the Haplic Luvisol from the 0.0–0.25 m layer and standard Vc (VermiVital, Ltd. Company) were used. Before filling pots with growing media, the plastic net was placed at the bottom of all pots, which prevented potential escape of EW. Pots with weighted substrate were put on dishmats, deep enough to be able to hold 1,000 mL of the leaked soil solution resulting from intensive precipitations. The leaked solution returned back to the pots.

The experiment was conducted according to the random arrangement method of pots with each treatment in four repetitions (one repetition = 1 pot). The model crop was radish (*Raphanus sativus* L.) cv. 'Granát' by the company Osiva Moravia, which is cultivated for root consumption. In both years, the sowing of sufficient number of seeds into the pots took place on 16 March. Subsequently, the experiment was irrigated to the level of 75% field water capacity (FWC). After the emergence of plant seedlings, they were unitised by thinning down their number to ensure the same number of seedlings per pot (50 plants per one repetition), that is, enough biomass for three samplings. In the following 3 weeks, all pots were irrigated by the same dose of water containing the minimal quantity of nutrients. During the last 14 days of the experiment, Treatments 2–13 were irrigated by higher doses of water, because plants evaporated more water because of a significantly larger leaf area. In the course of the growing season (24 April, and 3 and 9 May, i.e. in 27/39, 36/48 and 42/54 days after emergence of plants/sowing) a total of three samples of plant material were collected (plants of radish emerged after 12 days from the sowing). Ten average individuals were taken from each treatment and repetition, which served for the evaluation of root and leaf weights. The contents of nitrates and vitamin C were determined in the roots and leaves during the second and third samplings. The total chlorophyll content was determined in the leaves. The diameter of root thickness was measured by slide calliper. For the purpose of sales, the radish crop is usually harvested twice or even more times during the vegetation season, meaning the yield harvests follow shortly one after another. Therefore, the sampling of plant material was pursued twice, in only 6-day intervals (3 and 9 May).

Analyses of soil and Vc

The following analytical methods were used in the experiment to quantify the agrochemical parameters of the soil and Vc: N–NH₄⁺ by Nessler's colorimetric method; N–NO₃[–] by colorimetric method with phenol-2,4-disulphonic acid, where the extract from the soil was achieved by using water solution of 1% K₂SO₄

Table 1. Parameters of soil and Vc used in the experiment.

Subs.	N _{in}	P	K	Ca	Mg	S	N _{tot}	C _{ox}	C:N	EC	pH _{KCl}
	(mg · kg ^{–1})						(%)			(mS · cm ^{–1})	
S	9.2	17.8	173	3,100	452	4.4	0.07	0.90	11.88	0.12	6.35
Vc	310.1	3,085	8,763	5,135	3,252	2,068	2.97	19.89	5.53	4.98	7.33

Subs., substrate; S, soil; Vc, vermicompost.

(Kováčik, 1997). Inorganic N (N_{in}) was calculated as a sum of $N-NH_4^+$ and $N-NO_3^-$ ($N_{in} = NH_4^+ + N-NO_3^-$). The available P, K, Ca and Mg contents were determined by Mehlich 3 extraction procedure (Mehlich, 1984). The content of P was determined by colorimetric method, K by flame photometry, Ca and Mg by atomic absorption spectrophotometry, S was detected spectrophotometrically (in the leachate of ammonium acetate), N_t by distillation after mineralisation of strong H_2SO_4 (Bremner, 1960), C_{ox} spectrophotometrically after the oxidation according to Tyurin (Dziadowiec and Gonet, 1999), EC by specific electrical conductivity method and pH/KCl (in solution of $1.0 \text{ mol} \cdot \text{dm}^{-3}$ KCl) potentiometrically.

Determination of total chlorophylls and nitrates

The chlorophyll content in fully developed leaves was analysed from the 80% acetone extract spectrophotometrically according to the method of Šesták and Čatský (1966) and the absorbance of the extract was converted into the concentration unit ($\text{mg} \cdot \text{m}^{-2}$) after the equations of Lichtenthaler (1987).

Determination of nitrates content was conducted as the extracting method from fresh plant samples and measured by use of ion-selective electrode (type 07–35) and reference electrode (type RCE 101) as the electro-motoric power according to Hubáček and Bernatzik (1976).

Determination of L-ascorbic acid

L-ascorbic acid was determined by HPLC Agilent 1260 with quaternary solvent manager coupled with degasser,

sample manager, column manager and DAD detector. All analyses were performed on C18 end capped column. Mobile phases consisted of methanol (B) and 0.1% H_3PO_4 (C). The detection wavelength was set at 256 nm. The spectral data were collected and processed using the Agilent OpenLab ChemStation software for LC 3D Systems (Stan et al., 2014).

Statistical analysis

The obtained results were processed mathematically and statistically by multifactorial analysis of variance (ANOVA) and by the Pearson's correlation coefficient (r). The differences between the treatments were evaluated by LSD test at the significance level of $\alpha = 0.05$. The Pearson's correlation coefficient (r) was processed by simple regression analysis at the significance levels of $\alpha = 0.05$ and $\alpha = 0.01$. The PC statistical program Statgraphics (version 5.0) was used.

RESULTS AND DISCUSSION

Weight of aboveground and underground phytomass

Effect of time

With progressive days of the experiment, the weight of radish phytomass was being increased (Tables 2 and 3). On average, root weight increased 46.43 times (by 108.12 g per 10 individuals) between the first and second samplings, i.e. between the 27th and 36th days

Table 2. Impact of Vc and EW on the dynamics of radish roots and leaves weight changes.

Treatment		24. IV. (27 days after emergence of plants)		3. V. (36 days after emergence of plants)		9. V. (42 days after emergence of plants)	
No.	Mark	g per 10 individuals		g per 10 individuals		g per 10 individuals	
		Roots	Leaves	Root	Leaves	Root	Leaves
1	S	2.04 bc	14.75 a	20.92 a	16.00 a	29.94 a	18.63 a
2	SVC _{9:1}	2.94 h	21.08 de	149.60 f	83.91 def	186.92 e	104.60 cd
3	SVC _{4:1}	3.66 i	22.56 e	154.72 g	95.96 g	220.27 f	147.78 f
4	SVC _{3:1}	2.81 h	20.25 cde	146.70 f	85.99 fg	215.42 f	136.35 f
5	SVC _{1:1}	2.19 cd	17.32 abc	101.98 c	84.87 efg	141.51 c	113.23 de
6	SVC _{9:1} +EW ₁₀	1.99 b	15.47 ab	107.00 d	59.18 b	143.00 c	70.78 b
7	SVC _{9:1} +EW ₂₀	1.65 a	14.47 a	96.04 b	56.38 b	128.98 b	66.76 b
8	SVC _{4:1} +EW ₁₀	2.55 g	19.06 cd	117.12 e	75.58 cdef	183.60 e	95.74 c
9	SVC _{4:1} +EW ₂₀	2.25 df	17.21 abc	115.88 e	74.21 cde	181.44 e	91.58 c
10	SVC _{3:1} +EW ₁₀	2.54 g	18.25 bcd	109.02 d	72.99 cd	167.33 d	120.14 e
11	SVC _{3:1} +EW ₂₀	2.44 fg	17.96 abc	107.16 d	72.99 cd	163.26 d	118.60 e
12	SVC _{1:1} +EW ₁₀	1.96 b	17.38 abc	105.20 cd	70.77 c	141.77 c	115.76 de
13	SVC _{1:1} +EW ₂₀	1.98 b	17.34 abc	105.20 cd	71.02 c	139.64 c	114.80 de
1–13		2.38	17.93	110.50	70.76	157.16	101.13
2–5		2.90	20.30	138.25	87.68	191.03	125.49
6–13		2.17	17.14	107.83	69.14	156.13	99.27
6,8,10,12		2.26	17.54	109.59	69.63	158.93	100.61
7,9,11,13		2.08	16.75	106.07	68.65	153.33	97.94
LSD _{0.05}		0.195	3.477	4.734	11.429	9.371	13.378

No. – number, 24. IV. – 24 April, 3. V. – 3 May, 9. V. – 9 May, LSD_{0.05} – least significant difference at the level $\alpha = 0.05$; different letter behind a numerical value respond to the statistically significant difference at the level 95.0%

EW, earthworms; Vc, vermicompost.

from plant germination (totally 9 days). The weight of leaves was increased by only 3.95 times (by 52.83 g per 10 individuals). Between the second and third samplings (totally 6 days) the root weight accumulated only 1.42 times (by 46.66 g per 10 individuals) and the weight of leaves 1.43 times (30.37 g per 10 individuals), meaning that the growth dynamics of both the aboveground and underground phytomass were almost equal. This fact indicates that radish roots increased their weight most intensively after 27 days from plant emergence, i.e. in the second half of the radish growing season. Roots and leaves grew and increased their weight up to the 42nd day of the growing season, i.e. until the end of the experiment, when the highest weights of leaves and roots were recorded. From the 36th day of the growing season the growth dynamics slowed down, while the leaves and roots growth had almost the equal dynamics, in spite of the fact that the absolute value of weight gain of roots was higher than the absolute value of weight gain of leaves.

During the first days of the radish growing season the ratio of leaves to roots weight (L:R) was higher than 6:1 in each treatment (Table 3). It is evident that at the beginning of the growing season the aboveground phytomass was formed faster compared with underground phytomass. After 27 days of the growing season the root growth was more intensive as a result of the transfer of photosynthates from leaves to roots and, consequently, leaf growth decline. On the 36th day of the growing season the leaf weight was lower than the root weight. A faster root growth compared to leaves caused

that in the stage of technological ripeness (3 and 9 May) the ratio of roots-to-total phytomass was higher than 50% and achieved the values of 60.96% and 60.85% (Tables 2 and 3). Similarly, the roots of sugar beet, fodder beet and turnip can grow more intensively than the leaves. The change in the ratio of roots-to-leaves growth rate occurs predominantly during the changing sunlight intensity and nutrition intensity (Suqiura and Tateno, 2011). Formation of leaves is supported heavily by nutrition, however, the light sufficiency has the opposite effect (Poorter et al., 2012). The change of leaves-to-roots weight ratio occurs probably only to a certain extent, and it is determined genetically, via optimisation of the growth rate of the whole plants (Osone and Tateno, 2003). Nowadays, attention is focused on the possibility to predict the yield quantity, based on the determination of the dependence between the roots-to-leaves weight ratio and yield.

Effect of Vc

According to Table 2, the addition of Vc into the soil (Treatments 2–5) resulted in both the fast radish growth and the increase in the roots-to-leaves weight ratio. The increase of aboveground and underground phytomass weights was measurable already on the 27th day from the beginning of plant emergence. The speed of Vc effect was high, because of high content of available nutrients, as referred in Table 1. Many countries tend to state the nutrients content in their total forms, when declaring the parameters of organic fertilisers; however, these are not sufficient indicators of their quality. Therefore,

Table 3. Impact of Vc and EW on the dynamics of radish leaves to roots phytomass ratio and total phytomass content changes.

Treatment		24. IV. (27 days after emergence of plants)		3. V. (36 days after emergence of plants)		9. V. (42 days after emergence of plants)	
No.	Mark	L:R	L+R	L:R	L+R	L:R	L+R
1	S	7.23	16.79	0.76	36.92	0.62	48.57
2	SVc _{9,1}	7.17	24.02	0.56	233.51	0.56	291.52
3	SVc _{4,1}	6.16	26.22	0.62	250.68	0.67	368.05
4	SVc _{3,1}	7.21	23.06	0.59	232.69	0.63	351.77
5	SVc _{1,1}	7.91	19.51	0.83	186.85	0.80	254.74
6	SVc _{9,1} +EW ₁₀	7.77	17.46	0.55	166.18	0.49	213.78
7	SVc _{9,1} +EW ₂₀	8.77	16.12	0.59	152.42	0.52	195.74
8	SVc _{4,1} +EW ₁₀	7.47	21.61	0.65	192.70	0.52	279.34
9	SVc _{4,1} +EW ₂₀	7.65	19.46	0.64	190.09	0.50	273.02
10	SVc _{3,1} +EW ₁₀	7.19	20.79	0.67	182.01	0.72	287.47
11	SVc _{3,1} +EW ₂₀	7.36	20.40	0.68	180.15	0.73	281.86
12	SVc _{1,1} +EW ₁₀	8.87	19.34	0.67	175.97	0.82	257.53
13	SVc _{1,1} +EW ₂₀	8.76	19.32	0.68	176.22	0.82	254.44
1–13		7.66	20.32	0.65	181.26	0.65	258.29
2–5		7.11	23.20	0.65	225.93	0.67	316.52
6–13		7.98	19.31	0.64	176.97	0.64	255.40
6,8,10,12		7.83	19.80	0.64	179.22	0.64	259.53
7,9,11,13		8.14	18.83	0.65	174.72	0.64	251.27

No. – number, 24. IV. – 24 April, 3. V. – 3 May, 9. V. – 9 May, L – leaves, R – roots, LSD_{0.05} – least significant difference at the level $\alpha = 0.05$; different letter behind a numerical value respond to the statistically significant difference at the level 95.0%

EW, earthworms; Vc, vermicompost.

in the process of declaration of the quality of organic fertilisers, it is advisable to declare also the content of available nutrients, which affect plant growth markedly.

On the 36th day, the average weight of radish roots was 6.61 times higher and the average leaf weight was 5.48 times higher in the treatment with Vc (2–5), than in the control treatment without Vc (1). On the 42nd day of the growing season in treatments with Vc (2–5), the average weight of radish roots was 6.38 times higher and the leaf weight was 6.74 higher, compared with the control treatment (without Vc).

The significant multiple increases of phytomass weight resulting from the Vc addition into the soil approved the knowledge that the achievement of high yields is not possible without the application of considerable quantities of easily available nutrients (Cooke, 1982; Cong et al., 2019). At the same time, recording more dynamic growth of roots weight compared to leaves weight in treatments with Vc confirmed the fact that fertilisation by nitrogen usually determines a more significant growth of roots than leaves (Suqiura and Tatenno, 2011).

The L:R ratio in Treatment 5 (Table 3) was higher in all the three samples of plant material compared to the control treatment, and in contrast to the same ratio in Treatments 2–4, which means that the 50% proportion of used (high quality) Vc in the growing medium was ineffective. This must be taken into account, because the main utility part of radish during its cultivation is roots, not leaves. In Treatments 2–4 the L:R ratios were smaller, even comparable to the control L:R ratio. It signalises that 10%, 20% and 25% proportion of Vc resulted mainly in roots formation, or at least balanced roots-to-leaves formation. In many Asian countries, radish is grown not only for root consumption, but often predominantly for leaves consumption (Bhatnagar and Azhar, 2016). Thus, it is highly probable that growers of radish leafy varieties will like the information that the highest leaves-to-roots weight ratio was recorded in the treatment with the highest proportion (50%) of Vc.

Along with the rise of Vc proportion in the soil substrate (by decreasing the ratio of soil to Vc) to the ratio of 1 unit Vc to 4 units S (Treatments 2 and 3), the weights of radish roots and leaves were increased (Table 2). In terms of this ratio the highest weight of the radish aboveground and underground phytomass was achieved. The addition of Vc to S was above the ratio of 1:4, i.e. above 20% content Vc in the growing medium (Treatments 4 and 5) led to the gradual decreasing intensity of radish roots and leaves formation. This fact affirms that in order to achieve the highest yield of radish roots, the proportion of tested Vc in the soil with low contents of available N, P and K (Table 1) should not be higher than 20% (Treatment 3).

In the substrates with the ratio of Vc:S at the level 1:3 and 1:1, the smaller underground and aboveground phytomass were formed than in the treatment with the ratio of Vc:S at 1:4; however, it was still significantly

higher than in the treatment without Vc. This finding offers the opportunity to use Vc in soils with lower contents of available nutrients (Table 1) in relatively high doses (25% and 50% proportion in substrate), mainly in the case of a surplus production of Vc without risk of yield decreases.

In Slovakia, a local surplus production of composts is a serious problem. It is a consequence of disproportion between the increasing production of composts and the limited possibility of their application. The rising production of composts results from the legal obligation of inhabitants in Slovakia to compost biologically degradable wastes. The diminishing opportunity of their application into soils is caused, on one hand, by continuous decrease of private house gardens used for gardening, where so far the compost has been used; on the other hand, it results from the increasing disbelief in the quality of composts produced by non-agricultural companies. Therefore, the findings about the addition of Vc at the level of 50% of the total weight of soil substrate (in the top-soil layer) into soil with low available nutrient contents show that yield can be increased, which is a significant practical knowledge. It is necessary to take into account that application of high doses of Vc into soils should be carried out only in justified cases, in particular, in areas where the quality of groundwater and parameters of the environment will not be worsened.

The average root thickness of radish cultivated in the treatment without Vc (Treatment 1) was lower than 2.0 cm (1.46 cm and 1.69 cm). For this reason, roots cultivated in the control variant are almost unmarketable (Table 4). In the treatments with applied Vc (Treatments 2–5), the average root thickness was bigger than 2.0 cm, which satisfies the requirement of a majority of multiple stores. On the 36th day of the growing season the root thickness varied in the interval of 2.96 cm to 3.36 cm, and on the 42nd day of the growing season it varied from 3.08 cm to 3.72 cm.

The effect of Vc on root thickness corresponded with its impact on root weight. The highest root thickness was achieved in the treatment with S:Vc ratio of 4:1 (Treatment 3). The decrease of S:Vc ratio under 4:1, i.e. the increase of Vc proportion in the soil substrate above 20% (Treatments 4 and 5) led to the gradual decrease of radish root thickness. Analyses of Treatments 2–5 showed the smallest root thickness in Treatment 5.

This information proves that according to the normal distribution curve of the functional relationship of between the yield and N concentration in plants, the enhancement of N concentration in plants increases the yield up to a so-called breaking point, from which additional increases of N doses have a depressive impact on yield formation. The breaking point is determined by several factors, e.g. plant requirements for nutrients and soil nutrient reserves. In this sense, even low doses of fertilisers can result in decrease of yields in the case of their application into soils, which are supplied sufficiently by nutrients, or if the crops with very low requirements

Table 4. Impact of Vc and EW on the changes of radish roots diameter.

Treatment		3. V. (36 days after emergence of plants)		9. V. (42 days after emergence of plants)	
No.	Mark	cm	%	cm	%
1	S	1.46 a	100.00	1.69 a	100.00
2	SVc _{9:1}	3.15 fg	215.75	3.31 ef	195.86
3	SVc _{4:1}	3.36 g	230.14	3.72 g	220.12
4	SVc _{3:1}	3.21 fg	219.86	3.64 fg	215.38
5	SVc _{1:1}	2.96 ef	202.74	3.08 cde	182.25
6	SVc _{9:1} +EW ₁₀	2.78 cde	190.41	2.85 bcd	168.64
7	SVc _{9:1} +EW ₂₀	2.59 bcd	177.40	2.71 bc	160.36
8	SVc _{4:1} +EW ₁₀	2.97 ef	203.42	3.29 ef	194.67
9	SVc _{4:1} +EW ₂₀	2.94 def	201.40	3.22 de	190.53
10	SVc _{3:1} +EW ₁₀	2.76 bcde	189.04	3.04 cde	179.88
11	SVc _{3:1} +EW ₂₀	2.68 bcde	183.56	2.90 bcd	171.60
12	SVc _{1:1} +EW ₁₀	2.53 bc	173.29	2.79 bc	165.09
13	SVc _{1:1} +EW ₂₀	2.41 b	16.07	2.66 b	157.40
1–13		2.75	–	2.99	–
2–5		3.17	–	3.44	–
6–13		2.71	–	2.93	–
6,8,10,12		2.76	–	2.99	–
7,9,11,13		2.66	–	2.87	–
LSD _{0.05}		0.351		0.377	

No. – number, 24. IV. – 24. April, 3. V. – 3 May, 9. V. – 9 May, LSD_{0.05} – least significant difference at the level $\alpha=0.05$; different letter behind a numerical value respond to the statistically significant difference at the level 95.0%

EW, earthworms; Vc, vermicompost.

for nutrients are cultivated, as it was recorded by Berti et al. (2009); Liao et al. (2009); Li et al. (2015); and Adekiya et al. (2019). Disproportional and excessive plant nutrition is not only uneconomic, but also non-ecological (Chaudhuri et al., 2016).

Effect of the presence of EW

The EW affected mostly negatively formation of radish aboveground and underground phytomass during the whole experiment (Treatments 6–13 vs Treatments 2–5).

The influence of EW on root and leaf weights was not identical during the growing season. The percentual drop of radish roots weight as a result of presented EW in soil substrates was decreased in the course of the growing season. On the contrary, the negative impact of EW on leaves weight was higher in the 2nd and 3rd samplings (3 and 9 May) in comparison to the first sampling (Table 2).

On the 27th, 36th and 42nd days of the growing season, the roots weight treated with EW was lower (averages in Treatments 6–13) by 25.2%, 22.0% and 18.3%, i.e. by 0.73 g, 30.42 g and 34.9 g per 10 individuals, respectively, than the roots weight not treated with EW (averages in Treatments 2–5). Similarly, also the leaves weight in the treatments with EWs (average Treatments 6–13) was lower on the 27th, 36th and 42nd days of the growing season by 15.57%, 21.1% and 20.9%, i.e. by 3.16 g, 18.54 g and 26.2 g per 10 individuals, respectively, than the leaves weight cultivated in the treatments without EW (average Treatments 2–5). The submitted findings are in contradiction with the data published by Xiao et al. (2018), who, based on the meta-analyses,

argue that EW in soil substrate significantly elevated plant aboveground biomass by 16%, underground biomass by 29% and total biomass by 22%. On the contrary, they support the opinion that roots are one of the main contributors of the principal foodsource of EW and may act well as an attractant to them (Brown et al., 2000). The idea that root hairs can be attacked by EW in the initial period of plant growing was presented by Kováčik et al. (2018b). The gradual decrease of roots weight from the 27th to the 42nd days of the growing season caused by EW (Table 2) corresponds with the given view.

As a result of the presented EW, radish roots weight (overall of the second and third samplings) was decreased by 65.32 g per 10 individuals and leaves weight decreased by 44.74 g per 10 individuals. It is evident that EW had a more negative impact on the roots weight than leaves weight (Table 2). Therefore, the finding can be more significant for growers of radish root varieties.

The following comparisons, such as Treatment 2 vs Treatments 6 and 7, Treatment 3 vs Treatments 8 and 9, Treatment 4 vs Treatments 10 and 11, Treatment 5 vs Treatment 12 and 13 indicate that the percentage of roots weight decline cultivated in treatments with EW (in all three samplings) was the highest compared with treatments without EW, where the growing medium contained the least quantity of Vc (10%). The root weight decreases between Treatment 2 and Treatments (6+7)/2 were at the level of 38.59%, 32.14% and 27.2% on the 27th, 36th and 42nd days of the growing season, respectively. On the contrary, EW caused the least percentual fall of root weight cultivated in treatments,

where the substrate contained the maximum, i.e. 50% of Vc (Treatment 5 vs. 12 and 13). The drop of root weight between Treatment 5 and Treatments (12+13)/2 was on average 2.47% in all the three samplings. Based on these facts, it is possible to state the hypothesis that if red worms have enough appropriate fodder (compost, Vc, crop residues, etc.) in its environment, it will not attack the root hairs of young plants. The yield of cultivated crops will be higher.

EWs affected the root thickness (diameter) similar to the root weight (Treatment 2 vs Treatments 6 and 7, Treatment 3 vs Treatments 8 and 9, Treatment 4 vs Treatments 10 and 11, Treatment 5. vs Treatments 12 and 13). They decreased the root thickness in the second as well as in the third sampling. The only exception was Treatment 12 in the third sampling, where the drop in root weight was non-significant in relation to the treatment without EW (Treatment 5) (Table 4). The average root thickness in the treatments with Vc and without EW (Treatments 2–5) increased in comparison with radish average root thicknesses cultivated in the treatments with Vc and EW (Treatments 6–13) on the 36th day of radish growing season by 0.46 cm and on the 42nd day by 0.51 cm, respectively.

Effect of EW number

Not only the presence of EW in the substrate, but also their number determined the formation of radish phytomass (Treatment 6 vs Treatment 7, Treatment 8 vs. Treatment 9, Treatment 10 vs. Treatment 11, Treatment 12 vs. Treatment 13) (Table 2). The average root weight cultivated in the treatment with 20 individual EW per pot was on the 27th, 36th and 42nd days of the growing season, lower by 7.96%, 3.21% and 3.52% compared with the weight of roots in the variants with 10 individual EWs per pot. Nurhidayati et al. (2016) recorded both increase and decrease in cabbage yield with the increased number of EW of specie *P. corethrurus* in Vc. The composition of Vc and its origin decide what number of the EW will increase, and what number will decrease the crop yield.

In the first sampling in the treatment with 20 EWs, a significant decrease in the root weights was detected in two treatments in comparison to the radish root weights cultivated in the treatments with 10 numbers of EWs, in particular in the treatment with the S:Vc ratio of 9:1 and in the treatment with the S:Vc ratio of 4:1. In the second and third samplings, there was a considerable decrease in the root weights in the treatments with 20 numbers of EW, only in the treatment with the least (10%) content of Vc (S:Vc = 9:1) compared with the treatment with 10 EWs. This fact approves the hypothesis that red worm (*E. fetida*) probably attacks the root hairs in case of fodder insufficiency.

The number of EWs did not influence the thickness (diameter) of the roots (Table 4). The difference between the pairs of treatments (6–7, 8–9, 10–11, 12–13) was insignificant. Similarly, the differences in the leaf weights were insignificant, which indicates that

the number of EWs did not affect the leaf weights in a considerable way. The average decreases in leaf weights in the treatments with 20 EWs were lowered on the 27th, 36th and 42nd days of the growing season by 4.50%, 1.40% and 2.65% compared with the treatments with 10 EWs.

Content of chlorophylls

Effect of time

The total chlorophyll content (on average for all variants of the experiment) was lesser only by 2.43% (8.17 mg · m⁻²) on the 42nd day, comparing with that on the 36th day of the growing season. Similarly, the ratio of chlorophylls *a* content to chlorophylls *b* content was lower on the 42nd day, eventually similar to that on the 36th day of the growing season, highlighting that chlorophyll *a* always dominated over chlorophyll *b*. A slight decrease in the total chlorophyll contents in the radish plant leaves harvested 6 days later related to a shorter time interval between the particular samplings and also to the fact that the radish seeds did not germinate and emerge on the same day concurrently, but in the course of 3 days, so the age of the analysed leaves was lesser than the stated 6 days. It is evident that the recorded values are consistent with those of Ebbs and Uchil (2008), who stated that in the process of leaf ageing, the decrease in the total chlorophyll contents can be measured. The degradation of chlorophyll during ripening and plant ageing is a natural process (Kumar et al., 2019).

Effect of Vc

The contents of chlorophylls *a* and *b* in radish leaves of both samplings increased progressively along with the increasing proportion of Vc in soil. Concurrently the chlorophyll *a* to *b* ratio was lowered, as a result of the fact that along with the increasing content of available N, Mg, S and other nutrients in soil, the content of the total chlorophyll in plants increases (Kováčik et al., 2014).

On average of variants 2–5, the increase of chlorophyll *a*, *b*, *a+b* contents was at the level of 38.78 mg · m⁻², 27.05 mg · m⁻² and 65.83 mg · m⁻² on the 36th day of vegetation period compared to the contents in the control variant (Treatment 1). On the 42nd day of the growing season the increase achieved 41.9 mg · m⁻², 27.35 mg · m⁻² and 69.25 mg · m⁻². In the relative expression, on the 36th day of the growing season the increases were 19.57%, 33.69% and 23.64%, and on the 42nd day of the growing season the increases were 22.15%, 35.02% and 25.91%.

As the plant leaves contain more chlorophyll *a* than chlorophyll *b* (Novichkova et al., 2006, Noman et al., 2018), the absolute increase in total chlorophyll content as a result of the improved plant nutrition was higher in chlorophyll *a* than in chlorophyll *b*; however, the relative increase was higher in chlorophyll *b*. Relatively higher increase of chlorophyll *b* than chlorophyll *a* content explains recorded decrease of chlorophyll *a*:*b*

ratio, along with the rising proportion of Vc in soil. The Vc increased relatively more chlorophyll *b* than chlorophyll *a* content. The highest ratio of chlorophyll *a*:*b* was monitored in the control treatment.

On the 36th day of the growing season, the differences in the chlorophyll contents between the particular treatments with (Treatments 2–5) and without Vc (Treatment 1) were significant. On the 42nd day of the growing season, considerable differences occurred only in the treatments at 20%, 25% and 50% of the proportion of Vc in the soil. This finding is related to the decreasing positive impact of the added available nutrients on the formation of chlorophylls during running days of the growing season. The effect of the added nutrients depends on their doses, e.g. the lower the nutrient dose, the shorter is the effect.

Effect of the presence of EW

A comparison of the average values of chlorophyll contents in the treatments with (Treatments 6–13) and without EW (Treatments 2–5) indicate that the lower contents of chlorophyll *a*, chlorophyll *b* and, consequently the total chlorophyll content, were obtained in the treatments with EW. At the same time the lower chlorophyll *a*:*b* ratios were measured as a consequence of the fact that the decrease in chlorophyll *a* content was higher than that of chlorophyll *b*. The decrease in chlorophyll *a* on the 36th and 42nd days of the growing season was at the level of 2.40% and 2.84%, and the decrease in chlorophyll *b* achieved 0.79% and 0.29%, respectively. The declines in chlorophylls *a*,

b *a*+*b* contents, caused by the presence of EW in the soil, were not statistically significant in any treatment. Therefore, it can be stated that EW tend to decrease the chlorophyll content in radish leaves, or that the effect of the EW on the chlorophyll content was insignificant.

Effect of the number of EW

The differences in the chlorophyll contents found between the pairs of treatments (6 and 7, 8 and 9, 10 and 11, 12 and 13) were minimal and statistically insignificant. On average, in the treatments with 20 EWs (Treatments 6, 8, 10, 12) the chlorophyll *a*, *b*, *a*+*b* contents were lowered by 1.72%, 0.37% and 1.3% in comparison with the contents of chlorophylls in the treatments with 10 EWs (Treatments 7, 9, 11, 13). The lowest ratio of chlorophyll *a*:*b* was registered in the treatment with 20 individual EWs (Table 5). The findings of the experiment show a higher number of EWs tending to decrease the content of chlorophyll in radish leaves to more than a lower number; however, the drops were insignificant.

Vitamin C content

Effect of time

On the 36th day of the growing season the content of vitamin C in radish roots was lesser by 18.1 mg · kg⁻¹ compared with its content on the 42nd day of the growing season. On the contrary, the opposite tendency was recorded in the leaves (Table 6). On the 36th day of the growing season the content of vitamin C in the

Table 5. Impact of Vc and EW on chlorophyll *a*, chlorophyll *b* and total chlorophyll content in radish leaves.

Treatment		3. V. (36 days a.e)				9. V. (42 days a.e)			
No.	Mark	chl. <i>a</i>	chl. <i>b</i>	chl. <i>a</i> + <i>b</i>	chl. <i>a</i> : <i>b</i>	chl. <i>a</i>	chl. <i>b</i>	chl. <i>a</i> + <i>b</i>	chl. <i>a</i> : <i>b</i>
		mg · m ⁻²				mg · m ⁻²			
1	S	198.2 a	80.3 a	278.5 a	2.47	189.2 a	78.1 a	267.3 a	2.42
2	SV _{9:1}	232.4 bc	99.3 bc	331.7 bcd	2.34	206.5 ab	89.8 b	296.3 b	2.30
3	SV _{4:1}	234.3 bc	104.7 bcd	339.0 cde	2.24	235.4 c	105.6 c	341.0 cde	2.23
4	SV _{3:1}	238.6 c	109.9 bcd	348.5 de	2.17	240.1 c	111.1 c	351.2 cde	2.16
5	SV _{1:1}	242.6 c	115.5 d	358.1 e	2.10	242.4 c	115.3 c	357.7 d	2.10
6	SV _{9:1} +EW ₁₀	224.0 bc	97.8 b	321.8 bc	2.29	199.8 a	89.3 b	289.1 b	2.24
7	SV _{9:1} +EW ₂₀	214.4 ab	97.4 b	311.8 b	2.20	194.7 a	88.4 ab	283.1 ab	2.20
8	SV _{4:1} +EW ₁₀	230.2 bc	105.6 bcd	335.8 bcd	2.18	229.8 c	106.2 c	336.0 cd	2.16
9	SV _{4:1} +EW ₂₀	227.8 bc	106.4 bcd	334.2 bcd	2.14	225.9 bc	106.5 c	333.4 c	2.12
10	SV _{3:1} +EW ₁₀	238.6 c	109.9 bcd	348.5 de	2.17	237.9 c	111.2 c	349.1 cde	2.14
11	SV _{3:1} +EW ₂₀	237.2 c	109.3 bcd	346.5 cde	2.17	235.1 c	110.3 c	345.4 cde	2.13
12	SV _{1:1} +EW ₁₀	240.4 c	113.5 d	353.9 de	2.12	238.8 c	114.8 c	353.6 cd	2.08
13	SV _{1:1} +EW ₂₀	237.7 c	112.1 cd	349.8 de	2.12	234.3 c	114.4 c	348.7 cde	2.05
1–13		230.49	104.75	335.24	2.21	223.84	103.15	327.07	2.18
2–5		236.98	107.35	344.33	2.21	231.10	105.45	336.55	2.20
6–13		231.29	106.50	337.79	2.17	224.54	105.14	329.80	2.14
6,8,10,12		233.30	106.70	340.00	2.19	226.58	105.38	331.95	2.155
7,9,11,13		229.28	106.30	335.58	2.16	222.50	104.90	327.65	2.125
LSD _{0.05}		20.606	13.418	24.964	–	22.055	10.996	19.258	–

3. V. – 3 May, 9. V. – 9 May, days a.e – days after emergence of plants, chl. *a* – chlorophyll *a*, LSD_{0.05} – least significant difference at the level $\alpha = 0.05$; different letter behind a numerical value respond to the statistically significant difference at the level 95.0%.

EW, earthworms; Vc, vermicompost.

leaves increased by $15.1 \text{ mg} \cdot \text{kg}^{-1}$ in comparison to the content detected on the 42nd day of the growing season. A higher content of vitamin C in older than younger leaves of lettuce and broccoli was shown by Omary et al. (2003) and Yamada et al. (2003). Similarly, Cheptoo et al. (2019) claim a higher content of vitamin C in older than younger leaves of amaranth plants. On the contrary, the decrease in the content of vitamin C in dill leaves in successive days of the growing season was measured by Lisiewska et al. (2006).

During both terms of radish harvesting the content of vitamin C in the leaves dominated over that in the roots in all treatments of the experiment. On average, in all the treatments the content of vitamin C was 2.50 times higher in the leaves than in the roots on the 36th day of the growing season and 1.98 times higher on the 42nd of the growing season.

Effect of Vc

Along with increasing proportions of Vc in the growing media (Treatments 2–5), the content of vitamin C decreased in the radish phytomass aboveground and underground (Table 6). The reason was that the increasing proportion of Vc in the soil (S+Vc = 9:1; 4:1, 3:1, 1:1) also enhanced the content of inorganic nitrogen (the Vc contained 33.7 times more $N_{\min}$ than the soil) (Table 1). The negative correlation was usually recorded between the inorganic nitrogen content in the soil and the vitamin C content in plants (Lisiewska and Kmiecik, 1996). The opposite effect of Vc on increase in the

vitamin C content in cabbage leaves (*Brassica oleracea*) was presented by Nurhidayati et al. (2016).

The highest content of vitamin C in the roots and leaves was detected in the control treatment without Vc (Treatment 1). Conversely, the lowest content was recorded in the treatment with mixed Vc and S in the 1:1 ratio (Treatment 5), i.e. in the treatment where the highest quantity of Vc was used.

Along with the increasing content of Vc in the soil substrate, the roots-to-leaves vitamin C content ratio had increased (Table 6). It is evident that the decline in vitamin C content was more considerable in the leaves than in the roots as a result of higher applied doses of Vc. Similarly, the statistical significance of the decreases of vitamin C contents between Treatments 2–5 was more distinctive in the evaluation of the vitamin C contents in leaves compared with roots. These data prove the fact that Vc decreased the vitamin C content more heavily in leaves than in roots, as a result of more intensive ageing of radish leaves than roots.

The radish roots from the last harvest (9 May) had a higher content of vitamin C than roots from the previous harvest (3 May). On the contrary, in the leaves the content of vitamin C declined between 3 and 9 May. The older leaves contained less vitamin C than the younger ones.

Effect of EW

Embedding of EW into the soil substrates containing Vc did not significantly affect the content of vitamin C

Table 6. Impact of Vc and EW on vitamin C content in radish roots and leaves.

Treatment		3. V. (36 days a.e)		9. V. (42 days a.e)		3. V.	9. V.
		Roots	Leaves	Roots	Leaves	R:L	
No.	Mark	$\text{mg} \cdot \text{kg}^{-1}$					
1	S	111.22 c	350.44 e	159.72 e	295.84 g	0.317	0.540
2	SVc _{9:1}	100.14 b	260.54 d	118.68 d	241.32 ef	0.384	0.492
3	SVc _{4:1}	94.40 ab	237.95 c	110.00 bcd	222.74 d	0.397	0.494
4	SVc _{3:1}	92.00 ab	215.23 ab	105.20 abc	206.50 bc	0.427	0.509
5	SVc _{1:1}	87.20 a	202.00 a	99.42 a	188.98 a	0.432	0.526
6	SVc _{9:1} +EW ₁₀	98.92 b	257.06 d	117.82 d	240.88 ef	0.385	0.489
7	SVc _{9:1} +EW ₂₀	99.82 b	251.42 cd	118.00 d	242.36 f	0.397	0.487
8	SVc _{4:1} +EW ₁₀	94.88 ab	238.08 c	110.00 bcd	224.06 d	0.399	0.491
9	SVc _{4:1} +EW ₂₀	95.62 ab	239.64 c	111.80 cd	229.88 de	0.399	0.486
10	SVc _{3:1} +EW ₁₀	92.24 ab	216.34 ab	105.60 abc	209.50 c	0.426	0.504
11	SVc _{3:1} +EW ₂₀	93.60 ab	217.44 b	106.80 abc	209.70 c	0.430	0.509
12	SVc _{1:1} +EW ₁₀	88.10 a	204.64 ab	101.00 ab	192.66 a	0.431	0.524
13	SVc _{1:1} +EW ₂₀	89.10 a	206.88 ab	101.80 ab	196.66 ab	0.431	0.518
1–13		95.17	238.28	112.76	223.16	0.404	0.505
2–5		93.44	228.93	108.33	214.89	0.410	0.505
6–13		94.04	228.94	109.10	218.21	0.412	0.501
6,8,10,12		93.54	229.03	108.61	216.78	0.410	0.502
7,9,11,13		94.54	228.85	109.60	219.65	0.414	0.500
LSD _{0.05}		9.463	14.03	9.407	11.520	–	–

No. – number, 24. IV. – 24 April, 3. V. – 3 May, 9. V. – 9 May, days a.e – days after emergence of plants, LSD_{0.05} – least significant difference at the level $\alpha = 0.05$; different letter behind a numerical value respond to the statistically significant difference at the level of 95.0%.

EW, earthworms; Vc, vermicompost.

in radish phytomass aboveground and underground (Treatment 2 vs Treatments 6 and 7, Treatment 3 vs Treatments 8 and 9, Treatment 4 vs Treatments 10 and 11, Treatment 5. vs Treatments 12 and 13) (Table 5). In both harvesting terms the vitamin C contents measured in the radish roots and leaves were the same in the variants 6–13, or statistically insignificantly higher than the contents of vitamin C measured in the variants 2–5. The average increases were 0.60 and $0.57 \text{ mg} \cdot \text{kg}^{-1}$ (root) and $0.01 \text{ mg} \cdot \text{kg}^{-1}$ and $3.52 \text{ mg} \cdot \text{kg}^{-1}$ in the leaves. Xiang et al. (2016) published similar data; they also measured the statistically insignificant impact of EW of *E. fetida* specie on the vitamin C content in papaya fruits (*Carica papaya* L.).

The addition of EW to the treatment with 10% proportion of Vc of the total substrate weight tended to decrease the content of vitamin C in radish roots and leaves in comparison with the treatments containing more Vc (20%, 25% and 50%). The drops were insignificant. The probable reason for this insignificant difference was the insufficient quantity of fodder for red worms in the substrate with 10% proportion of Vc. The subsequent attack of root hairs by the EW induced a stress in radish plants. The positive effect of the EW (*P. corethrurus*) up to 25 individuals per m^2 on the vitamin C content in cabbage leaves was presented by Nurhidayati et al. (2016). On the contrary, along with the increasing number of EW in soil at above 25 individuals (50, 75 and 100 individuals per 1 m^2) the content of vitamin C in cabbage leaves decreased proportionally.

Effect of the number of EW

The number of EW did not significantly influence the vitamin C content in radish roots and leaves (Treatment 6 vs Treatment 7, Treatment 8 vs. Treatment 9, Treatment 10 vs. Treatment 11, Treatment 12 vs Treatment 13 – Table 6). Nevertheless, it can be claimed that the content of vitamin C was slightly higher with 20 EWs added per pot than with 10 EWs added per pot. The similar positive tendency of the impact of a higher number of EWs on the vitamin C content was measured also in the leaves.

Nitrate content

Effect of time

In the radish plants sampled during the first harvest (3 May), the nitrate content (NaNO_3) was higher than in plants sampled during the second harvest (9 May). The average decline of the nitrate contents in radish roots in the course of 6 days, i.e. between both harvest terms, was $197.57 \text{ mg} \cdot \text{kg}^{-1}$ and $153.75 \text{ mg} \cdot \text{kg}^{-1}$ in leaves, respectively – in all variants of the experiment (Table 7). The decrease in nitrate content in time (content of nitrates on 3 and 9 May) occurred in all the treatments. The decline in nitrate content with the following days of the growing season was also presented by Li et al. (2017). In their experiments the contents of nitrates in tobacco leaves measured from the 45th to 75th day after transplanting varied approximately from $100 \text{ mg} \cdot \text{kg}^{-1}$ to $1,250 \text{ mg} \cdot \text{kg}^{-1} \text{ NO}_3^- \text{--N}$. On the contrary, Tabaglio et al. (2020) did not record the unambiguous dependence between the nitrate content in lettuce leaves and

Table 7. Impact of Vc and EW on the nitrates (NaNO_3) content in radish roots and leaves.

Treatment		3. V. (36 days a.e)		9. V. (42 days a.e)		3. V.	9. V.
		Roots	Leaves	Roots	Leaves	R:L	
No.	Mark	$\text{mg} \cdot \text{kg}^{-1}$					
1	S	652.44 a	268.82 a	458.86 a	256.38 a	2.427	1.790
2	SV _{9:1}	1,680.32 c	583.10 b	1,127.08 c	550.86 b	2.882	2.046
3	SV _{4:1}	2,562.50 e	948.20 c	2,490.42 e	880.82 c	2.702	2.827
4	SV _{3:1}	2,633.00 e	1,272.42 d	2,390.52 de	1,098.42 d	2.069	2.176
5	SV _{1:1}	3,078.68 f	1,673.54 e	3,000.62 f	1,248.00 e	1.840	2.404
6	SV _{9:1} +EW ₁₀	1,477.26 b	566.20 b	981.78 b	530.40 b	2.609	1.851
7	SV _{9:1} +EW ₂₀	1,439.88 b	566.20 b	980.16 b	522.00 b	2.543	1.878
8	SV _{4:1} +EW ₁₀	2,342.48 d	920.46 c	2,335.00 d	864.76 c	2.545	2.700
9	SV _{4:1} +EW ₂₀	2,278.82 d	900.00 c	2,307.82 d	864.76 c	2.532	2.669
10	SV _{3:1} +EW ₁₀	2,578.82 e	1,200.00 d	2,382.50 de	1,056.76 d	2.149	2.255
11	SV _{3:1} +EW ₂₀	2,562.62 e	1,200.00 d	2,380.00 de	1,040.20 d	2.136	2.288
12	SV _{1:1} +EW ₁₀	3,004.06 f	1,650.86 e	2,950.00 f	1,248.00 e	1.820	2.364
13	SV _{1:1} +EW ₂₀	3,012.22 f	1,658.98 e	2,950.00 f	1,248.80 e	1.816	2.362
1–13		2,254.09	1,031.45	2,056.52	877.70	2.19	2.34
2–5		2,488.63	1,119.32	2,252.16	944.53	2.22	2.38
6–13		2,337.02	1,082.84	2,158.41	921.96	2.16	2.34
6,8,10,12		2,350.66	1,084.38	2,162.32	924.98	2.16	2.34
7,9,11,13		2,323.39	1,081.30	2,154.50	918.94	2.15	2.34
LSD		98.884	77.286	116.116	132.053	–	–

No. – number, 24. IV. – 24 April, 3. V. – 3 May, 9. V. – 9 May, days a.e – days after emergence of plants, LSD_{0.05} – least significant difference at the level $\alpha = 0.05$; different letter behind a numerical value respond to the statistically significant difference at the level 95.0%.

EW, earthworms; Vc, vermicompost.

duration of lettuce growing season in the last 6 days before lettuce harvest.

In the experiment, a higher decrease of nitrates content in roots compared to leaves was the result of higher nitrates content in the roots compared to the leaves. In the roots there was on average 2.26 times more nitrates than in the leaves in both the samplings. The opposite effect, i.e. higher content of nitrates in vegetable leaves than in roots is stated by Santamaria et al. (1999). Similarly, Zhen and Leigh (1990) detected a higher content of nitrates in wheat leaves than in roots. Conversely, the higher content of nitrates recorded in roots than in leaves corresponds with the data of Anjana and Iqbal (2007), who explained that vegetables forming reserve organs have a different mechanism for nitrates storage than leafy vegetables. A higher content of nitrates in roots than in leaves of different plant species was presented by Black et al. (2002). The site of accumulation of nitrates in plants is determined by the localisation of mechanisms reducing nitrates (leaf, root), which depends on a plant species (Hucklesby et al., 1990).

Effect of Vc

Along with the increasing quantity of Vc in the soil substrate, the content of nitrates was increasing in radish roots and leaves (Table 7). In Treatments 2–5 the content of NaNO_3 in radish roots increased by $1,790.68 \text{ mg} \cdot \text{kg}^{-1}$ and in leaves by $769.33 \text{ mg} \cdot \text{kg}^{-1}$ on average in both sampling compared with the control variant 1. The increase in content in the roots was 4.22 times and in leaves it was 3.93 times higher. The increase of nitrates content in radish phytomass along with the increase of quantity of Vc in the substrate was a consequence of the well-known dependence of the content of nitrates in a plant on the content N_{in} in soil, on the dose of inorganic

nitrogen applied into soil in the form of the mineral or organic N fertilisers (Yuan et al., 2014; Adekiya et al., 2019). Low N doses do not increase the nitrate contents in plants (Liao et al., 2009). The increase in nitrates content was accompanied by a decrease in the vitamin C contents (Tables 7 and 8). The increase in nitrate contents and the decrease in the vitamin C content along with the growth of application dose of Vc were presented by Papathanasiou et al. (2012).

Effect of EW

The comparison of nitrate contents in Treatments 2–5 with Treatments 6–13 (Table 7) indicates that the EW in the growing media showed a tendency to decrease the nitrate contents in radish roots and leaves. On average, in Treatments 2–5 versus 6–13, the drop in the content was insignificant in the leaves, at the levels of 3.26% and 2.39% between both the harvest periods (3 and 9 May). The decrease in the nitrate contents in the roots was significant in two treatments (with 10% and 20% content of Vc) and was insignificant in two instances (treatment with 25% and 50% content of Vc). On average, in Treatments 2–5 vs 6–13 the decline in nitrates contents in radish roots was 6.09% and 4.16% during the harvest period on 3 and 9 May, respectively. Based on the information that EW increases the nitrogen mobility in soils and the quantity of washed-up N-NO_3 from soil (Domínguez et al., 2004; Marhan et al., 2015), one may expect in the treatments with EW, an increased content of nitrates in radish plants. This assumption, however, was not true.

Interdependences between the measured parameters

Photosynthesis is a key process of maintaining life on the Earth, plant growth and the achievement of

Table 8. Relationship between the qualitative (nitrates and vitamin C contents) and quantitative yield parameters.

Parameter		Date of sampling	
		3. V. (36 days after emergence of plants)	9. V. (42 days after emergence of plants)
Dependent	Independent	Correlation coefficient (<i>r</i>)	
Weight of roots	Total chlorophyll	0.514 ⁺⁺	0.515 ⁺⁺
Diameter of roots		0.488 ⁺⁺	0.488 ⁺⁺
Weight of leaves		0.600 ⁺⁺	0.777 ⁺⁺
Vitamin C in roots	Total chlorophyll	−0.621 ⁺⁺	−0.740 ⁺⁺
	Diameter of roots	−0.340 ⁺	−0.585 ⁺⁺
	Weight of roots	−0.365 ⁺⁺	−0.645 ⁺⁺
	NaNO_3 in roots	−0.708 ⁺⁺	−0.773 ⁺⁺
Vitamin C in leaves	Total chlorophyll	−0.738 ⁺⁺	−0.843 ⁺⁺
	Weight of leaves	−0.730 ⁺⁺	−0.774 ⁺⁺
	NaNO_3 in leaves	−0.836 ⁺⁺	−0.900 ⁺⁺
NaNO_3 in roots	Total chlorophyll	0.759 ⁺⁺	0.911 ⁺⁺
	Diameter of roots	0.441 ⁺⁺	0.436 ⁺⁺
	Weight of roots	0.500 ⁺⁺	0.490 ⁺⁺
NaNO_3 in leaves	Total chlorophyll	0.707 ⁺⁺	0.880 ⁺⁺
	Weight of leaves	0.515 ⁺⁺	0.729 ⁺⁺

No.-52, + statistically significant ($p < 0.05$), ++statistically highly significant ($p < 0.01$), n – number of measurements.

desired yields (Ashraf et al., 2016; Roca et al., 2016). Chlorophylls play a key role in it. The dependence between the weights of radish phytomass, as reached on the 36th and 42nd day of the growing season and the total chlorophylls contents (Tch) in leaves, as expressed by the correlation coefficient r , was highly evident. A higher dependence was recorded between the weight of leaves and the content of Tch than between the root weights and Tch content (Table 8). It is presumable that plants with higher contents of chlorophylls form higher phytomass of roots and leaves than those of plants with lower chlorophylls contents.

Vegetables represent an important component of human nutrition, while also having an impact on human health. Therefore, vegetable growers should apply such growing procedures which allow the achievement of high-quality yields. Vitamin C is a significant antioxidant substance that decreases the threat of arteriosclerosis, diseases of the circulatory system and some neoplasms (Korus, 2011). Together with other antioxidants, it is a suitable vegetable also for diabetics because of its antidiabetic effects (Banihani, 2017). The data in Table 8 indicate that a negative dependence exists between the weight of roots and the contents of vitamin C, and a positive relationship between the weight of roots and the content of nitrates. Similar dependences were observed between the weight of leaves and the contents of vitamin C and the contents of nitrates in leaves. As the weight of plant roots and leaves and the content of chlorophylls depend considerably on the doses of N (Marschner, 2005), and also the chlorophylls content depends significantly on the N application rates and nitrogen content in the plant (Hallik et al., 2009; Gholizadeh et al., 2017), it is evident that the presented dependences (Table 8) affirm the impact of N nutrition on the vegetable quality, which is usually negative. Along with an increase of the N_{in} content in soil, the formation of phytomass and the quantity of nitrates is increased in it, akin to the quantity of vitamin C decreases (Chessin and Hicks, 1987; Lominadze and Nakashidze, 2016).

CONCLUSIONS

The impact of Vc on radish root and leaf weights increase was measurable on the 27th day of the growing season. With increasing quantity of Vc, the total chlorophylls content also increased proportionally. While the vitamin C content was decreasing, the nitrates content was rising in both the aboveground and underground phytomass. The weights of radish roots and leaves increased up to 20% of Vc content in the substrate. The Vc content above 20% led to a drop in root and leaves phytomass formation. The root and leaves yield was higher with 50% Vc content in the substrate compared with the control treatment.

The EW had mostly a negative impact on the radish phytomass formation, particularly on the root weight and root diameter. The highest percentage of root weight drop cultivated in the treatments with EW was in the

treatment where the growing medium contained the least quantity of Vc (10%), so it was the least quantity of fodder for the EW. On the contrary, the least percentage of root weight decrease, as resulted from the presented EW, was detected in the treatment where the substrate contained more Vc. The data allow to hypothesise that if red worms have sufficient fodder in their environment (compost, Vc, crop residues, etc.), they will not significantly attack the root hairs of young plants.

The impact of EW on the total chlorophylls, vitamin C and nitrate contents in the roots and leaves was non-significant. The number of EW did not influence the root diameter; the content of vitamin C, however, affected the root weight. The dependence between the roots (leaves) weight and vitamin C contents in roots (leaves) was negative, while the dependence between the roots (leaves) weight and nitrates content in the roots (leaves) was positive.

The rapid positive effect of Vc on the phytomass of cultivated plants makes this organic fertiliser possible to be applied in the spring before sowing crops. Regarding the effectiveness of the use of Vc, the proportion of Vc in the total substrate should not exceed 20%. Also, in soil substrates with a significant number of EW, it is not appropriate to grow radish, that is, plants with a short growing season.

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AUTHOR CONTRIBUTIONS

P.K. contributed to the experiments and manuscript preparation. P.K. and K.O. designed the overall study. K.O. performed the chlorophyll content analyses and English correction of the manuscript. S.S. and I.L.-S. contributed to the statistical analyses of measured data and helped with the manuscript preparation.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

- ADEKIYA, A. O., AGBEDE, T. M., ABOYEJI, C. M., DUNSIN, O., AND SIMEON, V. T. (2019). Effects of biochar and poultry manure on soil characteristics and the yield of radish. *Scientia Horticulturae*, 243, 457–463.
- AKIYAMA, H., AND TSURUTA, H. (2003). Effect of organic matter application on N_2O , NO , and NO_2 fluxes from an Andisol field. *Global Biogeochemical Cycles*, 17, 1100, doi: 10.1029/2002GB002016.
- ANJANA, S. U., AND IQBAL, M. (2007). Nitrate accumulation in plants, factors affecting the process, and human health implications. A review. *Agronomy for Sustainable Development*, 27, 45–57.

- ASHRAF, R., SULTANA, B., IQBAL, M., AND MUSHTAQ, M. (2016). Variation in biochemical and antioxidant attributes of *Raphanus sativus* in response to foliar application of plant leaf extracts as plant growth regulator. *Journal of Genetic Engineering and Biotechnology*, 14, 1–8.
- BANIHANI, S. A. (2017). Radish (*Raphanus sativus*) and diabetes. *Nutrients*, 9(9), 1014, doi: 10.3390/nu9091014.
- BERTI, M., FISCHER, S., WILCKENS, R., AND HEVIA, F. (2009). Flax seed response to N, P, AND K fertilization in south central Chile. *Chilean Journal of Agricultural Research*, 69, 145–153.
- BIELEK, P., AND KUDEJAROV, V. N. (1991). *Nitrogen cycle in the present agriculture*. Bratislava, Slovakia: Príroda.
- BHATNAGAR, M. K., AND AZHAR, M. (2016). A study of chemical composition of some leafy vegetables of fatehpur district. *International Journal of Science and Research*, 5, 408–410.
- BLACK, B. L., FUCHIGAMI, L. H., AND COLEMAN, G. D. (2002). Partitioning of nitrate assimilation among leaves, stems and roots of poplar. *Tree Physiology*, 22, 717–724.
- BREMNER, J. M. (1960). Determination of nitrogen in soil by the Kjeldahl method. *Journal of Agricultural Science*, 55, 11–33.
- BROWN, G. G., BAROIS, I., AND LAVELLE, P. (2000). Regulation of soil organic matter dynamics and microbial activity in the drilosphere and the role of interactions with other edaphic functional domains. *European Journal of Soil Biology*, 36, 177–198.
- BROWN, G. G., EDWARDS, C. A., AND BRUSSAARD, L. (2004). How earthworms effect plant growth: Burrowing into the mechanisms. In C. A. Edwards (Eds), *Earthworm ecology* (pp. 13–45). Boca Raton, USA: CRC Press.
- CHAKRABORTY, B., KUNDU, M., AND CHATTOPADHYAY, R. N. (2016). Organic farming with bio-mulching – A new paradigm for sustainable leaf yield & quality of mulberry (*Morus alba* L.) under rainfed lateritic soil condition. *Agriculture and Agricultural Science Procedia*, 11, 31–37.
- CHAUDHURI, P. S., PAUL, T. K., DEY, A., DATTA, M., AND DEY, S. K. (2016). Effects of rubber leaf litter vermicompost on earthworm population and yield of pineapple (*Ananas comosus*) in West Tripura, India. *International Journal of Recycling of Organic Waste in Agriculture*, 5, 93–103.
- CHEPTOO, G., OWINO, W., AND KENJI, G. (2019). Nutritional quality, bioactive compounds and antioxidant activity of selected African indigenous leafy vegetables as influenced by maturity and minimal processing. *African Journal of Food Agriculture Nutrition and Development*, 19, 14769–14789.
- CHESSIN, D. A., AND HICKS, J. R. (1987). The effect of nitrogen fertilizer, herbicides, and cultivar on nitrogen components of carrot roots. *Scientia Horticulturae*, 33, 67–73.
- CONG, W.-F., CHRISTENSEN, B. T., AND ERIKSEN, J. (2019). Soil nutrient levels define herbage yield but not root biomass in a multispecies grass-legume ley. *Agriculture, Ecosystems & Environment*, 276, 47–54.
- COOKE, G. W. (1982). *Fertilizing for maximum yield* (pp. 465). Granada and London: ELBS.
- DENG, M., HOU, M., OHKAMA-OHTSU, N., YOKOYAMA, T., TANAKA, H., NAKAJIMA, K., OMATA, R., AND BELLINGRATH-KIMURA, S. D. (2017). Nitrous oxide emission from organic fertilizer and controlled release fertilizer in tea fields. *Agriculture*, 7(3), 29, doi: 10.3390/agriculture7030029.
- DOAN, T. T., NGO, P. T., RUMPEL, C., AND NGUYEN, B. V. (2013). Interactions between compost, vermicompost and earthworms influence plant growth and yield: A one-year greenhouse experiment. *Scientia Horticulturae*, 160, 148–154.
- DOMÍNGUEZ, J., BOHLEN, P. J., AND PARMELEE, R. W. (2004). Earthworms increase nitrogen leaching to greater soil depths in row crop agroecosystems. *Ecosystems*, 7, 672–685.
- DU, Y.-L., HE, M.-M., XU, M., YAN, Z., ZHOU, Y.-Y., GUO, G.-L., NIE, J., WANG, L.-Q., HOU, H., AND LI, F.-S. (2014). Interactive effects between earthworms and maize plants on the accumulation and toxicity of soil cadmium. *Soil Biology and Biochemistry*, 72, 193–202.
- DZIADOWIEC, H., AND GONET, S. S. (1999). *A guide to the methods for determination of soil organic matter* (p. 65). Warszawa, Poland: Prace Komisji Naukowej PTG.
- EBBS, S., AND UCHIL, S. (2008). Cadmium and zinc induced chlorosis in Indian mustard [*Brassica juncea* (L.) Czern] involves preferential loss of chlorophyll b. *Photosynthetica*, 46, 49–55.
- ELMER, W. H. (2016). Effect of leaf mold mulch, biochar, and earthworms on mycorrhizal colonization and yield of asparagus affected by Fusarium crown and root rot. *Plant Disease*, 100, 2507–2512.
- EUROPEAN COMMISSION (EC). (1991). Directive of 12th December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC). *Official Journal of the European Communities*, L375, 1–8.
- EUROPEAN COMMISSION (EC). (1999). Council Regulation (EC) No 1804/1999 of 19 July 1999 supplementing Regulation (EEC) No 2092/91 on organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs to include livestock production. *Official Journal the European Communities*, L22, 1–28.
- GARG, P., GUPTA, A., AND SATYA, S. (2006). Vermicomposting of different types of waste using *Eisenia foetida*: A comparative study. *Bioresource Technology*, 97, 391–395.

- GHOLAMI, H., FARD, F. R., SAHARKHIZ, M. J., AND GHANI, A. (2018a). Yield and physicochemical properties of inulin obtained from Iranian chicory roots under vermicompost and humic acid treatments. *Industrial crops. Industrial Crops and Products*, 123, 610–616.
- GHOLAMI, H., SAHARKHIZ, M. J., FARD, F. R., GHANI, A., AND NADAF, F. (2018b). Humic acid and vermicompost increased bioactive components, antioxidant activity and herb yield of chicory (*Cichorium intybus* L.). *Biocatalysis and Agricultural Biotechnology*, 14, 286–292.
- GHOLIZADEH, A., SABERIOON, M., BORŮVKA, L., WAYAYOK, A., AND SOOM, M. A. M. (2017). Leaf chlorophyll and nitrogen dynamics and their relationship to lowland rice yield for site-specific paddy management. *Information Processing in Agriculture*, 4, 259–268.
- VAN GROENIGEN, J. W., LUBBERS, I. M., VOS, H. M. J., BROWN, G. G., DE DEYN, G. B., AND GROENIGEN, K. J. (2014). Earthworms increase plant production: a meta-analysis. *Scientific Reports*, 4, 6365, doi: 10.1038/srep06365.
- HALLIK, L., KULLA, O., NIINEMETS, Ü., AND AANA, A. (2009). Contrasting correlation networks between leaf structure, nitrogen and chlorophyll in herbaceous and woody canopies. *Basic and Applied Ecology*, 10, 309–318.
- HUBÁČEK, J., AND BERNATZIK, K. (1976). Evaluation of some methods of nitrate nitrogen determination in plant material. *Chemické listy*, 70, 513–524 (in Czech).
- HUCKLESBY, D. P., EMES, M. J., BOWSHER, C. G., AND CAMMACK, R. (1990). Nitrite reduction in the roots and leaves of *Pisum Sativum*. In W. R. Ullrich, C. Rigano, A. Fuggi, and P. J. Aparicio (Eds), *Inorganic nitrogen in plants and microorganisms* (pp. 210–215). Berlin–Heidelberg, Germany: Springer-Verlag.
- KMEŤOVÁ, M., KOVÁČIK, P., AND RENČO, M. (2013). The effect of different doses application of dry granulated vermicompost on yield parameters of maize and potatoes. *Acta Fytotechnica et Zootechnica*, 1, 8–14.
- KONG, X. B., LAL, R., LI, B. G., LIU, H. B., LI, K. J., FENG, G. L., ZHANG, Q. P., AND ZHANG, B. B. (2014). Fertilizer intensification and its impacts in China's HHH plains. *Advances in Agronomy*, 125, 135–169.
- KORUS, A. (2011). Level of vitamin C, polyphenols, and antioxidant and enzymatic activity in three varieties of kale (*Brassica oleracea* L. var. *acephala*) at different stages of maturity. *International Journal of Food Properties*, 14, 1069–1080.
- KOVÁČIK, P. (1997). *Analysis of soils, plants, fertilizers and calculation of nutrient doses to field and garden crops* (p. 104). Nitra, Slovakia: SUA in Nitra (in Slovak).
- KOVÁČIK, P., HAVRENTOVÁ, M., AND ŠIMANSKÝ, V. (2014). Growth and yield stimulation of winter oilseed rape (*Brassica napus* L.) by Mg-Titanit fertiliser. *Agriculture (Poľnohospodárstvo)*, 60, 132–141.
- KOVÁČIK, P., ŠALAMÚN, P., AND WIERZBOWSKA, J. (2018a). Vermikompost and *Eisenia foetida* as factors influencing the formation of radish phytomass. *Agriculture (Poľnohospodárstvo)*, 64, 49–56.
- KOVÁČIK, P., ŠALAMÚN, P., SMOLEŇ, S., ŠKARPA, P., ŠIMANSKÝ, V., AND MORAVČÍK, E. (2018b). Determination of the carrot (*Daucus carota* L.) yields parameters by vermicompost and earthworms (*Eisenia foetida*). *Slovak Journal of Food Sciences*, 12, 520–526.
- KUMAR, S., KUMAR, R., PAL, A., AND CHOPRA, D. S. (2019). Enzymes. In E. M. Yahia and A. Carrillo-López (Eds), *Postharvest physiology and biochemistry of fruits and vegetable* (pp. 335–358). Duxford, UK: Woodhead Publishing Limited.
- LICHTENTHALER, H. K. (1987). Chlorophylls and carotenoids: Pigments of photosynthetic biomembranes. *Methods in Enzymology*, 148, 350–382.
- LI, H., CONG, R., REN, T., LI, X., MA, C., ZHENG, L., ZHANG, Z., AND LU, J. (2015). Yield response to N fertilizer and optimum N rate of winter oilseed rape under different soil indigenous N supplies. *Field Crops Research*, 181, 52–59.
- LI, Y., SHI, H., YANG, H., ZHOU, J., WANG, J., BAI, R., AND XU, D. (2017). Difference between burley tobacco and flue-cured tobacco in nitrate accumulation and chemical regulation of nitrate and TSNA contents. *Journal of Chemistry*, 2017, 4357456, doi: 10.1155/2017/4357456.
- LIAO, Y., RONG, X., ZHENG, S., LIU, Q., FAN, M., PENG, J., AND XIE, G. (2009). Influences of nitrogen fertilizer application rates on radish yield, nutrition quality, and nitrogen recovery efficiency. *Frontiers of Agriculture in China*, 3, 122–129.
- LISIEWSKA, Z., AND KMIECIK, W. (1996). Effects of level of nitrogen fertilizer, processing conditions and period of storage of frozen broccoli and cauliflower on vitamin C retention. *Food Chemistry*, 57, 267–270.
- LISIEWSKA, Z., KMIECIK, W., AND KORUS, A. (2006). Content of vitamin C, carotenoids, chlorophylls and polyphenols in green parts of dill (*Anethum graveolens* L.) depending on plant height. *Journal of Food Composition and Analysis*, 19, 134–140.
- LEÓN, A. P., MARTÍN, J. P., AND CHIESA, A. (2012). Vermicompost application and growth patterns of lettuce (*Lactuca sativa* L.). *Agricultura Tropica et Subtropica*, 45, 134–139.
- LOMINADZE, S., AND NAKASHIDZE, N. (2016). The influence of nitrogen fertilizers on nitrate accumulation in leaves of orange Washington Navel. *Annals of Agrarian Science*, 14, 233–236.
- MANOJLOVIĆ, M., ČABILOVSKI, R., NIKOLIĆ, L., DŽIGURSKI, D., ŠEREMEŠIĆ, S., AND BAVEC, M. (2017). Ground cover management and farmyard manure effects on soil nitrogen dynamics, productivity and economics of organically grown lettuce (*Lactuca sativa* L.

- subsp. *secalina*). *Journal of Integrative Agriculture*, 16, 947–958.
- MARHAN, S., AUBERT, J., AND POLL, CH. (2015). Additive effects of earthworms, nitrogen-rich litter and elevated soil temperature on N₂O emission and nitrate leaching from an arable soil. *Applied Soil Ecology*, 86, 55–61.
- MARSCHNER, H. (2005). *Mineral nutrition of higher plants* (p. 889). San Diego, CA/London: Elsevier Academic Press.
- MEHLICH, A. (1984). Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. *Communication in Soil Science and Plant Analysis*, 15, 1409–1416.
- NAJJARI, F., AND GHASEMI, S. (2018). Changes in chemical properties of sawdust and blood powder mixture during vermicomposting and the effects on the growth and chemical composition of cucumber. *Scientia Horticulturae*, 232, 250–255.
- NURHIDAYATI, N., ALI, U., AND MURWANI, I. (2016). Yield and quality of cabbage (*Brassica oleracea* L. var. *capitata*) under organic growing media using vermicompost and earthworm *Pontoscolex corethrurus* inoculation. *Agriculture and Agricultural Science Procedia*, 11, 5–13.
- NOMAN, A., ALI, Q., MAQSOOD, J., IQBAL, N., JAVED, M. T., RASOOL, N., AND NASEEM, J. (2018). Deciphering physio-biochemical, yield, and nutritional quality attributes of water-stressed radish (*Raphanus sativus* L.) plants grown from Zn-Lys primed seeds. *Chemosphere*, 195, 175–189.
- NOVICHKOVA, N. S., ROMANOVA, A. K., IGNAT'EV, A. R., VLASOVA, T. A., KRESLAVSKII, V. D., AND IVANOV, B. N. (2006). Carbonic anhydrase in leaves during radish plant ontogeny and glucose effect. *Russian Journal of Plant Physiology*, 53, 439–448.
- NWEKE, I. A. (2017). Effect of compost and earthworm production on soil properties, growth and dry matter yield of maize in crude oil degraded soil. *Journal of Soil Science and Environmental Management*, 8, 1–10.
- OMARY, M. B., BROVELLI, E. A., PUSATERI, D. J., DAVID, P., RUSHING, J. W., AND FONSECA, J. M. (2003). Sulforaphane potential and vitamin C concentration in developing heads and leaves of broccoli (*Brassica oleracea* var. *italica*). *Journal of Food Quality*, 26, 523–530.
- OSONE, Y., AND TATENO, M. (2003). Effects of stem fraction on the optimization of biomass allocation and maximum photosynthetic capacity. *Functional Ecology*, 17, 627–636.
- PAPATHANASIOU, F., PAPADOPOULOS, I., TSAKIRIS, I. AND TAMOUTSIDIS, E. (2012). Vermicompost as a soil supplement to improve growth, yield and quality of lettuce (*Lactuca sativa* L.). *Journal of Food, Agriculture & Environment*, 10, 677–682.
- POORTER, H., NIKLAS, K. J., REICH, P. B., OLEKSYN, J., POOT, P., AND MOMMER, L. (2012). Biomass allocation to leaves, stems and roots: Meta-analyses of interspecific variation and environmental control. *New Phytologist*, 193, 30–50.
- ROCA, M., CHEN, K., AND PÉREZ-GÁLVEZ, A. (2016). Chlorophylls. In R. Carle and R. Schweiggert (Eds), *Handbook on natural pigments in food and beverages: Industrial applications for improving food color* (pp. 125–158). Cambridge, UK, Elsevier: Woodhead.
- RUIZ, E., ALONSO-AZCÁRATE, J., AND RODRÍGUEZ, L. (2011). *Lumbricus terrestris* L. activity increases the availability of metals and their accumulation in maize and barely. *Environmental Pollution*, 159, 722–728.
- RUSSELL, L., FARRISH, K., DAMOFF, G., COBLE, D., AND YOUNG, L. (2016). Establishment of earthworms on reclaimed lignite mine soils in east Texas. *Applied Soil Ecology*, 104, 125–130.
- SANTAMARIA, P., ELIA, A., SERIO, F., AND TODARO, E. (1999). A survey of nitrate and oxalate content in retail fresh vegetables. *Journal of the Science of Food and Agriculture*, 79, 1882–1888.
- SCHULTEN, H. R., AND SCHNITZER, M. (1998). The chemistry of soil organic nitrogen (review). *Biology and Fertility of Soils*, 26, 1–15.
- SHARMA, S., PRADHAN, K., SATYA, S., AND VASUDEVAN, P. (2005). Potentiality of earthworms for waste management and in other uses – A review. *The Journal of American Science*, 1, 1–16.
- SIZMUR, T., PALUMBO-ROE, B., WATTS, M. J., AND HODSON, M. E. (2011). Impact of the earthworm *Lumbricus terrestris* (L.) on As, Cu, Pb and Zn mobility and speciation in contaminated soils. *Environmental Pollution*, 159, 742–748.
- STAN, M., SORAN, M. L., AND MARUTOIU, C. (2014). Extraction and HPLC determination of the ascorbic acid content of three indigenous spice plants. *Journal of Analytical Chemistry*, 69, 998–1002.
- SUQIURA, D., AND TATENO, M. (2011). Optimal leaf-to-root ratio and leaf nitrogen content determined by light and nitrogen availabilities. *PloS ONE*, 6, e22236, doi: 10.1371/journal.pone.0022236.
- ŠESTÁK, Z., AND ČATSKÝ, J. (1966). *Methods of studying photosynthetic plant production* (p. 396). Praha, Czechoslovakia: Academia Praha.
- TABAGLIO, V., BOSELLI, R., FIORINI, A., GANIMEDE, C., BECCARI, P., SANTELLI, S., AND NERVO, G. (2020). Reducing nitrate accumulation and fertilizer use in lettuce with modified intermittent nutrient film technique (NFT) system. *Agronomy*, 10, 1208, doi: 10.3390/agronomy10081208.
- TRIPATHI, G., AND BHARDWAJ, P. (2004). Comparative studies on biomass production life cycles and composting efficiency of *Eisenia foetida* (Savigny) and *Lampito mauritii* (Kinberg). *Bioresource Technology*, 92, 275–283.
- VANĚK, V., LOŽEK, O., BALÍK, J., PAVLÍKOVÁ, D., AND TLUSTOŠ, P. (2013). *Výživa poľných a záhradných plodín* (p. 175). Nitra, Slovakia: Profi Press SK s.r.o.

- WRIGHT, S. F. AND UPADHYAY, A. A. (1998). A survey of soils for aggregate stability and glomalin glycoprotein produced by hyphae of arbuscular mycorrhizal fungi. *Plant and Soil*, 198, 97–107.
- WU, D., FENG, Y., XUE, L., LIU, M., YANG, B., HU, F., AND YANG, L. (2019). Biochar combined with vermicompost increases crop production while reducing ammonia and nitrous oxide emissions from a paddy soil. *Pedosphere*, 29, 82–94.
- XIANG, H., ZHANG, J., GUO, L., AND ZHAO, B. (2016). *In situ* earthworm breeding in orchards significantly improves the growth, quality and yield of papaya (*Carica papaya* L.). *PeerJ*, 4, e2752, doi: 10.7717/peerj.2752.
- XIAO, Z., WANG, X., KORICHEVA, J., KERGUNTEUIL, A., LE BAYON, R.-C., LIU, M., HU, F., AND RASMANN, S. (2018). Earthworms affect plant growth and resistance against herbivores: A meta-analysis. *Functional Ecology*, 32, 150–160.
- YAMADA, C., IWASAKI, Y., AND YOSHIDA, K. (2003). Effect of growth stage on contents of reducing sugar, ascorbic acid, oxalate and nitrate in spinach. *Journal of the Japanese Society for Nutrition and Food Science*, 56, 167–173.
- YUAN, W.-L., YUAN, S.-Y., WANG, Q.-F., GAN, C.-X., LIU, Y.-H., AND MEI, S.-Y. (2014). Effect of different amount of N-fertilizers on growth, root yield and nitrate content of white radishes in Southern China. *Journal of Food, Agriculture & Environment*, 12, 302–304.
- ZAYED, M. S., HASSANEIN, M. K. K., ESA, N. H., AND ABDALLAH, M. M. F. (2013). Productivity of pepper crop (*Capsicum annuum* L.) as affected by organic fertilizer, soil solarization, and endomycorrhizae. *Annals of Agricultural Science*, 58, 131–137.
- ZHEN, R. G., AND LEIGH, R. A. (1990). Nitrate accumulation by wheat (*Triticum aestivum*) in relation to growth and tissue N concentrations. *Plant and Soil*, 124, 157–160.

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