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Effect of the Genotype, Vermicompost Type and Dosage on Tomato Growth and Nutrient Uptake at Nursery Stage

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***Abstract* – The aim of this work was to evaluate (i) the effect of the type of vermicompost and (ii) the effect of the dosage of vermicompost on nutrient status and growth characteristics of tomato transplants; (iii) the variety response of tomato to vermicompost type and dose. The experiment was conducted in a greenhouse at Maritsa Vegetable Crops Research Institute, Bulgaria. The results revealed that synthetic fertilizers could be fully replaced by the vermicompost and there was no specific variety response to the treatments. The optimal dose for growing of tomato transplants is 25% from the volume of the potting mixture for two of the vermicomposts tested – Biohumus CM and Biohumus MM, while optimal dose of Lumbrical is 10% from the potting mixture volume. The results presented here constitute a new proof of feasibility of vermicompost as potting media constituent in sustainable culture practices and specifically in organic production.**

***Keywords* – Cluster Analysis, Potting Mixtures, *Solanum lycopersicum* L., Transplants, Worm Castings.**

I. Introduction

Vermicompost has been suggested as a cost-effective and environmentally friendly amendment for growing media in nurseries [1]. It was shown that vermicompost enhance seedling growth and development of a wide variety of crops [2]-[5]. The enhancement of plant growth is attributed to the fact that vermicompost improve the physical properties of the growing media, provide nutrients, readily available to plants as well as contain beneficial microorganisms and biologically active substances [6], [7]. In the literature it is well documented that containerized plants benefit from the presence of vermicompost in the potting mixture. A questionable is the issue with the quantity of the vermicompost in the mixture. Some authors suggested relatively small amounts of vermicompost in the growing substrate – 10-30% on volume basis [3], [5], [8]-[11], while others recommended as optimal high doses – 50, 75 and 100% [4], [12]. In some cases it was observed a negative effect of high dosage on plant growth [7]. These discrepancies are due to differences in the characteristics of vermicomposts used, since physical, chemical and biological properties of the vermicompost varied enormously depending on the used parent waste [4], [13]. In addition, specific variety response to different vermicomposts or different doses of vermicompost in the potting media should be considered when giving recommendations on the optimum proportion of vermicompost amendment to horticultural potting substrate [14].

High variability of vermicomposts parameters, on one hand, and on the other, their enormous potential as peat substitute and nutrient source impose need for more investigations on plant response to vermicompost with regard to its type, dose but also to the plant genotype. Therefore, the aim of this work was evaluate (i) the effect of different vermicomposts on nutrient status and growth characteristics of tomato transplants; (ii) the effect of the dosage of vermicompost on nutrient status and growth characteristics of tomato transplants (iii) the variety response of tomato to vermicompost type and dose in the potting mixture.

II. Material and Methods

The experiment was conducted during 2012 in an unheated greenhouse (N 42° 10’ 34”, E 24° 45’ 49”) at Maritsa Vegetable Crops Research Institute, Plovdiv, Bulgaria.

A. *Cultivation of tomato transplants*

Tomato seeds were sown, one seed per cell, in foamed polystyrene plug trays with 198 inverted pyramid cells, filled with peat moss and perlite in the ratio of 1:1 (v/v). At the first true leaf stage seedlings were transplanted into plastic pots containing 0.5 L of the corresponding potting mix (described below). The potting mix was prepared by unfertilized sphagnum peat moss (Rekyva, Lithuania), neutralized by 1 g L^{-1} $CaCO_3$ and perlite in the ratio of 1:1 (v/v), and further supplemented with vermicompost. Each pot contained one plant. Plants were irrigated with 100 mL non-chlorinated water twice a week. The duration of the experiment was 40 days.

B. *Experimental design*

Experimental design was carried out choosing three factors, namely: vermicompost type, concentration of vermicompost in the potting mix (dose) and tomato variety. They were coded as A, B and C, respectively. Three different vermicomposts were used as components of Factor A: Biohumus CM (Ecofarm Feratica, Bulgaria), Lumbrical (Ecofarm Prazova, Bulgaria) and Biohumus MM (Ecofarm Marinov-ECO, Bulgaria). Three concentrations of the vermicomposts in the potting mixtures were examined as Factor B: 0%, 10% and 25% from the potting mixture volume. Factor C was set from three tomato varieties: Ideal (old local variety), Kalina F_1 (Geosem Select, Bulgaria) and Monroe F_1 (Enza Zaden, the Netherlands), each with indeterminate growth. A comparison was made with a potting mixture, amended with only mineral (synthetic) fertilizers (Mineral Fertilization MF). For preparation of 1 m^3 mix from peat moss and perlite in the ratio of 1:1 (v/v) following substances were used: triple superphosphate 1200 g; ammonium nitrate – 500 g; potassium sulfate – 500 g and magnesium sulfate – 200 g. Usually tomato plants, grown in this media do not required additional fertilization until transplanting.

Each treatment was repeated in triplicate, each replication was composed by 10 plants. The experiment was repeated twice in consecutive order.

C. Analyses

Analyses of potting mixtures: samples from each treatment were analyzed before transplanting and 30 days after planting (DAP). Water soluble nutrients, pH and electrical conductivity were determined in aqueous extracts 1:1.5 (v/v) [15]. The following were quantified: NO_3^- – ion-selective analysis; P-colorimetric Mo blue reaction; K-flame photometery; Ca and Mg-complexometrically with EDTA.

Plant Analyses: N, P and K were quantified in dried shoots at the end of the experiment by: N – Kjeldahl method; P and K – colorimetry and flamephotometry, respectively, after dry ashing and subsequent extraction with 2 M HCl. Plant nutrient uptake was calculated by multiplying plant dry matter to the concentration of the certain element in plant tissues.

Plant Growth Analyses: at the end of the experiment (30 DAP) shoot fresh and dry weight, shoot length (distance from the substrate level to the top node), leaf number (excluding cotyledons), and total leaves area were determined.

Statistical analyses: all results are means of three replicates. Data were subjected to Duncan's Multiple Range Test to separate means. Three-way ANOVA with type of vermicompost, dose and tomato variety as fixed factors was applied. Relationships between all studied parameters were established by correlation analysis. Hierarchical cluster analysis of biometric data was also applied to estimate the similarity between the variants. The cluster separation was made on the base of the average Euclidian distance. The data were preliminary standardized.

III. Results and Discussion

A. Chemical and physicochemical properties of potting mixtures

Nutrient content, pH and EC of the potting mixtures before planting of tomato seedlings and 30DAP are presented in Table 1. Control and MF treatment had the lowest pH values. Among the other parameters, pH was considered as one of the most representative one for categorization of organic amendments [16]. After application of 10% vermicompost pH was increased with 0.6-1.1 units. Further increase of pH with 1.4-2.0 pH-units was recorded in potting mixtures with 25% vermicompost. The ability of vermicompost to reduce acidity was also observed by other authors [9], [17]. Highest capacity to increase pH possessed Biohumus MM, while the lowest – Lumbrical. The lowest EC, NO_3^- and K were recorded in Control variant. Potting mixes treated with synthetic fertilizers as well as with 10% vermicompost, regardless of its origin, had EC ranging 0.73-1.28 mS cm^{-1}, without significant differences between treatments. This suggested that the optimal amounts of nutrients in the potting mixtures could be supplied by application of 10% vermicompost. At this dosage Biohumus MM differed from Lumbrical regarding EC, suggesting that Lumbrical supplied more soluble nutrients than Biohumus MM. Application of 25% vermicompost led to further increase of EC of the potting mixtures up to 2.64 mS cm^{-1}. Similar tendency was observed concerning the content of NO_3^- and K: the treatment with synthetic fertilizers do not differ significantly from 10% vermicompost treatments, while 25% vermicompost treatments had increased NO_3^- and K content. Highest content of Mg was observed in L25% treatment, while the other vermicompost treatments did not differ significantly from MF treatment. An increase of available nutrients by raising the dose of vermicompost is logical and similar to the findings of other authors [18]. Phosphorus content in potting mixtures varied between treatments but statistical analysis has shown that there are no significant differences. Concerning Ca-content the highest value was recorded in MF treatment, while vermicompost treatments, regardless of the origin and concentration in the potting mixture, did not differ significantly.

30 DAP pH of the potting mixtures has increased compared to the initial values as follows: unfertilized Control – with 0.47 pH-units, MF-treatment – with 0.23 pH-units, 10% vermicompost treatments: 0.54-0.71 pH-units, 25% vermicompost treatments: 0.43-0.53 pH-units. Keeping the same tendency as in the beginning of the experiment, higher pH was observed in 25% vermicompost treatments, compared to 10% vermicompost treatments, demonstrating again the capacity of vermicompost to decrease acidity. Comparatively higher values of pH had potting mixtures prepared with Biohumus MM, compared to the other two examined vermicomposts. EC of the potting mixtures has decreased with 0.32-1.1 mS cm^{-1} compared to the initial values. As before planting, 30 DAP 10% vermicompost treatments had EC comparable with MF treatment. Higher the concentration of vermicompost in the potting mixture has led to higher EC at the 30^{th} DAP, suggesting that vermicompost steadily release plant essential nutrients into the substrate solution [17], [19]. Comparatively higher values of EC were observed in Lumbrical amended mixtures in both dossages. Nitrates in 10% vermicompost amended mixtures were comparable with MF treatment. At dose 25% of the vermicompost nitrates content was higher than MF. Potassium contents of CM10% and MF

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treatment were comparable to each other, while MM10% and L10% treatments had led to increased K-content over MF treatment. Higher the concentration of vermicompost in the potting mixture has led to higher content of K. The highest values of nitrates and potassium were observed in L25% treatment. Phosphorus content of Lumbrical amended mixtures 30 DAP was higher than that of MF or Biohumus CM or Biohumus MM amended mixtures, regardless of the concentration of the vermicompost. Potting mixtures with 25% Biohumus MM had lower P-content than that with 10% Biohumus MM.

Table 1: Chemical and physicochemical properties of potting mixtures

Treatment	Variety	pH	EC mS cm^{-1}	NO_3^- mg L^{-1}	P mg L^{-1}	K mg L^{-1}	Ca mg L^{-1}	Mg mg L^{-1}
Before planting								
0%		4.62 e	0.07 e	7.5 c	0.5 ns	3.7 d	16.5 c	12.6 c
MF		4.28 e	1.28 cd	117.5 b	108.8 ns	140.1 c	144.0 a	46.8 bc
	CM	5.48 cd	1.06 cd	175.0 b	81.7 ns	199.2 c	72.0 bc	68.4 bc
10%	L	5.27 d	1.41 c	175.0 b	112.6 ns	245.3 c	78.0 a-c	108.0 b
	MM	5.72 bc	0.73 d	112.5 b	47.7 ns	149.4 c	48.0 c	39.6 c
	CM	6.39 a	2.17 ab	310.0 a	38.9 ns	404.6 b	120.0 ab	104.4 b
	L	6.02 b	2.64 a	295.0 a	110.3 ns	541.6 a	120.0 ab	190.8 a
25%	MM	6.59 a	1.61 bc	285.0 a	45.2 ns	457.6 ab	78.0 a-c	64.8 bc
30 DAP								
Control (0%)	Ideal	4.91 g	0.17 g	2.8 f	1.0 j	3.1 h	9.0 j	8.4 g-i
	Kalina	5.18 f	0.15 g	2.8 f	0.5 j	3.1 h	9.0 j	6.6 i
	Monroe	5.17 f	0.15 g	3.0 f	0.6 j	3.1 h	8.5 j	7.2 hi
MF	Ideal	4.55 h	0.50 ef	27.5 ef	76.1 c-e	24.5 gh	54.0 d-h	21.6 f-i
	Kalina	4.47 h	0.44 ef	20.0 ef	60.7 e-g	24.1 gh	47.0 e-h	19.2 f-i
	Monroe	4.50 h	0.53 d-f	31.7 ef	94.8 c	34.7 gh	39.0 g-i	31.2 c-f
CM10%	Ideal	5.96 e	0.46 ef	21.3 ef	81.6 cd	55.0 fg	42.0 f-i	26.4 e-h
	Kalina	6.05 e	0.41 f	21.3 ef	52.8 f-i	55.0 fg	38.0 g-i	20.4 f-i
	Monroe	6.04 e	0.44 ef	20.5 ef	57.6 e-h	59.2 fg	36.0 hi	27.0 d-g
L10%	Ideal	6.00 e	0.71 d	47.5 de	145.8 a	87.6 ef	59.0 b-f	47.4 c
	Kalina	5.96 e	0.62 de	42.5 de	133.9 ab	97.9 e	50.0 e-h	46.2 cd
	Monroe	5.99 e	0.71 d	62.5 cd	148.0 a	108.8 e	56.0 c-g	50.4 c
MM10%	Ideal	6.40 d	0.40 f	19.3 ef	58.7 e-h	74.3 ef	28.0 i	27.6 d-g
	Kalina	6.41 d	0.40 f	14.5 ef	59.4 e-h	74.3 ef	40.0 g-i	19.8 f-i
	Monroe	6.41 d	0.44 ef	11.0 ef	61.7 d-g	79.7 ef	49.0 e-h	19.8 f-i
CM25%	Ideal	6.76 c	1.05 c	85.0 bc	72.1 d-f	202.4 d	61.0 b-e	43.8 c-e
	Kalina	6.94 b	1.07 c	89.7 bc	56.0 e-h	203.3 d	76.0 ab	35.4 c-f
	Monroe	6.75 c	1.06 c	92.5 b	59.6 e-h	209.1 cd	74.0 a-c	43.8 c-e
L25%	Ideal	6.55 d	1.93 a	123.3 a	141.4 a	325.7 a	84.0 a	157.2 a
	Kalina	6.49 d	1.68 b	144.2 a	116.9 b	312.4 a	72.0 a-d	118.8 b
	Monroe	6.52 d	1.64 b	120.0 a	116.3 b	297.9 a	86.0 a	114.0 b
MM25%	Ideal	7.10 a	0.96 c	91.7 b	38.4 hi	244.1 bc	48.0 e-h	32.4 c-f
	Kalina	7.12 a	0.92 c	82.5 bc	32.5 i	222.6 b-d	51.0 e-h	25.2 e-i
	Monroe	7.14 a	1.04 c	85.0 bc	46.6 g-i	255.2 b	64.0 b-e	24.6 e-i

a, b, c - Values in columns followed by different letters are significantly different at $P<0.05$, Duncan's Multiple Range Test
ns – Non-significant

Potting mixtures treated with 10% vermicompost, regardless of its origin, as well as MM25% treated mixtures had Ca-content equal to potting mixtures treated with MF.

In some instances specific variety reaction was recorded, usually concerned non-hybrid variety Ideal: for example, in L25% treatment potting mixtures with Ideal variety had EC, P and Mg content higher than that of potting mixtures from F1 hybrids Kalina and Monroe. Similarly to the findings of [20], the effect of vermicompost on chemical and physicochemical properties of the potting mixtures depended on the type of vermicompost and its dose. The overall tendency observed here was that increasing the dose of vermicompost increased pH, EC and most of the available nutrients in the potting mixtures and differences between treatments were kept even 30 DAP. The other observion was that potting mixtures treated with Lumbrical had higher content of nutrients compared to the other two vermicomposts. This supports the idea that the origin of the vermicompost, specifically the used parent waste, defines its chemical composition and hence the composition of the amended potting mixtures [13]. In the present study Biohumus MM applied at dose 10% has led to the lowest levels of nutrients in the potting mixture, compared to the other vermicompost treatments, while Lumbrical applied at dose

25% has led to the highest nutrient content, which in some instances was over the optimal ranges established by [21]. This suggests that the dose of Lumbrical in the potting mixtures should not further be increased (over 25%), while Biohumus MM should be applied at dose 25%, rather than 10%.

B. *Effect of vermicomposts on plant growth*

Analysis of variance conducted individually on each plant growth index showed that Vermicompost Concentration was the main factor that influenced all plant growth parameters (Table 2) and contributed to 75-91% from the total variation. Vermicompost Type x Vermicompost Concentration interaction was also significant indicating that optimal concentration of vermicompost in the potting media depends to some extent on vermicompost type. The single influence of Vermicompost Type was significant for leaves number and leaf area. Tomato variety influenced four out of six plant growth indexes. The absence of influence of Vermicompost Type x Tomato Variety, Vermicompost Concentration x Tomato Variety and three way interactions between examined factors indicated that the three tested tomato varieties responded in the same way to the different treatments. Considerable contribution to the total variation (4-20%) had so called error, which suggested that factors other than examined influence plant growth parameters.

Table 2: Analysis of variance for the effect of Vermicompost (VC) Type, Vermicompost Concentration and Tomato Variety on plant growth indexes

Source of variation	df	Sum of Squares					
		Stem h	Stem d	Leaf num	Shoot FW	Shoot DW	Leaves area
VC Type (A)	2	6.3	0.003	1.3 **	5.4	0.05	44.4 *
VC Concentration (B)	2	1594.3 ***	0.555 ***	109.5 ***	906.5 ***	6.3 ***	5145.1 ***
Tomato Variety (C)	2	174.2 ***	0.012	10.4 ***	14.4 **	0.01	41.3 *
A x B	4	99.0 **	0.035 **	3.0 ***	42.6 ***	0.3 **	212.9 ***
A x C	4	7.2	0.003	0.2	1.4	0.03	2.2
B x C	4	14.2	0.007	1.7 **	5.1	0.07	4.8
A x B x C	8	19.8	0.003	0.6	4.6	0.05	7.9
Error	54	252.7	0.147	4.8	62.4	0.85	278.5
Corrected total	80	2167.8	0.764	131.5	1042.3	7.63	5737.1

*, **, *** - significance at 5%, 1% and 0.1% probability level respectively

Plant response of three tomato varieties to different vermicomposts and different vermicompost concentrations are presented in Table 3. Application of vermicompost at 10% dose significantly increased all studied plant growth parameters compared to non-treated control. The most influenced index was shoot fresh weight, which was 4.6-5.1 times higher for plants treated with 10% vermicompost than for non-treated plants. Besides, up to 3.8-fold increase in shoot dry weight; up to 2.9-fold increase in leaf area; up to 2.1-fold increase in shoot length was observed in 10% vermicompost treatements, compared to control. Stem diameter and leaves number were influenced to lesser extent, but still significant from vermicompost application at dose 10%. Data, presented in Table 3 also revealed that plants from the three tomato varieties had more leaves, greater leaves area, higher stem length and diameter and greater shoot fresh weight when grown in Biohumus CM or Lumbrical amended mixtures, than that grown in Biohumus MM.

It was noticed that further increase of vermicompost concentration (from 10% to 25%) do not influence on tomato growth in the case of Biohumus CM and Lumbrical. But in the case of Biohumus MM plant growth was more stimulated at higher dose of the vermicompost. This observation was confirmed by three way ANOVA conducted on the same data as above, but for two variants of the factor B (Vermicompost Concentration) – 10% and 25% (Table 4). The data showed significant influence of factors A, B, C as well as of the two way interaction A x B on plant growth indexes. Comparing data from Table 2 with these in Table 4 it was clear that the influence of Factor B was not so strong, since this factor contributed to 7-33% from total variation. More significant became the interaction A x B, contributing to 10-25% from the total variation, factor C (with contribution 30-55%), as well as other factors (with contribution 17-75%). There is no influence of Vermicompost Type x Tomato Variety, Vermicompost Concentration x Tomato Variety and three way interaction between examined factors, which confirm again that the three tested tomato varieties responded in the same way to the different treatments.

Hierarchical cluster analysis conducted on biometrical data combined tested variants in several clusters (Fig. 1). The first cluster, which is the biggest one and the second cluster, attached to the first on the next stage, combined all the treatments but the Control of Kalina and Monroe varieties. The third combined almost all treatments of Ideal variety excluding MM10% treatment, which is attached to the cluster on the next stage. The Control treatments for the three varieties were not associated to the above clusters. At Lumbrical and Biohumus CM treatments doses 10 and 25% belonged to identical clusters (first cluster for Kalina and Monroe varieties and third cluster for Ideal variety), indicating that doses 10% and 25% provoked similar growth response. At Biohumus MM treatments doses 10% and 25% belonged to different clusters – MM25% treatments for Kalina and Monroe variety are combined in the first cluster, while MM10%

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treatments for these varieties belonged to the second cluster. For Ideal variety MM25% treatment belonged to the third cluster, while MM10% treatment is attached on a later stage. The observation indicated that growth response at 10% Biohumus MM treatment is different from 25% Biohumus MM treatment. Hierarchical cluster analysis also showed that at dose 10% Lumbrical and Biohumus CM treatments are different from Biohumus MM treatments, since for Kalina and Monroe varieties L10% and CM10% treatments belonged to the first cluster, while MM10% treatment belonged to the second one; for Ideal variety L10% and CM10% treatments belonged to the third cluster, while MM10% treatment is attached on a later stage. At dose 25% Lumbrical, Biohumus CM and Biohumus MM treatments for Ideal variety were combined in the third cluster and in the first cluster – for Kalina and Monroe varieties.

Table 3: Plant growth indices of tomato transplants, grown in vermicompost amended potting mixtures

Treatment	Variety	Shoot length, cm			Stem diameter, mm			Leaves number			Shoot fresh weight, g			Shoot dry weight, g			Leaves area, cm^2		
		mean	±SD		mean	±SD		mean	±SD		mean	±SD		mean	±SD		mean	±SD	
Control (0%)	Ideal	9.58	0.76	h	3.63	0.07	j	4.77	0.15	j	1.99	0.14	h	0.26	0.02	d	9.87	0.32	e
	Kalina	11.34	1.41	gh	3.15	0.26	k	5.07	0.21	ij	1.82	0.39	h	0.23	0.06	d	9.04	1.11	e
	Monroe	11.90	0.58	gh	2.88	0.18	k	4.58	0.34	j	1.69	0.27	h	0.25	0.03	d	8.51	1.28	e
MF	Ideal	17.17	1.15	d-f	5.11	0.12	d-f	6.83	0.43	fg	8.34	1.15	c-f	0.79	0.19	bc	25.70	2.71	a-c
	Kalina	21.37	1.26	a-d	4.49	0.09	hi	7.67	0.21	b-e	7.81	0.50	e-g	0.71	0.09	bc	24.21	1.27	bc
	Monroe	19.08	2.78	b-e	4.14	0.13	i	5.58	0.75	j	5.84	0.99	g	0.56	0.16	c	19.21	3.02	d
CM10%	Ideal	16.44	1.03	ef	5.56	0.15	b-d	6.83	0.20	fg	8.33	0.29	c-f	0.88	0.16	ab	26.51	0.64	a-c
	Kalina	20.84	0.42	a-e	5.10	0.21	ef	7.84	0.19	b-d	7.88	0.70	e-g	0.83	0.06	a-c	24.51	1.60	a-c
	Monroe	21.68	1.97	a-d	5.11	0.13	d-f	7.02	0.13	f	7.74	0.47	e-g	0.85	0.06	ab	24.03	1.28	c
L10%	Ideal	20.16	3.02	a-e	5.66	0.24	bc	6.97	0.43	f	10.18	2.02	a-d	0.91	0.13	ab	27.83	3.36	a-c
	Kalina	22.96	3.55	a-c	5.28	0.24	c-f	8.13	0.26	ab	8.63	1.58	b-e	0.87	0.19	ab	25.87	4.09	a-c
	Monroe	20.37	3.58	a-e	4.63	0.23	gh	6.79	0.31	f-h	7.60	1.57	e-g	0.87	0.17	ab	24.56	3.50	a-c
MM10%	Ideal	14.56	2.10	fg	5.38	0.55	c-e	6.20	0.38	h	6.29	1.58	fg	0.72	0.22	bc	19.74	2.74	d
	Kalina	18.59	0.79	c-f	4.92	0.24	fg	6.98	0.11	f	5.96	0.23	g	0.69	0.11	bc	19.18	0.96	d
	Monroe	18.58	0.81	c-f	4.48	0.26	hi	6.25	0.13	gh	5.67	0.41	g	0.71	0.06	bc	19.12	0.68	d
CM25%	Ideal	19.72	2.06	a-e	5.89	0.36	ab	7.17	0.23	ef	10.95	1.03	a	0.86	0.18	ab	29.11	2.93	ab
	Kalina	23.27	3.68	ab	5.38	0.28	c-e	8.48	0.10	a	10.64	1.37	ab	1.08	0.15	a	28.36	3.12	a-c
	Monroe	22.13	1.18	a-c	4.87	0.12	f-h	7.28	0.37	d-f	8.61	0.18	b-e	0.84	0.10	ab	26.31	0.22	a-c
L25%	Ideal	17.11	4.21	d-f	5.50	0.43	b-e	6.91	0.51	f	9.44	2.86	a-e	0.77	0.24	bc	26.87	6.35	a-c
	Kalina	20.70	4.76	a-e	5.05	0.07	e-g	7.76	0.69	b-e	9.12	2.05	a-e	0.77	0.20	bc	26.76	3.09	a-c
	Monroe	20.73	2.26	a-e	4.65	0.14	gh	7.22	0.41	d-f	8.21	0.57	d-f	0.67	0.11	bc	26.28	1.66	a-c
MM25%	Ideal	18.79	0.88	b-f	6.16	0.04	a	7.00	0.13	f	10.69	0.65	ab	0.85	0.14	ab	29.41	0.85	a
	Kalina	23.75	1.14	a	5.56	0.19	b-d	8.00	0.15	a-c	10.51	1.05	a-c	0.93	0.09	ab	29.42	1.73	a
	Monroe	23.74	2.38	a	5.37	0.18	c-e	7.43	0.31	c-f	9.71	0.80	a-e	0.94	0.17	ab	27.51	1.33	a-c

a, b, c - Values in columns followed by different letters are significantly different at $P<0.05$, Duncan's Multiple Range Test

Table 4: Analysis of variance for the effect of Vermicompost (VC) Type, Vermicompost Concentration and Tomato Variety on plant growth indexes, excluding 0% vermicompost concentration

Source of variation		Sum of Squares					
	df	Stem h	Stem d	Leaf num	Shoot FW	Shoot DW	Leaves area
VC Type (A)	2	9.5	0.42	2.0 ***	8.0	0.08	66.7 *
VC Concentration (B)	1	41.6 *	0.88 ***	3.0 ***	64.0***	0.02	249.2 ***
Tomato Variety (C)	2	161.6 ***	6.37 ***	10.9 ***	17.7	0.02	34.2
A × B	2	95.8 **	1.90 ***	2.3 ***	39.9***	0.28 **	190.6 ***
A × C	4	10.8	0.14	0.3	2.1	0.04	3.3
B × C	2	0.6	0.02	0.2	1.3	0.06	3.5
A × B × C	4	16.2	0.37	0.6	3.9	0.04	6.8
Error	36	235.5	2.36	3.7	61.0	0.82	260.6
Corrected total	53	571.5	12.45	22.8	198.0	1.36	814.9

*, **, *** - significance at 5%, 1% and 0.1% probability level respectively

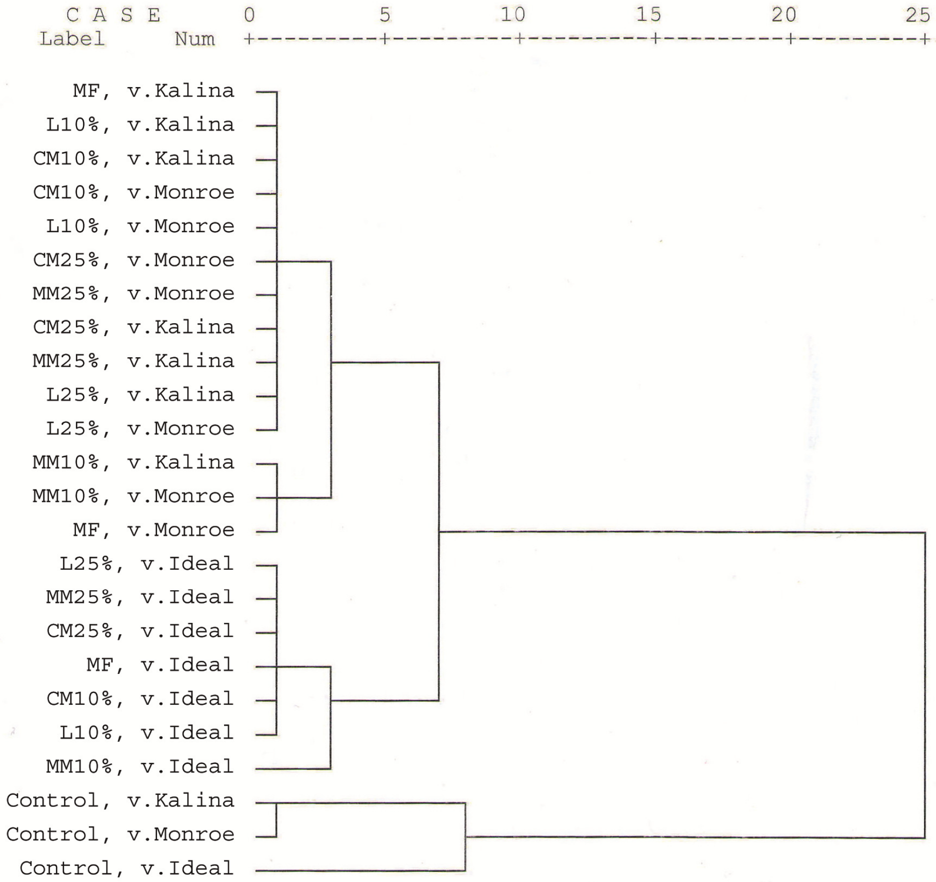

Fig.1. Hierarchical cluster analysis on biometrical data

Table 5: Nutrient concentration and content in tomato shoots

Treatment	Variety	N, mg g^{-1}	P_2O_5, mg g^{-1}	K_2O, mg g^{-1}	N, mg per shoot	P_2O_5, mg per shoot	K_2O, mg per shoot
Control (0%)	Ideal	15.4 ^{h}	3.3 ^{k}	21.5 ^{g}	0,41 ^{i}	0,09 ^{f}	0,57 ^{j}
	Kalina	14.4 ^{h}	2.7 ^{k}	23.7 ^{g}	0,33 ^{i}	0,07 ^{f}	0,55 ^{j}
	Monroe	16.1 ^{h}	2.7 ^{k}	23.2 ^{g}	0,40 ^{i}	0,07 ^{f}	0,58 ^{j}
MF	Ideal	34.5 $^{a-c}$	18.0 ^{b}	43.0 ^{c}	2,66 $^{b-d}$	1,41 ^{ab}	3,32 $^{e-i}$
	Kalina	37.3 ^{a}	16.2 ^{cd}	42.6 ^{c}	2,62 $^{b-d}$	1,15 $^{a-e}$	3,02 $^{f-i}$
	Monroe	35.6 ^{ab}	21.1 ^{a}	40.3 $^{c-e}$	1,97 ^{ef}	1,17 $^{a-e}$	2,22 ^{i}
CM10%	Ideal	23.5 ^{f}	13.1 $^{f-h}$	45.7 ^{c}	2,04 $^{d-f}$	1,16 $^{a-e}$	4,01 $^{b-f}$
	Kalina	20.9 ^{fg}	13.3 ^{fg}	43.4 ^{c}	1,73 ^{fg}	1,10 $^{b-e}$	3,61 $^{d-g}$
	Monroe	20.5 ^{fg}	16.3 ^{cd}	41.6 ^{cd}	1,73 ^{fg}	1,39 $^{a-c}$	3,54 $^{e-h}$
L10%	Ideal	24.5 ^{ef}	13.3 ^{fg}	46.0 ^{c}	2,22 $^{c-f}$	1,21 $^{a-e}$	4,21 $^{b-f}$
	Kalina	22.9 ^{f}	15.6 ^{de}	44.7 ^{c}	1,96 ^{ef}	1,34 $^{a-d}$	3,88 $^{c-f}$
	Monroe	23.6 ^{f}	17.5 ^{ab}	46.5 ^{c}	2,04 $^{d-f}$	1,52 ^{a}	4,05 $^{b-f}$
MM10%	Ideal	15.3 ^{h}	11.7 ^{hi}	34.6 ^{ef}	1,11 ^{h}	0,83 ^{e}	2,47 $^{g-i}$
	Kalina	16.1 ^{h}	12.5 ^{gh}	33.9 ^{f}	1,10 ^{h}	0,85 ^{e}	2,32 ^{hi}
	Monroe	18.5 ^{gh}	14.4 ^{ef}	36.3 $^{d-f}$	1,32 ^{gh}	1,02 $^{c-e}$	2,57 $^{g-i}$
CM25%	Ideal	34.8 $^{a-c}$	9.8 ^{j}	56.9 ^{ab}	2,95 ^{b}	0,84 ^{e}	4,86 $^{b-d}$
	Kalina	35.1 ^{ab}	10.2 ^{j}	59.4 ^{ab}	3,81 ^{a}	1,10 $^{b-e}$	6,44 ^{a}
	Monroe	34.2 $^{a-c}$	13.3 ^{fg}	54.5 ^{b}	2,85 ^{bc}	1,11 $^{b-e}$	4,48 $^{b-e}$
L25%	Ideal	32.5 ^{bc}	12.0 ^{gh}	57.9 ^{ab}	2,49 $^{b-e}$	0,92 ^{e}	4,44 $^{b-e}$
	Kalina	32.6 ^{bc}	12.8 ^{gh}	59.2 ^{ab}	2,50 $^{b-e}$	0,99 ^{de}	4,55 $^{b-e}$
	Monroe	32.9 ^{bc}	17.1 ^{bc}	61.1 ^{a}	2,18 $^{d-f}$	1,14 $^{a-e}$	4,06 $^{b-f}$
MM25%	Ideal	30.8 ^{cd}	10.5 ^{ij}	58.3 ^{ab}	2,59 $^{b-e}$	0,89 ^{e}	4,93 ^{bc}
	Kalina	27.6 ^{de}	10.1 ^{j}	54.2 ^{b}	2,56 $^{b-e}$	0,94 ^{e}	5,03 ^{bc}
	Monroe	27.9 ^{de}	12.9 $^{f-h}$	56.4 ^{ab}	2,57 $^{b-e}$	1,21 $^{a-e}$	5,26 ^{b}

a, b, c - Values in columns followed by different letters are significantly different at $P<0.05$, Duncan's Multiple Range Test

It is noteworthy that the treatment with mineral (synthetic) fertilizers (MF) for Kalina and Ideal varieties belonged to identical clusters (first cluster for Kalina and third cluster for Ideal) with L10% and CM10%, and L25%, CM25% and MM25% treatments, while for Monroe variety MF is equal to MM10%, but different from MM25% treatment. These indicated that at nursery stage synthetic fertilizers could be fully replaced by vermicomposts, as well as organic fertilization could be better choice for some tomato varieties than mineral fertilization.

The results of the present study support the general findings that small dosage of vermicompost in the growing media could increase significantly the growth of tomato plants in nurseries [3], [5], [8]-[11], since all studied plant growth parameters were influenced significantly after application of 10% vermicompost irrespectively of its type. The comparison between plant growth response to 10% vermicompost in the mixtures and to fertilization by synthetic fertilizers showed that in nursery stage Biohumus CM and Lumbrical supply plants with all needed nutrients, so they are suitable alternative to the mineral fertilizers, which is especially important for organic production. In the literature some authors suggested additional fertilization for better growth [10], [22]-[24], while others, similarly to the present results, reported that vermicompost could be used as a sole source of nutrients [14].

Similarly to the results of [3], [9], [25] the present study indicate that the optimal dose for growing of tomato transplants (irrespectively from the variety) is 25% from the volume of the potting mixture for two of the vermicomposts tested – Biohumus CM and Biohumus MM, while optimal dose of Lumbrial is 10% from the potting mixture volume

C. Concentration and uptake of N, P and K in tomato shoot as influenced by vermicompost type, vermicompost dosage and tomato variety

The concentration of the three nutrients per gram dry weight as well as per tomato shoot is presented at Table 5. The lowest concentration and content of nitrogen, phosphorus and potassium were quantified in the shoots from the control treatment irrespectively from the variety. The application of 10% vermicompost Biohumus CM or Lumbrical resulted in increased N concentration and content, The Biohumus MM treatment did not influenced the concentration of N but increased the content of N in the three tested varieties. The increase of vermincompost dosage to 25% has led to further increase of N concentration in tomato shoots, similarly to the MF treatment. Comparing the three types of vermicompost at dose 25% Biohumus CM and Lumbrical resulted in similar N concentration in the shoots, while Biohumus MM – in lower values, especially in Kalina and Monroe varieties. The content of N was higher in 25% treatments compared to 10% treatments in the cases with Biohumus CM and Biohumus MM. In the case with Lumbrical the dose 25% did not influence N content of tomato shoots.

Increasing the dose of vermicompost from 0% to 10% has led to an increase of K concentration and content in tomato shoots. CM10% and L10% resulted in similar K concentration and content in the shoots, while MM10% gave comparatively lower values. The highest K concentration was measured in tomato shoots from 25% dosage of vermicompost irrespectively from the vermicompost type and tomato variety.

Table 6: Correlation matrix of the studied parameters and level of significance of the correlation coefficients

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	~	0.58 ***	0.63 ***	0.12	0.77 ***	0.55 **	0.33	0.50	0.64 ***	0.54 **	0.61 ***	0.61 ***	0.58 **	0.10	-0.63	0.66 ***
2		~	0.96 ***	0.54 ***	0.95 ***	0.88 ***	0.89 ***	0.46	0.49	0.52 **	0.65 ***	0.45	0.64 ***	0.64 ***	0.23	0.86 ***
3			~	0.46	0.96 ***	0.84 ***	0.79 ***	0.51 **	0.50	0.55 **	0.69 ***	0.49	0.67 ***	0.67 ***	0.18	0.90 ***
4				~	0.36	0.66 ***	0.69 ***	0.44 ***	0.43	0.42	0.51 **	0.49	0.55 ***	0.38	0.67 ***	0.50
5					~	0.81 ***	0.75 ***	0.51 **	0.54 **	0.54 **	0.67 ***	0.49	0.65 ***	0.54 **	0.11	0.87 ***
6						~	0.72 ***	0.70 ***	0.60 ***	0.72 **	0.80 ***	0.71 ***	0.81 ***	0.74 ***	0.51 ***	0.91 ***
7							~	0.23	0.30	0.31	0.40	0.23	0.42	0.44	0.26	0.62 ***
8								~	0.61 ***	0.89 ***	0.80 ***	0.84 ***	0.82 ***	0.56 **	0.62 ***	0.75 ***
9									~	0.74 ***	0.91 ***	0.88 ***	0.90 ***	0.42	0.38	0.74 ***
10										~	0.86 ***	0.88 ***	0.87 ***	0.53 **	0.46	0.78 ***
11											~	0.92 ***	0.99 ***	0.67 ***	0.46	0.91 ***
12												~	0.93 ***	0.48	0.54 **	0.78 ***
13													~	0.68 ***	0.55 **	0.91 ***
14														~	0.49	0.77 ***
15															~	0.42
16																~

*** - significance at P<0.001; ** - significance at P<0.01

Potting mixtures analysis 30 DAP: 1 – pH; 2 – EC; 3 – NO_3^-; 4 – P; 5 – K; 6 – Ca; 7 – Mg.
Biometry: 8 – Stem height; 9 – Stem diameter; 10 – Leaves number; 11 – Shoot FW; 12 – Shoot DW; 13 – Leaves area
Plant nutrient concentration: 14 – N; 15 – P; 16 – K

Similarly to the changes in N and K values, increasing the vermicompost dose form 0% to 10% has resulted in an increase of P concentration and content in tomato shoots. Further increase of the vermicompost dose up to 25% has resulted in most cases in decrease of P concentration. This parameter varied between vermicompost type and tomato genotype: higher values were quantified in Lumbrical treated plants and in Monroe variety. The highest values for P concentrations in tomato shoots were recorded in MF treatment, in which the three tested varieties differed from each other. P content was similar for MF, CM10% and L10% treatments and comparatively high than MM10%, CM25%, L25% and M25% treatments.

Other authors reported that when all necessary nutrients were supplied by additional fertilization the accelerated growth due to amendment with vermicompost is attributed to the presence of humic acids, plant growth hormones and increased populations of microorganisms [26], [27]. In the present study potting mixture was prepared from extremely poor in nutrients peat and perlite without additional fertilization. Since the sole source of nutrients was vermicompost, the increased growth and improved nutritional status was attributed to the availability of nutrients provided by vermicompost. The present study is a new proof that vermicompost could be valuable source of nutrients, supplying plants with all needed nutrients at least at nursery stage, which is very important for organic nurseries.

D. Correlations between studied components

Growth response and nutrient concentration depended to the content of nutrients in the potting mixtures since strong correlations were established between most of the studied parameters. Data presented at Table 6 showed that leaves area correlated strongly with pH, EC and the content of nutrients (except Mg) in the potting mixtures 30 DAP. Leaves number and shoot FW also correlated with pH, EC and the content of the most nutrients (except P and Mg) in the potting mixtures 30 DAP. Strong correlations were also established between N concentration in tomato shoot and EC, NO_3^-, K and Ca-content in the potting mixtures 30 DAP. K concentration in shoots correlated with all studied chemical (except P) and physicochemical parameters of potting mixtures at the end of the experiment, while P correlated strongly only with P and Ca in the mixtures. The content of Ca in the potting mixtures was in strong positive relationships with all studied parameters. The same tendency was observed for the content of K with some exceptions.

The established strong correlations between some plant growth parameters and the chemical and physicochemical parameters of the potting mixtures suggest that availability of nutrients is a key factor determining plant response to vermicompost application. Therefore, and as suggested by [6] testing of vermicompost before use for its nutrient composition is of primary importance in order to determine the optimal dose.

Conclusion

The results from the present study indicate that the effect of vermicompost on chemical and physicochemical properties of the potting mixtures depended on the type of vermicompost and its dose. Increasing the dose of vermicompost increased pH, EC and most of the available nutrients in the potting mixtures and differences between treatments were kept even 30 DAP.

Application of vermicompost at dose 10% (by volume) significantly increased all studied plant growth parameters compared to non-treated control. The most influenced index was shoot fresh weight, which was 4.6-5.1 times higher. Up to 3.8-fold increase in shoot dry weight; up to 2.9-fold increase in leaf area; up to 2.1-fold increase in shoot length was observed in 10% vermicompost treatements, compared to control. Vermicompost Concentration was the main factor that influenced all plant growth parameters, followed by the factor Vermicompost Type x Vermicompost Concentration interaction, indicating that optimal concentration of vermicompost in the potting media depends to some extent on vermicompost type.

Further increase of vermicompost concentration (from 10% to 25% by volume) do not influence on tomato growth in the case Lumbrical and slightly increase plant growth in the case of Biohumus CM. But in the case of Biohumus MM plant growth was more stimulated at higher dose of the vermicompost. The results from the Cluster Analysis and the Three Way ANOVA revealed that the three tested tomato varieties responded in the same way to the different treatments.

The results from the present study indicated that at nursery stage synthetic fertilizers could be fully replaced by vermicomposts, which is especially important for organic nurseries.

The overall conclusion is that the optimal dose for growing of tomato transplants (irrespectively from the variety) is 25% from the volume of the potting mixture for two of the vermicomposts tested – Biohumus CM and Biohumus MM, while optimal dose of Lumbrical is 10% from the potting mixture volume.

Although the characteristics of vermicompost might vary widely depending on the used parent waste and the optimal dose in potting mixtures should be determined individually, and there might be specific variety response, the results presented here constitute a new proof of feasibility of vermicompost as potting media constituent in sustainable culture practices and specifically in organic production.

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