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A case study of woody leaf litter vermicompost as a promising calcium fertilizer

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Abstract

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Vermicomposting of organic wastes aimed to obtain fertilizers and other beneficial substances is of major importance in modern bioresource technologies. Earthworms *Eisenia fetida* may be used for the decomposition of woody leaf litter from Southwestern Siberia. We have analyzed physicochemical and rhizogenic properties of peat moss vermicomposts obtained from tree leaf litter substrate of poplar, *Populus nigra* L., willow, *Salix fragilis* L., and birch, *Betula pendula* Roth., compared to traditional horse manure-based substrate. There is a determination of pH, electroconductivity (EC), K^+, Ca^{2+}, and NO_3^--concentrations in water extracts of initial pure substrates (manure and litter) as well as their mixtures with peat moss before and after three-weeks vermicomposting. Among water extracts of prepared peat-based vermicomposts and substrates "manure…poplar…willow…birch", having EC of 165…121…100…95 μS.cm^{-1}, pH – 7.0…7.4…7.3…7.2, NO_3^--ions of 87…22…19…12 [mEq.kg^{-1} of dry weight] and Ca^{2+}/K^+ ratio – 0.47…6…4.5…4, respectively, we have chosen mostly Ca-enriched vermicompost of peat moss and poplar leaf litter (Ca^{2+}-concentration till 100 [mEq.kg^{-1} of dry weight). The sprouting of wheat seeds and isolated potato shoots using poplar leaf litter vermicompost extracts resulted in a significant increase (18 and 28%) in the relative weight of the roots compared to the seeds and shoots grown on tap water (12 and 14%) and horse manure vermicompost extracts (12 and 19%).

Keywords: vermiculture; Eisenia fetida; leaf litter; Siberian; woody species; vermicompost; peat moss

Introduction

Soil degradation, caused by high human activity, is a worldwide phenomenon. Nutrients deficiency is considered as the main cause of its poor productivity and crop failure (Hurni et al., 2015; Salvati, 2013). Furthermore, a higher number of depredators and plants illnesses lead to a constant decrease in harvesting of agricultural products, hence, explaining the demand for chemical products aiming to defend plants in a soil. However, numerous studies have shown that most agricultural practices involving the use of fertilizers and pesticides induce irreversible negative effects related to both product quality and soil environment (Hall et al., 2010; Popp et al., 2013; Leong et al., 2016; Yang et al., 2016). Therefore, a development and usage of environmentally friendly fertilizers stimulating plants growth, pest resistance, and stress tolerance has gained an increased interest of scientists and farmers (Aziable et al., 2017; Cycon et al., 2017).

The usage of earthworms for the production of organic fertilizers and in farmer waste-disposal practice is attracting global attention (Kernecker et al., 2014). The earthworm *Eisenia fetida* (Savigny) appeared to be highly productive and suitable for manure recycling technology. Being ubiquitous, it easily adapts to various organic substrates, and belongs to so-called epigeic category of earthworms. *Eisenia fetida* is a particularly fecund species, represents a source of technological cultures, can be grown artificially, and frequently used for organic waste management and vermicomposting (Stewart, 2004; Hatti et al., 2010).

The general world tendency for vermicomposting involves recycling of manure at animal and poultry farms by *Eisenia fetida* earthworms. Yet, the vermicomposting strategy for nitrogen poor substrates with high content of cellulose remains underexplored (Edwards et al., 2004; Arancon et al., 2008). An example of such kind of substrate can be leaf litter, which vermicomposting potentially brings several benefits. This is a more eco-friendly process in comparison with burning of fallen leaves, not speaking that vermicomposting notably facilitates the return of minerals present in a litter, e.g. calcium (Ponge et al., 1999; Reich et al., 2005) that concentrates in old leaves in a form of poorly soluble compounds. A presence of calciferous glands in worms (Canti & Piearce, 2003) allows flowing of organic residues and leaf litter through the digestive tract and transforming calcium salts into coprolites. The structure and functions of calciferous glands of earthworms, as well as patterns of biogeneous calcium and carbon circulation through the contribution of this group of organisms, has been thoroughly analyzed in following works (Leiber & Maus, 1969; Wiecek & Messenger, 1971; Piearce, 1972; Morgan, 1981; Armour-Chelu & Andrews, 1994; Canti, 2003; Canti & Piearce, 2003; Lambkin et al., 2011a; Lambkin et al., 2011b;). Generally, a vermicompost obtained from leaf litter can be considered as an organomineral calcium-enriched fertilizer. Optimization of calcium nutrition of plants makes positive effects for its root formation and its non-specific resistance (Poovaiah & Reddy, 1993; Bressan et al., 1998).

The aim of this work was to obtain vermicomposts via recycling leaf litter from Southwestern Siberia by *Eisenia fetida* and to estimate their rhizogenic properties.

Material and Methods

In the experiments we used bidistilled water obtained with a double-distiller GFL 2102 (Germany) with an electrical conductivity of 2 $\mu S.cm^{-1}$ and a pH of 6.0…6.5. To weigh the glassware, substrate components and worms, the balance HCB 123 (ADAM, United Kingdom, ± 0.001 g accuracy) was used.

Peat substrate

Sphagnum peat moss (air-dry storage) was used as an absorbing material. The peat moss, which we used in our studies, was kindly provided by Siberian Research Institute of Agriculture and Peat (Russia, Tomsk) and was collected on peat-field “Ust-Bakchar” of Tomsk Region (57°34′47″N; 82°16′22″E). This choice was governed by the whole range of physicomechanical and physicochemical properties of this material, allowing for its efficient use in the vermicomposting technology (Edwards & Burrows, 1988; Manh & Wang, 2014; Mendoza-Hernández et al., 2014). The pH and conductivity of the peat aqueous extracts were monitored by potentiometric and conductometric methods, described in (ISO, 1995; ISO, 2005).

Substrate collection

As a nutritional component for vermicomposting substrates we used leaf litter of woody plants growing on the territory of the University Grove, a natural complex that is part of the historical and architectural ensemble of the Tomsk State University (Russian Federation, N56°28′08″ E84°56′55″). Among tree species that provide leaf litter in this area, there are three typical representatives of the poplar, willow, and birch genus. In this work the litter of *Populus nigra* L. (as poplar), *Salix fragilis* L. (willow), *Betula pendula* Roth. (birch) species were used. The leaf litter was collected during the period of September 20 – October 20, 2011–2014, at a positive average day temperature, before the formation of a stable snow cover. The collected litter was dried in a universal oven MEMMERT UN30 (Memmert, Germany) at a temperature of 105 ± 0.5°C until a constant weight, and was kept in an air-dry state. Shortly before vermicomposting, the litter was ground with scissors and tweezers to a size of 5 × 5 mm.

Horse manure was used in the form of pure excrement cleaned from bedding materials. Manure was provided by the private equestrian club “Bagheera” (Tomsk, Russia). The collected horse manure was dried in the same way as a leaf litter, to a constant weight, and stored in an air-dry state.

Earthworms storage

The culture of *Eisenia fetida* (Savigny) used in this work was kindly provided by Dr. Yury Morev (Institute of Biology and Soil, Kyrgyzstan). In experiments we used immature specimens. The density of cultures was kept at the value around 40–60 individuals/dm^3 at the temperature of 20–25ºC and 70–80% humidity.

Preparation of vermicomposts

As a vermicomposting substrate, a mixture of sphagnum peat moss and dried leaf litter or horse manure was used in 1:8 ratio by air-dry weight: 4 g of a dry nutritional component (manure or one of the three litter species) and 32 g of peat. Horse manure is a traditional food substrate for *E. fetida*. Therefore, it served as a control for leaf litter vermicompost comparison. The nutritional components (leaf litter or manure) were mixed with peat, and then the mixtures were moistened with bidistilled water 5 days before introducing worms into containers. By this time, the pH of substrate became 5.5–5.7, an optimal range for the vital activity of the used worm species (Edwards & Bohlen, 1996).

Vermicomposting technique

A 250-ml plastic container was filled with a prepared substrate. Then, worms with a total weight of 1.5 ± 0.1 g were placed in a container. 120 ml of bidistilled water was added in a dry mixture to reach the humidity of 77%. During experiment, closed with perforated caps containers were stored in a dark room at the temperature of +21±3ºC. Vermicomposting was let to proceed for 21 days until the end of the growth phase of worm biomass and clear tendency to its decrease. Afterwards, the worms were eliminated, and obtained substrates were dried in a drying chamber (t = 105ºC). The resulted vermicompost was used to prepare aqueous extracts and to study the effect on the root formation of higher plants. We designated vermicomposts as PMVerm (peat moss and horse manure vermicompost), PPLVerm (peat moss and poplar leaf litter vermicomposts), PWLVerm (peat moss and willow leaf litter vermicomposts), and PBLVerm (peat moss and birch leaf litter vermicomposts).

Water extracts preparation and characterization

To prepare the extracts, 95 ml of bidistilled water was added to 5 g of the dried vermicompost or initial substrates. The samples were transferred to 100 ml dark glass vials covered with lids, mixed for 3 minutes with a DSMS-100 magnetic stirrer (Digisystem, Taiwan) at 150 rpm, and left at room temperature for another 24 hours for final extraction. The extracts were then filtered with filter paper, blue band 110 mmØ, 589/3 (Buch & Holm, Denmark) and the measurements were carried out as described below.

The concentration of K^+ and NO_3^- ions as well as the pH value in aqueous extracts were determined by the potentiometric method (Moore, 1969). The measurements were performed using an ionometer IPL-103 (Multitest, Russia). The electrode cell was comprised of an ELIS-121K (to measure K^+ activity) or ELIS-121NO_3 (to measure NO_3^- activity) ion-selective electrode and a reference electrode EVL-1 M3.1. ESL-43-07 glass electrode was used for pH measurements (all electrodes were produced in Russia). The relative error of the instruments for potentiometric measurements did not exceed 2%. The limit of detection for K^+ and NO_3^- ions was 10^{-5} and 10^{-4} mol×L^{-1}, respectively. The concentration of Ca^{2+} was estimated by ethylenediaminetetraacetic acid (EDTA) titration (Panumati et al., 2008). The electrical conductivity was measured using a portable conductometer Dist-3 (HANNA instruments, USA). The relative instrumental error of EDTA titration and conductometry did not exceed 2%.

Rhizogenic properties of vermicomposts

In the work we studied the effect of vermicomposts on the root formation of wheat seeds (*Tríticum aestivum* L.) of the Irgina variety and isolated potato sprouts (*Solanum tuberosum* L.) of the Nevsky variety. Root formation indicators are widely used in plant growth stimulators studies (Ibrahim et al., 2015).

The Irgina variety was supplied by Narymskaya breeding station (Kolpashevo, Russia). Ripening time of this variety is 70-85 days, height of plants is 65-80 cm, and productivity is 2-6 tones/ha. The Nevsky variety was supplied by Vsevolozhskaya breeding station (Vsevolozhsk, Russia). It is an early, ecologically resilient variety with a high yield in different climatic conditions.

Three sprouts of potatoes with a weight of 0.5-1 g or 25 seeds of wheat were placed on a filter paper (blue band, Buch & Holm, Denmark) in glass Petri dishes. The filter paper was further wetted by an aqueous extract (1:20) from dried samples of manure- or poplar leaf litter based vermicompost. For the control group, tap water with a total hardness of 6 mEq.L^{-1} and a pH of 7-7.5 was added instead of nutrient solutions. The dilution of vermicompost samples was selected in such a way that the electrical conductivity of the obtained extracts was approximately equal to the electrical conductivity of tap water (600 ± 50 µS.cm^{-1}). Petri dishes with the cultivated potato sprouts and wheat seeds were placed in an air thermostat TS1-80 (Russia). The volume of the working chamber of the thermostat was 80 l; the discreteness of the temperature setting was 0.1°C; the maximum deviation from an average temperature at any point in the working volume was ± 0.4°C. The cultivation of potatoes and wheat was carried at 20 ± 1°C for 4 and 3 days, respectively for potato and wheat. The ratio of the raw weight of the roots formed to the total raw weight of the sprout (for potatoes) or to the total raw weight of the germ (for wheat) was calculated in percentages. Hereinafter, we refer to this index as a "relative root weight", and use it as the main morphophysiological indicator of vermicomposts rhizogenic properties.

The experiment was conducted in nine replicates. Data analysis included calculation of mean, standard error of mean, 95-% confidence intervals for mean, and t-test for independent samples.

Results and Discussion

Characterization of peat moss and initial substrates

The initial peat moss had a light brown colour; its aqueous extract had an acidic medium (Table 1). The low values of conductivity (no more than 3.58 ± 0.01 μS.cm^{-1}) indicated a low degree of the peat mineralization, which allowed us to trace the processes of decomposition of nutrient substrates by worms without the interfering influence of exterior electrolytes. Besides, similarly to vermicompost, peat can be aerated, has absorbability, mechanical lightness, dispersity and high absorption functions (Manh & Wang, 2014). The manure extract had a slightly alkaline medium (pH = 7.4) and contained a large number of electrolytes, potassium, and nitrates. The high concentration of nitrates in the manure (102.09±2.34 mEq.kg^{-1} DW) reflects a high content of total nitrogen, in particular, ammonium (Atiyeh et al., 2000a; Atyieh et al., 2000b; Nedunchezhiyan et al., 2011).

Table 1 shows that all extracts from leaf litter had a weak acid medium. The electrical conductivity of extracts decreased in a row "poplar litter – willow litter – birch litter" and was 857, 638 and 459 μS.cm^{-1}, respectively. The low content of NO_3^--ions in the leaf litter (no more than 25 mEq.kg^{-1} DW) testified that leaf litter belongs to organic substrates that are depleted in nitrogen (relative to carbon and cations-macronutrients). The K^+-content in the leaf litter in terms of a dry weight was 225 ... 280 mEq.kg^{-1}. This value is in agreement with the literature data on the accumulation of this macroelement in green leaves of woody plant species, according to which its amount is varied in the range of 2.5…25 g/kg (Wang & Moore, 2014).

Calcium was the most abundant macroelement in the poplar and willow litter; its content exceeded the potassium by 2.7 and 1.6 times, respectively. Birch litter is calcium-depleted compared to potassium (Table 1). These data correlate with the patterns of ontogenetic changes in the status of mineral nutrition of higher glycophytes (Osmolovskaya et al., 2007). Undergoing these changes, tree and herbaceous plants gradually lose potassium (as a result of outflow to younger organs and subsequent reutilization), accumulating instead a higher number of calcium ions. In aging and dying leaves the latter macroelement is fixed in a form of oxalates and other poorly soluble compounds, though a certain amount of calcium in tissues of leaves is still present in an ionic form, along with potassium and nitrate ions.

Table 1. pH, electrical conductivity, and ions concentration in water extracts obtained separately from initial moss, manure, and leaf litter

Parameter	Substrate				
	Peat moss	Horse manure	Poplar litter	Willow litter	Birch litter
pH	4.48±0.06	7.4±0.10	6.13±0.15	5.80±0.06	6.30±0.12
EC, [μS.cm^{-1}]	3.58±0.01	953.14±15.54	857.33±44.20	638.67±100.94	459.67±16.05
K^+, [mEq.kg^{-1} DW]*	< DL	644.79±14.89	279.61±20.92	275.03±51.97	225.23±16.54
NO_3^-, [mEq.kg^{-1} DW]	< DL	102.09±2.34	20.76±5.01	24.24±1.53	25.45±3.98
Ca^{2+}, [mEq.kg^{-1} DW]	< DL	75.88±3.52	763.13±101.76	451.55±76.50	178.47±38.47

mEq.kg^{-1} – milli-equivalents per kg; DW – dry weight; EC – electroconductivity; μS – microsiemens; water extracts were diluted in 100 times; DL – detection limit; means and 95% confidence intervals are given in the table

Table 2. pH, electrical conductivity, and ions concentration in water extracts obtained from initial and vermicomposted (VC) substrates (peat mixtures with manure and leaf litter)

Parameter	Water extracts of substrates							
	PMVerm		PPLVerm		PWLVerm		PBLVerm	
	Initial	VC	Initial	VC	Initial	VC	Initial	VC
pH	5.95 ±0.20	7.0±0.05	5.32±0.25	7.40±0.1	5.15±0.15	7.33±0.07	5.4±0.2	7.23±0.09
EC, [μS.cm^{-1}]	105.9 ±1.7	164.83±0.54	98.44 ±5.08	121.33±4.69	74.14±11.72	99.63±3.81	54.25±1.89	94.50±4.48
K^+, [mEq.kg^{-1} DW]	71.64 ±7.96	88.29±6.3	31.07 ±2.32	16.56±0.5	30.56±5.77	18.75±0.8	25.03±1.84	18.85±0.6
NO_3^-, [mEq.kg^{-1} DW]	11.34 ±0.26	86.75±2.5	2.31±0.56	22.13±2.0	2.69±0.17	19.1±2.05	2.83±0.44	12.45±2.0
Ca^{2+}, [mEq.kg^{-1} DW]	8.43 ±0.94	41.5±3.2	84.79±11.31	98.50±1.75	50.17±8.50	85.00±2.0	19.83±4.27	77.00±1.75

Characterization of initial vermicomposting substrates

Mixing nutritional components (substrates) with peat (Table 1) allowed for a significant decrease of nitrate and electrolyte contents in the aqueous extracts (Table 2). These compounds are known for adverse effects on vital activity of earthworms (Petrochenko et al., 2014). The water extracts of initial vermicomposting substrates had pH shift to a weakly acidic range: the pH of initial PMVerm extract was 6, whereas the extract of peat and leaf litter mixtures had pH of 5.1-5.4 (Table 2). The PMVerm extract exceeded all other substrates in the total content of salts (EC=105.9 µS.cm^{-1}), as well as in the concentration of K^+ and NO_3^- ions. In all peat leaf litter mixtures Ca^{2+} ions were predominant, that evidently made the main contribution to the electrical conductivity of this type of substrates. Generally, by the total content of ions-macroelements the mixtures of peat can be arranged in the following order "PMVerm > PPLVerm > PWLVerm > PBLVerm".

Application of vermicomposting

The main quantitative indicator showing the decomposition degree of leaf litter was the accumulation of ions in the peat fraction as a result of composting. The content of NO_3^- was below the limit of detection of the ionometric method. However, the other measured parameters revealed the processes of leaf litter decomposition at the chosen experimental conditions. It was found that at the end of the experiment, the absolute values of pH, electrical conductivity and the content of individual ions changed significantly in aqueous extracts.

Vermicomposting resulted in a significant increase in pH values in all tested extracts: the pH of PMVerm increased by 18%, whereas in leaf litter based vermicomposts the growth was by 39%, 42% and 34% (relative to initial mixtures) for PPLVerm, PWLVerm, and PBLVerm, respectively. Among vermicomposts the highest values of pH (up to 7.4, Table 2) was observed in PPLVerm water extract. The EC value of extracts increased by 56% in case of vermicomposted PMVerm relatively to initial mixture, and by 23%, 34% and 74% in PPLVerm, PWLVerm, and PBLVerm extracts, respectively.

The content of K^+ ions in the vermicompost extracts changed ambiguously. In the extracts of PMVerm K^+ concentration in the process of vermicomposting increased by 23%, while for PPLVerm, PWLVerm, and PBLVerm it decreased by 47%, 39% and 25%, respectively.

Most pronounced changes during the recycling of substrates by worms were observed for the concentration of nitrates. In the manure-based substrate the content of NO_3^- increased in 8 times, in the litter-based substrates – in 5…10 times. The NO_3^--content in PMVerm extracts was approximately 4 times higher than in the most nitrogen-enriched litter vermicompost (PPLVerm). In contrast, Ca^{2+} content was 2–2.5 times lower in PMVerm extracts in comparison with litter ones. The highest concentration of Ca^{2+} (up to 100 mEq-kg^{-1} DW) was in recycled PPLVerm extracts. In fact, in all samples Ca^{2+} content was increased. It was clearly the predominant ion in the leaf litter based substrate, whereas K^+ and NO_3^- were most abundant in PMVerm extracts (Table 2).

We have shown earlier that the content of water-soluble calcium can reach more than 150 mEq.kg^{-1} DW in the leaves of plants (Kurovskiy, 2009). We suggest that pH and EC changes combined with ions accumulation clearly demonstrate the main aspects of leaf litter vermicomposting. Earthworms process the litter by its transfer in the digestive tract, owing to which a significant part of deposited elements in the plant mineral nutrition is transformed into a more soluble form compared to initial state of the litter. In contrast to manure, in leaf litter among all macronutrients the most abundant was calcium. This is in accordance with the study (16), where it was stated that one of the main physicochemical aspects of woody leaf litter recycling by earthworms was the transfer of calcium from the litter to soil, as well as elimination of excessive soil acidity. Leaf litter calcium is known to be mainly presented in the form of oxalate (Osmolovskaya et al., 2007), which is barely soluble and, thus, cannot be absorbed by plant and does not play role in the regulation of soil acidity. Calcium glands of earthworms absorb calcium and transfer it to the form of carbonate (Canti & Piearce, 2003; Lambkin et al., 2011b; Versteegh et al., 2014), that is likewise poorly soluble, but in certain conditions, e.g. at low pH, can be transformed in hydrocarbonate – the main source of Ca^{2+} in a soil. Decomposition of leaf litter without earthworm contribution still occurs as a result of the activity of saprophytic mushrooms, but earthworms significantly accelerate this process. This is confirmed both by our experiments (Table 2) and by the data of other authors (Ponge et al., 1999; Ma et al., 2014).

The relative ratio of ions content in water extract can give important information towards its physicochemical and agrochemical properties. For example, Ca^{2+}/K^+ ratio in some cases has strong effect on plants nutrition (Berger et al., 2006), and can drastically vary in plants depending on their ecological and taxonomic group (Larher, 1978; Kurovskiy, 2009).

In litter-based initial substrates Ca/K ratio was much higher, than in PMVerm extracts, in which the content of potassium was 10 times higher compared to calcium (Table 3). Among initial leaf litter mixtures only birch leaf litter mixture had Ca/K ratio below 1. In the poplar leaf litter extracts the content of calcium was nearly 3 times higher, than the content of potassium. In all samples the ratio notably increased during the process of vermicomposting. However,

Table 3. Average Ca^{2+}/K^{+} ratio (relative units) in water extracts obtained from initial substrates and from peat mixtures with manure and leaf litter

Ca^{2+}/K^{+}	Substrate vermicomposting			
	PMVerm	PPLVerm	PWLVerm	PBLVerm
Initial	0.12	2.73	1.64	0.79
Transformed	0.47	5.95	4.53	4.08

in PMVerm extracts the ratio was still below 1, whereas in all leaf litter vermicomposts, including birch, this index was far above 1. Besides, the difference between Ca/K values for vermicomposts obtained from different types of leaf litter became much smaller relative to the values of initial mixtures – from 4 for PBLVerm to 6 for PPLVerm extracts.

Rhizogenic properties of vermicomposts

Based on the pH, EC, Ca^{2+}, NO_3^-, and Ca/K ratio data, two most alternative vermicomposts were revealed – conventional PMVerm and leaf litter vermicompost PPLVerm. The extracts of chosen vermicomposts were studied in terms of their effects on the root formation of wheat seeds and isolated potato sprouts. According to our findings, the growth of both species in PPLVerm resulted in a statistically significant increase in the relative weight of the roots relative to the control sample. It was determined that the root weight increased by 38% and 57% for potatoes and wheat, respectively (Fig. 1). This effect was not observed in PMVerm experiment: the increase in the relative weight of wheat roots was nonsignificant (did not exceed 22%), and for potatoes, the weight changed within the error.

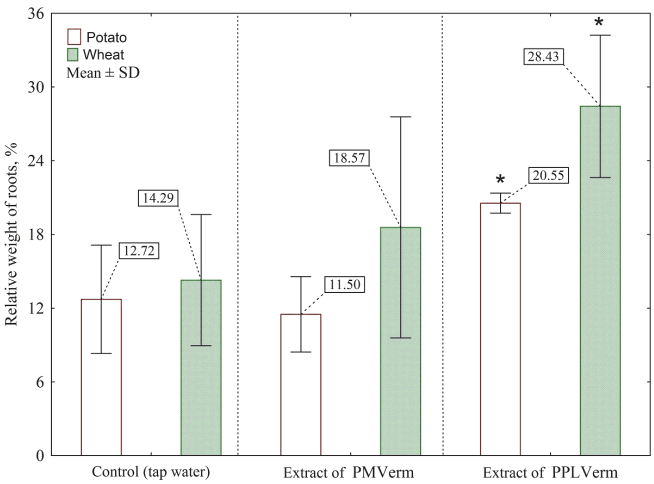

Fig. 1. Variation of relative root weight of wheat seeds and isolated potato shoots depending on the kind of food substrate, used in vermicomposting. Means with asterisks indicate significant difference from control series at $p < 0.05$

To analyze these data, it worth mentioning that one of the most vulnerable moments in potato growth is a contact of sprouts with the nutrient solution. The isolated sprout does not have either a sufficient morphophysiological adaptation for optimal absorption of nutrients, or reception and transport systems to change the permeability of membranes in cases of sudden fluctuations in ionic strength, the pH of the surrounding solution, or the appearance of toxic substances in it. Herein, calcium plays an important role as a macroelement of a mineral nutrition with its anti-stress properties. The mechanisms of Ca-protection activity are various but poorly understood. Some authors emphasize the ability of calcium ions to trigger the universal cascade of adaptation reactions, thus acting as a secondary messenger in cells (Poovaiah & Reddy, 1993; Bressan et al., 1998). On the other side, Ca is well known for its ability to stimulate the processes of root formation (Schiefelbein et al., 1992). This may explain the observed effect of root mass increasing in case of both potato sprouts and wheat seeds.

Besides, there are data showing a dramatic shift in the cationic balance of plant tissues with an increase of Ca/K ratio in stressful situations as at the seed sprouting stage (Nasr et al., 1977; Tromp and Ovaa, 1981; Berger et al., 2006). Ca/K ratio is often considered in terms of antagonistic interactions between potassium and calcium in plants. Potassium has an impact on the processes of vegetative growth, while calcium is of importance in reproductive processes, stress adaptation, and root formation. As a matter of fact, the stimulation of root formation itself is one if the major adaptation mechanisms in response to the action of a wide range of unfavorable environmental factors (Diem & Godbold, 1993, Karnataka et al., 2011).

We suppose that the results of experiments with potato sprouts and wheat seeds showing the stimulating effect of the vermicompost on the basis of poplar leaf litter on the root formation are largely due to the high value of the Ca/K ratio.

Conclusion

Vermicomposting of organic wastes aimed to obtain fertilizers and other beneficial substances is of major importance in modern bioresource technologies. Every year this domain is expanding thanks to the development of technologies for vermicomposting of wastes that earlier were not included in the range of food substrates – traditional medium for vermicultivation. Generally, the experiments carried in this work helped to address current problems on the optimization of calcium nutrition in plants from a complex perspective of biotechnology, ecology, and biogeochemistry. Calcium is one of the most problematic elements of mineral nutrition of plants due to its weak degree of reutilization and a slow, difficult return from litter to the root area. Earthworms significantly accelerate this process. Our findings demonstrate that *Eisenia fetida* vermiculture can be efficiently used in the recycling process of the leaf litter of woody plants characterizing the dendroflora of the south of Southwestern Siberia and used in city landscaping. The vermicompost obtained in a result of such recycling has a number of physicochemical and rhizogenic features, among which the main one is a high relative content of calcium. By the calcium content (from highest to lowest), leaf litters studied in this work can be arranged in the following order: 'poplar litter – willow litter – birch litter'. Additionally, our data show a strong stimulating influence of poplar leaf litter extracts on the root formation of the potato sprouts of the Nevsky variety and the wheat seeds of the Irgina variety.

Despite the degree of development of calcium glands in *Eisenia fetida* is relatively small (in comparison with soil species of worms) (Canti & Piearce, 2003), high technological efficiency (fertility, ecological flexibility and simplicity in stocking) of this compost species allows for its advantageous use in the processing of leaf litter of woody plants of the Siberian dendroflora, among others. Ultimately, this will permit to significantly optimize and increase the efficiency and variability of the use of vermicompost as a fertilizer in crop growing.

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