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The Peculiar Physicochemical and Agrochemical Properties of Vermiculture-processed Poplar Leaf Litter

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Abstract. In the vermicompost obtained from horse manure the concentration of K^+ and NO_3^- was, on average, 112.2 and 82.9 milliequivalents/kg of dry weight, respectively. It was significantly higher than in the vermicompost obtained from poplar leaf litter (73 and 5.6 milliequivalents/kg of dry weight, respectively). The pH-values and concentration of calcium ions in the vermicompost from poplar leaf litter were significantly higher than in the vermicompost from horse manure (7.6 vs 6.9 and 112.3 vs 83 milliequivalents/kg of dry weight, respectively). The sprouting of wheat seeds and isolated potato shoots of Nevsky breed using poplar leaf litter vermicompost extractions resulted in a significant increase in the weight of the roots compared to the seeds and shoots grown on tap water. We did not observe the effect in the case with horse manure vermicompost extracts.

Introduction

Vermicultivating – cultivating earthworms in organic substrates – is widely spread in many countries, as it is a progressive technology of processing organic waste and getting a highly effective fertiliser and zoogenic feed protein [1,2]. The vermicompost obtained from various household and agricultural wastes is a good fertiliser and growth stimulator for various crops [3,4]. In a number of cases the specific microbial strains were secured from earthworms' coprolites for effective protective bacterization of grain crops [5]. Nowadays the main type of the substrate used for vermiculture is manure of farm livestock [6]. Manure-based compost often contains a lot of inorganic nitrogen and potassium. Using the vermicompost with a high concentration of NO_3^- and K^+ as fertiliser enhances vegetative growth of plants and raises yield. However, increased nitrogen background can prolong the vegetative growth phase and prevent fruit, root tubers and root crops from forming and ripening, which may result in a considerable decrease in yield in the conditions of a short vegetative period. The oversupply of potassium causing the increase in tissues watering [8] facilitates a faster spread of various disease agents. On the other hand, potassium is known to be an important nutrient that enhances the stability of plants to stresses and diseases [9,10]. In the vermicomposts obtained on the basis of the substrates rich in nitrogen-containing organic matter the calcium/potassium ions ratio is usually characterised by the latter prevailing [7], while in most natural food substrates of earthworms including leaf litter a reverse situation is observed [11-15]. In the last years more and more attention is given to studying the processes of leaf litter decomposition that is one of the most important biogeochemical cycles [16,17]. However, these processes can be realised in artificial conditions as a technological task of vermicomposting that has two important aspects at least. Firstly, leaf litter is usually burnt, which is irrational and harmful for the environment. At the same time leaf litter is a nearly free substrate easy to process. Secondly, leaf litter vermicomposting allows obtaining vermicompost samples enriched with calcium compounds. As we see it, using this biotechnological product as organic and mineral fertiliser (during definite development periods) will have positive influence on root forming and non-specific resistance of plants.

Our paper is aimed at comparative analysis of some agrochemical properties of vermicompost produced with basic food substrates of horse manure (traditional substrate) and poplar leaf litter.

Materials and methods

The object of the research is the earthworm *Eisenia fetida* Savigny (*Lumbricidae*); the species is the most producible and adapted for vermicomposting. For vermicomposting we used 250-mililitre plastic containers filled with the substrate. We put several earthworms with the total weight 1.5±0.1 g into each container. We used the mixture of terrestrial peat used as adsorbent and one of two feed substrates, either horse manure or dried poplar (*Populus nigra* L.) leaf litter, as vermiculture substrate. We chose this poplar species because it is widely spread over the territory of Siberian Botanical Garden (Tomsk) and is used in greenery planting in Tomsk.

The initial substrates were taken in the ratio 1:8 by air-dry weight: 4 g of dry food component (manure and poplar leaf litter) and 32 g of peat. 120 ml of distilled water was added to the dry mixture. Thus, the initial vermicompost substrate moisture was 77%. Later on the substrate moisture was maintained at the level of 70±10% by means of regular adding distilled water. The containers with perforated lids were kept in a dark room, the temperature being +21±3ºC. Vermicomposting continued till the end of the phase of earthworms' biomass build-up. During our experiments it happened, on average, by the 21st day of vermicultivating.

The experiment over, we screened the vermicompost from earthworms and dried it in the oven at a temperature of 105ºC. To make extracts from the vermicomposts obtained we poured 95 ml of distilled water to the samples with an air-dry weight of 5 g. We stirred the samples for 3 minutes in a magnetic mixer and left them for a day in the room at an indoor temperature to complete extracting. The extracts were filtered and their physical and chemical parameters were measures.

The concentration of potassium ions and nitrates in the extracts from the vermicomposts was determined with the potentiometric method using ionoselective electrodes. The concentration of Ca^{2+} in the extracts under study was determined with the complexonometry method.

The physiological effects of the obtained samples of the vermicompost were studied in wheat seeds and isolated potato shoots of Nevsky breed widely spread in Russia. We put filter paper to the bottom of Petri dishes. In each dish we put 3 potato shoots with a weight of 0.5–1 г. or 25 wheat seeds. The filter paper was moistened with food solutions – water extracts (1:25) from dried vermicompost samples based on horse manure and poplar leaf litter. To the Petri dishes of the control group we added settled tap water with a total permanent hardness of 6 milliequivalents/l instead of food solutions. The Petri dishes with cultivated potato shoots and wheat seeds were placed to a small-scale phytochamber with a light-period day/night being 16:8. The duration of the shoots cultivating was 4 days at an air temperature 20ºC. The duration of wheat seeds sprouting was 3 days at an air temperature 20ºC. The correlation between wet weight of the roots formed and the total wet weight of a shoot (potato) or the total wet weight of a seed (wheat) was expressed as a percentage. This indicator is further referred to as «relative root weight».

Data analysis included calculation of mean, standard deviation, standard error of mean, 95-% confidence intervals for mean, and t-test for independent samples. We used a preliminary Shapiro–Wilk normality test for the samples under study.

Results and discussion

The processes of an ontogenetic change in the status of mineral nutrition in higher plants, glycophytes, has been studied thoroughly [18]. On the whole, one of the general tendencies is that leaves of both trees and herbs gradually lose potassium (due to the outflow to younger organs and further reutilization) in the course of ontogeny and accumulate calcium. In mature and dying leaves this macro element is found in the form of oxalates and other low-soluble compounds; however, a definite quantity of calcium in litter tissues is also found in the form of ions together with potassium ions and nitrate-anions.

Table presents the data on pH and electroconductivity of water extracts, the concentration of calcium and potassium cations, nitrate-anions and the quantitative calcium/potassium ratio in the vermicompost samples obtained from two substrates.

The table shows that the vermicompost produced from poplar leaf litter significantly yields to the one produced from horse manure in the extracts' electroconductivity and the concentration of potassium ions and nitrates. The difference in the concentration of nitrates amounts to a multiple of 15. Such distribution of nitrate-anions in the studied samples is quite predictable as leaf litter belong to the group of substrates impoverished in nitrogen [19]. At the same time the concentration of calcium ions and pH in the samples of poplar leaf litter vermicompost is much higher than in the ones of the vermicompost produced form horse manure.

An important characteristic of vermicompost as an organic and mineral fertiliser is the quantitative ratio «calcium/potassium». This marker chemical property in plants is known to be determined both genetically and ecologically [20,21]. As the table indicates the ratio Ca^{2+}/K^{+} is shifted to calcium prevailing in the vermicompost samples produced from the mixture of peat and poplar leaf litter. The apparent prevalence of potassium was characteristic of the samples of the vermicompost produced from horse manure. The differences were statistically significant.

Thus, studying the properties of the vermicompost produced from two different initial substrates we found two alternative variants (in accordance with the total of experimental variables): the "traditional" manure vermicompost and poplar leaf litter vermicompost.

Table. The physical and chemical parameters of the samples of the vermicompost produced while vermicomposting the peat-manure mixtures and the mixtures of peat and poplar leaf litter

Parameter	Peat + manure	Peat + litter
pH of water extract	6.9±0.17	7.61±0.22
EC of water extract, [μS•cm^{-1}]	1226.17±69.33	1057.67±67.21
K^{+}, [mEq/kg DW]	112.23±12.73	72.98±3.74
NO_3^{-}, [mEq/kg DW]	82.83±31.20	5.58±3.66
Ca^{2+}, [mEq/kg DW]	83.0±6.47	112.33±9.24
Ca^{2+}/K^{+}	0.74±0.07	1.54±0.13

Note: mEq – milliequivalents/kg; DW – dry weight; EC – electroconductivity; means and 95-% confidence intervals are given in the table.

These two variants were tested in plant objects in hydroponic experiments on sprouting wheat seeds and cultivating isolated potato shoots of the Nevsky potato breed. The results of the experiments are presented in Figure.

As the figure shows the exposition of Nevsky breed potato shoots on the vermicompost produced from poplar leaf litter resulted in a statistically significant, nearly two-fold increase in the relative root weight compared to both the control variant and the one with the vermicompost produced from horse manure.

One of the most vulnerable aspects of sprout potato reproduction is a direct contact of the sprouts with the food solution. An isolated shoot does not have full-fledged morpho-physiological parts for optimal consuming nutrients, receptor and transportation systems to change membrane permeability in cases of acute fluctuations of ionic strength, pH of surrounding solution or toxic substances' emerging in it. Here the anti-stress properties of calcium as a macro element of mineral nutrition dominate. The mechanisms of protective properties of Ca^{2+} are various, but they still need further investigating. Some authors accentuate a universal cascade of adaptive reactions triggered by calcium ions that play the role of second messengers in cells [9,10]. However, the results we got are obviously related to a different, equally well known effect of Ca^{2+} – stimulating the processes of root formation [22].

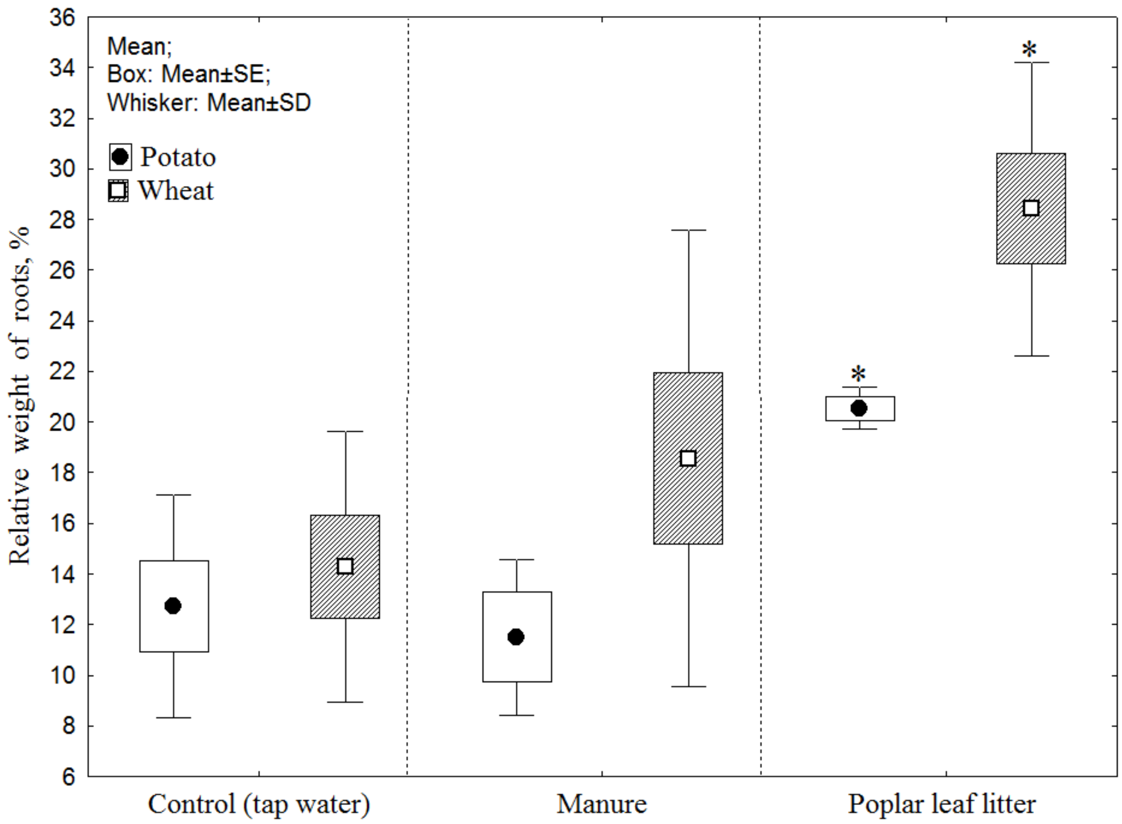

Fig. Variation of relative root weight of wheat seeds and isolated potato shoots depending on the kind of food substrate, used in vermicomposting. Means with asterisks indicate significant difference from control series at $p<0.05$.

This is why the pronounced effect of the increase in root weight was observed not only in potato shoots but also wheat seeds. This corresponds to the data of the physical and chemical analysis of the obtained vermicompost samples, especially the «calcium/potassium» ratio (Table).

The obtained data make it possible to conclude that the vermicompost extracts produced from poplar leaf litter have a stimulating effect on the root formation of potato shoots of Nevsky breed and wheat seeds.

On the whole, the researches done allowed viewing urgent issues of optimization of calcium nutrition of plants from the point of view of biotechnology. Calcium is one of the most problematic elements of mineral nutrition, in terms of its recovery and return from leaf litter to the root-horizons [23, 24]. This problem is to be solved with the help of earthworms that have unique anatomic and physiological properties related to extracting calcium from substrate and its further metabolism. This refers to the so-called calcium glands [25].

Though the calcium glands of *Eisenia fetida* are not developed very well compared to soil species of worms, the high producibility (fertility, ecological plasticity, and easy maintenance) of this compost species makes it possible to successfully use it to process leaf litter. In the long term it may increase in effectiveness and variability of using vermicompost as a fertiliser in plant raising.

References

[1] C.A. Edwards, I. Burrows, K.E. Fletcher, B.A. Jones, The use of earthworms for composting farm wastes, in J.K.R. Gasser (Eds.), Composting Agricultural and Other Wastes, Elsevier, London and New York, 1985, pp, 229-241.

[2] R. Hartenstein, M.S. Bisesi, Use of earthworm biotechnology for the management of effluents from intensively housed livestock, Outlook on Agriculture 18 (1989) 3-7.

[3] N. Arancon, C. Edwards, A. Babenko, J. Cannon, P. Galvis, J. Metzger Influences of vermicompost produced by earthworms and micro-organisms from cattle manure, food waste and paper waste, on the germination, growth and flowering of petunias in the greenhouse, Applied Soil Ecology 39 (2008) 91-99.

[4] R.M. Atiyeh, S. Subler, C.A. Edwards, G. Bachman, J.D. Metzger, W. Shuster, Effects of vermicomposts and composts on plant growth in horticultural container media and soil, Pedobiologia 44 (2000) 579-590.

[5] N.N. Tereshchenko, A.V. Kravets, E.E. Akimova, O.M. Minayeva, A.P. Zotikova Effectiveness of applying microorganisms isolated from earthworm coprolites in increasing yielding capacity of grain crops, Sib. Her. Agricul. Sci 5 (2013) 10-17.

[6] P.L.S. Chan, D.A. Griffiths, The vermicomposting of pre-treated pig manure, Biological Wastes 24 (1988) 57-69.

[7] R.M. Atiyeh, C.A. Edwards, S. Subler, J.D. Metzger, Pig manure vermicompost as a component of a horticultural bedding plant medium: effects on physicochemical properties and plant growth, Bioresource Technology 78 (2001) 11-20.

[8] T.C. Hsiao, A. Lauchli, Role of potassium in plant-water relations, in B. Tinker, A. Lauchli (Eds.), Adv. Plant Nutr., Praeger Sci., New York, 1986, pp. 281-312.

[9] R.A. Bressan, P.M. Hasegawa, J.M. Pardo, Plants use calcium to resolve salt stress, Trends in Plant Science, 3 (1998) 411-412.

[10] B.W. Poovaiah, A.S.N. Reddy, Calcium and Signal Transduction in Plants, Critical Reviews in Plant Sciences 12 (1993) 185-185.

[11] T. Sariyildiz, J.M. Anderson, Variation in the chemical composition of green leaves and leaf litters from three deciduous tree species growing on different soil types, Forest Ecol. Manag 210 (2005) 303-319.

[12] B. Lemma, I. Nilsson, D.B. Kleja, M. Olsson, H. Knicker, Decomposition and substrate quality of leaf litters and fine roots from three exotic plantations and a native forest in the southwestern highlands of Ethiopia, Soil Bio. Biochem 39 (2007) 2317-2328.

[13] M. Carnol, M. Bazgir, Nutrient return to the forest floor through litter and throughfall under 7 forest species after conversion from Norway spruce, Forest Ecol. Manag 12 (2013) 66-75.

[14] Y. Ma, T.R. Filley, K. Szlavecz, M.K. McCormick, Controls on wood and leaf litter incorporation into soil fractions in forests at different successional stages, Soil Bio. Biochem 69 (2014) 212-222.

[15] L. Cizungu, J. Staelens, D. Huygens, J. Walangululu, D. Muhindo, O.V. Cleemput, P. Boeckx, Litterfall and leaf litter decomposition in a central African tropical mountain forest and *Eucalyptus* plantation, Forest Ecol. Manag 326 (2014) 109-116.

[16] T. Li, Y. Ye, Dynamics of decomposition and nutrient release of leaf litter in *Kandelia obovata* mangrove forests with different ages in Jiulongjiang Estuary, China, Ecological Engineering 73 (2014) 454-460.

[17] A. Cuchiettia, E. Marcotti, D.E. Gurvich, A.M. Cingolani, N. PérezHarguindeguy, Leaf litter mixtures and neighbor effects: Low-nitrogen and high-lignin species increase decomposition rate of high-nitrogen and low-lignin neighbours, Appl. Soil Ecol 82 (2014) 44-51.

[18] N.G. Osmolovskaya, L.N. Kuchaeva, V.A. Novak Role of organic acids in the formation of the ionic composition in developing glycophyte leaves, Rus. J Plant Phys 54 (2007) 336-342.

[19] K. Petrochenko, A. Kurovskiy, A. Babenko, Ionic homeostasis and some other features of *Eisenia fetida* (*Oligochaeta*) cultivated on substrates of various characters and of different chemical composition, Advances in Earthworm Taxonomy VI (*Annelida*: *Oligochaeta*), Heidelberg, Kasparek Verlag (2014) 171-176.

[20] W. Larcher, Plant Ecology, Verlag Eugen Ulmer, Stuttgart, 1978.

[21] A.V. Kurovskiy, Ecological-physiological aspects of calcium requirement of herbs, Tomsk State Univ. J. 329 (2009) 237-240.

[22] J.W. Schiefelbein, A. Shipley, P. Rowse, Calcium influx at the tip of growing root-hair cells of Arabidopsis thaliana, Planta 187 (1992) 455-459.

[23] J.F. Ponge, N. Patzel, L. Delhaye, E. Devigne, C. Levieux, P. Beros, R. Wittebroodt, Interactions between earthworms, litter and trees in an old-growth beech forest, Bio. Fert. Soils 29 (1999) 360-370.

[24] P.B. Reich, J. Oleksyn, J. Modrzynski, P. Mrozinski, S.E. Hobbie, D.M. Eissenstat, J. Cho-Rover, O.A. Chadwick, C. Hale, M.G. Tjoelker, Linking litter calcium, earth-worms and soil properties: a common garden test with 14 tree species, Ecology 8 (2005) 811-818.

[25] M.G. Canti, T.G. Piearce, Morphology and dynamics of calcium carbonate granules produced by different earthworm species, Pedobiologia 47 (2002) 511-521.

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DOI References
[3] N. Arancon, C. Edwards, A. Babenko, J. Cannon, P. Galvis, J. Metzger Influences of vermicompost produced by earthworms and micro-organisms from cattle manure, food waste and paper waste, on the germination, growth and flowering of petunias in the greenhouse, Applied Soil Ecology 39 (2008).
10.1016/j.apsoil.2007.11.010
[4] R.M. Atiyeh, S. Subler, C.A. Edwards, G. Bachman, J.D. Metzger, W. Shuster, Effects of vermicomposts and composts on plant growth in horticultural container media and soil, Pedobiologia 44 (2000) 579-590.
10.1078/s0031-4056(04)70073-6
[6] P.L.S. Chan, D.A. Griffiths, The vermicomposting of pre-treated pig manure, Biological Wastes 24 (1988) 57-69.
10.1016/0269-7483(88)90027-4
[7] R.M. Atiyeh, C.A. Edwards, S. Subler, J.D. Metzger, Pig manure vermicompost as a component of a horticultural bedding plant medium: effects on physicochemical properties and plant growth, Bioresource Technology 78 (2001) 11-20.
10.1016/s0960-8524(00)00172-3
[9] R.A. Bressan, P.M. Hasegawa, J.M. Pardo, Plants use calcium to resolve salt stress, Trends in Plant Science, 3 (1998) 411-412.
10.1016/s1360-1385(98)01331-4
[10] B.W. Poovaiah, A.S.N. Reddy, Calcium and Signal Transduction in Plants, Critical Reviews in Plant Sciences 12 (1993) 185-185.
10.1080/713608046
[11] T. Sariyildiz, J.M. Anderson, Variation in the chemical composition of green leaves and leaf litters from three deciduous tree species growing on different soil types, Forest Ecol. Manag 210 (2005) 303-319.
10.1016/j.foreco.2005.02.043
[12] B. Lemma, I. Nilsson, D.B. Kleja, M. Olsson, H. Knicker, Decomposition and substrate quality of leaf litters and fine roots from three exotic plantations and a native forest in the southwestern highlands of Ethiopia, Soil Bio. Biochem 39 (2007).
10.1016/j.soilbio.2007.03.032
[13] M. Carnol, M. Bazgir, Nutrient return to the forest floor through litter and throughfall under 7 forest species after conversion from Norway spruce, Forest Ecol. Manag 12 (2013) 66-75.
10.1016/j.foreco.2013.04.008
[14] Y. Ma, T.R. Filley, K. Szlavecz, M.K. McCormick, Controls on wood and leaf litter incorporation into soil fractions in forests at different successional stages, Soil Bio. Biochem 69 (2014) 212-222.
10.1016/j.soilbio.2013.10.043
[15] L. Cizungu, J. Staelens, D. Huygens, J. Walangululu, D. Muhindo, O.V. Cleemput, P. Boeckx, Litterfall and leaf litter decomposition in a central African tropical mountain forest and Eucalyptus plantation, Forest Ecol. Manag 326 (2014) 109-116.
10.1016/j.foreco.2014.04.015

[16] T. Li, Y. Ye, Dynamics of decomposition and nutrient release of leaf litter in Kandelia obovata mangrove forests with different ages in Jiulongjiang Estuary, China, Ecological Engineering 73 (2014) 454-460.
10.1016/j.ecoleng.2014.09.102
[17] A. Cuchiettia, E. Marcotti, D.E. Gurvich, A.M. Cingolani, N. PérezHarguindeguy, Leaf litter mixtures and neighbor effects: Low-nitrogen and high-lignin species increase decomposition rate of high-nitrogen and low-lignin neighbours, Appl. Soil Ecol 82 (2014).
10.1016/j.apsoil.2014.05.004
[18] N.G. Osmolovskaya, L.N. Kuchaeva, V.A. Novak Role of organic acids in the formation of the ionic composition in developing glycophyte leaves, Rus. J Plant Phys 54 (2007) 336-342.
10.1134/s1021443707030077
[20] W. Larcher, Plant Ecology, Verlag Eugen Ulmer, Stuttgart, (1978).
10.1002/fedr.4910890213
[22] J.W. Schiefelbein, A. Shipley, P. Rowse, Calcium influx at the tip of growing root-hair cells of Arabidopsis thaliana, Planta 187 (1992) 455-459.
10.1007/bf00199963
[23] J.F. Ponge, N. Patzel, L. Delhaye, E. Devigne, C. Levieux, P. Beros, R. Wittebroodt, Interactions between earthworms, litter and trees in an old-growth beech forest, Bio. Fert. Soils 29 (1999) 360-370.
10.1007/s003740050566
[24] P.B. Reich, J. Oleksyn, J. Modrzynski, P. Mrozinski, S.E. Hobbie, D.M. Eissenstat, J. ChoRover, O.A. Chadwick, C. Hale, M.G. Tjoelker, Linking litter calcium, earth-worms and soil properties: a common garden test with 14 tree species, Ecology 8 (2005).
10.1111/j.1461-0248.2005.00779.x
[25] M.G. Canti, T.G. Piearce, Morphology and dynamics of calcium carbonate granules produced by different earthworm species, Pedobiologia 47 (2002) 511-521.
10.1078/0031-4056-00221