Chapter 10

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Modelling the Processes of Vermicomposting in an Ecological Box – Recognized Critical Points

1. Introduction

Statistical data shows that the production of waste is constantly growing which results with increase of the environmental pollution. As inadequate neutralization of organic waste can endanger surface and underground water, as well as soil and air, more effective methods of limiting the negative impact of this group of waste on the environment is necessary.

The problem of organic waste management has always been inadequately dealt with in many European countries including Poland. After Poland became the member of the European Union the problem of waste management has taken a new – legal, organizational, as well as social, meaning. It stems from rapid economic growth and the lack of modern and effective mechanisms of waste management, although the problem of waste management became global long time ago and includes not only environmental protection but also the protection of life and health of Man.

An urgent need to formulate pro-environmental systems of waste management is in accordance with the Waste Management Act dated 27th April 2001 (Journal of Laws 2001.62.628) and is based on the idea of preventing the production of waste (education is of significant importance), reusing waste that could not be prevented (the importance of recycling, including organic recycling) and safe neutralization of waste before its introduction to adequately equipped dump sites. Such principles cannot be implemented without engaging all citizens – waste producers whose interest in adequate behaviour must start at household level where they have to decide on proper waste segregation for recycling streams (including organic recycling). It concerns both city as well as country dwellers (Kostecka 1996, Kostecka, Dunin-Mugler 2011).

Improper storage of organic waste endangers the environment as it causes the following:

- dysfunction of biogeochemical cycles in the environment,
- eutrophication of surface and underground water,
- decrease in the acreage of agricultural and forest production areas,
- intensification of gas emission to the atmosphere,
- microbiological pollution,
- increase in the number of insects and rodents traditionally regarded as pests to Man.

In Poland, similarly to other European countries, actions towards the segregation and various forms of neutralization of *organic waste* must become more important in the future strategy for waste management. According to the Landfill Directive UE 1999/31/WE dated 26th April 1999 and the National Plan of Waste Management 2014 (MP 2010 nr 101, pos. 1183) waste segregation should become a common responsibility of all citizens and communal authorities. According to these documents, in 2010 Poles should have guaranteed recycling and neutralizing of organic waste to the point where only 75% of waste produced in 1995 would have been stored. In 2013 the amount of stored organic waste should decrease even more (50% of waste produced in 1995). As a final step the amount of biodegradable waste stored at dump sites cannot exceed 35% by 2020 (waste produced in 1995).

Meanwhile, in Poland 162 million tonnes of organic waste is produced annually, out of which no less than 8% is stored at dump sites. It happens despite the fact that the Waste Management Act from 2001 (article 10) obliges to select waste.

When talking about types of municipal waste generated in cities and rural areas it is impossible not to mention organic waste produced in every household every day. Usually it is fruit and vegetable peels, stale bread, coffee dregs and tea leaves, eggshells, paper, cardboard or food leftovers. In a farmyard it can be mowed grass, raked leaves and wood (in such amounts that it can be placed in a container or a bag). A dozen or so years ago such waste was commonly used to feed livestock; nowadays though, as breeding animals has been stopped in many rural households, organic waste produced in the kitchen has become a serious environmental problem as it is stored at dump sites and landfill sites. Meanwhile, selected waste (which is biodegradable and of good quality) can be used in the production of compost and vermicompost which improve soil fertility and increase the amount and quality of crops.

2. Vermiculture and sustainable organic waste management

All organic waste is valuable in terms of nutrients and stored energy. That is why rich countries, when formulating the principles of waste management in accordance with the concept of sustainable development, implement the idea of organic recycling. According to the EU Strategy for Soil Protection (IP/06/1241 22.09.2006, C282E/139 COM/2006/231) the cultivation of soil in areas where the amount of organic substances in soil is smaller than 2% must be connected with activities which will lead to soil stabilization or gradual increase in the amount of organic waste found in it. As soil in Europe has been exploited for crop production the average amount of organic waste varies from 2 to 3.5%. That is why adequate organic waste management and the use of the entire potential of biowaste should be implemented in all EU countries. In Poland 30-50% of the capacity of a rubbish dump is taken by unsegregated organic waste, whereas it could be used in the production of compost which is crucial in supplementing soil with organic substances.

It is fundamental to segregate organic waste as soon as it is produced. Thanks to it material will be of good quality (not polluted). It was proved long time ago that composting selected biowaste considerably improves its quality and that produced compost can be used on a larger scale (Table 1). After adequate segregation, the processing of organic matter decreases the volume of stored waste by 25-40%.

Table 1

Qualities of compost according to the origin of material used in composting (after Wasiak, Mamełka 1999)

The content of a substance in dry mass of compost	Compost derived from mixed municipal waste	Compost derived from selected biowaste
Content of organic waste (%)	36 – 53.7	45.6 – 50.7
Content of nitrogen (%)	0.24 – 1.2	11.2 – 1.4
Content of phosphorus (%)	0.25 – 0.75	0.60 – 1.54
Content of potassium (%)	0.10 – 0.70	0.70 – 1.10
Content of Cd ($mg \cdot kg^{-1}$)	1.0 – 13.9	0.5 – 0.8
Content of Pb ($mg \cdot kg^{-1}$)	230 – 1040	35 – 54
Content of Zn ($mg \cdot kg^{-1}$)	660 – 2321	210 – 240

Organic waste can be composted (also vermicomposted on technical and household scale). It can undergo fermentation (producing biogas) and, in justified cases of waste pollution, it can also be burnt in accordance with the Directive of Cogenerated Energy (2004/8/WE dated 11th February 2004). Are there any advantages of vermicomposting of organic waste?

Vermiculture means breeding earthworms on organic waste. It is a part of the process of building the reality of sustainable development of sustainable organic waste management through:

- biodegradation and stabilization of municipal and industrial organic waste processed into fertilizer which is rich in nutrients - vermicompost,
- regained and improved soil fertility as well as the increase in food production without using chemical methods harmful to the environment,
- production of fodder (biomass of earthworms rich in protein and other nutrients is valuable as a fodder supplement for many species of livestock).

Terms: breeding earthworms, i.e. vermiculture, and the product of their activity i.e. vermicompost, have been known in research as well as in practice all over the world for a long time now. Since vermicomposting is a specific process which uses life functions of concentrated population of earthworms a separate term for such a specific biotechnology seems to be appropriate – thus vermiculture.

Vermiculture means breeding concentrated population of earthworms on various organic waste in prepared and controlled conditions. The main directions of the use of vermiculture are:

- neutralizing plant and animal waste through its transformation into valuable fertilizer – vermicompost – which can be used as a supplement to gardening substrate,
- the production of biomass of earthworms rich in protein (including easily digestible aminoacids) which is a potential supplement to fish, poultry and pig fodder.

In times when pro-environmental reality is being built vermiculture can again become a way to earn money.

Research on the process of vermicomposting showed that the majority of earthworm species is able to process daily the amount of organic waste matter which equals half their body mass (Sinha *et al.* 2010). In Northern Europe the best species to be used in vermiculture is *Eisenia fetida* (Sav.). At the temperature of 20-25°C and humidity of 60-70%, one tonne of earthworm biomass can process one tonne of organic waste within 5 days. Five kilograms of earthworms per one square meter is suitable for intensification of vermicomposting of organic waste (regardless of its structure). Polish sources indicate 100 specimens of earthworms per one square decimetre of soil bed. Fast pace of vermicomposting described above requires an indicated earthworm concentration and big breeding beds (a multiple of a basic unit 1 x 2 meters).

The conditions in which the process of vermicomposting takes place are considerably different from the conditions of the technology of composting because the process of vermicomposting takes place in temperatures lower than 35ºC. Perfect temperature for the process ranges from 20 to 25ºC with humidity of substrate in bed within the range of 60-70% and the reaction of pH 6.8-8.0. In the process of vermicomposting the reaction changes which is probably caused by the mineralization of nitrogen to nitrates and phosphorus to orthophosphorus as well as by the production of organic acids. Substrate should be adequately shredded and oxidized with salinity smaller than 3 g NaCl dm^{-3} (Lee 1985). However, during long, e.g. one year, process of vermicomposting (without thinning the population of earthworms) salinity can rise to 12.6 ± 0.6 g NaCl dm^{-3} and be tolerated by earthworms (Kostecka 2000). The process of mixing and ventilating organic matter takes place while earthworms are tunnelling. The ratio of C : N should be about 20 : 1 and the level of protein substances introduced with organic waste cannot be too high.

There are various scientific opinions concerning the sanitary state of vermicompost. It is due to the fact that traditional process of composting, i.e. high temperature, eliminates pathogens. In the process of vermicomposting however, if the temperature is higher than 35^{o}C for a longer period of time, the population of earthworms die out. On the other hand, if vermiculture has favourable conditions (thanks to natural biological processes) the number of bacteria, actinomyces, fungus and protozoan is increasing improving quality of vermicompost (Aira *et al.* 2007, Dominquez *et al.* 2010). The pace of processing waste into vermicompost depends on the type of waste, its fraction and the species and the concentration of earthworms.

Various organic wastes (produced in paper, alcohol, vegetable oil industry as well as potato, corn, sugar cane, coffee and tea processing industry) can be utilised in the process of vermicomposting all over the world. Multilevel research on vermicomposting of sludge from municipal and industrial sewage treatment plants (including leather waste) has been also carried out in Poland.

3. Vermiculture in „an earthworm ecological box"

The study of earthworm ecology and the use of earthworms in the neutralization of organic waste have been carried on in Rzeszow since 1986 (previously known as the branch of University of Agriculture in Krakow and nowadays the University of Rzeszow). The aim of this publication is to present kitchen waste in "earthworm ecological boxes" in relation to the modelling of vermicomposting. Studies were conducted in a laboratory as well as in houses. Household waste was introduced into "earthworm ecological boxes" and a concentrated population of earthworm *Eisenia fetida* (Sav.) was used for their vermicomposting. The earthworm' life functions, observed in substrate which contained the above mentioned waste, made it possible to form coprolitic fertilizer (vermicompost). The results of the study have also been used in broad educational actions.

Vermicomposting can take place on large and small scale as well as technical or semi-technical scale. To vermicompost organic waste on small scale "earthworm ecological boxes" are needed. These are containers of various sizes (depending on the amount of waste to be processed) which are built from various materials including recycled materials. As the size of the boxes is moderate they can be used in households, schools and even offices (Kostecka 2003) where organic waste would be eliminated in the place of its production and processed into fertilizer – vermicompost.

The use of earthworm *E. fetida* in neutralizing waste on small scale was problematic due to inefficient ecological awareness which was however gradually rising (leading to clean households and organic waste segregation). Nowadays, no one questions the need to segregate waste thanks to ecological education which helped society understand that this is the necessity of our times.

Vermiculture on small scale means not only the neutralization of organic waste in the place where it is generated but also the production of earthworm biomass which can be used as fodder for various animal species or as a source of nutrients for plants – natural fertilizer – vermicompost (Fig. 1).

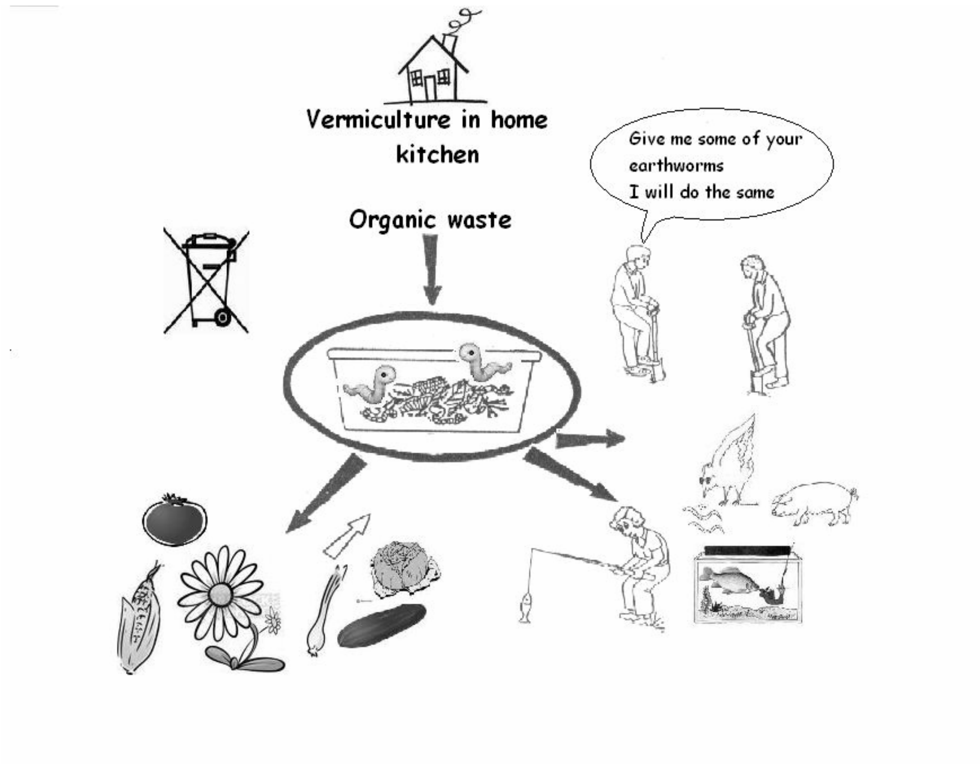


Fig. 1. „Earthworm ecological box” as vermiculture on organic kitchen waste

Earthworm ecological boxes are suitable in the reduction of organic waste produced in agriculture (fallen or rotten fruit and vegetables e.g.: carrot roots, fallen tomatoes, yellow cucumber, outer cabbage leaves, potato and tomato stalks, outgrown lettuce and many more).

Vermiculture on household scale, which utilizes organic waste in a place where it is produced, helps to limit costs of waste collection and transport and the negative results of its storage at landfill sites and illegal dump sites. Earthworm ecological boxes also play an important role in environmental protection education (Kostecka, Pączka 2005).

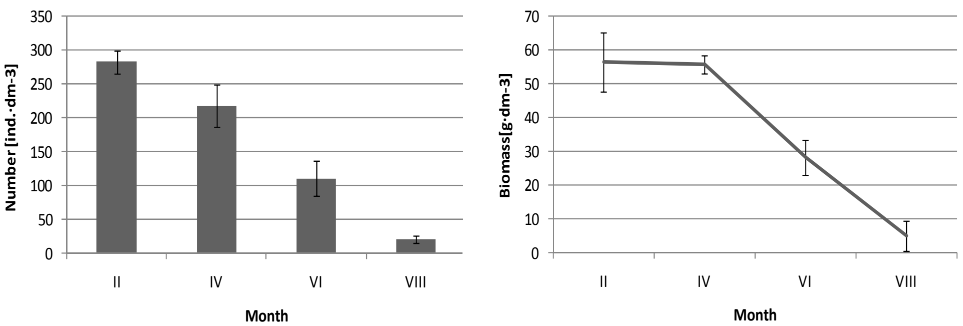
4. Critical points in „earthworm ecological boxes”

Similarly to breeding beds used in the process on large scale, appropriate vermicomposting of waste in the presence of earthworm *Eisenia fetida* in an ecological box requires:

- appropriate pH of substrate (6.5-7.5),
- appropriate temperature (12-28^{o}C),
- humidity (about 70%),
- ratio of C/N (about 20),
- ventilation.

Vermicomposting on large scale requires large space for earthworms which makes the conditions of vermiculture similar to those natural for earthworms. They can easily move around in search for the most favourable conditions. Biotic and abiotic factors in large beds influence one another in many ways and in case of any dysfunction they can regain their balance relatively easy. It is different in small containers where, due to limited environmental capacity, homeostatic processes take place slowly and thus the pace of vermicomposting and the condition of an earthworm population depend on many factors, which often work together as synergism.

Vermicomposting on small scale is slightly more problematic as an ecological box at home, school or an office can meet certain difficulties which consequently can lead to the decrease in an earthworm population (Fig. 2) and in the effectiveness of vermicomposting.

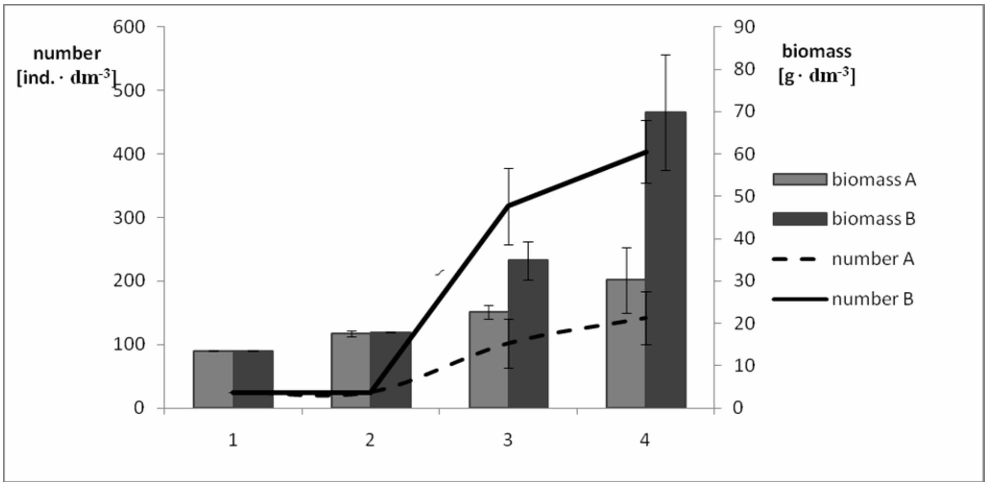


Number Biomass

Fig. 2. Disappearance of number and biomass of *E. fetida* in the „earthworm ecological box" with too high density of pedigree population

For the first critical point we can take inadequate density of an earthworm population. The frequent segregation of an earthworm population and substrate of ecological boxes has a positive influence on the quality of *E. fetida*. The implementation of such a technological aspect every four weeks has proved to be effective in the processing of organic waste into vermicompost as well as in increasing the average number of earthworms by 65% and the sum of biomass by 57% (when compared to boxes where breeding was conducted without segregation of substrate and an earthworm population (Fig. 3).

Similar tendency has been observed with a species *Eudrilus eugeniae* (Kinberg) indicating that larger concentration of specimens in vermiculture slowed down the growth of earthworms (Dominquez *et al.* 2001). Also, with the density over 32 earthworms per 10 gram of substrate, annelids lost their biomass or even died. It has been a phenomenon similar to species *E. fetida* observed by Neuhauser *et al.* (1980) and Reinecke and Viljoen (1993) and also to species *E. andrei* described by Domingues and Edwards (1997). It has been also proved that in containers with segregated substrate the number of cocoons was larger. It was in accordance with the observation made by Reinecke and Viljoen (1990) who has found that smaller concentration of earthworms in vermiculture resulted in the production of the larger number of cocoons. They also came to the conclusion that twice as small concentration of earthworms results in twice as big production of cocoons. The presented study revealed that technology without the segregation of substrate resulted in 61% smaller production of cocoons, as compared to boxes where the technology of the segregation of substrate and population has been used.



A- containers in the technology without segregation
B- containers in the technology with segregation of substrate and earthworm population

Fig. 3. Dynamics in the average number and the sum of biomass of earthworms *E. fetida* depending on vermiculture technology in an earthworm ecological box

For the second critical point in „an earthworm ecological box" we can take the presence of white worms *Enchytraeidae* which are not only food competitors to earthworms and but also produce excretions which can have a negative impact on feeding patterns of *Lumbricidae.* This can consequently lead to changes in the condition and size of its population (Kostecka, Zaborowska-Szarpak 2001) and finally in the effectiveness of vermicomposting.

Described researches show that early presence of white worms in four tested kitchen waste (pasta leftovers, boiled potatoes, bread and carrot) has significantly influenced ($p<0.001$) the concentration of earthworm *E. fetida* (Fig. 4). An amount of 18.5% out of 300 tested earthworms populated waste which was stored for two days without concentrated population of white worms, whereas waste previously populated by *Enchytraeidae* was chosen by a significant smaller number of earthworms (6.5%). The average number of earthworms gathered in each clean waste was three times higher than the number of specimens gathered in waste contaminated with white worm excretions.

It has been shown that the domination of white worms or earthworms in ecological boxes to large extent influence the quality of vermicompost in relation to the content of ash, organic substance, nitrogen, potassium, calcium, iron, copper, mangan, zinc, sodium and nickel Kostecka *et al.* (1999).

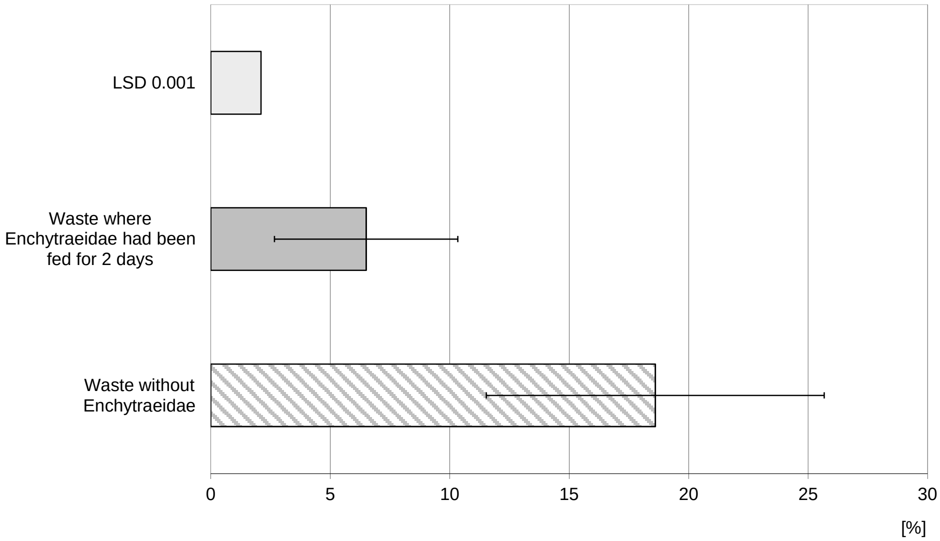


Fig. 4. Average aggregation of *E. fetida* individuals in tested waste (%) as dependent on its previous contamination with secretions of feeding *Enchytraeidae* (after Kostecka, Zaborowska-Szarpak 2001)

The presence of white worms in „an ecological box" can be modified with the way the process of vermicomposting of kitchen waste takes place. Adding a small amount of ground cellulose not only significantly improved the parameters of an earthworm population (the number and the biomass of specimens and cocoons) but also reduced the presence of *Enchytraeidae* (Fig. 5). In boxes with clean kitchen waste the number of white worms in 1 dm^3 was 2 464, whereas in boxes with waste and cellulose only 196 white worms was found. Such significant differences in the average number of white worms also applied to fresh waste added to a box which was becoming populated with white worms. After six months the average concentration of white worms in 1 dm^3 of substrate was 694 specimens and 74 specimens in waste with cellulose ($p < 0.001$).

Another critical point of „an earthworm ecological box" is the possibility of the presence of a fly *Sciaridae*. The problem can be solved by the introduction of certain insecticides to vermicomposted waste. Three insecticides (Dimilin 25WP, Nomolt 150SC and Dar 2.5GR) and two natural preparations (Owinema and aliophilic preparation) were compared in terms of their influence on the number and the sum of biomass of earthworms, on the reproduction processes and the production of cocoons as well as their impact on immature specimens. It led to the choice of three preparations whose presence was the most and the least favourable in terms of the reduction of flies and their influence on the condition and reproduction processes of earthworms *E. fetida*. Compared to natural preparations ($p<0.05$) all xenobiotics led to the decrease in the number of earthworms in a relation to controlled substrate (without preparations). Natural preparations – Owinema and aliophilic preparation did not cause any significant changes ($p>0.05$) in the number of *E. fetida* (Fig. 6).

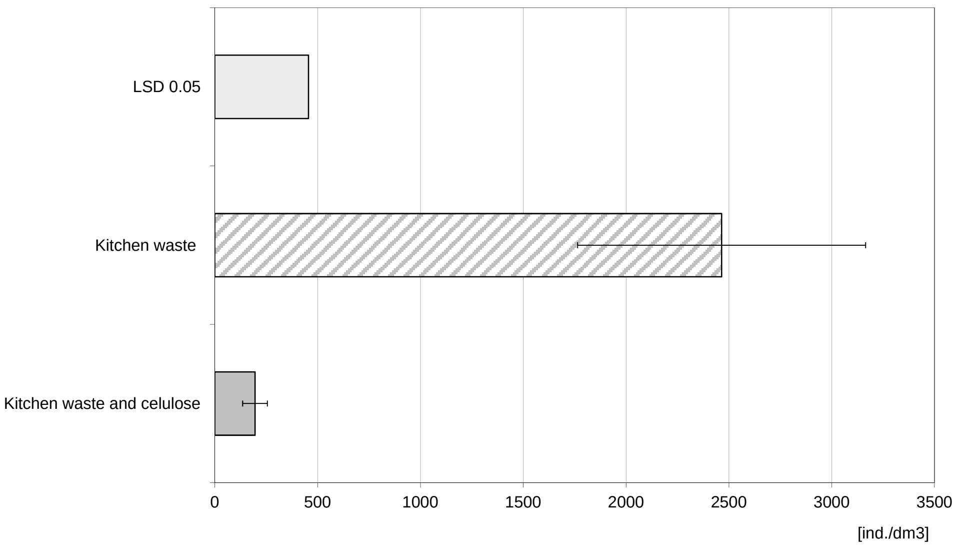


Fig. 5. Mean number of *Enchytraeidae* dependent on the way of feeding - fed on kitchen waste without and with cellulose 1:0.5

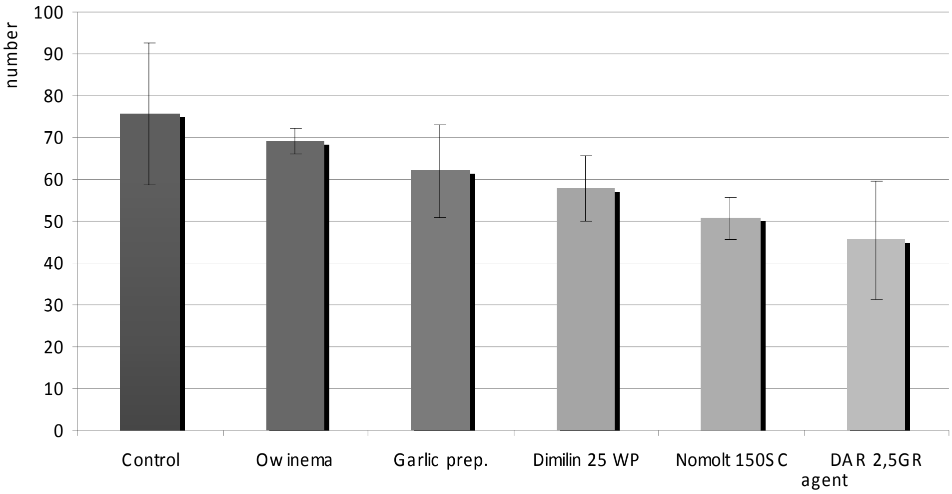


Fig. 6. Impact of natural preparations and xenobiotics on the number of earthworms *E. fetida* after five months of vermicomposting of kitchen waste in a climate chamber [ind. / container]

After five months of vermicomposting the most significant decrease in the number of *E. fetida* was caused by the following xenobiotcs: Dimilin 25WP < Nomolt 150SC <Dar 2.5GR (Fig. 6). The smallest number of earthworms was found in boxes with Dar 2.5GR and Nomolt 150SC (the decrease in number by 41% and 33% consecutively).
All preparations used (apart from Owinema) significantly decreased the sum of biomass of earthworms ($p<0.001$) (Fig. 7) where again Dar 2.5GR and Nomolt 150SC were the least favourable in terms of the number of specimens.

It can be concluded that the most favourable preparation was Owinema. Although it reduced the number of earthworms (but insignificantly when compared to controlled substrate and other xenobiotics used), it did not change the sum of their biomass. This bio-preparation had also a positive influence on the reproduction of earthworms (Table 2); a significant increase in the number of cocoons was observed in relation to controlled substrate ($p<0.05$) as well as to another tested xenobiotic Dar 2.5 GR ($p<0.001$).

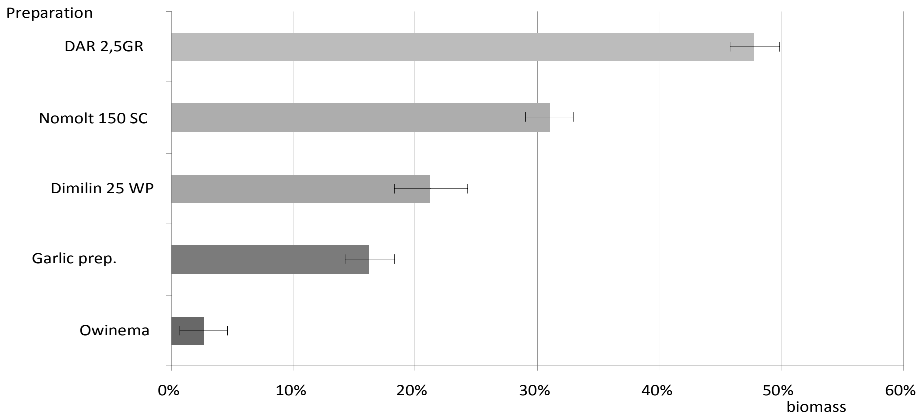


Fig. 7. Average decrease in the sum of earthworm *E. fetida* biomass in relation to controlled substrate after introducing preparations to organic waste (%)

Although it was proved that all preparations used to reduce larvae of a fly *Sciaridae* decreased their number, the most favourable turned out to be again Owinema based on nematodes. It reduced the population of *Sciaridae* larvae by 13% of controlled population, whereas xenobiotics Nomolt 150SC and Dar 2.5GR left the average of 37% and 34% of their population. Bio-preparation Owinema had the most positive impact on the average pace of vermicomposting of organic waste (it caused the highest increase of daily pace of neutralizing waste – by 30%).

For another critical point of „an earthworm ecological box” we can take its higher salinity and consequently higher salinity of vermicompost produced. This problem has been first discussed in the research of Kiepas-Kokot and Szczech (1998). It is also crucial for normal life functions of earthworms. There is not much data on the negative effect of high salinity on earthworms. Lee (1985) thinks that the concentration of salt above 0.5% is toxic to earthworm *E. fetida*.

Table 2

Impact of natural preparations and xenobiotics on the number and sum of biomass of cocoons after five months of vermicomposting of kitchen waste (g)

Preparation	Controlled substrate	Owinema	Aliophilic preparation	Dimilin 25 WP	Nomolt 150 SC	Dar 2.5 GR
Number / container	184 ±28 a	234 ±44 b	169 ±13 a	211 ±28 a,b	162 ±15 a	137 ±16 c
Biomass / container	3.2 ±0.3 a	3.6 ±0.8 a	2.9 ±1.0 a	3.1 ±1.0 a	2.4 ±0.3 b	1,9 ±0.3 b

Various letters mean statistically important differentiation ($p<0.05$)

The influence of sodium chloride on survival rate of matured earthworms *E. fetida* has been assessed during a 24-hours Contact Filter Paper Test. The research showed that a dose equal 10 g NaCl $\cdot$ dm^{-3} of medium caused the mortality of 50% of individuals, and none of the representatives of the tested population survived on the dose of 16 g NaCl dm^{-3}. However, after a year of breeding earthworms Kostecka (2000) found that the salinity was at the level of 12.6 ± 0.6 and that earthworms survived and grew. This means probably that a part of a population was gradually adjusting to such unfavourable conditions and also that the influence of various factors (the number of which is usually significant) on one another is very complex.

5. Conclusions

Pro-environmental biotechnology of vermiculture is so far known and popularized to small extent in Poland, whereas in other countries e.g. Germany, France, Spain, Sweden, Canada, China, India, the USA the process is much more common. To sum up, it needs to be stated that “an earthworm ecological box” is so far an unconventional activity. However, it offers the possibility to participate in organic waste management in accordance with the principles of sustainable development and can prevent the negative effects of biowaste stored at landfills. Starting „an earthworm ecological box”, one needs to be aware of its critical points which will make it easy and more pleasant to use.

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