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RESEARCH ON ANAEROBICALLY TREATED ORGANIC WASTE SUITABILITY FOR SOIL FERTILISATION

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Abstract. One of the most promising methods to convert organic waste into alternative energy and still obtain fertiliser is anaerobic digestion of waste in bioreactors. To evaluate the suitability of biodegraded organic waste for soil fertilisation, an experiment aimed at determining the amount of total nitrogen, total phosphorus and heavy metals contained in this waste and testing of its pH was carried out. The following organic waste was used for the research: sewage sludge from wastewater treatment plants, fruit and vegetable waste, hen manure, piggery slurry and grain. The biggest contents of nitrogen and phosphorus were determined in anaerobically treated swine manure and therefore, it was found the most suitable organic fertiliser to remediate exhausted soils and used-up areas. Treated swine manure contains 8.27 mg/*l* of nitrogen and 293.1 mg/*l* of phosphorus. The biggest contents of heavy metals were determined in anaerobically treated sewage sludge from wastewater plants. The concentration of chromium amounts to 1.53 mg/kg, that of zinc – 21.28 mg/kg, manganese – 50.03 mg/kg, lead – 10.46 mg/kg, copper – 50.48 mg/kg and nickel – 12.88 mg/kg. In none of the researched cases heavy metal concentrations in treated organic waste exceeded the maximum permissible concentration (MPC). Anaerobically treated swine manure and sewage sludge with the highest pH indicators, 7 and 7.1, respectively, are most suitable for the fertilisation of acid soils. It could be proposed that digested pig manure is best soil fertilizer from all investigated organic wastes when biogenic elements, heavy metals and pH were measured.

Keywords: soil, fertilisation, total nitrogen, total phosphorus, heavy metals, pH, organic waste.

1. Introduction

Big amounts of generated waste are one of the most important environmental problems. Organic waste accounts for a big share in the total composition of waste (Savickas and Vrubliauskas 1997). EU Directive 1999/31/EC lays down the requirement to reduce the amount of waste disposed in landfills.

Methane, carbon dioxide, hydrogen and hydrogen sulphide are discharged into the environment during biodegradation of organic waste. Methane, evolving during the anaerobic process, is a gas which causes the greenhouse effect. Attention should be paid to the fact that methane is 21 times more active in causing the greenhouse effect than carbon dioxide (Baltrėnas *et al*. 2005). Disposal of liquid organic waste to fields causes excess of nutrients and there is a danger of penetration of some waste into the soil and pollution of underground waters (Paulauskas *et al*. 2006; Mašauskas *et al*. 2006). In addition, during the process of biodegradation organic waste produces unpleasant odours.

One of the most promising techniques to convert biowaste into alternative energy and still obtain fertiliser is anaerobic digestion of waste in bioreactors (Gunaseelan 1997; Results ... 2004). It also helps to a certain extent deal with the problem of unpleasant odours. Prior to being supplied to users, gas is cleaned from unpleasantly smelling hydrogen sulphide which has evolved during biodegradation (Stankevičiūtė *et al*. 2007) and therefore, its content in treated organic waste is already low.

Treated organic waste contains biodegraded organic waste that could be used for soil fertilisation but it has to comply with the requirement of nitrogen, phosphorus and heavy metals' contents in it as well as the level of pH.

Nitrogen is vital for plant growth. Plants draw nitrogen almost only through their roots from soil and its main sources are ammonium and nitric acid salts (Tognetti *et al*. 2007). They can assimilate nitrogen in the form of ammonium (NH_4) and nitrate (NO_3) nitrogen. A nitrate form is contained in the soil solution and an ammonium form is absorbed by soil (fixed in humus). Plants easily assimilate the dissolved nitrate nitrogen from the soil solution but have to compete for hardly mobile ammonia nitrogen absorbed by soil (Petrauskas 2005).

Consequently, plants can assimilate nitrate nitrogen faster, whereas ammonia nitrogen becomes more accessible to plants only after the process of nitrification is completed, i.e. when nitrogen is converted into nitrate nitrogen (Piaulokaitė-Motuzienė and Končius 2007). However, this form of nitrogen is rapidly leached out and therefore plants have to be fertilised (Staugaitis and Dalangauskienė 2007).

Even though nitrogen is a fertiliser but upon accessing ground waters it can pollute them (Skurdenienė *et al.* 2007) and therefore, its content in soil is curtailed by fertilising with sludge. The content of nitrogen in soil is

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regulated by LAND 20-2005 “Requirements for Sewage Sludge Usage for Fertilisation and Remediation”. Pursuant to the LAND, the maximum rate of fertilisation with sludge should ensure that soil is accessed by no more than 170 kg/ha of nitrogen per year.

Phosphorus is also very important for plant growth. Since 98–99% of phosphorus that accesses soil is not leached out, even upon applying bigger amounts of the phosphoric fertiliser, plants can take its excess later (Petrauskas 2005). This is the reason why the content of phosphorus in soil is stricter regulated than that of nitrogen during fertilisation with sludge. The amount of phosphorus in soil is regulated by LAND 20-2005 “Requirements for Sewage Sludge Usage for Fertilisation and Remediation”. It stipulates that the maximum rate of fertilisation with sludge should ensure that soil is accessed by no more than 40 kg/ha of phosphorus per year.

Concentration of heavy metals in soil is especially relevant issue which is regulated by HN 60:2004 “The Maximum Permissible Concentrations of Dangerous Chemicals in Soil” and LAND 20-2005 “Requirements for Sewage Sludge Usage for Fertilisation and Remediation”. Heavy metals have a long-term negative complex effect on flora and fauna as well as people (Butkus *et al.* 2004; Jankaitė and Vasarevičius 2005).

A carbonaceous layer depth has some effect on soil acidity. If it is at a small depth, 40–50 cm, the acidity of top soil layers is close to neutral and when it lies deeper the soil is more acid (Environmental Information Centre 2008).

The majority of cultivated plants can efficiently grow and fruit only in non-acid soils and therefore, soils with the pH indicator lower than 5 have to be limed. Soil acidity also has a big effect on the quantity of microorganisms (Piaulokaitė-Motuzienė *et al.* 2004). Soils with the pH indicator lower than 5 contain almost no bacteria introducing atmospheric nitrogen (except lupine's tuberous bacteria). Acid soils also contain smaller quantities of other bacteria and degrade plant residues slower, which results in worse nutrition of plants. If plants do not receive necessary nutrients, they are weak, less resistant to diseases and pests (Environmental Information Centre).

Pursuant to LAND 20-2005 “Requirements for Sewage Sludge Usage for Fertilisation and Remediation”, the use of all types and categories of sludge in agriculture is prohibited where the soil pH <5.5.

To evaluate the suitability of biodegraded organic waste use for soil fertilisation, an experiment aimed at determining the contents of total nitrogen, total phosphorus and heavy metals in this waste and measuring the pH indicator was carried out.

2. Research methods

The research determined the level of nitrogen and phosphorus, the key elements ameliorating the properties of infertile soil, and of heavy metals in a biologically treated substrate having a negative effect on soil and plants as well as the pH indicator of the treated substrate. The experiment was carried out under laboratory conditions.

The following organic waste was used for the experiment: sewage sludge, fruit and vegetable waste, hen manure, piggery slurry and grain. These are the main types of waste being generated in biggest amounts (Kvasauskas and Baltrėnas 2008). Organic waste was digested under mesophilic conditions (at 22±2 °C) for 60 days.

A sample of the treated organic waste was taken after the waste had been kept under anaerobic conditions in a bioreactor for 60 days plus one day allowed for it to settle. The mixture that remained after pouring off the filtrate was mixed up and 1 l of the organic waste was taken for the analysis.

The total nitrogen was determined pursuant to LAND 59:2003 (LST EN ISO 11905-1:2000 Water Quality. Determination of Nitrogen. Part 1: Method using oxidative digestion with peroxide sulfate (ISO 11905-1:1997).

The total phosphorus was determined pursuant to LAND 58:2003 (LST EN ISO 1189-1:2000 Water Quality. Determination of Phosphorus. Spectrometric method using ammonium molibdate.

The concentrations of the most frequent basic heavy metals, whose amounts are regulated by certain documents, were determined. The concentrations of heavy metals (chromium, copper, lead, manganese, nickel and zinc) were determined based on the measurements of the element’s concentration in an extract of the sample treated with Royal vodka using the flame atomic absorptive spectrometry.

The treated organic waste’s pH was measured with a pH-meter whose accuracy is ±0.1.

The results of all the experiments are presented as an average value derived from three established values of the measured parameter. Values that differed from the other two values by more than 30% were excluded.

The results were evaluated statistically with the Excel program.

3. Research results

Nitrogen is one of the main biogenic elements contained in soil necessary for plant growth. Figure 1 shows the total nitrogen concentration in anaerobically digested substrates. The biggest content of nitrogen was recorded in biodegraded swine manure, i.e. 8.27 mg/*l*, and the lowest – fruit and vegetable waste, i.e. 4.09 mg/*l*.

Research carried out in Lithuania and other countries shows the dependence of agricultural plant yield and nitric fertiliser efficiency on the content of mineral nitrogen in soil (Mattsson 1990; Lazauskas *et al.* 1996). Considering this, more nitric fertilisers are necessary for plants growing in soils with a lower nitric content whereas with the increase of the nitric content in soil, the quantity of the fertiliser has to be reduced (Mattsson 1990; Lazauskas *et al.* 1996).

It is most expedient to apply biodegraded swine and hen manure on infertile soils or land areas under remediation where the biggest amount of nitrogen is required. The biodegraded fruit and vegetable substrate with a lower content of nitrogen can be applied on soils where the deficiency of nitrogen is not big.

Upon expressing the total nitrogen concentration in anaerobically digested substrates in percent and equating the maximum concentration (in swine manure) with 100%, the total nitrogen concentration in other substrates is equal to: 92.7% in hen manure, 84.9% in grain, 56.3% in sewage sludge, 49.5% in fruit and vegetable waste. It is known that nitrogen concentration in treated waste is related to the composition of waste: poultry manure and swine manure contain the biggest amount of proteins in the process of decomposition of which nitrogen forms. However, the content of proteins in waste for the most part depends on the composition of feed. Since fruit and vegetables are richest in carbodydrates the obtained content of nitrogen is the lowest.

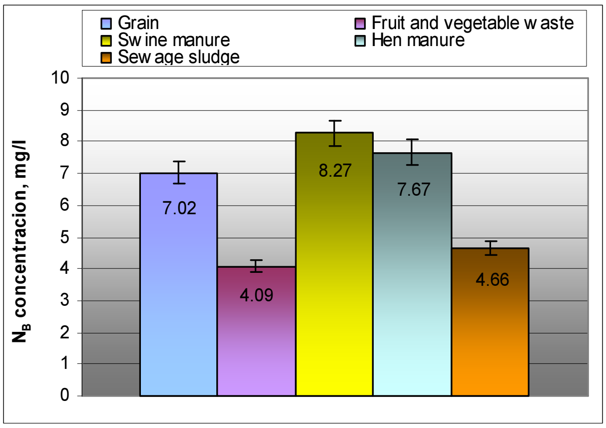

Fig. 1. Total nitrogen concentration in anaerobically digested substrates

Phosphorus is another important biogenic element necessary for plants. The total phosphorus concentration is shown in Fig. 2. The biggest content of phosphorus is in biodegraded swine manure, i.e. 293.1 mg/*l*, whereas the lowest, 13.1 mg/*l*, – in fruit and vegetable waste. Soils with a rich content of phosphorus contain around 200 mg/kg of phosphorus, whereas those with a low content of phosphorus – up to 100 mg/kg. Consequently, it is most expedient to apply biodegraded swine manure and sewage sludge on infertile soils or land areas under remediation where the biggest amount of phosphorus is required.

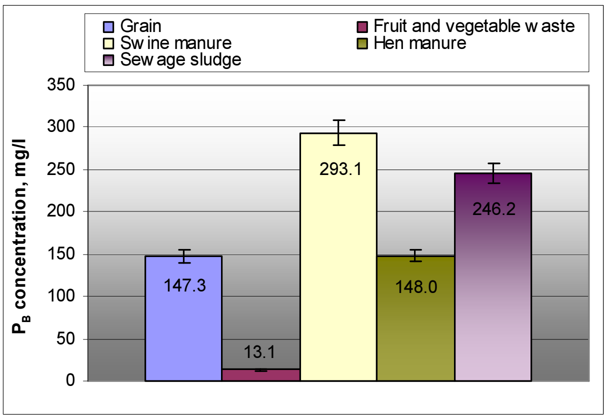

Fig. 2. Total phosphorus concentration in anaerobically digested substrates

A biodegraded fruit and vegetable substrate with a lower content of phosphorus can be applied on soils where the deficiency of phosphorus is not big. Soil fertilisation with anaerobically treated grain or hen manure would also significantly increase the content of phosphorus in soil.

Upon expressing the total phosphorus concentration in anaerobically treated substrates in percent and equating the maximum concentration (in swine manure) with 100%, the total phosphorus concentration in other substrates is equal to: 84.0% in sewage sludge, 50.5% in hen manure, 50.3% in grain and 4.5% in fruit and vegetable waste. These results clearly show that the content of phosphorus in treated fruit and vegetable waste is 22 times lower than in biologically treated swine manure.

Excessive amounts of trace elements do harm to all live microorganisms and thus the curtailment of heavy metals' concentration is very important. The discussion of the obtained experimental findings concerning heavy metal's concentration in an anaerobically treated substrate covers their comparison with the MPC regulated by HN 60:2004.

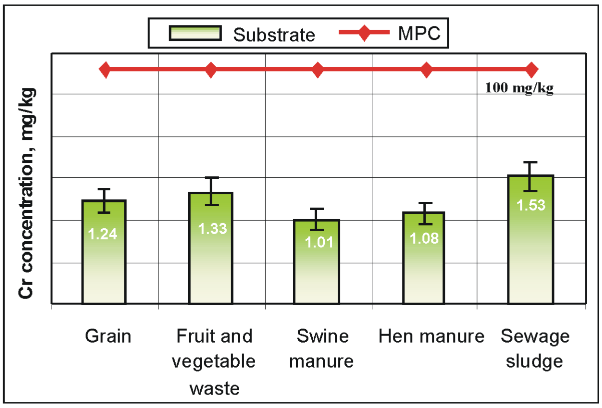

Fig. 3. Chromium concentration in anaerobically digested substrates

The analyses of chromium concentration in the above mentioned digested substrates show that the treated sewage sludge contains the highest concentration of chromium, i.e. 1.53 mg/kg of a dry material, whereas the lowest chromium concentrations are in swine manure and hen manure, i.e. 1.01 mg/kg and 1.08 mg/kg of a dry mass, respectively (Fig. 3).

The comparison of the MPC of this metal and the concentrations in substrates produce the following values: 1.2% in grain, 1.3% in fruit and vegetables, 1.0% in swine manure, 1.1% in hen manure and 1.5% in sewage sludge.

The biggest difference between the obtained chromium concentration and the MPC in hen manure and sewage sludge is 1.5 times. A higher value of chromium in treated sewage sludge is directly dependent on a composition of sewage. As a rule, the content of heavy metals in sewage discharged from wastewater treatment plants of cities is higher because of industrial facilities operating there.

Experiments carried out by Eitminavičiūtė *et al.* (2005) show that the content of chromium is 106.0 mg/kg in soil that was forming when landfills were remediated with sewage sludge for 9 years.

This is a very big content compared to the results of the experiment covered by this paper, as the difference reaches even 69 times. This might be the result of the improved environmental condition of sewage in Vilnius in the recent decade.

The analysis of zinc concentration in the anaerobically digested substrates showed that the sewage sludge contained the highest concentration of zinc, i.e. 21.28 mg/kg of a dry material, whereas the lowest zinc concentrations were in grain and swine manure, i.e. 4.74 mg/kg and 5.05 mg/kg of a dry mass, respectively (Fig. 4).

Thus, this is a similar situation like in the previous analysis – a larger content of heavy metal (zinc) was determined in treated sewage sludge.

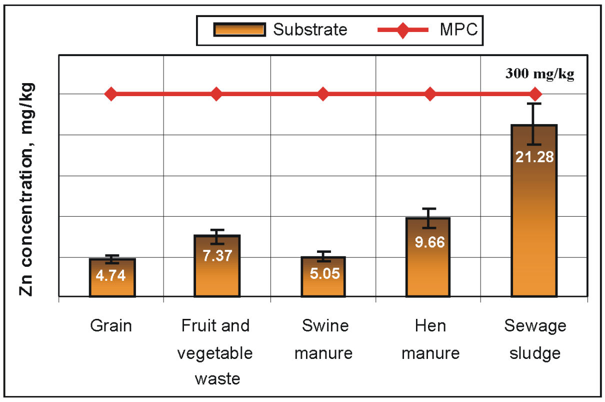

Fig. 4. Zinc concentration in anaerobically digested substrates

The comparison of the MPC of zinc and its concentration in substrates produces the following values: 1.6% in grain, 2.5% in fruit and vegetables, 1.7% in swine manure, 3.2% in hen manure and 7.1% in sewage sludge. The biggest zinc concentration in sewage sludge was likely because of a sewage composition.

Previously mentioned experiments carried out by Eitminavičiūtė *et al*. (2005) also showed a 306.5 mg/kg content of zinc in the forming soil after remediating landfills with sewage sludge for 9 years. Again, the obtained results show 14 times bigger difference compared to the current research data. The change in the composition was most probably influenced by the changed environmental situation.

The analysis of manganese concentration in the anaerobically digested substrates showed that the sewage sludge contained the highest concentration of manganese, i.e. 50.03 mg/kg of a dry material, while the lowest manganese concentrations were in grain and swine manure, i.e. 4.91 mg/kg and 8.30 mg/kg, respectively (Fig. 5).

The comparison of the MPC of manganese and its concentration in substrates produces the following values: 0.3% in grain, 1.4% in fruit and vegetables, 0.6% in swine manure, 2.6% in hen manure and 3.3% in sewage sludge. The biggest difference between the obtained concentrations of manganese in grain and sewage sludge is somewhat over 10 times (Fig. 5).

The highest manganese concentrations in sewage sludge were also likely because of a sewage sludge composition, while the increased manganese concentration in treated hen manure may be related to the used feed and its composition.

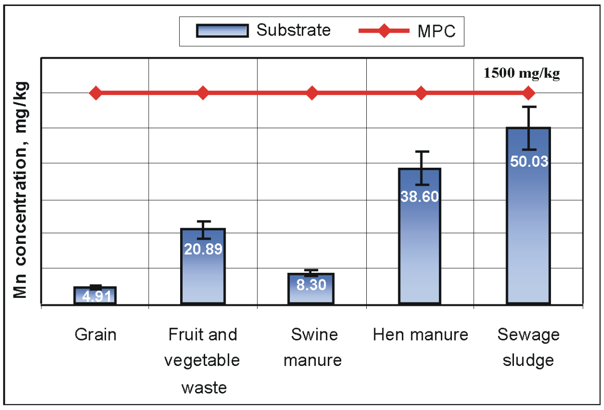

Fig. 5. Manganese concentration in anaerobically digested substrates

Lead is another important heavy metal whose content in soil has to be curtailed. The analysis of lead concentration in anaerobically digested substrates shows the highest lead concentration in sewage sludge- 10.46 mg/kg, and the lowest in grain- 2.08 mg/kg of a dry material. This makes a 5-times difference. Such a concentration of lead in sewage sludge might have been determined by the sewage from industrial facilities. Anyway, this is not a big concentration since a normal lead concentration in soil is around 10 mg/kg (Pichtel *et al*. 2000).

The comparison of the MPC of lead and its concentration in substrates produces the following values: 2.1% in grain, 2.2% in fruit and vegetables, 2.9% in swine manure, 2.4% in hen manure and 10.5% in sewage sludge. As Fig. 6 shows, lead concentrations do not differ much in all the substrates and upon estimating the errors of measuring and methods none of substrates has an exceptional concentration.

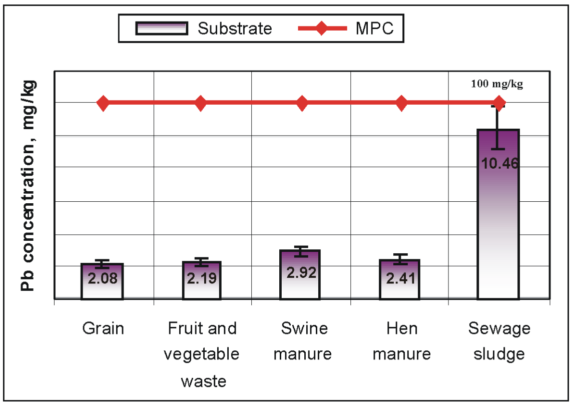

Fig. 6. Lead concentration in anaerobically digested substrates

The analysis of copper concentration in anaerobically digested substrates shows the highest copper amount in sewage sludge- 50.48 mg/kg, and the lowest in fruit and vegetable waste- 3.03 mg/kg of a dry material (Fig. 7).

The comparison of the MPC of copper and its concentration in substrates produces the following values: 4.0% in grain, 3.0% in fruit and vegetable waste, 4.6% in swine manure, 5.3% in hen manure and 50.5% in sewage sludge.

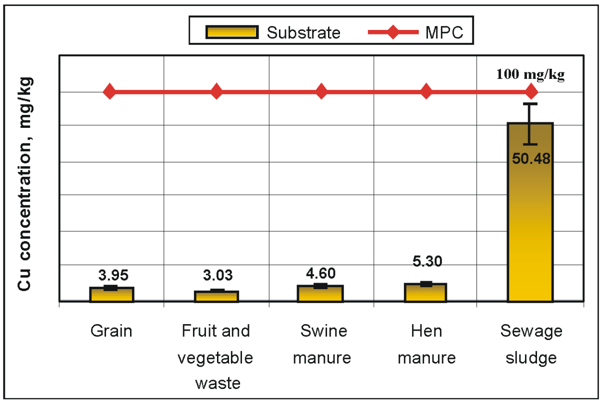

Fig. 7. Copper concentration in anaerobically digested substrates

The biggest concentration of copper in sewage sludge was likely due to a sewage composition. The content of copper in biologically treated swine manure and hen manure, when compared to fruit and vegetable waste, was 1.5 and 1.7 times higher, respectively. This could have been determined by the presence of this trace element in feed used as a supplement (Hansen 2002) for faster growth of animals like a number of other trace elements.

The analysis of nickel concentration in anaerobically digested substrates shows that the highest nickel amount is in sewage sludge- 12.88 mg/kg, and the lowest in swine manure- 1.24 mg/kg of a dry material (Fig. 8).

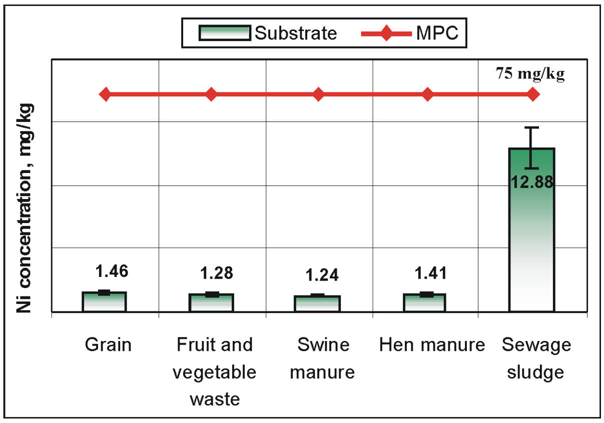

Fig. 8. Nickel concentration in anaerobically digested substrates

The concentration of nickel in soil, like those of other heavy metals, is being regulated. The comparison of the MPC of nickel and its concentration in substrates produces the following values: 1.9% in grain, 2.5% in fruit and vegetable waste, 1.7% in swine manure, 1.9% in hen manure and 17.2% in sewage sludge.

As Fig. 8 shows, that concentration of nickel does not differ much in all substrates, whereas its highest amount in sewage sludge could have been determined by a content of nickel in sewage sludge. The biggest difference between the determined nickel amount in swine manure and sewage sludge slightly exceeds 10 times.

Soil quality depends not only on the biogenic elements (nitrogen and phosphorus) analysed in this paper and heavy metals concentrations in soil but also on soil acidity. Species of plants depend on the medium of pH and that is why the plant growth is very complicated and difficult where the soil pH is low (<5).

The research results show that anaerobically treated swine manure has the highest indicator of pH, and fruit and vegetable waste – the lowest, i.e. 7.1 and 5.1, respectively. The pH indicator of grain and hen manure is slightly acid and that of fruit and vegetable waste – acid.

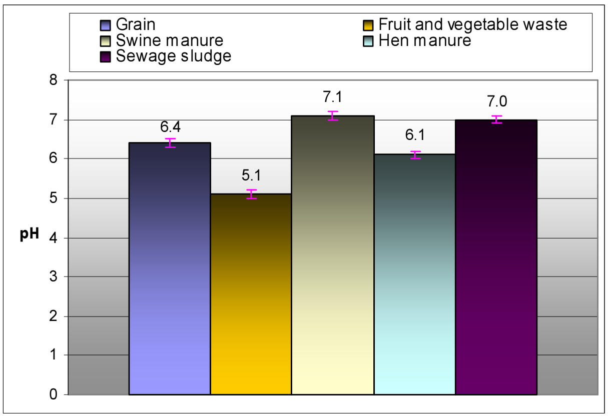

Fig. 9. pH of anaerobically digested substrates

As determined by S. R. Jain *et al.* (1995), when biodegrading fruit and vegetable waste, pH varies in the range of 6.5 and 7. However, the experiments were carried out in the thermophilic environment, at 40 °C temperature, and the methanogenic bacteria managed to degrade acids. As previously mentioned, the experiments described in this paper were carried out at the mesophlic temperature of around 22 Celsius, which had an effect on the pH indicator values.

All organic wastes analysed in this paper, except fruit and vegetable waste, can be used for soil fertilisation. To use the fruit and vegetable waste as well, it should be mixed up with other organic waste having a higher (alkaline) pH.

4. Conclusions

1. The biggest contents of nitrogen and phosphorus were determined in anaerobically treated swine manure and therefore, it is the most suitable organic fertiliser to remediate exhausted soils and used-up areas. It was found out that treated swine manure contains 8.27 mg/*l* of nitrogen and 293.1 mg/*l* of phosphorus.

2. The lowest contents of biogenic elements, nitrogen and phosphorus, were found in anaerobically treated fruit and vegetable waste, where nitrogen amounts to 4.09 mg/*l* and phosphorus – 13.1 mg/*l*.

3. The highest contents of heavy metals were determined in anaerobically treated sewage sludge, where the concentration of chromium amounts to 1.53 mg/kg, that of zinc – 21.28 mg/kg, manganese – 50.03 mg/kg, lead – 10.46 mg/kg, copper – 50.48 mg/kg and nickel – 12.88 mg/kg.

4. The lowest contents of heavy metals were found in grain.

5. In none of the researched cases heavy metal concentrations in treated organic waste exceeded the maximum permissible concentration (MPC).

6. Anaerobically treated swine manure and sewage sludge with the highest pH indicators, 7 and 7.1, respectively, are most suitable for the fertilisation of acid soils.

7. The evaluation of all the analysed parameters of the suitability of anaerobically treated organic waste for soil fertilisation shows that swine manure treated in a bioreactor is most suitable for soil fertilisation.

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ANAEROBIŠKAI PERDIRBTŲ ORGANINIŲ ATLIEKŲ TINKAMUMO DIRVOŽEMIUI TRĘŠTI TYRIMAI

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Santrauka

Vienas iš perspektyviausių metodų organines atliekas paversti alternatyvia energija ir dar gauti trąšą – anaerobinis atliekų skaidymas bioreaktoriuose. Biologiškai suskaidytų organinių atliekų tinkamumas panaudoti dirvai tręšti įvertintas atlikus eksperimentą. Jo tikslas buvo ištirti bendrojo azoto, bendrojo fosforo, sunkiųjų metalų kiekius šiose atliekose bei nustatyti jų pH. Tyrimams naudotos organinės atliekos: nuotekų valymo dumblas, vaisių ir daržovių atliekos, vištų mėšlas, kiaulidžių srutos ir žlaugtas. Nustatyta, kad daugiausia azoto ir fosforo turi anaerobiškai perdirbtas kiaulių mėšlas, todėl jis tinkamiausias kaip organinė trąša labiausiai nualintiems dirvožemiams bei išeksploatuotiems plotams rekultivuoti. Azoto perdirbtame kiaulių mėšle yra 8,27 mg/*l,* fosforo – 293,1 mg/*l*. Didžiausi sunkiųjų metalų kiekiai nustatyti anaerobiškai perdirbtame nuotekų valyklos dumble. Chromo koncentracija siekia 1,53 mg/kg, cinko – 21,28 mg/kg, mangano – 50,03 mg/kg, švino – 10,46 mg/kg, vario – 50,48 mg/kg, nikelio – 12,88 mg/kg. Nė vienu iš tirtų atvejų sunkiųjų metalų koncentracijos perdirbtose organinėse atliekose neviršijo DLK. Labiausiai rūgštiesiems dirvožemiams tręšti tinka anaerobiškai perdirbtas kiaulių mėšlas ir nuotekų valymo dumblas, kurių pH rodiklis didžiausias – siekia atitinkamai 7 ir 7,1. Įvertinus biogeninių elementų ir sunkiųjų metalų kiekį bei pH, galima teigti, kad dirvai tręšti iš tirtųjų organinių atliekų tinkamiausias yra kiaulių mėšlas.

Reikšminiai žodžiai: dirvožemis, tręšimas, bendrasis azotas, bendrasis fosforas, sunkieji metalai, pH, organinės atliekos.

ИССЛЕДОВАНИЕ ПРИГОДНОСТИ АНАЭРОБНО ПЕРЕРАБОТАННЫХ ОРГАНИЧЕСКИХ ОТХОДОВ ДЛЯ УДОБРЕНИЯ ПОЧВ

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Р е з ю м е

Одним из наиболее перспективных методов преобразования органических отходов в альтернативную энергию и удобрения является анаэробное сбраживание отходов в биореакторах. Для оценки пригодности внесения в почву биологически переработанных органических отходов в виде удобрений проводился эксперимент с целью определения суммы содержащихся в отходах общего азота, общего фосфора, тяжелых металлов и pH. Для исследований в качестве органических отходов использовался ил сточных вод из очистных сооружений, фруктово-овощные отходы, куриный помет, навоз и навозная жижа. Наибольшее содержание азота и фосфора было определено в анаэробно переработанном свином навозе, поэтому он наиболее приемлем в качестве органического удобрения для восстановления и рекультивации почв. Обработанный свиной навоз содержит 8,27 мг/л азота и 293,1 мг/л фосфора. Наибольшее содержание тяжелых металлов было установлено в анаэробно переработанном иле из сточных вод предприятий. Концентрация хрома в нем составляла 1,53 мг/кг, цинка – 21,28 мг/кг, марганца – 50,03 мг/кг, свинца – 10,46 мг/кг, меди – 50,48 мг/кг, никеля – 12,88 мг/кг. Ни в одном из исследованных случаев концентрации тяжелых металлов в переработанных органических отходах не превышали максимально допустимых концентраций (ПДК). Для удобрения кислых почв наиболее приемлем анаэробно переработанный свиной навоз и ил стоков из очистителей, содержащие высший показатель pH (соответственно 7 и 7,1). На основании полученных величин биогенных элементов, тяжелых металлов и pH можно утверждать, что из всех исследованных органических отходов наиболее пригоден для удобрения почв свиной навоз.

Ключевые слова: почва, удобрения, общий азот, общий фосфор, тяжелые металлы, pH, органические отходы.

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