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Composting as a "golden method" to solve the organic household waste problem? – short revision

Introduction

According to the Act (*Dz. U. 2013 poz. 21*), waste is defined as each substance or object that the owner disposes of, intends to dispose of, or is obligated to dispose of. The Regulation of the Minister of Environment (*Dz.U. z 2014 r., poz. 1923*) divides the waste into 20 groups according to the source of its origin, including, among others litter from the leather and fur industry, agricultural, gardening, hydroponic farming, fishery, forestry, game shooting, food processing as well as a household with fractions collected selectively. The waste catalogue divides such waste into subgroups and types, assigns their codes, and specifies hazardous. This classification distinguishes 3 basic refuse selection criteria – by its source of origin, properties, and components.

Each of us is a daily "producer" of refuse. Waste produced by private individuals has been classified into the code 20 group – household with fractions collected selectively. Household litter includes waste from private houses as well as from other sources (except for hazardous) whose nature and composition are similar to those of household. Such refuse is the main source of pollution in all parts of the environment and is a major nuisance contributing to environmental degradation (Czop, Hatlapa, 2007; Sklamowski, 2009).

Based on the Regulation of the Minister of Environment (*Dz.U. z 2014 r., poz. 1923*), the household waste group is divided into three subgroups: segregated household and selectively collected household refuse (e.g. paper and cardboard, glass, clothes), litter from garden and park (biodegradable, soil and earth, including rocks and other non-biodegradable) and other household litter (e.g. sink basin deposits, large-size waste).

According to information provided by Statistics Poland, in 2017, the quantity of household waste produced in Poland reached 11.969 thousand tons. This figure is 2.7% higher than in the previous year, hence we are seeing an increase in the quantity of produced household litter (https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/srodowisko/zmiana-systemu-gospodarki-odpadami-komunalnymi-w-polsce-w-latach-2012-2016,6,1.html). The highest quantity of household refuse produced in 2020 per one resident was recorded in Dolnośląskie province (400 kg), and the lowest quantity in Podkarpackie province (236 kg) (https://bdl.stat.gov.pl/BDL/dane/podgrup/tablica).

The Act of 14 December 2012 outlines the hierarchy of waste management methods. First and foremost, it is necessary to minimize the production of waste (1), next prepare it to be reused (2), recycle it (3), then put it through other recovery processes (4), and finally neutralize it (5). Compliance with those rules is of utmost importance to decrease the adverse impact of litter on human health and the environment. Moreover, it will contribute to optimising the utilisation of refuse-derived materials. In Poland, mixed waste is subjected to the following processes according to their management methods hierarchy: recycling, thermal transformation, other processing methods, and depositing in landfills. The fact that the quantity of selectively collected refuse in Poland is growing every year is the cause for optimism (Fig. 1).

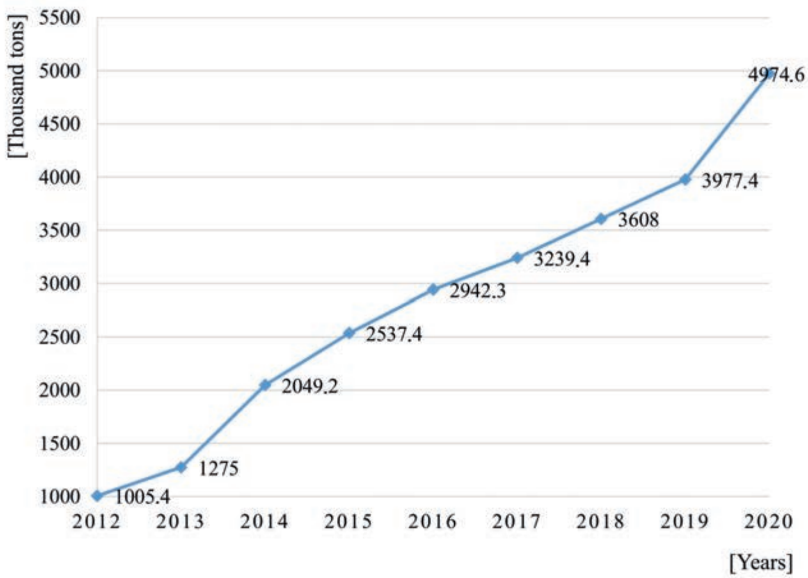

Fig. 1. The comparison of selective waste collection in Poland in 2012–2020 (Source: https://bdl.stat.gov.pl/BDL/dane/podgrup/tablica)

The increase in the quantity of selectively collected litter is undoubtedly attributable to the introduction of an amendment to the Act of 13 September 1996 on Maintaining Cleanliness and Order in Municipalities (*Dz.U. z 1996 Nr 132 poz. 622*), which entered into force on January 1, 2012. According to Article 6k. sec. 1 item 3 of that Act, if waste is not collected and collected selectively, the Municipal Council shall introduce higher rates of fees. It is also the responsibility of the commune to obtain an appropriate level of recycling and to limit biodegradable municipal refuse deposited.

The main component of household waste is organic matter. Its share amounts to 40%, therefore it is important to implement the procedures aiming at reintroducing the organic components into the environment. The processing of household rubbish by biological methods, including composting, can be employed to recover the matter in the form of a fertiliser or gas, and, at the same time, to reduce the quantities of refuse sent to landfills. Composting is a method that is based on natural processes occurring in the environment through the activity of microorganisms, whose effectiveness is augmented by artificially optimized conditions. The composting process may involve the following types of waste: selectively collected kitchen and garden, refuse from green areas (city parks and green spaces), household-like litter generated by the industry and artisan shops and organic from the food industry, as well as sediments from sewage treatment plants (Czop, Hatlapa, 2007; Wengierek, 2014; Czop, Żydek, 2017).

Compost is an organic fertiliser. It contains decomposed remnants of plant-based materials. It may contain faecal sludge and natural fertilisers. After the humification process is finished, the compost looks like hummus. It is dark and its smell can be compared to that of damp garden soil. Depending on the type of substrate, it may contain nitrogen, potassium oxide, Teraphosphorus decoxide, as well as macro and microelements (Krysztoforski, 2011).

The analysis of the quantities of refuse subjected to the composting processes in Poland in 2012–2020 shows that the largest volume of waste was composted in 2018, and the smallest – in 2020, when it was more than 3 times less than in 2018 (Fig. 2). Recently, i.e. in 2016–2020, the largest volumes of rubbish were composted in Świętokrzyskie province. It should be noted that in 2018, that province recorded a significant, more than six-fold increase in the quantity of composted waste as compared to the previous year. On the other hand, the smallest quantities of composted household waste were recorded in 2016 in Łódzkie province. It turns out that between 2014 and 2020, Lubelskie and Lubuskie provinces did not at all utilise composting as a refuse disposal method et all (Fig. 3).

Certain local governments have assigned a high priority to composting through implementation special programs. One of the examples is the Environment and Agriculture Department of the Wrocław City Hall (south-west Poland), which has been realising a program of compost bins distribution among Wrocław residents as well as educational institutions located throughout the city. The purpose of the program is to educate the residents on correct composting of household refuse, promote composting of waste for the residents' own needs, increase the quantities of recycled biodegradable rubbish and, at the same time, reduce the quantities of household waste generated in the city

Fig. 2. Quantities of waste recycled through composting in Poland in 2012–2020 (Source: https://bdl.stat.gov.pl/BDL/dane/podgrup/tablica)

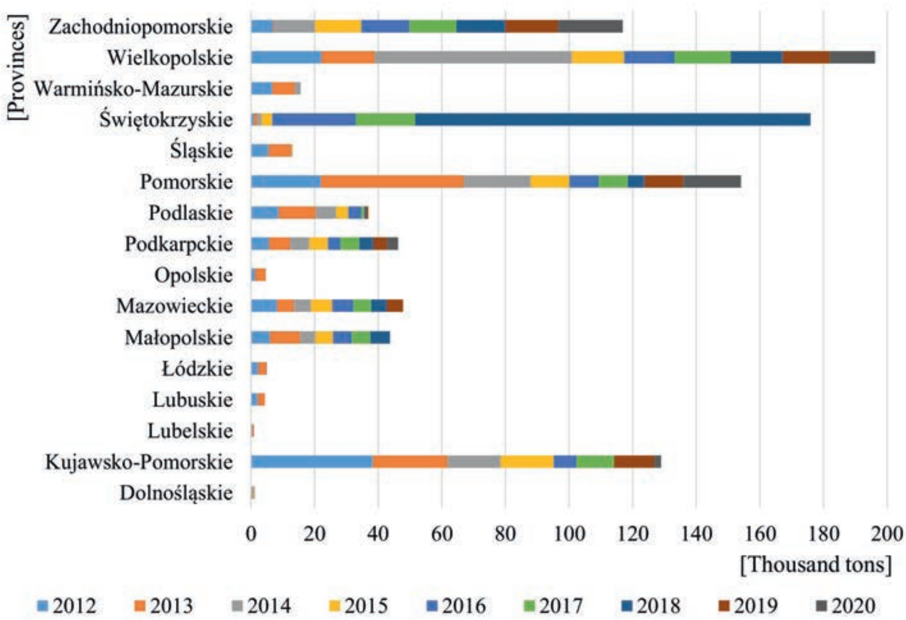

Fig. 3. Amount of waste subjected to recovery – composting in individual provinces in Poland in 2012–2020 (Source: https://bdl.stat.gov.pl/BDL/dane/podgrup/tablica)

of Wrocław that are being sent to landfills. Beneficiaries of the program receive a compost bin free-of-charge for 36 months, and after that time the bin becomes the property of the user. The compost bin can be used for 12 years and can recycle up to 1274 kg of biological waste per year provided that it is used according to the instructions and it is fully utilised (http://bip.um.wroc.pl/artykul/305/5331/program-udostepniania-kompostownikow).

The advantages of employing the composting method in refuse management processes include recirculation of significant quantities of biodegradable litter, sanitary and epidemiological hygienisation treatment of rubbish, reduction of the quantities of refuse sent to landfills by 30–50%, technical availability and easiness of use, economic availability, simultaneous disposal of several types of organic waste, and the potential for utilising the products of the composting process (Drozd et al., 1996; Manczarski, 2007; Skalmowski, 2009; Olczyk, 2012; Łabętowicz et al., 2019).

This paper attempts to evaluate the waste composting process as partial solution to the issue of management of refuse, both mixed and segregated. In addition, the article evaluates the potential for utilising the products of the household rubbish composting process.

Composting systems

Composting is a biothermal process that is divided into two main phases:

I –thermophilic composting – a high-temperature phase during which the temperature may exceed 70°C; this phase is very important to the hygienisation treatment process;

II – mesophilic composting – the maturity phase which is characterized by a drop in temperature and the creation of humins (Manczerski, 2007; Skalmowski, 2009).

Some authors distinguish as many as 4 phases of this process: I – initial composting, in which the composting process is initiated and the multiplication of microorganisms, II – thermophilic or intensive composting phase, III – mesophilic phase known as proper composting, IV – compost maturation (temperature drop, humins formation) (Manczerski, 2007).

The overall course of the composting process is affected by several factors, including organic matter content, temperature of the compost mass, ambient temperature, structure, humidity, carbon/nitrogen (C/N) ratio and volatile compounds (Sasaki et al., 2003; Ozimek, Kopeć, 2012; Shimizu, 2017). The duration of those phases depends on the applied technology and the composition of biomass to be composted. The intensity of exothermic decomposition of organic substances depends on their susceptibility to decomposition. Lignin and scleroproteins, such as e.g. keratin, are very resistant to decomposition. Hemi-

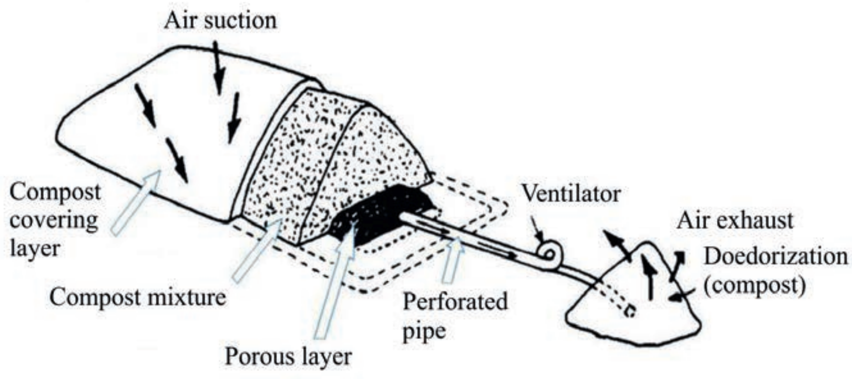

Fig. 4. Scheme of composting in prisms with active aeration (Source: Public domain, changed)

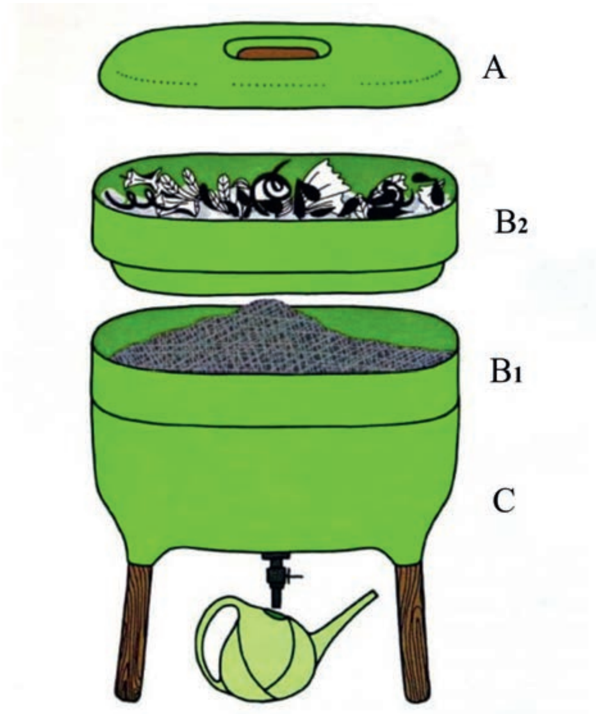

Fig. 5. Scheme of an exemplary gazebo composter: A – cover, B1, B2 – chambers for bio-waste and earthworms, C – lower chamber for a liquid fertiliser (Source: Public domain, changed)

cellulose and cellulose also do not decompose well. On the other hand, fats as well as most of sugars and proteins decompose very well (Jędrczak, Haziak, 2005).

There are several ways of classifying the composting systems. Selectively collected organic waste may be composted in open air on prisms under natural conditions (Fig. 4). This process is preceded by pre-treatment of refuse. It involves removing materials that may be harmful and grinding the compost to obtain the appropriate granulation. In addition, composting processes may take place in artificial conditions, in chambers or on concrete slabs; in that case, the waste is also pre-treated. Composting prisms may be set up in open air, under the roof or in an enclosed space. They are usually placed on concrete slabs, which make it easier to drain leachate and artificially aerate the prisms. From time to time, the prisms may be flipped using specialised machinery. Composting chambers may have different forms (Fig. 5). In most cases, they are enclosed, may be movable or immovable, and may take various shapes (drums, tunnels, towers, rectangular chambers). Composting chambers intensify the composting processes and create optimal conditions for their course. They make it easier to drain leachate and neutralise odours (Manczarski, 2007; Juda-Rezler, Manczarski, 2010; Gawała-Widera et al., 2011).

Depending on various factors such as quantity and quality of refuse, location and conditions of the factory, the biomass composting processes are carried out in different systems. In most cases, the refuse is shredded, all contaminations (mostly metals) are separated from it, and then the waste is mixed with mature compost, sawdust and other wood by-products which act as structural material and keep moisture at an adequate level. Organic waste collected separately is usually composted in the open air, sometimes after installing an external insulation layer. The prisms are periodically flipped, and they are fitted with aeration and leachate discharge systems. Sometimes this process is shielded from the external environment by installing a total or partial roof over the prisms. The best way of composting kitchen organic waste is the storage in chambers due to odours neutralisation, while green waste should be composted in prisms (Manczarski, 2007; Manczarski, 2013).

Potential for utilising of household waste composting process products

Biological processing of household waste has many advantages. Products created through the household refuse composting processes are a source of thermal energy and biogas, and, as such, they may be practically utilised. Some composted material, e.g. coffee grounds or lipid fraction from swine manure are used as biofuel feedstocks (Liu, Price, 2011; Cho et al., 2021). Compost, as a final product of that process, is used as a fertiliser and soil additive for growing plants (Mylavarapu, Zinati, 2009). It is used in reclamation of degraded areas, to improve the soil structure, and as a component of fodders and mulches (Czop, Żydek, 2017).

The final use of compost depends on its chemical and physical properties. It should not contain "hard" contaminants, such as e.g. glass or plastics. It should be "rich" in organic matter as well as substances that can be absorbed by plants. In addition, its characteristics that are taken into consideration include not the presence of disease-causing microorganisms, the degree of its maturity as well as the type of its raw material. (Baran et al., 2011; Czop, Żydek, 2017).

Composting process as a source of energy

The composting process turns organic waste into a fertiliser. This process is accompanied by production of large quantities of thermal energy, which could be utilised in practice e.g. in agriculture and horticulture. According to Rosik-Dulewska and Grabda's (2001) research, increase of soil temperature in foil tunnels accelerates growth and development of plants and boosts the crop yields. Sołowiej (2007a) used the compost-generated thermal energy for optimising the conditions for vegetable cultivation in foil tunnels. Utilisation of that thermal energy resulted in a shorter plant development period and increased crop yields. Such type of energy does not cost anything, so there is also an economic incentive to use it. Moreover, in his work devoted to the concept of using a compost prism as a low-temperature thermal energy source in vegetable cultivation, he (Sołowiej, 2007b) proposed a design of an installation which transfers the heat from the compost prism via the pipe collector which is connected to the soil-heating pipes in the foil tunnel. Such installation would have to be fitted with a circulating pump, which would force the circulation of water through the system. Such system would allow the transfer of heat under certain conditions, and it would not have an adverse impact on the composting process. Sołowiej (2007b) emphasized that usage of compost as a low-temperature thermal energy source would improve the profitability of vegetable cultivation in foil tunnels through significant acceleration of plant growth and increased vegetable crop yields, it would save conventional energy carriers, and, at the same time, reduce the quantities of pollutants discharged into atmosphere which usually accompany the traditional heating methods.

Compost can be used as a renewable sour of energy due to its organic carbon content. However, the problem is the moisture content of the compost, which can be reduced e.g. by adding cardboard. Moreover, it was found that adding cardboard after the completion of the composting process increases the energy content of the compost (Raclavská et at., 2011). Lignocellulosic biomass is also one of the renewable energy sources. It is a source of biofuels, including biofuel, biohydrogen, and biogas. The use of lignocellulosic biomass will contribute to the reduction of fossil fuel consumption (Koul et al., 2022).

Compost used as fertiliser and soil additive for growing plants

Compost is used for fertilising the soil in orchards arable fields, forestry, and green areas. Its composition may be enriched depending on the needs of the soil in which it is supposed to be used. To enrich the compost, the following products are added: fertilisers, alkalising agents (to increase pH) as well as peat/lignite (to increase the number of carious substances) (Czop, Żydek, 2017). Compost rich in microelements, e.g. zinc, and copper, can be used for the production of fertiliser mixtures (Baran et al., 2011).

One of the properties of compost is nutrient retention in the soil and improvement of soil structure due to the carious substance content. In addition, compost reduces the erosion of phosphorus, making it easier to absorb it by plants and microorganisms (Czop, Żydek, 2017). In the study on composting process with the addition of animal-derived refuse, Anders and Nowak (2008) concluded that adding meat waste during the composting process yielded a very good quality compost that could be used as an organic fertiliser.

To be used as a fertiliser, the compost must meet priority quality requirements that are prescribed by the regulations. Therefore, it is very important to know the origin of the material which will be used in the composting process. Composts obtained from mixed household waste are of much lower quality than those produced from selectively collected waste, mostly because mixed household waste is contaminated with heavy metals (for example zinc, chromium, copper), plastics, and glass (Manczarski, 2007; Olczyk, 2012).

In the study on the impact of selective collection of household waste on the properties of composts, Olczyk (2012) proved that the biodegradable fraction selected from the household waste had met the requirements stipulated in the Regulation of the Minister of Agriculture and Rural Development of 18 June 2008 in the matter of Implementation of Selected Provisions of the Act on Fertilisers and Fertilisation (*Dz.U. 2008 nr 119 poz. 765*), and, therefore, after processing, it could be used as a fertiliser. After analysing the composition of the compost obtained from mixed and not segregated at the source waste, Olczyk (2012) noted that it contained large quantities of heavy metals which disqualified it from being used in agriculture.

Compost used as a soil supplement significantly enhanced strawberry plant (*Fragaria ×ananassa* Duchesne ex Rozier) growth and fruit quality. In experiments, Peter nutrient solution (50% fertiliser) was added to a mixture of 50% soil plus 50% compost. This increased the dry weight of the plants twice, fruit yield by over 70%, and fruit size by 15% compared to control. Compost with fertiliser also enhanced leaf chlorophyll content (Wang, Lin, 2002). The addition of compost improved the physical and chemical properties of soils and increased parsley (*Petroselinum crispum* (Mill.) Fuss.) yields in research provided by Mylavarapu and Zinati (2009). Poultry manure used in combination with tillage increased grain yield by about 40% compared with tillage only (Agbede, Ojeniyi, 2009). Compost from unsorted municipal solid waste (MSW) and bark and sewage sludge (BS) had a positive effect on soil softness, porosity, availability of nutrients for plants, and water holding capacity. Both materials influenced the growth of apple (*Malus* sp.) and vine (*Vitis vinifera* L.) cuttings and prevented the development of weeds (Pinamonti, Zorzi, 1996). But inadequate processing of farmyard manure, compost or slurry can be a reason for increased weeds. To kill the weed seeds, the temperature must be sufficiently high during the composting phase (Bàrberi, 2002).

Compost that meets the relevant standards can be used in ecological agriculture. As reported by Illera-Vives et al. (2013) compost with seaweed, fish refuse (their skin, heads and spine) and pine bark are used in such agriculture. They found that fish waste contained a lot of nitrogen and phosphorus. The sea wood contained high amounts of potassium, sodium and moisture. On the other hand, pine bark had a high C/N ratio. Due to the low metal content of all types of waste, this compost is suitable for cultivation and it can be used in ecological agriculture.

Compost used in reclamation of degraded areas

Research conducted by Kujawska et al. (2016) has shown that mixing a mineral component (containing mining waste) with an organic component (in the form of compost originating from an organic fraction of household waste) creates a mineral and organic base that can be used to create a reclamation layer for degraded areas. This research evaluated the following parameters of mixes: the content of biogenic elements, macroelements, and microelements as well as the toxicity of the obtained base to an experimental plant – common wheat (*Triticum aestivum* L.). Despite increased contents of heavy metals in the obtained base, they did not accumulate in the plant biomass. The obtained organic base had physical and chemical properties which were similar to the properties of the soil.

Compost BS is a valid alternative to the soil and organic soil conditioners on the market in the recovery of the degraded area. In the studies conducted by Pinamonti and Zorzi (1996) compost secured a rapid emergence and regular growth of herbaceous species covering degraded areas.

Compost used to improve the structure of the soil and as a component of fodders and mulches

Compost has a broad application in terms of the improvement of the soil structure. It decreases erosion processes through the reduction of rainwater surface runoff; it increases the durability of the surface of park pathways as well as recreation and sports amenities; it helps reduce the creation of puddles when mixed with sand, clay, or small gravel (Czop, Żydek, 2017). To improve the structure of the soil and increase the amount of carbon in it, manure is used, appropriate irrigation, cover, and energetic plants are planted, as well as agroforestry (Lal, 2004).

Some crop residues were used in soil mulching and producing animal fodder (Koul et al. 2022). As a component of fodders and mulches, compost contributes to the development and growth of pigs and chickens. Due to the content of vitamin B12, natural antibiotics, and iron ions, compost was observed to have a positive impact on poultry which is less susceptible to diarrhoea and contagious diseases (Czop, Żydek, 2017).

Utilisation of compost and legal regulations

According to the requirements stipulated in the National Waste Management Plan 2022 (*M.P. 2016 poz. 784*), by 2020, no more than 35% of the mass of biodegradable household waste should be sent to landfills, taking as a base the quantity of waste produced in 1995 (4.38 million megatons). Under the Regulation of the Minister of Environment of 25 May 2012 in the matter of Limiting the Mass of Biodegradable Household Waste Sent to Landfills and the Method of Estimating the Limits of Such Waste (*Dz.U. z 2012 r., poz. 676*), in 2012, the limit of the mass of biodegradable household waste sent to landfills was 70%, in 2013–2015 – 50%, in 2016–2017 – 45%, and 2018–2019 – 40%.

Based on the aforementioned regulations, the priority objective of biodegradable household waste management is to reduce the quantities of waste that is being sent to landfills. The implementation of that plan may be significantly aided by composting, which contributes to the reduction of quantities of household waste sent to landfills by as much as 40%. In addition, composting allows recovering the organic matter in the form of a fertiliser which may be used in agriculture or orchards. However, it must meet the quality requirements which are evaluated based on the following three criteria: composition, physical properties, physicochemical properties, and chemical properties; sanitary and hygienic condition; and degree of maturity or stabilisation. Such criteria for organic fertilisers and soil additives for growing plants are defined in the Regulation of the Minister of Agriculture and Rural Development of 18 June 2008 in the matter of Implementation of Selected Provisions of the Act on Fertilisers and Fertilisation (Tab. 1–2).

Tab. 1. Quality requirements for solid fertilisers (Based on *the Regulation of the Minister of Agriculture and Rural Development of 18 June 2008 in the matter of Implementation of Selected Provisions of the Act on Fertilisers and Fertilisation*)

Parameter	Unit	Organic fertiliser	Organic and mineral fertilises	Mineral fertiliser
Organic substance	[% dry mass]	≥ 30	≥ 20	-
Potassium, K_2O	[% mass]	≥ 0.2	≥ 1	≥ 2
Phosphorus, P_4O_{10}		≥ 0.2	≥ 0.5	≥ 2
Total nitrogen, N		≥ 0.3	≥ 1	≥ 2

Tab. 2. Permissible quantities of contaminants in fertilisers (Based on *the Regulation of the Minister of Agriculture and Rural Development of 18 June 2008 in the matter of Implementation of Selected Provisions of the Act on Fertilisers and Fertilisation*)

Contamination	Organic fertiliser	Organic and mineral fertiliser	Mineral fertiliser
	Unit [mg/kg dry mass]		
Arsenic (As)	-	-	≤ 50
Chromium (Cr)	≤ 100	≤ 100	-
Cadmium (Cd)	≤ 5	≤ 5	≤ 50
Nickel (Ni)	≤ 60	≤ 60	-
Lead (Pb)	≤ 140	≤ 140	≤ 140
Mercury (Hg)	≤ 2	≤ 2	≤ 2

Fertilisers and soil additives for growing plants must meet certain sanitary-hygienic requirements in terms that they must not contain any live eggs of intestinal parasites *Ascaris* sp., *Trichuris* sp., *Toxocara* sp. or *Salmonella* bacteria. An equally important quality requirement that the compost must meet so that it could be used as a fertiliser is its maturity. Compost maturity is taken into consideration when evaluating the usefulness of compost as a fertiliser and an additive for growing plants. According to the Regulation of the Minister of Agriculture and Rural Development of 18 June 2008 in the matter of Implementation of Selected Provisions of the Act on Fertilisers and Fertilisation, mature compost meets the following criteria: AT_4 (transpiration) – below 10 mg O_2/g of dry mass, LOI (Loss On Ignition) – below 35% of dry mass, and TOC (Total Organic Carbon) – below 20% of dry mass.

Conclusions

The organic matter from household waste may be recovered through composting in the form of a fertiliser, which can be broadly used, as well as in the form of thermal energy and biogas. In addition, less waste will be sent to landfills thanks to composting. Therefore, this process can benefit us in two ways: it protects the environment and helps agriculture. When it comes to environmental protection, there is less organic matter that is being sent to landfills, and, therefore, the landfills will occupy a smaller area. On top of that, composting eliminates sanitary hazards. When it comes to aiding agriculture, the products of the composting process can be used as a fertiliser. To be used as a fertiliser, the compost must meet priority quality requirements that are prescribed by the regulations. Composts obtained from mixed household waste are of much lower quality than those produced from selectively collected waste. However, due to growing quantities of selectively collected household waste, including biodegradable refuse, and due to the increasing percentage of its volumes being biologically transformed, we can be optimistic that one day we will see widespread use of waste-derived fertilisers. Thus, composting can be the "golden method" of solving household waste problems, but it still requires additional financial outlays and regulations, as well as an appropriate incentive for society.

Conflict of interest

The authors declare no conflict of interest related to this article.

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Kompostowanie – „złota metoda" na rozwiązanie problemu organicznych odpadów domowych? – krótki przegląd

Streszczenie

W Polsce ilość odpadów poddanych recyklingowi organicznemu – kompostowaniu począwszy od roku 2015 wzrasta. Obserwuje się także rosnącą ilość selektywnie zbieranych odpadów komunalnych, w tym biodegradowalnych. Recykling organiczny bioodpadów daje możliwość odzyskania materii w formie kompostu lub stabilizatu, przy jednoczesnym zmniejszeniu ilości odpadów kierowanych na składowiska. Kompost przeznaczony na nawóz musi spełnić określone wymagania jakościowe zgodnie z Ustawą o nawozach i nawożeniu. Otrzymany nawóz znajduje szerokie zastosowanie m.in., jako: środek wspomagający uprawę roślin, podłoże w rekultywacji terenów zdegradowanych, dodatek do pasz i ściółek.

Słowa kluczowe: materia organiczna, unieszkodliwianie odpadów, nawozy, wysypiska śmieci

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