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Original article

Preparation of bio-compost and chemical analysis of compost

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Abstract

One of the principles of the circular economy requires the effective recycling of organic waste, especially since its volume is increasing from year to year. Therefore, one of the best solutions to solve this problem is the composting of organic waste. This paper presents the results of a comparative study of 10 different composts in terms of their quality. The composts varied with regard to waste materials used for composting, the adopted composting method, and the degree of compost maturity. Both biological (seed germination rate and intensity of plant root growth) and chemical methods (contents of macro- and micronutrients, presence of heavy metals, as well as the quality and quantity of humus compounds) were applied to evaluate the fertilisers, providing comprehensive characteristics of individual composts. It was found that composts prepared on the basis of sewage sludge had the highest contents of macro- and micronutrients as well as heavy metals. In addition, these composts contained the greatest amounts of humic substances, although these were of low quality. These composts also strongly inhibited seed germination and plant root growth. The least desirable chemical composition was found for the composts based on yard trimmings and household wastes prepared in home composters. These composts contained good quality humus compounds and had a positive effect on seed germination and plant root growth.

Keywords*:* biowastes; sewage sludge; composts; quality; biotest; agriculture

Introduction

Intensive and quick urbanisation is not only observed in developing countries, but also in those of the former communistic block, such as Poland. Unfortunately, the intensive development of cities is accompanied by a number of negative phenomena, among them primarily rapidly growing amounts of municipal solid waste (MSW) and sewage sludge (SS) [**1**,**2**]. Currently due to the rapid increase in the mass of municipal solid waste, it must be perceived as a multidimensional global problem, and proper waste management needs to be developed to attain such goals as the prevention of waste generation and reduction of its volume, increasing resource efficiency, diminishing the quantity of waste intended for landfills, as well as encouraging its reuse and raw material recovery. The principles of circular economy and the assumptions of the zero waste program [**3**] are helpful, because recyclable materials are reintroduced into the economy as new raw materials, thus increasing the security of their supply. Taking the above into consideration, in addition to plastic, paper, glass, and metals, biowaste is increasingly being sorted in municipalities as well. Thanks to adapting such a system of municipal waste collection in recent years, the mass of biowastes has significantly increased in Poland, amounting in 2018 to 28.4% of total mass [**4**]. It presents a new challenge, because according to the Landfill Directive [**5**], the EU member states are obliged to reduce the amount of biodegradable municipal waste going to landfills and simultaneously alternative strategies should be developed, such as composting (including fermentation), incineration and pre-treatment, e.g., mechanical–biological treatment (including physical stabilisation). As indicated by data given on the Bio-waste in Europe website [**6**], across the European Union, somewhere between 118 and 138 million tonnes of biowaste are generated annually, of which currently about 25% are composted or digested yearly, with composting predominating over anaerobic digestion. In Poland, composting also prevails and is dedicated to organic wastes. Due to the fact that the group of organic waste is large and diversified, two separate subgroups of biowaste and biodegradable wastes can be distinguished within it.

Biowastes are obligatory collected selectively by residents and include garden and park wastes, food, and kitchen wastes from households and restaurants. In contrast, biodegradable wastes include both wastes collected selectively by residents (paper, cardboard) and those resulting from agricultural and forestry activities (forestry and agricultural residue) or municipal wastewater treatment (sewage sludge).

Urbanisation and agglomeration processes, enhancing wastewater infrastructure development as well as the introduction of more advanced methods of municipal wastewaters purification, are factors playing a major function in the increase of sewage sludge mass. This biodegradable, noxious waste should also be considered as an additional civilisation-related problem, because landfills are the least desirable manner of SS utilisation and for example in Poland according to the Polish legal regulations [**7**], starting from 2016 such wastes may not be deposited at landfills. In order to implement sewage sludge application for environmental purposes, it is a very important strategy to comply with the above-mentioned Landfill Directive [**5**] and the principles of the circular economy. In Poland in 2018, of the total SS mass generated, almost 30% were used for applications in the natural environment, e.g., agriculture, land reclamation, or the cultivation of plants intended for composting [**4**].

Regardless of organic waste type, the best and most sustainable method of their utilisation seems to be the composting process, because it allows reusing their potential by incorporating nutrients and organic matter into circulation while maintaining the waste–soil–plant production continuum. The composting process has been presented as an environmentally friendly alternative applied to manage and recycle organic waste to obtain products used as amendments in agriculture [**8**,**9**]. Thomas et al. [**10**] listed positive aspects related to the utilisation of recycling organic wastes as crop fertilisers. Among other things, the cited authors pointed to the reduction of greenhouse gas emissions or enhanced carbon sequestration. Most studies [**2**,**11**,**12**,**13**] clearly demonstrate that soil amendment with compost affects various soil properties, including physical, chemical, physicochemical, and biological, especially enhancing TOC, Ntot amounts, and the contents of available macronutrients (N mineral, P, K, S, Mg). Despite many positive aspects connected with compost application, some disadvantages should also be underlined. Obviously, its slow mineralisation and the resulting sluggish progress of nutrient release diminish the agricultural value of composts. Especially the low level of nitrogen is of importance in this respect and thus to meet nitrogen requirements of crops, composts must be applied at higher rates [**13**]. However, bigger doses of composts may be accompanied by the introduction of larger amounts of undesirable metals such as Cd, Cr, and Pb, which are also present in compost composition [**2**]. In view of the above, it is essential to evaluate the quality of composts prior to soil application, which is required because of the vast variability in the chemical composition of organic wastes used for compost production. The above-mentioned diversity results from the origin of various raw materials and the technologies applied to convert wastes into organic fertiliser [**14**]. In Poland, the composting process may be carried out in both technologies: large-scale commercial (composting facilities) and small-scale household facilities (home composters). Commercially produced composts are always certified products used for agriculture and horticulture, the reclamation of industrial areas, as well as the maintenance of municipal green areas. Composts from home composters do not undergo any evaluation, since they are only used in home gardens as fertilisers in the small-scale growing of vegetables and ornamental plants.

Regardless of the chemical composition and used technology, only the application of stable and mature compost can improve soil fertility by increasing soil organic matter, suppressing soil-borne plant pathogens and enhancing plant growth. However, immature compost may have adverse effects on plant growth and the environment because of the presence of phytotoxic compounds, low molecular weight organic acids, ethylene oxide, and pathogens [**15**]. Maturity refers to the degree of decomposition of phytotoxic organic substances produced during the active composting phase and to the absence of pathogens. Stability is related to the rate of microbial activity in compost, and it is evaluated by different respirometric measurements and/or by studying transformations in chemical properties [**15**,**16**]. Various and numerous methods have been used to determine the maturity and stability of composts. Jakubus [**17**] reviewed these methods and distinguished four groups concerning physical parameters (temperature, colour, moisture, content, and aeration); chemical parameters (C:N ratio, NH_4:NO_3 ratio, cation exchange capacity—CEC, pH, electrical conductivity—EC, and humification indexes); microbiological parameters (respiration analysis, ATP content, and enzyme activities) and biological parameters (germination index and plant growth bioassay). In view of the above, there are different methods that in routine practice are difficult to apply simultaneously. Nowadays, methods that will be fast, simple, cheap, and at the same time provide real and repeatable results are sought for and required. Considering the compost soil application and its impact on this environment, compost evaluation should be based on an assessment of nutrient abundance. Moreover, information on the phytotoxic effect of composts as well as the intensity and direction of transformation of organic matter introduced into the soil is also important [**11**]. Thus, the main aim of this study was to valorise 10 various composts using selected chemical and biological parameters in terms of their fertilising quality and potential usability for application in horticulture, agriculture, or land reclamation. The analysed composts were prepared from commonly used wastes (garden and park waste) as well as those less popular (sewage sludge and spent mushroom substrate). The performed qualitative evaluation made it possible to differentiate composts among themselves, regardless of the raw materials used for composting. In addition, an attempt was made to assess the usefulness of the indicators used in the practical assessment of compost maturity and stability.

Composting Procedure and Raw Materials

Ten different composts prepared from various organic wastes using different technologies were analysed in this study. Two composting methods were applied: aerobic composting (AC) and aerobic–anaerobic composting (AANC). The aerobic composting process was applied mainly for such wastes as garden and park waste (cut grass, leaves, shredded branches, plant residues), paper and cardboard collected from the local municipality containers or bags as well as forestry and agricultural residue. In addition, less conventional materials (municipal sewage sludge and spent mushroom substrate) have been used for composting, and they are an alternative substance proposed for compost production and then practical use. The raw materials were mechanically chopped into smaller size particles to ensure the preferred particle size in the range of 15–40 mm. Next, the mixture was placed in long narrow piles called windrows. In the aerobic method, compost piles were prepared as static, triangular-shaped profiles with approximate dimensions of 8 m × 1.2 m × 3 m (length × height × width). Before the formation of the compost piles, all organic materials were thoroughly mixed. Using a specialised Backhus compost mixing machine, the piles were mixed weekly during the first month to ensure adequate aeration conditions, while subsequently the process was performed at monthly intervals. The moisture content of the composted mixture was measured using a moisture meter. Moisture content in the piles was adjusted by adding the amount of water required to obtain 60–70% of dry matter (water was applied as needed to maintain the respective moisture level). In the aerobic–anaerobic method, composts were prepared as a fertiliser for their home gardens by private homeowners. The composting process was carried out in home composters made of thermoplastic. The organic material (bigger particles were chopped into smaller ones, maximum size of 15–40 mm) was successively collected in containers without any mixing of the bulk volume. This established a crust on the upper layer, leading to the development of anaerobic conditions in the center of the container, whereas the top layer was exposed to ambient air and thereby to aerobic conditions. Under such conditions, the organic waste mixture was kept for a year. After this time, the whole mass was mixed to homogenise it and then transferred to dark plastic bags to complete the maturation stage. The analysed composts also differed in their degree of maturity. All composts except for composts number 7 and 8 were prepared in composting facilities for commercial purposes. The used raw materials, composting technology, as well as the length of the maturation period followed standards of the individual composting process carried out and were not subject to the researcher’s interference.

Composted samples were collected after the maturation stage from individual composting facilities and private gardens. Subsamples were collected from places located at equal distances from each other being on the top, middle, and bottom of each composting pile and then the three, approximately 100 g samples were mixed together precisely to create one mean bulk sample of approximately 300 g. In the case of composts prepared by the AANC method, the samples were taken from the bags after their contents had been mixed.

The samples of composts were divided into fresh and dry samples, and the latter were dried at 105 °C for a period of 12 h. The dried samples was ground into a fine powder and stored in plastic bags at a temperature of 4 °C.

Chemical Analysis of Compost

The chemical analyses were conducted on dried samples. The loss-on-ignition test was used to determine organic matter (OM) in composts. For this purpose, compost samples were subjected to dry combustion for 6 h at a temperature of 550 °C. Total organic carbon (TOC), nitrogen (N), and sulphur (S) contents were assayed using a Vario Max CNS elemental analyser. To determine the amounts of macro- and micronutrients as well as heavy metals in analysed materials, the composts were ground and ashed in a furnace at 450 °C for 6 h. The ash was dissolved in 5 mL of 6 mol·dm^3 HCl and diluted to a constant volume with distilled water [**18**]. The obtained extracts were analysed to determine the amounts of macronutrients (K, Ca, Mg, Na), micronutrients (Fe, Mn, Zn, Cu, Ni), and heavy metals (Pb, Cd) using atomic absorption spectrophotometry in a Varian

Spectra AA 220 FS apparatus. The total phosphorus (P) content was measured colorimetrically by the vanadium–molybdenum method [**18**].

Humus fractionation was performed according to the method proposed by Kononova and Bielczikova, in which humic substances (HS) were determined in a mixture of 0.1 mol·dm^{-3} $Na_4P_2O_7$ + 0.1 mol·dm^{-3} NaOH solution [**19**,**20**]. The fulvic acid fraction (FA) was separated after the precipitation of humic acids at pH 1.5 (HA). Carbon in the obtained fractions (C_{HS} and C_{FA}) was oxidised by 0.1 mol·dm^{-3} $KMnO_4$ in the H_2SO_4 medium. Humic acid carbon (C_{HA}) was calculated by subtracting C_{FA} from C_{HS}. The optical density ($Q_{4/6}$) of the obtained fractions was determined at 465 nm and 665 nm. All the assays determining the amounts of individual elements in the tested samples were performed in three replications, and the presented results are their mean values.

The maturity and stability of composts may also be assessed by various humification indexes, which is important when comparing composts produced from similar raw organic materials. Thus, the three popular indexes, i.e., humification ratio (HR), humification index (HI), and degree of polymerisation (DP), were used in these analyses. The humification indexes were calculated using the following equations [**21**]:

HR(%)=CHSTOC·100

(1)

HI(%)=CHATOC·100

(2)

DP=CHACFA

(3)

Phytotoxicity Biotests

In this study, two independent biotests were used to determine the phytotoxicity of composts: the germination index (GI) and the Phytotoxkit [**22**] evaluating the rate of seed germination inhibition and root growth. The tests were performed using 10 seeds of cress (*Lepidium sativum* L.). Compost extracts were obtained by shaking 10 g of compost fresh matter with 100 cm^3 of distilled water for 2 h at room temperature.

In order to perform the germination index test, 10 seeds of cress were placed in Petri dishes (diameter 10 cm and depth 1.5 cm) covered with blotting paper soaked with 5 cm^3 mL compost extract and incubated for 48 h in the dark at 25 °C. The seed germination percentage and root elongation of the plants in 5 cm^3 mL distilled water were also measured, and the sample was used as the control. A 5-mm primary root was considered as the operational definition of seed germination [**23**]. The percentages of relative seed germination (RSG), relative root growth (RRG), and germination index (GI) were calculated according to the following formula [**24**]:

RSG(%)=mean number of seeds germinated in compost extractmean number of seeds germinate in control·100

(4)

RRG(%)=mean root lenght in compost extractmean root lenght in control·100

(5)

GI(%)=RSG·RRG100

(6)

In order to determine the effect of composts on seed germination, a 3-day root growth Phytotoxkit test by Tigret® was used. The experiment was conducted under controlled conditions at 25 °C in the dark. Ten seeds of plant were placed on plates covered with blotting paper with composts. After 3 days of the experiment, images of the plates were recorded using a camera, and next, the shoot length and root growth inhibition were determined using the ImageJ 1.8.0 graphic programme. The software and the calculation formula given below have been developed by Tigret® and form an integral part of the Phytotoxkit test.

Based on the collected data, the percentages of seed germination inhibition (SGI) and root growth inhibition (RGI) were calculated using the following formula:

(SGI) or (RGI) (%) =A−BA·100

(7)

where *A* denotes the mean seed germination rate or root length in the control, and *B* denotes the mean seed germination rate or root length on the compost extract.

Despite the opinion on GI being rapid and sensitive, it has also been subjected to criticism, because it is a tedious bioassay to perform, as it requires about 48–72 h to run and involves complicated operations, while the sensitivity of plant species to phytotoxic chemicals in compost may vary. Unfortunately, data obtained on the basis of that biological assay are neither comparable nor standardised. Therefore, in the present study, apart from the popular GI, also a 3-day Phytotoxkit test was applied. This bioassay meets the requirement of the ISO standard and evaluates the rate of inhibition for seed germination and root growth. The results of this test were consistent with the previously presented finding of GI recorded for the above-mentioned composts and confirmed their lowest degree of inhibition for seed germination and root growth. The application of the Phytotoxkit test to evaluate the quality of composts prepared from various organic waste should be considered as an innovative approach to the issues raised. The obtained data showed its considerable usefulness, indicating that it can be a valuable supplementation of other methods.

The lack of harmonised standards and threshold values for individual indexes makes it difficult to interpret the analysed composts in terms of their maturity and stability. The results of the research carried out clearly revealed these imperfections, indicating at the same time the advisability of further research in order to develop common and uniform criteria for assessing the quality of composts prepared from various organic wastes. Especially based on the above data, it may be concluded that compost maturity was assessed differently depending on the applied index. From among the examined group of composts, the maturity of the following composts was most often assessed positively: 2, 3, 5, 6, 7 and 8. With regard to compost stability assessed by the bioassay, composts 2, 4, 7, 8, 9 and 10 showed the lowest phytotoxic effect.

Conclusions

As confirmed by statistical analysis, the differences in the chemical composition of composts primarily resulted from the use of raw material for composting, and to a lesser extent from the process technology used. Despite the fact that composts prepared with biowastes using the AANC method (C7 and C8) were evaluated as fertilisers with low abundance in nutrients and organic matter, they were characterised by favourable stability and maturity parameters. Similarly, the opinion concerning the quality of composts could be related to the composts being a mixture of biodegradable wastes and biowastes collected separately by the inhabitants of a medium-sized town (C2) and a mixture of biowastes and manure in a 1:1 ratio (C9). The above-mentioned composts 2 and 9 were characterised by a slightly higher abundance in nutrients and organic matter in relation to composts 7 and 8. As a result, these types of fertilisers may be recommended for small-scale vegetable cultivation, ornamental gardens, or the maintenance of urban greenery, where cultivated plants do not have such high nutritional requirements. Taking into account the high contents of nutrients and organic matter and the satisfactory quality of humic compounds, composts prepared with a share of sewage sludge (C5 and C6) are worth recommending as organic fertilisers used for reclamation of post-industrial areas, where the soil production capacity should be rebuilt in the first stage. Due to the strongest phytotoxic effect of this type of compost, it should not be proposed for horticultural and agricultural crops.

Referring to the indexes evaluating maturity and stability of organic fertilisers applied in the presented studies, it should be stated that there are no uniform critical values that can be applied to compost assessment in a reliable and universal manner. Especially the very popular indicator such as the C:N ratio should be interpreted as not fully descriptive of the compost maturity index, while more reliable parameters such as DP should be taken under consideration for compost evaluation. Based on the results of the author’s research for evaluation of composts, the bioassay may be recommended, as well as the degree of polymerisation of humic compounds expressed by the DP (C_{HA}:C_{FA} ratio) index.

Summing up, composts as organic fertilisers were found to be a valuable source of nutrients and organic matter. From the economic aspect, it should be underlined that raw materials used for composting are easily available locally, and thus the final product is relatively cheap and marketable for gardeners or farmers in comparison to expensive mineral fertilisers. In addition, local authorities responsible for managing organic waste should opt for this form of their recycling, increasing the attractiveness and popularity of this type of fertiliser.

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