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EVALUATION OF THE FERTILISING PROPERTIES OF COMPOSTS CONTAINING HERBAL WASTE

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ABSTRACT: This study aimed to investigate the physicochemical properties of fertiliser granules and compare their fertiliser value. The study used analytical methods, including potentiometric pH determination, the Kjeldahl method for nitrogen determination, spectrophotometry for phosphorus determination, and flame photometry for potassium and sodium determination. The content of heavy metals (Cr, Ni, As, Cd, Pb) was determined by inductively coupled plasma mass spectrometry (ICP-MS). The test material consisted of pellets made from compost (consisting of green waste: grass cuttings, leaves, and pruned branches) and slurry made from dried nettle. The results showed that the granules had pH values ranging from 7.44 to 8.20. The nitrogen content ranged from 1.77 to 2.18%, phosphorus from 0.17 to 0.38%, potassium from 0.77 to 0.90%, and sodium from 0.02 to 0.05%. In addition, the concentrations of heavy metals (Cr, Ni, As, Cd, Pb) were within acceptable limits for organic fertilisers. Studies have shown that granules made from compost and nettle slurry have favourable physicochemical properties that allow their use as a supplement to mineral fertilisation. They are characterised by an optimal pH value and a balanced content of key nutrients such as nitrogen, phosphorus, potassium, and sodium while maintaining acceptable concentrations of heavy metals. The results confirm that the tested materials meet standards for nitrogen, phosphorus, potassium, and heavy metals, confirming their suitability as safe and effective organic fertilisers. Their use can contribute not only to improving soil quality and increasing crop yields but also support sustainable development goals and fit into the concept of a circular economy.

KEYWORDS: compost, fertiliser, granulation, organic waste

Introduction

The increase in agricultural and industrial production is associated with the generation of increasing amounts of waste, which poses significant environmental challenges. Waste management focuses on waste minimisation, disposal, and reuse, and one effective way to manage organic waste is through organic recycling or composting. In the context of sustainable agriculture and the rising cost of mineral fertilisers, composting is a valuable alternative, promoting both organic waste recycling and soil quality improvement (Wei et al., 2017; Ayilara et al., 2020; Abubakar et al., 2022).

Compost is an organic fertiliser produced by decomposing plant residues and other biodegradable materials, often enriched with sewage sludge or natural fertilisers. The composting process involves both mechanical and biochemical transformation of matter. Mechanical treatment involves the preparation and maintenance of proper aerobic conditions, humidity, and temperature, which promote the activity of microorganisms responsible for the decomposition of organic matter. Biochemical processes, on the other hand, carried out by bacteria, fungi, and actinomycetes, occur as a result of the simultaneous mineralisation and humification of organic matter. The result of these transformations is a final product free of pathogens and weed seeds, rich in stable humus compounds that improve soil fertility (Wang et al., 2021; Szewczyk, 2016). Mature compost is characterised by its dark brown colour, earthy odour, amorphous form, and optimal moisture content (Zhang et al., 2011). Its fertiliser value depends on its raw material composition – it typically contains 0.75 to 1.5% nitrogen (N), 0.25-0.5% phosphorus (P_2O_5), and 0.5-1.0% potassium (K_2O). In addition, it provides substances that promote plant growth, such as vitamins, natural hormones, and organic acids. The stable form of nitrogen limits its loss as ammonia, minimising the risk of damage to emerging plants (Ayilara et al., 2020).

The suitability of waste for composting is determined by its fertiliser properties, assessed by the content of macronutrients (nitrogen, phosphorus, potassium), carbon, some heavy metals, and the total organic matter content (Ignatowicz, 2017). For compost to be considered an organic fertiliser, it must meet the criteria outlined in the Ordinance of the Minister of Agriculture and Rural Development of August 9, 2024, on the implementation of certain provisions of the Law on Fertilisers and Fertilisation (Rozporządzenie, 2024). According to this regulation, solid organic fertilisers must have a minimum organic matter content of 30% dry matter and contain no less than 0.3% total nitrogen (N), 0.2% phosphorus per P_2O_5, and 0.2% potassium per K_2O. In addition, the regulation specifies permissible concentrations of heavy metals, which must not exceed the following values: 100 mg/kg for chromium (Cr), 5 mg/kg for cadmium (Cd), 60 mg/kg for nickel (Ni), 140 mg/kg for lead (Pb) and 2 mg/kg for mercury (Hg). Sanitary and hygienic criteria include rules against the use of fertilisers and cultivation aids found to contain live eggs of intestinal parasites such as Ascaris sp., Trichuris sp., Toxocara sp., and Salmonella bacteria. In the composting process, additives are often used to speed up the process, enrich the compost with nutrients, and balance the carbon and nitrogen balance. When establishing a new pile the following year, it is usually sufficient to add the previous year's compost, which allows the introduction of beneficial microorganisms, initiating the desired and effective transformation. Various ready-made substances are also available on the market that can be topped up or added directly to the compost pile, enriching the compost with organically bound nitrogen (Barthod et al., 2018).

Composting organic waste has numerous environmental and agronomic benefits. It improves soil structure, optimising air-water relations. On light soils, it increases water-holding capacity, while on heavy soils, it improves airiness. Compost is a complete fertiliser, rich in macro- and micronutrients necessary for plant growth. In addition, it introduces beneficial microorganisms into the soil that promote root health and overall plant health. A key component provided by compost is humus, which plays an important role in maintaining soil fertility (Cai et al., 2007; Bai et al., 2010; Pocius et al., 2014; Jędrczak, 2018; Toledo et al., 2018; Yu et al., 2019; Cwalina et al., 2024).

Despite its many benefits, the composting process comes with some challenges. It requires significant time, typically 6 to 12 months, for the waste to turn into a fertiliser with agricultural value. An important aspect is the need for proper ingredient selection and regular mixing of the compost every 2 months to maintain an optimal carbon and nitrogen balance. In addition, the unpleasant odour and peculiar appearance of compost can pose additional difficulties in managing the process (Jędrczak, 2018).

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Nowadays, one of the challenges is to ensure that waste fertiliser is in the right physical form for uniform spreading on the soil with agricultural machinery. The pressure agglomeration process, which converts compost into a granular form with a uniform structure, has numerous benefits. It reduces volume through compaction, reduces waste management costs, and facilitates transportation and storage. Dry granules are much cheaper and easier to transport than raw products. In addition, granulation allows for precise dosing of nutrients, which is particularly important in precision agriculture (Šarauskis et al., 2021).

Therefore, the purpose of this study was to examine the physicochemical properties of compost and nettle slurry, as well as granules made from their mixtures, in the context of their potential use as a supplement to mineral fertilisation. An analysis of the effect of the addition of different proportions of nettle slurry (10%, 15%, 20%) on the fertiliser properties of the granules was also carried out.

Materials and research methods

Materials

The material used for the study was compost from the municipal waste treatment plant and dried nettle slurry collected as waste from a herb factory specialising in the production of herbal teas (Figure 1).

The compost consisted of green waste such as grass, leaves, and cut branches. It was approved for distribution based on the organic fertiliser certificate from 2019, which received a positive opinion from the Ministry of Agriculture and Rural Development. The stinging nettle slurry was prepared under laboratory conditions by weighing approximately 100 g of dried residues and adding an appropriate amount of water. The samples were then stored for 3 weeks at a temperature of about 20°C.

Figure 1. Raw materials used in research: compost from the Municipal Waste Disposal Plant, nettle slurry (from the left)

In addition to the substrates, their effects on the flow of granules were also used in the research. The addition of nettle manure to the compost was 10%, 15%, or 20%. Detailed research material was obtained:

A. compost,
B. nettle slurry,
C. compost and 10% nettle slurry granules,
D. compost and 15% nettle slurry granules,
E. compost and 20% nettle slurry granules.

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Research methods

The process of preparing raw materials for granulation began with grinding them to the appropriate fraction of 3mm maximum. Shredding was carried out in a STILER CF198 flail shredder. A Bosch PSB 6-16 RE 600 drill was used to prepare the mixtures, and the moisture content of the resulting mixtures was 17%. Compaction of clean compost and prepared mixtures was carried out on the SS-5 test stand, where the main component was a PRIME-200 granulating device from Techno-MaszBud, equipped with a working system based on the principle of "flat matrix – rotating compaction rollers"(Obidziński et al., 2023).

The pH of the substrates and granules analysed was tested, and the levels of nitrogen, phosphorus, potassium, and sodium were determined.

The pH was determined by the potentiometric method in an aqueous solution according to the PN-EN ISO 10390:2022-09 standard. Nitrogen content was determined by the Kjeldahl method by standard PN-G-04523:1992.

The samples were mineralised for the determination of phosphorus, potassium, and sodium. The determination of total phosphorus was then carried out using the vanadium-molybdenum method on a Shimadzu spectrophotometer. The procedure was carried out according to the PN-EN ISO 6878:2006 standard. The potassium and sodium contents were determined using a BWB flame photometer.

The content of heavy metals such as chromium, nickel, arsenic, cadmium, and lead was determined by inductively coupled plasma mass spectrometry (ICP-MS) on an Agilent Technologies 8800 Triple Quadrupole ICP-MS spectrometer by PN-EN ISO 17294-2:2024-04.

The statistical analysis of the collected laboratory results was performed using the statistical package STATISTICA v. 13.3. To compare the characteristics of granular fertilisers with different percentages of substrate, an analysis of variance was used with Tukey's HSD (Honestly Significant Difference) post hoc test for equal samples. The significance level was set at $\alpha = 0.05$, and results were considered statistically significant if the p-value ≤ 0.05.

Research results and discussion

Adequate pH of fertilisers is a key factor affecting the effectiveness of their application, as both too high and too low pH can negatively affect the solubility and assimilation of nutrients by plants. Acceptable pH values for compost range from 6.50 to 8.50 (Peña et al., 2020). In our study, the obtained pH results of the tested materials ranged from 7.44 to 8.20 (Figure 2). In the case of granules containing different proportions of nettle manure (10%, 15%, 20%), there was a gradual increase in pH values as the proportion of the additive increased. Granules with 10% nettle slurry addition had pH values close to those of pure compost, while granules with 20% addition showed the highest pH values, approaching the upper limit of the acceptable range. These results suggest that the addition of nettle manure may contribute to the alkalinization of the mixture, which is important in the context of adjusting the reaction of fertilisers to the requirements of the soil and the crops grown. Statistical analysis showed that there were no statistically significant differences in the pH values of individual substrates and granules, compared by Tukey's test at $\alpha<0.05$. Nevertheless, a linear relationship was found between the amount of the additive and the pH value – the greater the additive, the higher the pH value. Fertiliser pH should be tailored to the specific requirements of the soil and plants to maximise fertiliser efficiency. A study by Peña et al. (2020) on compost extracted from fruit processing waste, sewage sludge, and fried food production waste showed similar pH values, which were 7.87, 7.88, and 7.73.

Nitrogen is a macro element in the structure of nucleic acids and configurations and is also a component of vitamins and chlorophyll, which affects the action of plant pigments and their use. It is one of the key elements that influence plant growth and development, resulting in inhibition of growth and yield. From an agricultural point of view, nitrogen has a major impact on the quality of crops, taking into account the size and quality of the plant mass (Sinha & Tandon, 2020). The research found that when nettle slurry was added, the nitrogen in the granules was as stated on the packaging (Figure 3). When granules from deliveries of 10%, 15%, and 20% nettle slurry were analysed, the nitrogen content was 1.77%, 2.05%, and 2.18%, respectively. Identification of additional growth due to

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side effects. It contains a statistical analysis that is divided between the nitrogen content of granulates with fertiliser devices, which is the larger part that is not separated into the content of this element. Sykorova et al. (2012), in their studies on compost from grass clippings, showed that the nitrogen content ranged from 0.59% to 1.35%. In turn, research by Khater (2015) on the type of compost shows that the nitrogen content in compost made from cattle manure is 0.95%, and in a mixture of cattle manure with residues of herbal plants and sugar cane, it is 1.26% and 1.32%. The highest nitrogen content (1.68%) occurs in composts with sugar cane residues. The results are consistent with the trend of increasing nitrogen content with the addition of organic matter.

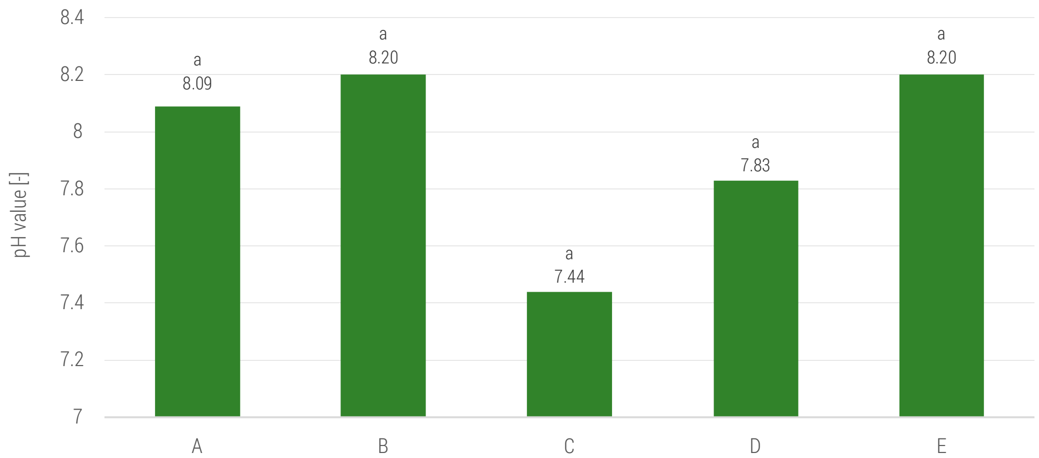

Figure 2. pH value of substrates and prepared granules (A: compost; B: nettle slurry; C: compost and 10% nettle slurry granules; D: compost and 15% nettle slurry granules; E: compost and 20% nettle slurry granules; the same letters in the columns next to the means indicate no statistically significant differences compared with the Tukey test at α<0.05)

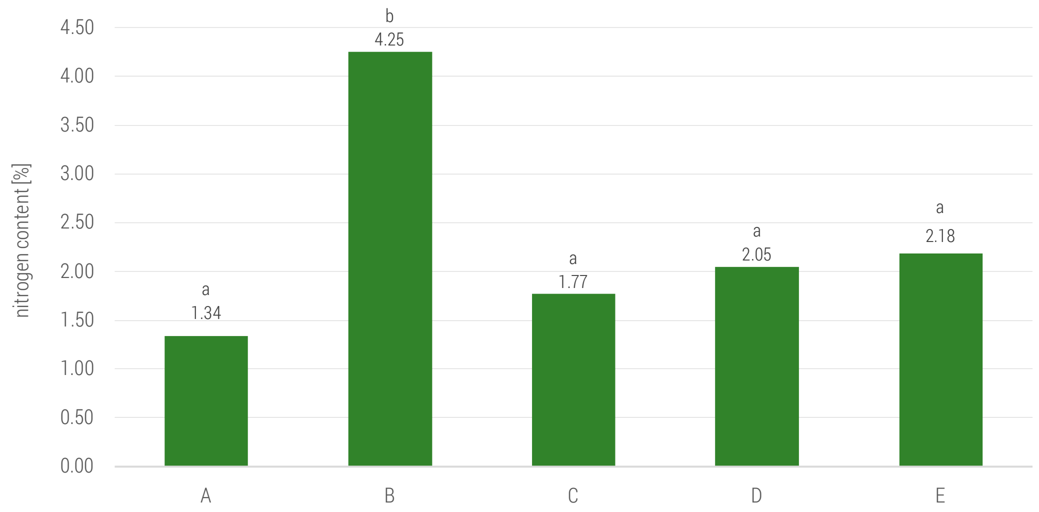

Figure 3. Nitrogen content of substrates and granulates

Phosphorus is a key macroelement necessary for the proper functioning of the root system, flowering process, and plant yield (Sinha & Tandon, 2020). The research showed that when nettle manure was added to the compost, the phosphorus content gradually increased, reaching values from 0.166% to 0.380% (Figure 4). Moreover, statistically significant differences in phosphorus content were found between granules containing different amounts of manure, suggesting that this addition can significantly improve the quality of organic fertiliser and, consequently, its effectiveness in fertilising plants. The results of the study by Lanno et al. (2021) showed that compost made from green waste, such as leaves, branches, and plant residues, has a relatively low phosphorus content of only 0.273%. In comparison, sewage sludge compost contained much higher levels of phosphorus, up to 1.627%. For comparison, a study by Khater (2015) found that cattle manure compost contained 0.31% phosphorus, cattle manure compost and herbaceous plant residues contained 0.27%, cattle manure compost and sugarcane plant residues contained 0.51%, compost from herbaceous plant residues contained 0.32%, and compost from sugarcane plant residues contained 1.13%. The data cited and the results of our research suggest that composts derived from green waste may need to be enriched with appropriate additives to improve their phosphorus content, which may be crucial to increase their fertiliser value and effectiveness of use in agriculture.

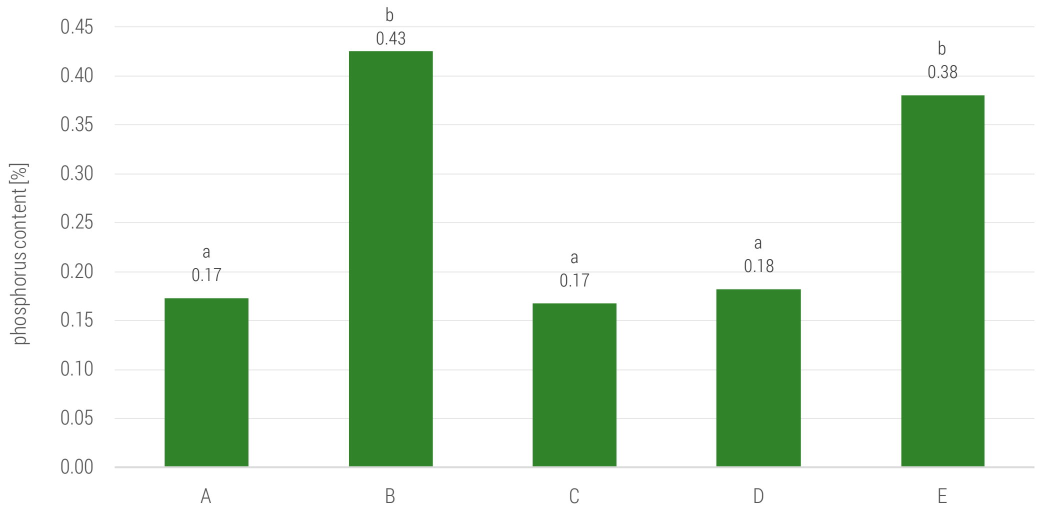

Figure 4. Phosphorus content of substrates and granulates

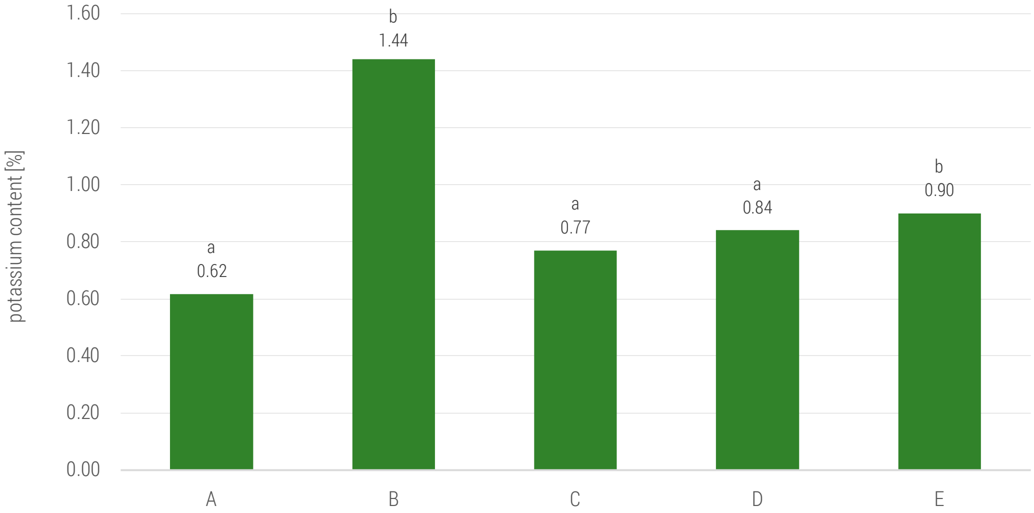

Figure 5. Potassium content of substrates and granulates

Both excess and deficiency of potassium can lead to deterioration of crop quality (Górski & Saba, 2015). In studies on granules, the highest potassium content was obtained with the addition of 20% nettle manure (0.90%) and the lowest with the addition of 10% nettle manure (0.77%; Figure 5). There was a clear upward trend in potassium content with increasing addition. Statistical analysis showed significant differences between the samples, suggesting that increasing the amount of nettle manure contributes to increasing the content of this element in the granules. This result confirms

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that the addition of organic components, such as nettle manure, can have beneficial effects. However, it should be noted that at higher concentrations, there may be a counteracting effect that reduces the potassium content, which is unfavourable from a fertilisation point of view. In turn, research by Khater (2015) showed that the potassium content in various composts was: in cattle manure compost 0.27%, in cattle manure and herbaceous plant residue compost 0.35%, in cattle manure and reed plant residue compost 0.62%, in herbaceous plant residue compost 0.51%, and in sugarcane plant residue compost 2.11%. These data indicate that the potassium content of composts can vary considerably depending on the additives used, which should be taken into account when optimising the composition of organic fertilisers.

The tests carried out showed that the sodium content was very low (Figure 6). The highest was found in the granules with 20% addition and the lowest in the 15% slurry. The absence of significant statistical differences suggests that the effect of nettle on this parameter is limited.

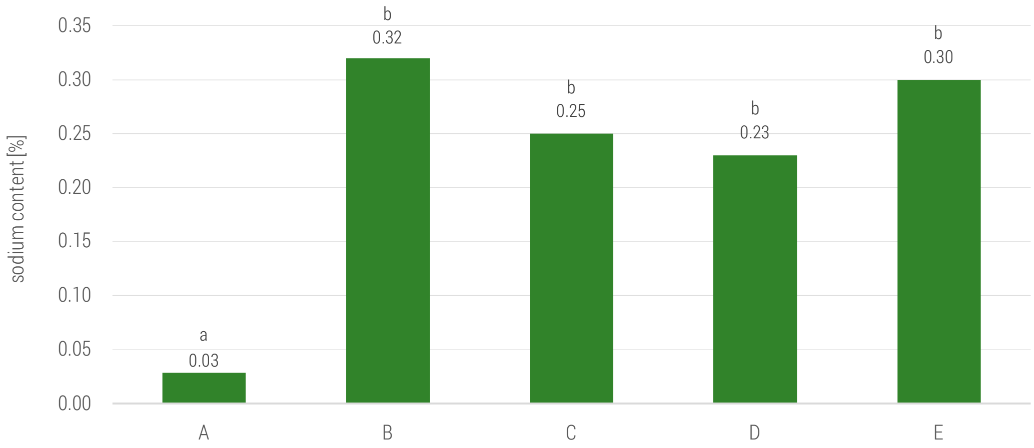

Figure 6. Sodium content of substrates and granulates

According to the Ordinance of the Minister of Agriculture and Rural Development dated August 9, 2024 (Rozporządzenie, 2024), on the implementation of certain provisions of the Law on Fertilisers and Fertilisation, permissible limits have been set for the content of heavy metals in fertilisers and soil conditioners. These limits apply to both solid and liquid products. The tests carried out showed that the granules produced, regardless of the proportion of nettle manure added, are characterised by a heavy metal content within the permissible limits (Figure 8; Figure 9). Therefore, it can be concluded that the granules meet the legal requirements for their safe use in agriculture, which confirms their suitability as alternative organic fertilisers.

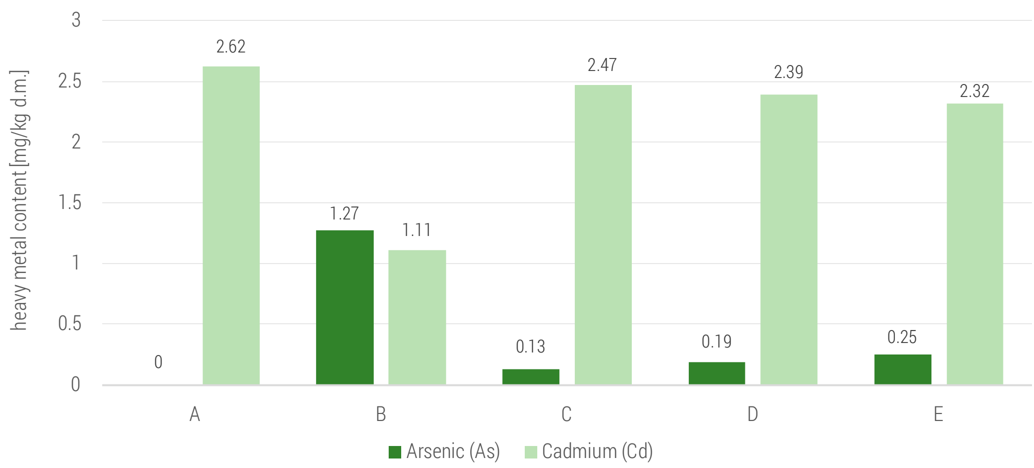

Figure 7. Heavy metal content (As, Cd) of substrates and granulates

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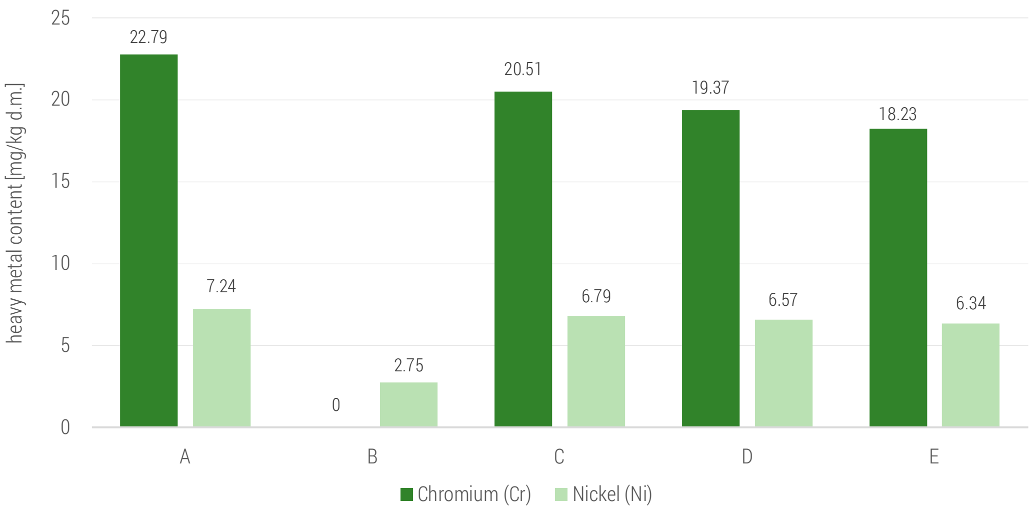

Figure 8. Heavy metal content (Cr, Ni) of substrates and granulates

Composting is an effective method of converting organic waste into a valuable fertiliser, and the introduction of suitable additives to compost can increase the fertiliser usefulness of the resulting granules. The results of the study confirm that the resulting granules have an optimal pH, which may suggest their usefulness in regulating soil pH. In addition, the granules contain balanced amounts of key nutrients such as nitrogen, phosphorus, potassium, and sodium while keeping the level of heavy metals within acceptable standards, which is important from the point of view of the safety of their use in agriculture. The results of the study showed that the content of nitrogen, phosphorus, and potassium in the tested granules significantly exceeds the minimum requirements specified in the Decree of the Minister of Agriculture and Rural Development dated August 9, 2024 (Rozporządzenie, 2024), which confirms their suitability as organic fertilisers.

Studies have shown that the addition of nettle manure increases the content of key macronutrients, such as nitrogen, phosphorus, potassium, and sodium, in the pellets produced. Of particular note is phosphorus, which showed the greatest susceptibility to increase with an increase in the amount of manure, which may translate into higher fertiliser efficiency. In contrast, a moderate effect of the additive was observed for nitrogen and potassium, with higher amounts of manure resulting in higher contents of these elements, but these changes were not statistically significant. Sodium, although present in small amounts, showed low variability depending on the addition of manure, suggesting that this component is not significantly modified by this organic component. In addition, the heavy metal content of the pellets was within acceptable legal standards, confirming the safety of their use in agriculture.

In conclusion, proper balancing of the amount of nettle manure addition in the organic fertiliser production process is key to maximising the content of desired nutrients while maintaining the economic viability of production. The results of the study showed that the content of nitrogen, phosphorus, and potassium in the tested pellets exceeds the minimum requirements specified in the Ordinance of the Minister of Agriculture and Rural Development dated August 9, 2024 (Rozporządzenie, 2024), which confirms their compliance with the current regulations. The conducted research shows that the use of optimal proportions of components can lead to fertilisers with a fairly high utility value, which has a direct impact on the quality and quantity of agricultural yields.

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Conclusions

In summary, the research carried out has led to the following conclusions:

- The addition of nettle manure increased the pH of the granules, but further research is needed to evaluate the practical use of this additive in regulating fertiliser pH.
- The granules show a balanced content of key nutrients such as nitrogen, phosphorus, potassium, and sodium. In addition, an increase in content, especially for phosphorus and sodium, was observed as the amount of added nettle manure increased. Enriching compost with additives can increase its fertiliser usefulness.
- The heavy metal content of the granules does not exceed acceptable standards, and the nutrient content meets the requirements necessary for their use as organic fertilisers.
- Compost pellets are a promising alternative to traditional soil fertilisation.
- The use of fertiliser granules made from compost with the addition of nettle manure shows potential as a source of nutrients such as nitrogen, phosphorus, and potassium. The studied granules can supplement mineral fertilisation, and their use fits in with the concept of sustainability.

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The contribution of the authors

Conceptualisation, K.K., M.K. and J.P.; literature review, K.K., M.K., P.C. and O.K.; methodology, K.K., M.K., J.P., S.O. and M.K.S.; formal analysis, K.K., M.K., J.P. and S.O.; writing, K.K., M.K., P.C. and M.K.S.; conclusions and discussion, K.K., M.K., J.P., P.C., M.K.S. and S.O.

The authors have read and agreed to the published version of the manuscript.

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OCENA WŁAŚCIWOŚCI NAWOZOWYCH KOMPOSTÓW ZAWIERAJĄCYCH ODPADY ZIELARSKIE

STRESZCZENIE: Celem niniejszej pracy było zbadanie podstawowych właściwości chemicznych i fizycznych granulatów nawozowych oraz porównanie ich wartości nawozowej. W badaniach zastosowano metody analityczne, w tym potencjometryczne oznaczanie pH, metodę Kjeldahla do oznaczania azotu, spektrofotometrię do oznaczania fosforu oraz fotometrię płomieniową do oznaczania potasu i sodu. Zawartość metali ciężkich (Cr, Ni, As, Cd, Pb) oznaczono metodą spektrometrii mas z plazmą wzbudzaną indukcyjnie (ICP-MS). Materiał badawczy stanowiły granulaty wytworzone z kompostu (składającego się z odpadów zielonych: skoszonej trawy, liści i przyciętych gałęzi) oraz gnojówki z suszonej pokrzywy. Wyniki badań wykazały, że granulaty charakteryzują się wartością pH w zakresie od 7,44 do 8,20. Zawartość azotu wynosiła od 1,77 do 2,18%, fosforu od 0,17 do 0,38%, potasu od 0,77 do 0,90%, a sodu od 0,02 do 0,05%. Ponadto, stężenia metali ciężkich (Cr, Ni, As, Cd, Pb) mieściły się w granicach dopuszczalnych dla nawozów organicznych. Przeprowadzone badania wykazały, że granulaty wytworzone z kompostu i gnojówki z pokrzywy charakteryzują się korzystnymi właściwościami fizykochemicznymi, które umożliwiają ich zastosowanie jako uzupełnienie nawożenia mineralnego. Odznaczają się optymalną wartością pH oraz zrównoważoną zawartością kluczowych składników odżywczych, takich jak azot, fosfor, potas i sód, przy jednoczesnym zachowaniu dopuszczalnych stężeń metali ciężkich. Wyniki potwierdzają, że badane materiały spełniają normy dotyczące zawartości azotu, fosforu, potasu oraz metali ciężkich, co potwierdza ich przydatność jako bezpiecznych i efektywnych nawozów organicznych. Ich zastosowanie może przyczynić się nie tylko do poprawy jakości gleby i zwiększenia plonów, ale również wspierać cele zrównoważonego rozwoju oraz wpisywać się w koncepcję gospodarki o obiegu zamkniętym.

SŁOWA KLUCZOWE: odpady organiczne, kompost, nawóz, granulacja

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