6 Scientific articles

6.1 The effect of recycle amount on the properties of organic fertilizers

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Abstract

Food and agriculture waste generated worldwide poses significant challenges, as decomposing waste releases substantial amounts of gas, contributing to climate change. One way to address this issue could be the use of organic waste from the food industry for fertilizer production. Granulated organic fertilizers would not only help reduce waste and emissions but also improve soil fertility. During the industrial production of such fertilizers, some granules do not meet the required size and must be returned to the process as recycle. This recycle can affect the properties of the final product, and its use requires additional technological equipment. In this study, biomass, buckwheat husks, buckwheat husk ash—which contains plant nutrients (C, N, P, K, Ca, Mg, Zn, Fe, Mn, Cu)—molasses solution, beaten eggs, and polyvinyl acetate were used for organic fertilizer granulation. The obtained results show that the highest amount of commercial granules was produced with 30% and 40% recycle; however, recycle does not significantly change other properties of fertilizers. Fertilizer granules were plastic or had a static strength between 7.03–10.05 N/granule, because the strength depends on the nature of solid raw materials and especially the liquid binder. The bulk density of fertilizers ranged from 232.2 kg·m^{-3} to 429.0kg·m^{-3}, and the pH interval was 6.9–13.6, depending on the composition of the raw material mixture.

Introduction

Agricultural industries have always been the foundation of global food production, with fertilizers playing a key role in increasing crop yields (Sutton et al., 2013). Fertilizers provide essential nutrients for plant growth and development, with the most important being nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O). However, the excessive use of concentrated mineral fertilizers is linked to harmful impacts on ecosystems (Javed et al., 2022). Soil degradation, loss of organic matter, reduction in microorganisms, erosion, and declining fertility pose significant challenges to sustainable farming, underscoring the need for more efficient and sustainable fertilizer use (Roy et al., 2006; Buneviciene et. al., 2021). Farmers must strive to achieve high yields while minimizing their negative environmental impact, in line with the goals of the Green Deal.

Innovations such as nutrient recycling, biofertilizers, and improved nutrient use efficiency are becoming increasingly important. According to the World Bank, waste generation is projected to increase by 70% by 2050 (The World Bank, 2018). The Food and Agriculture Organization (FAO) reports that global food waste amounts to 1.6 billion tons, including 1.3 billion tons of edible waste (FAO, 2013). When biodegradable waste decomposes in landfills, it releases methane, a potent greenhouse gas that contributes to climate change.

One solution is to recycle organic waste from food industries, crop residues, and animal by-products into fertilizers. Organic fertilizers improve soil structure, fertility, and water retention, supporting sustainable agriculture and reducing reliance on synthetic fertilizers (IFA, 2021). Recycling waste into fertilizers represents a significant step toward reducing the environmental impact of waste and promoting a circular economy. This process includes composting and other conversion methods, transforming waste into nutrient-rich fertilizers for agricultural use.

While traditional methods such as composting, vermicomposting, and pyrolysis are common, they have limitations (Karps et al., 2017; Greinert et al., 2019). Composting, for example, releases greenhouse gases, and the inconsistent composition of compost makes direct application less effective. Therefore, producing granulated fertilizers with consistent composition and added value is a better option. These granules can be applied evenly using standard spreading equipment (Le Capitaine, 2023).

Granulation combines various raw materials containing essential plant nutrients to create a balanced and effective fertilizer. This process converts powdered materials into 2–5 mm granules, making them easier to handle. However, the process is complex, and obtaining high-quality granules often requires process improvements, including the reuse of granules that do not meet size specifications. These granules, known as "recycle," can improve product properties when used properly.

Materials

In this study, the waste materials used were sourced from the Lithuanian company "Ekofrisa", a buckwheat groats producer. The main materials included uncleaned biomass (BM), buckwheat husk (BH), and buckwheat husk ash (BHA). These materials contain essential nutrients such as carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu). They were combined with binders such as molasses solution (MS), beaten eggs (BE), and polyvinyl acetate (PVA) to produce organic fertilizers.

The properties of the granulated fertilizers, including particle size distribution, granule strength, bulk density (loose and compacted), moisture content, and pH, were analysed using standardized laboratory methods.

Methodology

Granulation was performed using a laboratory drum granulator-dryer (Figure 1.). Depending on the mixture's thermal stability, the temperature was maintained at 50–60 °C or 70–80 °C. The drum was inclined at a 5° angle and rotated at 20 rpm.

Moisture content was measured using a KERN MLS 50-3HA160N electronic moisture analyser (Germany).

Particle Size Distribution of raw materials and granulated products was determined using a set of sieves with different mesh sizes. Different fractions were weighed to an accuracy of ±0.001 g using KERN EW/EG-(N) electronic scales (Germany).

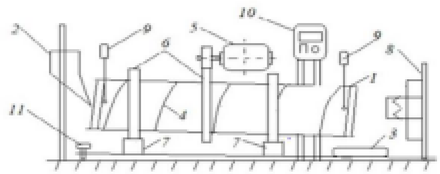

Figure 6.1.1 Laboratory drum granulator-dryer. 1 – granulator drum; 2 – raw material vent; 3 – product discharge opening; 4 – blades; 5 – electric motor; 6 – gearwheel; 7 – support roller; 8 – hot air supply; 9 – thermocouples; 10 – control panel; 11 – tilt angle lock.

pH values of 10% fertilizers aqueous solutions were determined by dissolving samples in distilled water and filtering the suspension through a 2–3 µm filter. Measurements were made using a HANNA Instruments pH 211 microprocessor pH–meter (USA).

Static Granule Strength was measured using the IPG-2 device (Russia) on 2–3 mm and 3–4 mm granules. At least 20 granules of similar size and shape were tested for each fraction.

Bulk density was determined by weighing an empty cylinder, then filling it with granules and measuring the weight difference. For the tapped density, the cylinder is subject to vibrations and compaction occurs until constant volume. The calculated mass difference between the empty cylinder and the cylinder with material is equal to the mass of tapped material per volume unit.

Scanning electron microscopy (SEM) whit electron microscope model S-3400N, (Japan) was used to determined surface morphology of organic fertilisers analysis.

Results

Even though fertilizers are produced industrially in large quantities and granulation processes are usually well known, the development of new fertilizers requires additional research and equipment improvements. To produce high-quality, stable fertilizers, many different factors (raw materials properties, moisture content, granulator parameters, process conditions) play an important role (Muranda, 2018; Woodroof, 2021). Therefore, this work attempted to evaluate the numerous factors mentioned and determine their influence on the organic fertilizers. Since organic materials are not inherently plastic or polar, their particles exhibit weak adhesion and cohesion forces. As a result, agglomeration is poor, making the use of binders essential for granulation. Organic fertilizers were produced from biodegradable raw materials (BHA, BH, BM), combined in different ratios with binders (PVA, BE, MS) and 20%, 30%, 40% recycle (R). For the granulation of bulk organic fertilizers, mixtures of raw materials with four different compositions were prepared, using the mentioned solid materials, liquid binders, and recycle. These fertilizers were dried, fractionated, and their physical properties evaluated.

The dependence of the amount of the commercial fraction (granule size 2–4 mm) of the granular product on the amount of recycle used in the raw material mixture and the moisture content of this mixture is presented in Figure 6.1.2. Other properties characterizing the quality of the fertilizer are presented in Table 6.1.1.

Table 6.1.1 Properties of the bulk organic fertilizer

Sample No.	Conditions of granulation process		The main properties of fertilizers				
	Amount of recycle (%)	Amount of binder (%)	Crushing strength of granules, (N/granule)	Density of granules ($kg \cdot m^{-3}$)		Humidity of granules (%)	pH of 10% fertilizer solution
				Bulk	Tapped		
I. 40% BHA : 60% BM + PVA (Binder)							
1	20	50.0	Plastic	375.9	396.9	13.40	13.2
2		48.7		312.4	333.7	12.58	13.1
3		47.4		310.8	321.8	11.72	13.3
4	30	50.0		370.9	393.0	15.08	13.6
5		48.7		364.1	351.1	13.30	13.2
6		47.4		308.7	328.8	12.38	13.2
7	40	48.7		350.8	373.2	13.38	13.1
8		47.4		348.3	372.7	12.95	13.3
9		46.0		335.9	365.7	11.15	13.3
II. 20% BHA : 80% BM + PVA (Binder)							
10	20	51.2	Plastic	323.6	336.6	20.84	8.0
11		50.0		298.3	314.2	17.77	8.5
12		48.7		289.7	310.4	16.65	9.2
13	30	51.2		417.2	429.0	21.27	9.1
14		50.0		376.9	397.8	18.48	9.2
15		48.7		336.5	361.1	16.90	9.8
16	40	51.2		405.2	415.2	21.46	9.8
17		50.0		372.6	383.8	18.19	10.1
18		48.7		364.2	381.7	17.18	10.5
III. 20% BHA : 40% BH : 40% BM R + BE (Binder)							
19	20	47.4	7.64	353.4	372.7	11.43	6.9
20		46.0	7.03	306.8	321.6	10.22	7.4
21		44.4	7.23	276.8	288.0	9.51	7.5
22	30	48.7	9.44	346.4	368.4	11.17	7.2
23		47.4	8.42	345.4	363.3	9.54	6.9
24		46.0	7.29	310.5	330.1	8.16	7.5
25	40	47.4	7.81	398.4	364.5	9.69	7.5
26		46.0	8.60	342.8	350.7	9.55	7.5
27		44.4	10.05	311.1	327.1	8.58	7.5
IV. 20% BHA : 40% BH : 40% BM + MS (Binder)							
28	20	50.0	Plastic	326.4	342.7	10.55	7.4
29		48.7		309.2	332.5	9.81	7.3
30		47.4		306.3	334.4	9.64	7.4
31	30	50.0		339.3	354.2	11.63	7.0
32		48.7		336.4	351.5	11.00	7.2
33		47.4		326.7	342.9	9.52	7.2
34	40	50.0		359.2	381.4	13.71	7.4
35		48.7		337.9	358.1	10.23	7.1
36		47.4		232.2	239.0	9.41	7.0

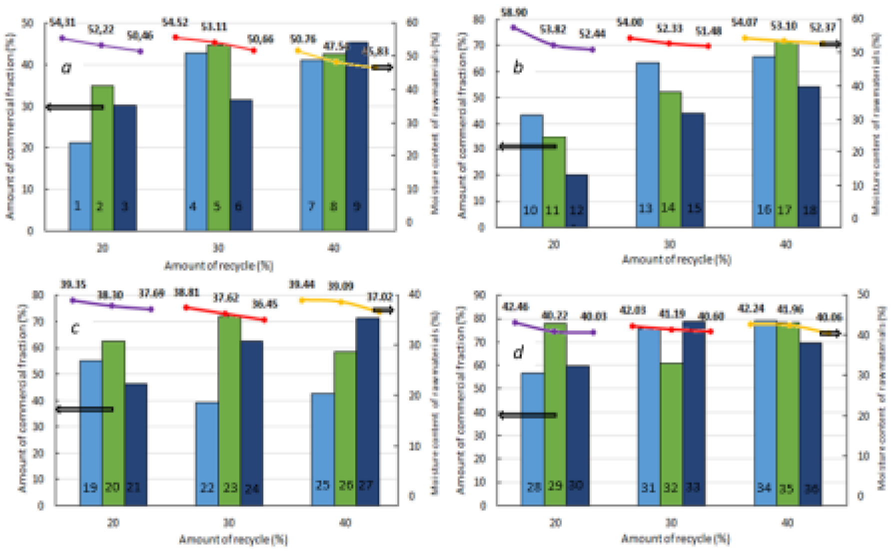

Figure 6.1.2 The influence of the humidity and the amount of recycle in the raw material mixture on the amount of the commercial fraction: a – composition IV.

In composition I (solid materials BHA, BM, R, and PVA solution as the liquid binder), the highest commercial fraction (35.07%) with 20% recycle and moisture content of 52.22% was obtained in sample 2. With 30% recycle, the highest commercial fraction (44.78%) was obtained in sample 5 where the moisture content was 53.11%. Using 40% recycle resulted in the highest commercial fraction (45.36%) in sample 9, despite the moisture being lower than that of the other samples. Other properties were influenced by moisture level and changed consistently.

In composition II, using the same raw materials but in a different ratio, a similar trend was observed. A higher commercial fraction correlated with an increase in the amount of recycle used: 43.21% (20% recycle, 58.90% moisture), 63.44% (30% recycle, 54.00% moisture), and 71.75% (40% recycle, 53.10% moisture). However, when 40% recycle was used, the binder's effect became inconsistent, and increasing the binder quantity did not necessarily improve granulation.

In composition III, where BH was added to BHA, BM, and R, and BE was used as a binder, the highest commercial fraction was obtained in samples 23 and 27. Sample 23 (30% recycle) had 37.62% moisture and yielded 72.18%, while sample 27 (40% recycle) had 37.02% moisture and yielded 71.45%. When 20% recycle was used (sample 20), the marketable fraction was lower (62.69%) with 38.30% moisture. In accordance with the conclusions of other scientists (Walker, 2003; Szluc, 2024), it can be stated that the amount of commercial fraction of fertilizers and the strength of granules depend on both the nature of the binder and the amount of liquid phase used. BE, a strong binder, was used here, making this composition's granules the only ones with measurable static strength (7.03–10.05 N/granule).

In composition IV, BHA, BM, BH, and R were used, moistened with MS. A consistently high commercial fraction (~78–79%) was achieved regardless of the recycle percentage. Sample 34, with 40% recycle and 42.24% moisture, yielded the highest fraction (79.03%). The pH of these compositions was neutral due to the high biomass content and the properties of the molasses solution binder.

It can be said that the granules obtained in all compositions except III are plastic. This means that they would not break up into smaller particles during transportation, which is an undesirable process (Woodroof, 2021). However, on the other hand, they may stick together because they are very humid. Also, due to their chemical composition, the granules are heterogeneous and porous (Figure 3), so they may start to mould when stored in a humid environment. More research is needed to solve these problems, but we assume that the quality of the granules could be improved by changing the drying conditions and coating them with conditioning agents.

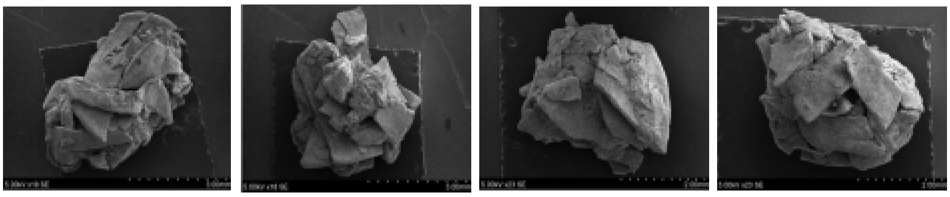

Figure 6.1.3 SEM image of granules: a – composition I; b – composition II; c – composition III;

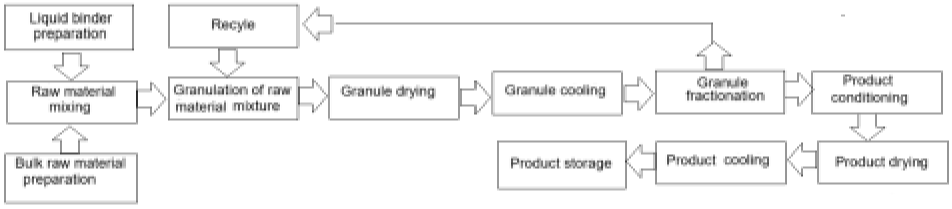

Figure 6.1.4 Scheme of organic fertilizer production with recycle

After evaluating the obtained results and the parameters of the granulation process, an organic fertilizer production scheme was created, which is presented in Figure 6.1.4

In conclusion, the use of recycle and binders significantly affects the granulation process and the quality of the final product, with 30-40% recycle often providing the optimal balance for high commercial fractions and consistent properties.

Conclusions

The results showed that using recycle especially 30 and 40%, resulted in a high amount of commercial fraction in all compositions. The highest commercial fraction yield, approximately 80%, was obtained in composition IV (20% buckwheat husk ash, 40% buckwheat husk, 40% biomass, and molasses solution as a binder), regardless of the amount of recycle used. However, other properties, such as pH, density of granules, and static strength, were more influenced by the composition and type of raw materials, as well as the binder's amount and type, than by the recycle. The pH of the first composition was highly alkaline (13.1–13.6) due to the high ash content, whereas the second composition had a lower pH (8.0–10.5). The third and fourth compositions had nearly neutral pH values (6.9–7.5). Granules in the first, second, and fourth compositions were plastic, while those in the third composition exhibited static strength (7.03–10.05 N/granule), influenced by the beaten egg binder. The loose bulk density of granules across all compositions ranged from 232.2 to 417.2 kg·m^{-3} and their tapped density, ranging from 239.0 to 429.0 kg·m^{-3}, indicated that the granules were lightweight.

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References

Buneviciene, K., Drapanauskaite, D., Mazeika, R., Baltrusaitis, J. A. 2021. Mixture of Green Waste Compost and Biomass Combustion Ash for Recycled Nutrient Delivery to Soil. Agronomy. 11, 641. https://doi.org/10.3390/agronomy11040641.

Sutton, M.A, Bleeker, A., Howars, C.M. et al. 2013. Our Nutrient World Centre for Ecology and Hydrology (CEH), Edinburgh UK. P. 128. ISBN: 978-1-906698-40-9.

FAO. Food wastage footprint. Impacts on natural resources. Summary report 2013. https://www.fao.org/3/i3347e/i3347e.pdf

Greinert, A., Mrówczyńska, M., Szefner, W. 2019. Study on the Possibilities of Natural Use of Ash Granulate Obtained from the Combustion of Pellets from Plant Biomass. Energies. 12, 2569. https://doi.org/10.3390/en12132569.

IFA. 2021. Re-thinking the Role of Plant Nutrients. Food System Summit. https://www.scribd.com/document/521183161/2021-IFA-Re-thinking-the-Role-of-Plant-Nutrients.

Javed, A., Ali, E., Afzal, K.B., Osman, A., Riaz, S. 2022. Soil Fertility: Factors Affecting Soil Fertility, and Biodiversity. Responsible for Soil Fertility. Int J Plant Anim Environ Sci. 12 (1): 021-033. DOI: 10.26502/ijpaes.202129.

Karps, O., Aboltins, A., Palabinskis, J. 2017. Biomass ash utilization opportunities in agriculture Proceedings of the 8th International Scientific Conference Rural Development. 193-198. DOI: 10.15544/RD.2017.083.

Le Capitaine, S. Systems for Granular Fertilizer and Soil Amendment Production. Feeco International. 2023. https://feeco.com/systems-for-granular-fertilizer-and-soil-amendment-production/.

Muranda, F. Effect of fertilizer formulation on dust formation. 2018.

Senhaji, M.I., Hafnaoui, A., Khouloud, M., Agri A.E., Boulahna, A., Asri M.E., Formulation of anti-dust coating agent for monoammonium phosphate fertilizer using experimental design. Chemometrics and Intelligent Laboratory Systems. 2021, 216. https://www.sciencedirect.com/science/article/pii/S016974392100143X

Szulc, A., Skotnicka, E., Gupta, M., Krolczyk, J. Powder agglomeration processes of bulk materials – A state of the art review on different granulation methods and applications. Powder Technology. 2024. No. 413. https://www.sciencedirect.com/science/article/pii/S0032591023008756?via%3Dihub

Roy, R.N., Finck, A., Blair, G.J., Tandon, H.L.S. 2006. Plant nutrition for food security. FAO Fertilizer and Plant Nutrition Bulletin 16. https://www.fao.org/3/a0443e/a0443e.pdf.

The World Bank. 2018. Press release. https://www.worldbank.org/en/news/press-release/2018/09/20/global-waste-to-grow-by-70-percent-by-2050-unless-urgent-action-is-taken-world-bank-report.

Walker, G.M., Moursy, H.E.M.N., Holland, C.R., Ahmad, M.N. Effect of process parameters on the crush strength of granular fertiliser. Powder Technology. 2003, No.132. https://www.sciencedirect.com/science/article/pii/S0032591003000391

Woodroof, N. Size Matters. Word Fertilizers. 2021. https://www.worldfertilizer.com/special-reports/05042021/size-matters/?utm_source=chatgpt.com