3rd International Scientific Virtual Conference
AGROECOSYSTEM SUSTAINABILITY
Links between Carbon Sequestration in Soils, Food Security and Climate Change
Vytautas Magnus University Agriculture Academy, Lithuania, 2-3 December, 2020

The physical-mechanical properties evaluation of experimental granulated poultry manure and biofuel ash fertilizer

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Relevance of the investigation

- In 2016 the draft of the EU commission Regulation of the European Parliament and of the Council promoting the production of fertilizers from organic waste was presented (Circular Economy Document). According to document only 5 % of bio-waste is recycled in Europe. According to estimates, if more bio-waste was recycled, it could replace up to 30% of non-organic fertilizers.
- Replacing mineral fertilizers with organic fertilizers provides additional benefits: reduced energy consumption for the production and transportation of mineral fertilizers, less pollution, improved soil properties. In addition, recycled organic matter is more homogeneous and more evenly distributed in the fields. Better physical and mechanical properties of the fertilizer are provided by the granular form: increased material density, bulk density, mechanical durability, strength, etc. Granular products are easier to handle, transport and use in various technological processes
- The recycling of organic waste reduces the risk of raw material supply, especially in ecological farming.
- By processing manure with organic waste additives into cleaner products and, at the same time, disposing them as waste, the use of granular organic fertilizers for production has been analyzed.

The aim of this work is to carry out a feasibility study for the combination of agricultural waste biomass ash and poultry manure recycled into granular fertilizer by considering the technological means of raw waste material preparation, a theoretical pressure analysis, and a physical–mechanical property determination of the obtained product

The following tasks must be performed

1. To investigate experimentally the physical-mechanical properties of poultry manure and its compost granules and the influence of ash additives on the properties of the new composition granules;
2. To perform a theoretical analysis of the compression process of granulated poultry manure and biofuel ash additives;
3. To determine the chemical composition of manure organic granules.

Waste EWC codes used for experiments

Waste type	EWC code
"Animal faeces, urine and manure (including spoiled straw), effluent, collected separately and treated off site"	02 01 06
"Bottom ash from incineration (non-hazardous)"	19 01 12
"Fly ash from incineration (non-hazardous)"	19 01 14

- According to Regulation (EC) no 2150/2002 of the European parliament and of the Council of 25 November 2002 on waste statistics (European Commision, 2002) the manure should be utilized so that it is used by livestock owners as a fertilizer for crops, thereby reducing environmental pollution. But not treated and stabilized manure can be harmful for the environment etc. soil, ground water.
- Another problem in agriculture is biomass ash utilization. In agreement with the EU waste legislation (Directive 2008/98/EC, 2008), biomass ash should be reused or recycled.
- Several uses of fuel ash are known in global practice. Not traditional in the Scandinavian countries is the incorporation of ash into construction and road surfacing mixtures. However, ash has long been used as a source of Ca, Mg, K, P and micro elements for agricultural crops

Quantities of agricultural organic waste in Lithuania

- Based on the official statistical data during the year 2018 in Lithuania, agriculture, produced about In **3876** thous. tonnes of manure. (Official, 2020)
- Total solid manure quantities is about **9293** thous. tonnes in 2017. Poultry manure quantities consist about **1383** thous. tonnes (Lithuanian Institute of Agrarian Economics data)
- According to our calculations, the average annual amounts of manure in Lithuania can reach **9.5** million. t. (about **5.3** million tons of solid manure and **2.52** million tons of manure during the grazing period remained in the pastures) . There are practically no reliable data on the amount of manure generated in small farms and households
- In Lithuania during the year 2018 , about **30** thous. tonnes biomass ash ()an average of about **25** thousand. t. molasses, about **5** thous. tonnes lime sludge (Official, 2020)

These materials can be used for manure granulation as quality improving additives.

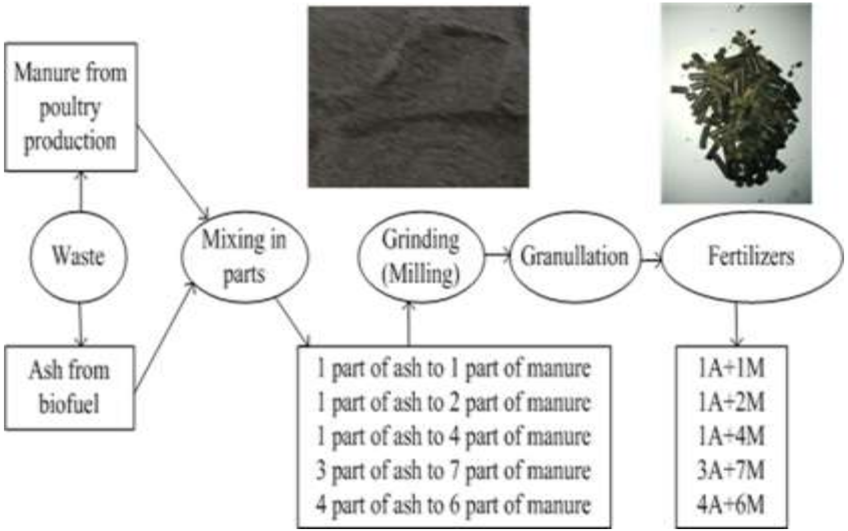
- It can be stated that the supply of raw materials for processing manure or its compost into granular fertilizers is stable and sufficient, and the resulting product is economically and environmentally beneficial.

Types of organic agricultural waste (raw materials) used in the research

Biomass ash and poultry manure samples codes

No.	Biomass ash and poultry manure sample ratio (*wt/wt*, %)	Samples Codes
1	1 part of ash to 1 part of manure (ratio of 50/50)	1A + 1M
2	1 part of ash to 2 part of manure (ratio of 33.3/66.6)	1A + 2M
3	1 part of ash to 4 part of manure (ratio of 25/75)	1A + 4M
4	3 part of ash to 7 part of manure (ratio of 30/70)	3A + 7M
5	4 part of ash to 6 part of manure (ratio of 40/60)	4A + 6M

Note Poultry manure used in this study was obtained from industrial poultry farm. Manure samples without litter was collected from different places in the poultry house. Biomass ash was collected from the industrial burner unit of a power plant of an energy company in Lithuania where biomass was used as fuel. The biomass burned was comprised of forest residues and wastes from the wood processing industry, in the form of sawdust and chips. Mixed raw material was prepared to reach a total of 10 kg.



Technological scheme of manure and ash mixture granular fertilizers production

Methods for determining the physical - mechanical properties of manure raw materials and granules

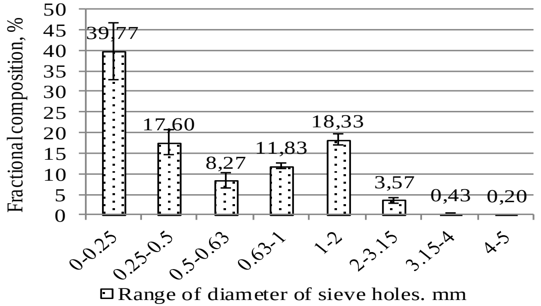
Indicators describing physical-mechanical properties	Equipment	Setting parameters, standards
Fractional composition	Hammer mill GMM-1 (Lithuania) Sieve shaker RETSCH AS 200 wtih sieve complect (Germany)	The fractional composition of milled manure samples was determined, mm Tests were repeated 3 times
Bulk density of manure raw material and granules	6 dm^3 cylindrical vessel, scales KERN ABJ (Germany), accuracy 0,01 g.	Bulk density is calculated, kg m^{-3} LST EN 15103: 2010 repeated 3 times
Moisture content of manure raw material and granules	Scales KERN ABJ (Germany), accuracy 0, 01 g. Drying oven, 24 h., 105 ° C.	EN 12048:1996 LST EN 13040: 2007 repeated 3 times
Biometric indicators of granules	Granulator ZLSP200B (POLEXIM, Poland) 7.5 kW 300 kg h^{-1} Caliper LIMIT 150 mm (KLR), accuracy 0,01 mm Scales KERN ABJ (Germany)	Granule dimensions, mm. Volume, m^3 Density kg m^{-3} repeated 10 times
Granule strength	Instron 5965 test machine (test load up to 5 kN), Bluehill data storage software	Granule is pressed with a quasi-static force at a speed of 20 mm min^{-1} until it is damaged. Strength (compressive strength),N; Deformation Δl, mm; Load force F, N repeated 5 times
Raw material compression process experiments	A cylindrical chamber (12.2 mm diameter) with a piston device was filled with material till 120 mm height Instron 5965 test machine, Bluehill data storage software	Deformation a Δl, mm; Load force F, N repeated 5 times

The research was performed in the laboratories of the Institute of Agricultural Engineering and Safety of Vytautas Magnus University

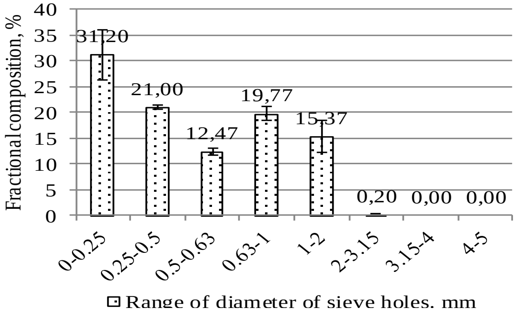
Results of main experimental physical-mechanical studies of raw material and produced granules

Fractional composition of prepared grounded raw material (%) dependence on sieves holes diameter (mm)

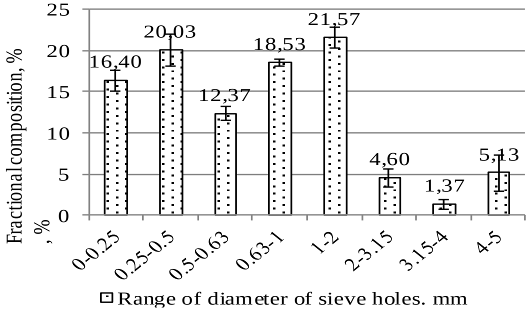
Note We can see that manure quantity in mixture (in example 3A+7M) influences particle size and that's why there is bigger particle distribution in all diameters



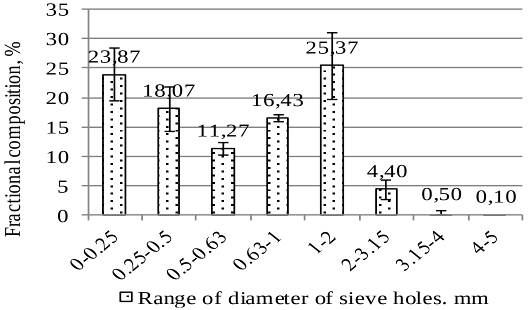
a) 1A+1M



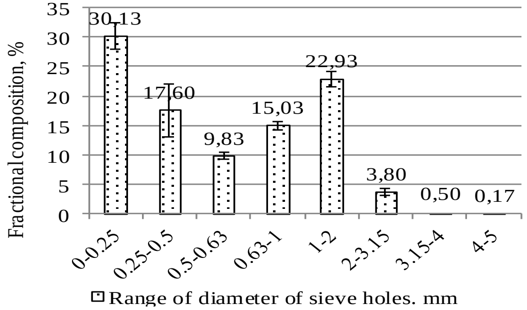
b) 1A+2M



c) 1A+4M



d) 3A +7M



e) 4A+6M

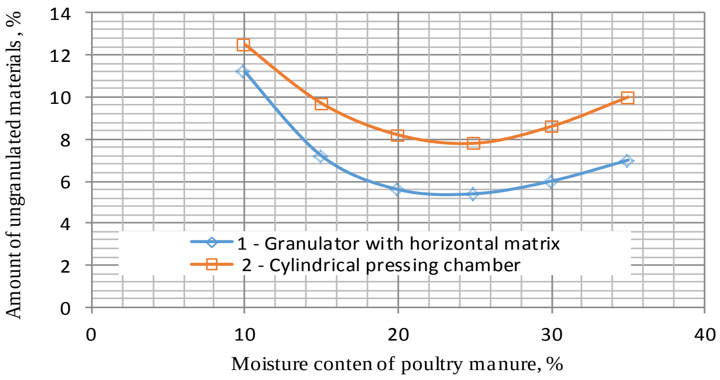
The moisture content and density of poultry manure and biomass ash granules A+M series granules

No.	Granules code	Raw material moisture content, %	Density (D.M.), kg m^{-3}	Bulk density, kg m^{-3}
1	1A+1M	16.42±0.36	1694.61±118.7 D.M. 1416.35±99.27	485.7±0.92
2	1A+2M	26.32±1.54	1483.35±182.43 D.M. 1092.93±134.41	437.6±3.82
3	1A+4M	30.53±1.00	1384.51±86.13 D.M. 961.82±59.83	456.7±2.36
4	3A+7M	27.57±2.79	1386.45±79.46 D.M. 1004.21±57.55	415.0±0.73
5	4A+6M	24.23±1.31	1315.01±108.6 D.M. 996.43±82.29	438.2±12.31

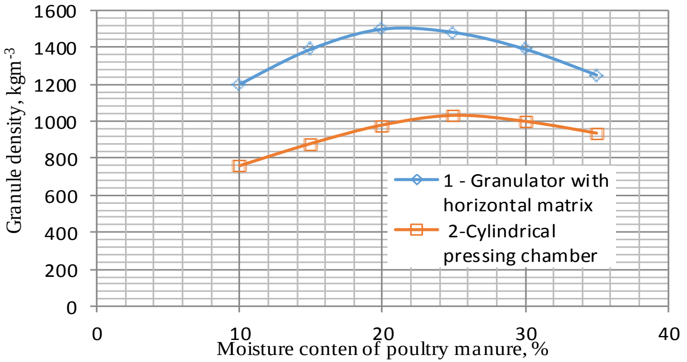
Note After estimating the density of poultry manure and biomass ash manure granular products, it was found that the highest density was released **1694.61±118.7** kg m^{-3} in 1A+1M series case with biggest proportion of ash, and the lowest obtained **1315.01±108.6** kg m^{-3} in 4A+6M series case

The moisture content of raw material and granules

Note Depending on the minimum amount of ungranulated mass and the maximum density of the produced granules, the optimum moisture content of the mass fed to the granulator should be in the range of 20 to 25%. However, at a raw material moisture content of 15 to 35%, the obtained manure mill granules meet the technical requirements for granulation.
When the moisture content of the granulated mass is less than 15%, the raw material needs to be additionally moistened, and when the moisture content of the raw material mass exceeds 35%, the strength of the granules decreases

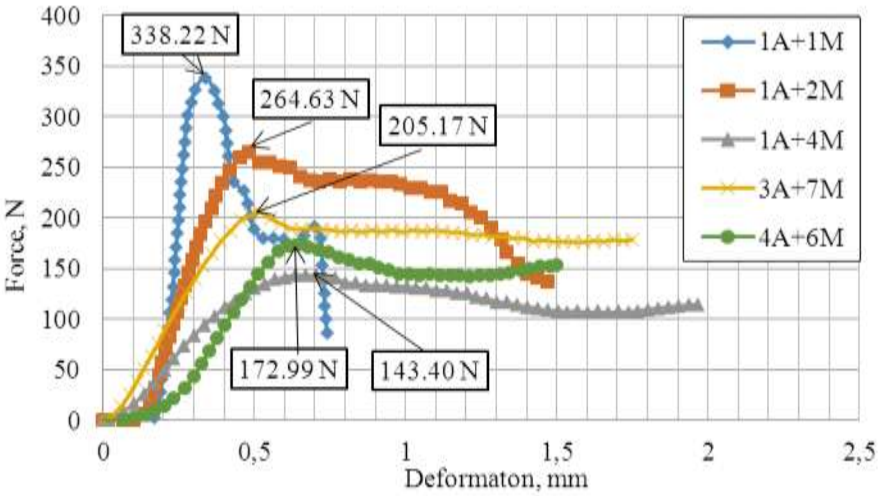


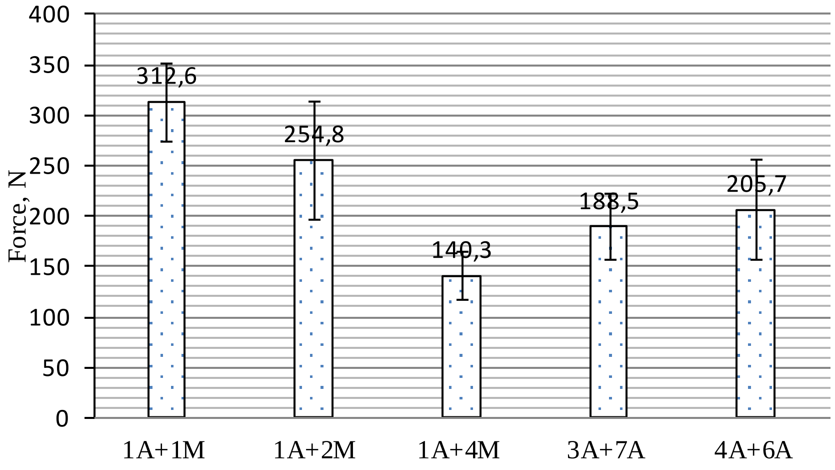
a)



b)

Strength test of organic fertilizer granules





Note Experimental results show that the average strength of granules was around 220.4±75.6 N in horizontal direction. Increasing the concentration of ash has shown stronger binding properties of the granules. The manure and ash granules (1A+1M) with quasi–static stability of 312.6 N were found to be the most mechanically stable. There was made analogical granules strength experiments in vertical direction

Theoretical research of the compression process of granular materials

The compression process is analyzed in two stages: in the first stage, when the compressed mass is expelled by air, and the compression process is described by a system of linear equations.

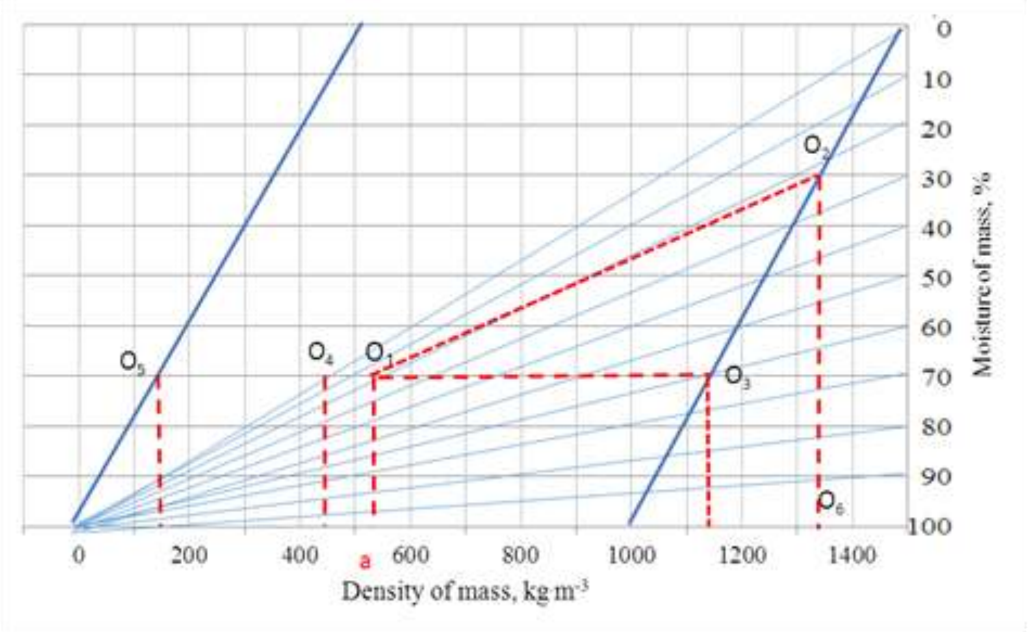
Changes in the properties of granulated organic matter are described by a system of equations compiled by the author (*Sirvydis and Dravininkas, 2005*):

$$\begin{cases} 1 = \dfrac{\rho}{1.5(1-w)} + \rho w + \varepsilon \\ \rho = \rho_{kw}(1-\varepsilon) \\ \rho_{kw} = \dfrac{1.5}{1+0.5-w} \\ \rho_s = \rho(1-\varepsilon) \\ M = \rho w \\ \varepsilon = 1 - \dfrac{\rho}{\rho_{kw}} \end{cases}$$

where ρ is density of manure compost, kg m^{-3}; ρ_{kw} is density of manure compost, when V_o=0, kg m^{-3}; ε is porosity of mass, $\varepsilon = V/V_o$; w is moisture of mass, %; ρ_s is density of mass, expressed as dry matter (DM), kg m^{-3}; M is water content by mass, %.

In modeling the pressure conditions, it is assumed that the total volume V of the manuref mill consists of composite volume components, such as the volume V_s of the solid part, the volume V_w of the liquid part and the volume V_a of the air.

$$V = V_s + V_w + V_a$$



Graphical expression of the system of equations

The developed theoretical model of the manure compaction process and its graphical solution is convenient to determine the technological parameters according to the moisture content of the granulated material.

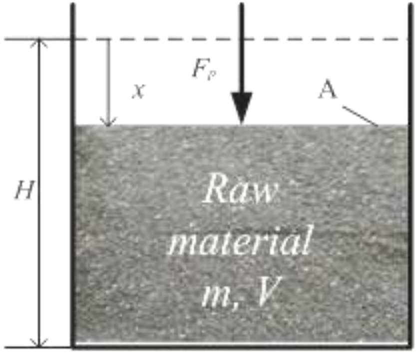
In the second stage, when plastic deformations begin, the orientation of the particles and the intermolecular bonds change, and as the pressure continues to increase, the density increases according to the indicator functions.

$$p = C \cdot \rho^k \qquad (2.1)$$

where p is required pressure, MPa; C is coefficient describing the mechanical properties of the granulated material; k is coefficient of density variation; ρ is density required to compress the raw material, kg m^{-3}.

In practice, the coefficients of the equation are calculated from the pressure-density curves obtained experimentally. Changes in pressure and density during the pressure process were estimated from the equation (according to Miao *et al.*, 2015):

$$E = \int_{\rho_0}^{\rho} \frac{p}{(\rho')^2} d\rho' = \int_{\rho_0}^{\rho} \frac{C(\rho)^n}{(\rho')^2} d\rho' \qquad (2.2)$$



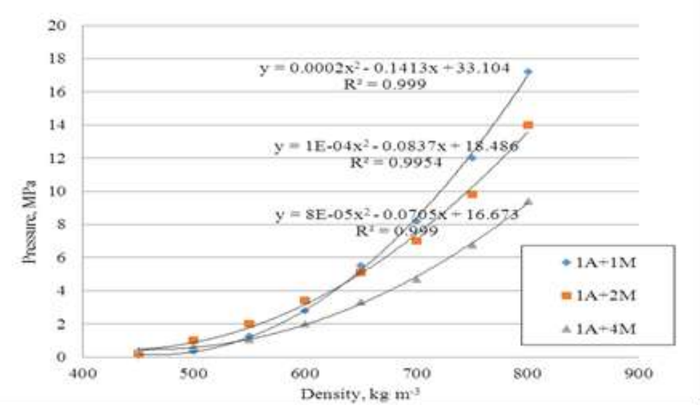
H is initial height, x is piston stroke, Fp is force and A is area of the pressurized surface

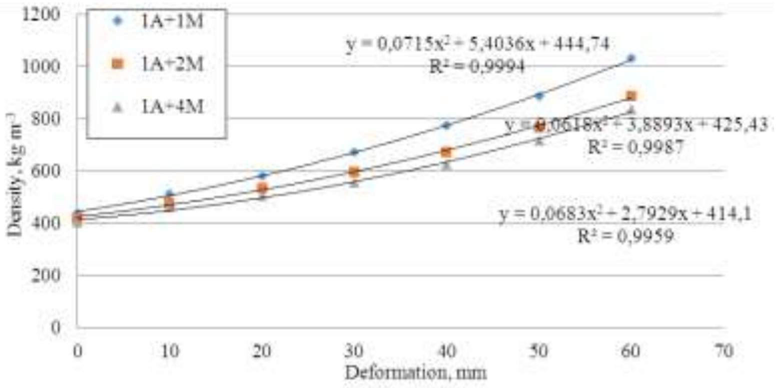
where E is energy, kJ kg^{-1}; ρ_0 is bulk density of the raw material, kg m^{-3}.

The energy demand for the pressure process was calculated according to the equation:

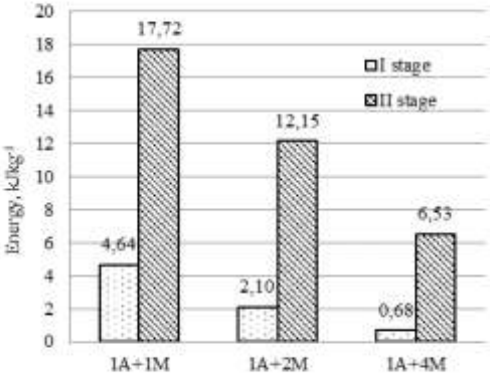
$$E = \frac{C}{k-1}(\rho^{k-1} - \rho_0^{k-1}) \qquad (2.3)$$

Experimentally determined pressure and density functions
Theoretical estimation of energy required for the pressure process





Pressure dependence of poultry manure and ash (A + M series) mill on density and deformation



Results of the calculation of the energy E required for the compression process of poultry manure with ash (A + M series) in the first and second compression stages

Determination of coefficients summarizing the characteristics of the indicative function of the compression process

Dependence of changes in density $\Delta\rho$ and pressure Δp on the deformation of the compressive mass (I stage till 30 mm)

Deformation, mm		10	20	30	40	50	60
1A+1M	$\Delta\rho$, kg·m^{-3}	72	77	83	102	112	146
	Δp, Mpa	0.82	2.5	4.9	7.6	8.7	10.2
1A+2M	$\Delta\rho$, kg·m^{-3}	55	60	63	75	96	128
	Δp, Mpa	0.46	1.25	2.00	4.1	5.96	7.8
1A+4M	$\Delta\rho$, kg·m^{-3}	50	51	53	70	90	118
	Δp, Mpa	0.09	0.31	0.85	1.62	3.26	4.86

Calculation of the coefficients *C* and *k* according to the experimentally obtained pressure and density distribution curves

Deformation, mm		10	20	30	40	50	60
1A+1M	*C*, MPa	$5.6 \cdot 10^{-4}$	$6.44 \cdot 10^{-4}$	$3.9 \cdot 10^{-4}$	$1.33 \cdot 10^{-4}$	$2.33 \cdot 10^{-5}$	$3.09 \cdot 10^{-6}$
	k	1.16	1.34	1.53	1.76	2.01	2.35
1A+2M	*C*, MPa	$4.35 \cdot 10^{-4}$	$5.9 \cdot 10^{-4}$	$4.2 \cdot 10^{-4}$	$2.33 \cdot 10^{-4}$	$7.2 \cdot 10^{-5}$	$10.3 \cdot 10^{-6}$
	k	1.13	1.27	1.42	1.6	1.83	2.14
1A+4M	*C*, MPa	$9.53 \cdot 10^{-5}$	$2.93 \cdot 10^{-4}$	$2.0 \cdot 10^{-4}$	$1.33 \cdot 10^{-4}$	$5.1 \cdot 10^{-5}$	$9.39 \cdot 10^{-6}$
	k	1.12	1.25	1.38	1.55	1.78	2.07

Chemical composition of tested granules

Standards for the determination of the elemental composition of organic granules

Elementas	Standartas
N, %	EN 13342:2000
P , %	EN 13657:2002; EN ISO 11885:2009
K , %	EN 13657:2002; ISO 9964-3:1993
Cd, mg kg^{-1}	EN 13657:2002; EN ISO 15586:2003
Zn, Ni, Pb, Cu, mg kg^{-1}	EN 13657:2002: ISO 8288:2002
Cr , mg kg^{-1}	EN 13657:2002; ISO 9174:2003

Note The addition of ash was found to increase the amount of heavy metals in all samples. The lowest Cd content of **4.01** mg kg^{-1} (rate up to **1.5** mg kg^{-1}) was in the 1A + 4M sample because there was the lowest (25%) ash content. The same situation was with other heavy metals, except Nickel (Ni). Smallest amount of Ni was found in 4A+6M sample

Chemical composition of tested granules (A+M series)

Test parameters	Sample code and test results					Biomass ash raw material
	1A+1M	1A+2M	1A+4M	3A+7M	4A+6M	
pH	10.3	7.9	8.0	8.8	9.2	13.0
In dry matter (DM):						
Nitrogen (N), %	1.50	1.89	2.27	2.14	1.95	-
Phosphorus (P), %	1.29	1.16	1.24	1.16	1.11	-
Potassium (K), %	3.18	2.50	2.18	2.22	2.12	-
Cadmium (Cd), mg·kg^{-1}	6.85	6.29	4.01	6.88	8.08	17.1
Zinc (Zn), mg·kg^{-1}	5350	4567	2800	4100	5000	2667
Nickel (Ni), mg·kg^{-1}	18.6	21.5	19.5	18.2	17.8	15.3
Lead (Pb), mg·kg^{-1}	288	217	142	206	264	111
Copper (Cu), mg·kg^{-1}	59.7	61.0	60.9	65.6	64.4	60.4
Chrome (Cr), mg·kg^{-1}	27.2	26.3	23.6	24,4	26.3	24.7

CONCLUSIONS

1. The biggest raw material mill fraction was accumulated on 0.25 mm sieves (39.77% ± 7.07%) in the case of sample 1A + 1M. The largest amount of 1A + 2M was also accumulated on the 0–0.25 mm diameter sieve (31.20% ± 4.81%), while the 1A + 4M sample accumulated mostly on the 1.0–2.0 mm diameter sieve. The particle distribution was larger in samples with higher manure quantities.

2. The determined moisture content of the raw materials ranged from 16.42% ± 0.36% to 30.53 ± 1.00%. The bulk density of the raw material was the lowest in the 3A + 7M sample case (415.0 ± 0.73 $kg \cdot m^{-3}$) and the bulk density of 1A + 1M was the highest (485.7 ± 0.92 $kg \cdot m^{-3}$), which showed the best results in the granule strength experiments. The granule density obtained from the granulator was obtained from 1416.35 ± 99.27 $kg \cdot m^{-3}$ DM (in the 1A + 1M case) to 961.82 ± 59.83 $kg \cdot m^{-3}$ DM (in the 1A + 4M case) and, with the laboratory equipment pressure chamber, a density range of 836–1032 $kg \cdot m^{-3}$ was obtained.

3. Experimental study of physical-mechanical properties of the produced manure granules showed that increasing ash concentration in poultry manure from 25 to 50%, the granule strength increased to 55% (from 140.3–312.6 N on average in the horizontal direction and from 101.5–327 N on average in the vertical direction). Depending on the minimum amount of un-granulated mass and the maximum density of the produced granules, the optimum moisture content of the mass fed to the granulator should be in the range of 20 to 25%.

4. After theoretical modeling of the milled manure compression process, the coefficients describing the physical-mechanical properties of the manure mass were determined, when air is removed from the pressed material, and the required granule density is reached in the next compression stage. The dependence of changes in density and pressure on deformation of the compressed mass was determined. Theoretically, it was estimated that, when the concentration of ash additives in poultry manure increased to 50%, the pressure energy consumption increased from 6.53 to 17.72 kJ kg^{-1} The developed theoretical model and graphical solution are convenient to determine technological parameters, such as air, liquid and dry matter quantities and the density of manure granules, based on moisture content of the granulated material.

5. Based on the chemical composition of granular poultry manure and biomass ash granules, it was found that addition of ash to poultry manure increased the content of heavy metals. In conclusion, the results of this study suggest that the granulation of a manure/ash mixture using biomass granulators dedicated to forestry and other agricultural residue granulation produces granules of high density (1694.61 ± 118.70 in the 1A + 1M case). It has been theoretically proven that manure and ash mixture raw material can be used at lower pressures and energy consumptions, resulting in a lower environmental impact.

Thank You

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