STUDIES OF GRANULES OF VARIOUS DIGESTATE AND WOOD ASH MIXTURES

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Abstract. Latvian biogas plants use various organic agricultural waste as raw materials, first of all cattle and pig manure. Digestate, a processed product obtained by anaerobic fermentation, is a good fertilizer. The addition of wood ash could further improve its properties, especially on acid soils. In order for it to be advantageous to transport this fertilizer to further fields, it would be desirable to granulate this fertilizer - a mixture of ash and digestate. In this study, granules were prepared from ash and digestate, which were predominantly cattle manure mixtures, and also from ash and digestate, which was predominantly pig manure. With wood ash of the heat production company Fortum, the digestate was prepared in four different mixtures and granulated. The granules were dried with a stream of warm air (40-50 ºC) and also naturally kept at laboratory temperature for thirty days. The dried granules were subjected to strength tests. Granules produced from pig or cattle manure with ashes at different proportions were tested for breaking durability. The material testing device INSTRON (accuracy class - 0.5) was used to determine the compressive strength of the granules placed upright on the end surface. To increase the accuracy of measurements 5 batches each consisting of 10 granules (diam. 6 mm, length 10 mm) were tested, and the average breaking force per single granule was calculated. The highest strength in longitudinal direction 60.5 N was determined for the granules made from the pig farm biogas plant digestate: ash at a ratio of 3:1, and the lowest strength 41.0 N was found for the granules composed of the pig farm biogas plant digestate: ash in a ratio of 4:1 or less by 32% compared to the most durable granules. High average strength 67.2 N was found in the granules made from the cattle farm biogas plant digestate and ash at a ratio of 1:1, but the granules made from the cattle farm biogas plant digestate and ash at a ratio of 3:1 withstand a compression force 49.0 N or less by 27% compared to the most durable granules. However, both artificially and naturally dried granules are still sufficiently stable and suitable for transport and fertilization.

Key words: digestate, wood ash, granules, strength.

Introduction

Both the current growth strategy and environmental policies of the European Union aim to increase the amount of renewable energy and to improve the use of waste streams. This will increase the amount of bio-ash from biomass combustion in the future, thereby increasing the need for its utilization, with fertilizer use the most natural target for bio-ash. Wood ash, in particular, contains all the nutrients that plants need in almost the correct proportions, excluding nitrogen, which is released into the atmosphere during combustion. Nitrogen could be added to ash fertilizers by co-granulating bio-ash, for example, with cattle and pig farms biogas plant digestate. However, co-granulation has not been studied extensively. The thick fraction of digestate is suitable for granulation. The solid/liquid separation of digestate generates two outputs, the liquid and the solid fraction of digestate [1]. The liquid fraction of digestate is a pumpable liquid fraction, richer in nitrogen than thick digestate. The solid fraction consists of stackable fibrous material, rich in organic matter [2]. There are several separation methods, such as the belt press, sieve drum, screw press, sieve or decanter centrifuge. Alternative fertilizer resources have drawn attention in recent times in order to cope up with ever increasing demand for fertilizers. By-products of the bioenergy system are considered favourable as organic fertilizer due to their ability to recycle plant nutrients. Indian researchers [3] evaluate fertilizer suitability of by-products of two bioenergy systems. "Two types of anaerobic digestion by-products (digestate) from local surplus biomass such as cow dung, *Ipomoea carnea*: cow dung (60:40) and rice straw: green gram stover: cow dung (30:30:40). Digestates were assessed considering 4 different application options of each *viz.* whole, solid, liquid and ash from solid digestates. Digestate characteristics (organic matter, macronutrients, micronutrients and heavy metal content) were found to be a function of feedstock and processing (solid liquid separation and ashing). *Ipomoea carnea* based digestates in all application options showed comparatively higher N, P, K, NH_4^+-N, Ca, Mg, S and micro nutrient content than other digestates. Separation concentrated plant nutrients and organic matter in solid digestates, making these suitable both as organic amendments and fertilizer. Separated liquid digestate shared a larger fraction of ammonium nitrogen (61-91% of total content), indicating the suitability as readily available N source. However, fertilizer application of liquid digestate may not match crop requirements due to lower total nutrient concentration. Higher electrical conductivity of the liquid digestates (3.4-9.3 $mS\cdot cm^{-1}$) than solid digestates (1.5-2 $mS\cdot cm^{-1}$) may impart phyto–toxic effect upon fertilization due to salinity. In case of by-products with unstable organic fraction, i.e. whole and solid digestates of rice straw: green gram stover: cow dung digestates (humification index 0.7), further processing (stabilization, composting) may be required to maximize their fertilizer benefit. Heavy metal contents of the by-products were found to be within the permitted range specified for organic fertilizer (vermicompost) in India. However, higher Al content of the digestates in the whole, solid and ash phase (0.06-16.97 $g\cdot kg^{-1}$ fresh matter) can be a concern in acid soil which may cause Al toxicity" [3].

The need to find and maximize the use of alternative sources of nutrients for plants and soil environment have been on the forefront of the research in sustainable agriculture. These alternatives have to be affordable, accessible, reproduceable, and efficient to compete with established inorganic fertilizers, while at the same time reduce any potential negative impacts on the environment. Lithuanian researchers [4] aimed to evaluate the effectiveness of digestate fertilization in an agricultural system over a period of three years. The digestate utilized in the study consisted of animal waste-based digestates, namely pig manure digestate, chicken manure digestate, and cow manure digestate, and were compared with synthetic nitrogen fertilizer. Every year, the digestate and the synthetic nitrogen fertilizer were split applied at the rate of 90 and 80 kg $N\cdot ha^{-1}$. The soil chemical composition after three years of fertilization showed a slight decrease, significantly different nitrogen and carbon changes, while phosphorus and potassium were significantly higher in the digestate treatments. The third year of digestate application showed higher grain yield than previous years and the yields from the digestate treatments were significantly different from the synthetic nitrogen fertilizer. The nitrogen use efficiency for the three years was in the range of 20-25 percent in the digestate treatments, with a strong correlation between the nitrogen use efficiency and the grain yield. There were varied results in the grain quality and straw quality in the digestate and synthetic nitrogen fertilizer with no clear trend observed. Our results showed a relatively high potential of animal waste digestates over the short to mid-term use with a positive result obtained in comparison to synthetic nitrogen fertilizer under favourable climatic conditions [4]. Concentration of trace metals is one of the most crucial factors determining the quality of cereal grains. The aim of this study [5] was to evaluate the effect of digestate, manure, and NPK fertilization on trace metal concentration in grains and straw of two cereal crops-winter wheat and spring barley - and trace metal (TM) transfer from soil to plants. ,,The experiment was carried out between 2012 and 2016. Every year, the same treatment was used on each plot: control (without fertilization), digestate, digestate + straw, cattle slurry, and mineral NPK fertilization. In general, fertilization increased the concentration of TM that belong to the micronutrient group (Zn, Cu, Fe), particularly after application of digestate and cattle slurry. At the same time, fertilization, regardless of the fertilizer type, led to an increase in Cd concentration in the grain of winter wheat in comparison with the control. Despite the increase in Cd and micronutrient content as a result of fertilization, the concentration of elements remained below the applicable standards. Among trace metals, only Pb content exceeded the European Union limits. The increased concentration of Pb was, however, an effect of other factors, rather than fertilization. The results clearly indicated that the biogas digestate from anaerobic co-digestion of cattle slurry and agricultural residue could be utilized as fertilizer in agricultural applications without a risk of contaminating the food chain with trace metals'' [5]. Wood ash is a good source of potassium (K) ~5%, calcium (Ca) ~25%, phosphorous (P) ~2%, and magnesium (Mg) ~1% which are essential plant nutrients. Crops have been shown to positively respond to K and P from wood ash. Other micro-nutrients in wood ash include boron, copper, molybdenum, sulphur and zinc. A field study [6] was carried out to evaluate the potential of wood ash as a fertilizer in grassland systems in combination with enriched N organic wastes. Overall, the combined use of wood ash and biogas digestate can constitute an efficient way for the disposal and recycling of both products and additionally, it may constitute an environmentally friendly alternative to mineral fertilizers for acid soils. This study [7] investigated co-granulation of bio-ash with sewage sludge and lime. It measured compressive strengths, neutralizing values, and elemental concentrations of the granules. The concentrations of heavy metals (As, Cd, Cr, Cu, Pb, Ni, and Zn) in the granules were sufficiently low not to prevent their forest fertilizer use according to Finnish legislation. The addition of sewage sludge considerably lowered the compressive strength of the granules, and the addition of lime (slaked lime) did not improve the strength of the granules. From a technical point of view, the co-granulation was very successful.

Table 1

Digestate produced in Latvia

Year	Number of plants	Total installed capacity, MW	Produced, t
2014	50	53.063	1101136
2015	50	53.063	1278744
2016	49	51.083	1197604
2017	49	51.083	1235336
2018	46	49.633	1183528
2019	43	45.633	1101416
2020	43	45.633	1037865
2021	41	44.984	977669

As it can be seen from Table 1 (results calculated approximately), Latvia biogas plants every year produce 0.97- 1.2 bn tons of digestate, only in recent years there has been a sharp decline [8]. Digestate consists of a liquid rich in minerals and undispensed organic matter, containing bacterial cells and substances rich in lignin. All the main nutrients (N, P, K) have been preserved in the digestate, but N has partially passed to the plants in a more easily perceived form – ammonium. Digestate gives higher yields compared to unprocessed manure. If the liquid digestate is incorporated into the soil by the topsoil loosening method, the N losses are negligible. The composition of the digestate depends on the raw materials used in the anaerobic fermentation process. We have obtained many different digestates in our laboratory. Granulation of digestate from cattle and pig farms with wood ash mixture has not been studied so far. The aim of this study was also to obtain results on the strength of the granules.

Materials and methods

Digestate contains significant amounts of nutrients and is suitable for use in field fertilizers and as an additive in animal feed. The composition depends on the chemical composition of the raw materials and the technological process. In this study, we analyze the raw materials used in the biogas plants of cattle and pig farms, as well as the digestate obtained from anaerobic fermentation processes.

For each sample delivered to the laboratory of the University of Life Sciences and Technologies chemical composition was determined according to ISO 6496: 1999. For each sample dry matter, organic solids and ash content were determined. The analysis was made by standard methods [9]. Full dry matter was determined by the dry weighing-drying equipment Shimazu at 105 ºC temperature, composition of organic matter with the help of a drying oven Nabertherm and the drying process was done with a special program at 550 ºC. Digestate thick fractions from the biogas plant were mixed with wood ash. Granules were made from the digestate thick fractions, which have the moisture content 24.43-27.32%. The granules were dried with a stream of warm air (40-50 ºC) and also naturally kept at laboratory temperature for thirty days. With wood ash of the heat production company Fortum, the digestate was prepared in four different mixtures and granulated. The granulator KL 200 B/C was used for granulation. The material testing unit INSTRON (accuracy class – 0.5) was used to determine the compressive strength of the granules placed upright on the end surface.

Results and discussion

Table 2 shows the average raw material and digestate analyzes obtained from the same raw materials in the laboratory as from the cattle farm biogas plant.

Note: TS stands for full dry matter; DOM – dry organic matter (% of total dry matter).

Table 3 shows the average raw material and digestate analyzes obtained from the pig farm biogas plant raw materials in the laboratory. Thick digestate TS = 26.64% can be used for mixture with wood ash and granulation.

Thick digestate TS = 24.25% can be used for mixture with wood ash and granulation. The pig farm changed the digestate when we had already started to work, so both are shown. Table 4 shows the analyses of granules formed from different mixtures of digestate and wood ash.

Table 2

Raw material and digestate analyzes of cattle farm biogas plant

Raw material	pH	TS, %	Ash, %	DOM, %
Cattle manure	7.88	7.02	16.94	83.06
Digestate	7.85	6.6	21.34	78.66
Maize silage	-	29.59	4.11	95.89
Grass silage	-	27.8	8.53	91.47
Fluor	-	89.32	6.15	93.85
Total average	7.66	7.86	17.53	82.47
Average thick digestate in laboratory	7.68	5.79	26.64	73.36

Table 3

Raw material and digestate analyzes of pig farm biogas plant

Raw material	pH	TS, %	Ash, %	DOM, %	pH	TS, %	Ash, %	DOM, %
Pig manure	7.5	2.58	28.23	71.77	7.5	2.58	28.23	71.77
Digestate liquid	8.01	3.84	31.64	68.36	8.0	5.53	10.48	89.52
Digestate thick	-	24.25	10.3	89.7	-	24.24	9.63	80.37
Maize silage	-	43.64	11.47	88.53	-	43.64	11.47	88.53
Sludge	-	14.38	15.69	84.31	-	14.38	15.69	84.31

Table 4

Granules of digestates and ash mixtures

Granules from mixture	TS, %	Ash, %	DOM, %
CMD: A 1:1	95.39	76.36	23.64
CMD: A 2:1	93.77	64.15	35.85
CMD: A 3:1	92.15	60.20	39.80
CMD: A 4:1	91.28	55.44	44.56
PD:A 1:1	93.62	68.46	31.54
PD:A 2:1	92.37	62.50	37.50
PD:A 3:1	92.13	60.97	39.03
PD:A 4:1	90.65	53.88	46.12

Granules produced from the pig farm biogas plant digestate and cattle farm biogas plant digestate mixed with ashes at different proportions were tested for breaking durability. The testing process was automated, and the results were registered in machine memory. To increase the accuracy of measurements 5 batches were tested, and each batch consists of 10 granules (diam. 6 mm, length 10 mm) and the average breaking force per single granule was calculated by dividing of the measurement value by10. The highest strength in longitudinal direction 67.2 N was found in the granules from the cow farm biogas plant digestate and ash at a ratio of 1:1, but the granules made from the cow farm biogas plant digestate and ash at a ratio of 3:1 withstand a compression force 49.0 N or less by 27%. The high strength in longitudinal 60.5 N was determined also for the granules made of the pig farm biogas plant digestate and ash at a ratio of 3:1 that was by 32% higher compared to the granules made of the pig farm biogas plant and ash mixture at a ratio of 4:1. Average breaking force of granule in longitudinal direction in dependence on digestate: ash ratio is shown in Fig.1.

In cross direction most durable 63.5 N were the pellets made from the cow farm biogas plant digestate and ash at a ratio of 2:1, but the granules made from the cow farm biogas plant digestate and ash at a ratio of 4:1 withstand a compression force 58.3 N or less by 8%. The high strength in cross direction 58.5 N was determined also for the granules made of the pig farm biogas plant digestate and ash at a ratio of 4:1 that was by 26% higher compared to the granules made of the pig farm biogas plant digestate and ash at a ratio of 2:1. Average breaking force of granule in cross direction in dependence on digestate: ash ratio is shown in Fig.2.

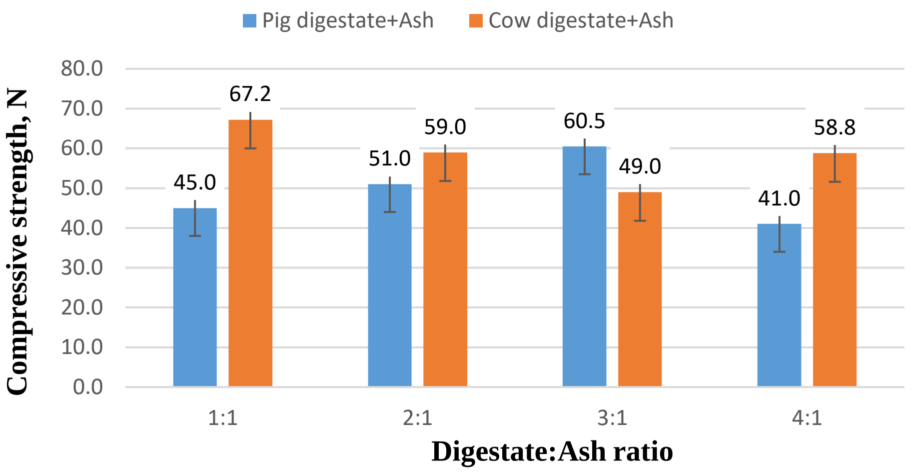

Fig 1. **Average breaking force of granule in longitudinal direction in dependence on digestate: ash ratio**

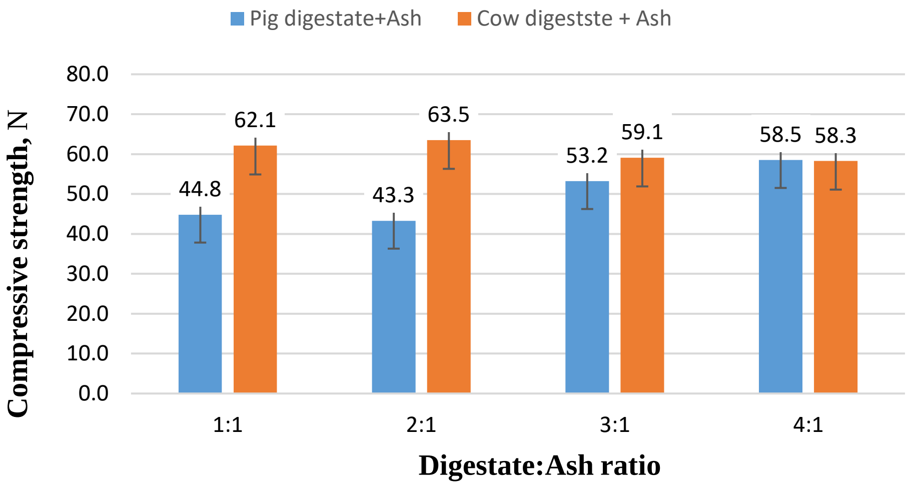

Fig 2. **Average breaking force of granules in cross direction in dependence on digestate: ash ratio**

The highest strength 60.5 N was determined for the granules in cross direction made of the pig farm biogas plant digestate: ash at a ratio of 3:1, and the lowest strength 41.0 N was found for the pellets composed of the pig farm biogas plant digestate: ash in a ratio of 4:1 or less by 32% compared to the most durable granules.

High average strength 67.2 N in longitudinal direction was found in the granules made of the cow farm biogas plant digestate and ash at a ratio of 1:1, but the granules made of the cow farm biogas plant digestate and ash at a ratio of 3:1 withstand a compression force 49.0 N or less by 26% compared to the most durable pellets.

Conclusions

1. Both artificially and naturally dried granules are still sufficiently stable and suitable for transport and fertilization.
2. Analyzes of the composition of both types of granules show that the more ash they contain, the more dry matter, but less DOM.

3. In general, the granules made of the cattle farm biogas plant digestate and ash mixtures (63,5N) are slightly more durable compared to the granules made of the pig farm biogas plant digestate and ash mixtures (58,5N).

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Author contributions

The contribution of each author. Conceptualization, V.D.; methodology, V.D.; software, V.D. and A.A.; validation, A.A. and V.D; formal analysis, V.D.; investigation, V.D., A.K. and I.P.; data curation, V.D. and I.P.; writing – original draft preparation, V.D.; writing – review and editing, A.A. and V.D.; visualization, V.D.,I.P. and A.K. ; project administration, V.D. All authors have read and agreed to the published version of the manuscript.

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