POSSIBILITIES FOR IMPROVEMENT OF PLANT NUTRIENT MANAGEMENT IN BIOGAS PLANTS IN LATVIA

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Abstract. Pollution resulting from agricultural activities, including biogas plant operation, accounts for majority of phosphorus and nitrogen compounds that reach the Baltic Sea after being discharged into rivers. The number of agricultural biogas plants in Latvia reached its maximum number of 50 in 2017, and decreased to 43 plants in 2021, due to the reduction of state aid for mandatory procurement of electricity. To assess the potential risks of environmental contamination with plant nutrients and to identify the possible nutrient losses 22 biogas plants were inspected, and 98 samples of raw materials and fermentation residues were collected and analysed in a certified laboratory. In the surveyed biogas plants, the input biomass consisted of silage (31%), various types of manure (58%), food industry residues (8%), and sewage sludge 3%. Silage analyses show that 39% of samples had dry matter content less than 30%, indicating an increased risk of silage effluent runoff. The carbon-nitrogen (C: N) ratio in most of input biomass and digestate was below the optimum value range (1:25 - 1:35), indicating the risk of inhibition of the anaerobic fermentation and risk of gaseous ammonia emissions from both biogas fermenters and digestate storages. Comparing the content of plant nutrients in the separated and dried fractions of digestate, an increased risk of nitrogen loss due to the evaporation of volatile nitrogen compounds during the drying process was determined. Improvements of plant nutrient management may include addition of raw materials having high C:N ratio, e.g., straw, other lignocellulosic materials in input substrate, covering the silage bunkers and digestate storages with a plastic layer with increased gases impermeability.

Keywords: anaerobic fermentation, digestate, effluents, plant nutrients, silage.

Introduction

The maximum number of biogas plants in Latvia reached 50 in 2017, and then decreased to 47 in 2020, due to decrease in support for the mandatory purchase of electricity from biogas plants that have been operating for more than 10 years. Many biogas plants use the energy crops, e.g., maize, requiring high raw material costs for cultivation, pre-processing, and storage. Maize has the lowest concentration of nitrogen, phosphorus, and potassium and the highest organic dry matter mass, compared to sunflower or energy beets [1]. To minimise the environmental impact from biogas plant operation, all stages of the biogas production process need to be reviewed in terms of minimisation of risk of leakages, efficient use of plant nutrients and stability of the anaerobic fermentation process.

Ensilaging of energy crops is used widely in biogas plants, as it provides feedstock for round-year production of biogas. In laboratory conditions, ensilaging of green biomass harvested in Southern Finland shows the increase of methane production by 12% or 29% from maize or hemp silage after 8-month storage compared to methane obtained from fresh biomass [2]. At field scale, storage periods of up to 1 year for properly ensiled crops could be possible without losses in methane production or even with surplus methane yield 3-6% also considering the losses of dry matter during the storage period [3]. Biological ensilage additives can improve methane production by 1% [4] or by 5-11%, if the combination of enzymes, yeast and fungi was used [5].

Effluent production accounts for a major part of ensiling losses in silages with a low dry-matter (DM), and effluent can have negative impacts on the environment. Biological oxygen demand (BOD) of silage effluent exceeded 49,000 mg L t^{-1} and one litre of effluent can deplete the dissolved oxygen in 10,000 L water to below critical levels for fish survival [6]. The amount of effluent strongly depends on the dry matter content in biomass before ensilage and the typical values were 0-100 L t^{-1} for corn silage with the dry matter content 30-25%, and 180-290 L t^{-1} for fresh grass or clover with the dry matter content 22-18% [7]. The amount of silage effluent and methane production can vary not only from the dry matter content of biomass, but also the climate, density, particle size [8] and sealing of silage to prevent aerobic deterioration. These phenomena can lead to up to 40% methane loss if inappropriate management practices are used [9]. To calculate the amount of silage runoff in Latvian climatic conditions, it is assumed that there is no leakage of silage juice from maize with a dry matter content of more than 30% and wastewater reaching 280 litters if the dry matter content in ensiled maize is 15% [10].

Silage effluent can be used as a source for biogas production successfully. Anaerobic digestion of silage effluent having COD of 14,460 mg litre^{-1} in a laboratory scale, upflow, fixed-bed reactor provided reduction of pollution potential by 75.7% with respect to COD and average yield of biogas 5.1 m^3 per cubic metre feed effluent with methane content 84% in biogas [11]. Silage effluent can be added to slurry or digestate tanks to lower pH and reduce ammonia and/or methane emissions, for example, addition of 7% of grass silage effluent or maize silage effluent to grass silage effluent or to cattle slurry reduced ammonia (NH_3) emissions by 38% and 13% respectively [12].

Biogas plant operators face a risk of inhibition of the anaerobic fermentation process with ammonia concentrations from 1,700 mg L^{-1} to 14,000 mg L^{-1} showing an inhibitory effect by 40% on the biogas process at concentration greater than 3,000 mg L^{-1} NH^{+4} [13]. A simple strategy to overcome ammonia inhibition is to optimize feedstock C: N ratios to guarantee an optimal microbial growth. Two simulations using bio-degradable feedstocks such as food waste, fruit and vegetable waste, green waste, and paper waste, show that C: N ratio 32 had about 30% less ammonia in digestate as compared to that with C: N ratio 27 [14].

Emissions from digestate storage are always in the form of ammonia and methane losses, unless the digestate storage is covered with a gas-tight plastic layer equipped with a gas collection system. The experiment, carried out at a 1 MWe anaerobic digestion plant, demonstrated that collecting the residual biogas from the digested liquid fraction storage tank made it possible to avoid atmospheric emissions of up to 1260 t CO_{2eq} annually and to increase the methane yield of the installation by 3% [15].

Digestate mixing before emptying the storage, digestate transportation and application in soil also can release ammonia if proper technology is not used. Minimisation of emission can be achieved by mixing of digestate in the storage covered by a plastic layer and digestate transporting in sealed tankers or via pipelines. Usage of acidified digestate (pH 6.4) compared to unacidified digestate (pH = 7.9) causes decrease of cumulative ammonia losses by 1.7 or 2.7 times compared to unacidified digestate uncovered or covered with growing plants within 24 h period following spreading respectively [16].

The aim of this study is to assess the risks of leakages and emissions of nutrients from biogas plants and to propose possible solutions to minimize the loss of nutrients in the environment.

Materials and methods

To assess the potential risks of environmental contamination with plant nutrients and to identify the possible nutrient losses 22 biogas plants (or 48% of agricultural biogas plants in Latvia) were inspected, and 98 samples of raw materials and fermentation residues (digestate) were collected and analysed in a certified laboratory in 2021. Following plant nutrient and physical parameters were tested, Table 1.

Table 1

Test parameters and method for feedstock and digestate

Parameter	Unit	Feedstoc k	Digestate	Testing method
Dr matter	%	+	+	LVS EN 13040:2008
Organic matter	%	+	+	LVS EN 13039:2012
Total nitrogen (N)	%	+	+	LVS EN 13654-1:2003 /NAC:2004
Total phosphorus (P2O5)	%	+	+	LVS 398:2002
Total potassium (K2O)	%	+	+	LVS ISO 11466:1995 LVS ISO 9964-3:2000
Ammonium nitrogen (in dry matter)	$g \cdot kg^{-1}$	-	+	LVS ISO 14256-2:2005
pH (in KCl)	pH	-	+	LVS ISO 10390:2006

Biogas plant biomass samples were collected by the staff of the certified laboratory in biogas plants in every region in Latvia – in 14 biogas plants in Zemgale, and in 2 plants in every other region (Latgale, Kurzeme, Vidzeme and Lielrīga). Liquid digestate samples were collected from lagoons during mixing before digestates were used for soil fertilisation in March-April 2021.

The samples were transported to the laboratory and were analysed according to standardized methods, Table 1.

Results of analysis and calculations were provided in a separate report for each sample, and the report included conditions of the sampling site, values of physical parameters, concentration of chemical elements and accuracy of measurement. The obtained results were used for comparing of physical and chemical parameters of different groups of input raw material or digestate with similar properties or treatment methods.

Also, data on the amount of input and output biomass in biogas plants were obtained by interviewing of operators of biogas plants or using values provided in permits on polluting activities issued for respective plants. Carbon to nitrogen (C: N) ratio was calculated using known value of organic matter content in biomass and total nitrogen in samples.

Results and discussion

Most of biogas plants in Latvia use manure for biogas production [17], and manure was the main raw material also in the investigated biogas plants, where 14 of 22 biogas plants used cow manure, 2 biogas plants used pig manure and 3 biogas plants used poultry manure. The total input of raw materials consists of silage (31%), cattle manure (41%), pig manure (8%), poultry manure (9%), food industry wastes (7%), wastewater sludge (3%) and industrial wastewater (1%).

While cow manure was the largest input biomass in biogas plants, the second highest feedstock share was silage, which was used in 18 of the 22 biogas plants and was the highest source of organic matter for energy production in these biogas plants.

Good quality of silage is an important factor for effectivity of biogas plant production. Important parameters are the silage moisture and ash content, as both parameters have influence on the amount of silage effluent and organic matter losses from the silage, Fig.1.

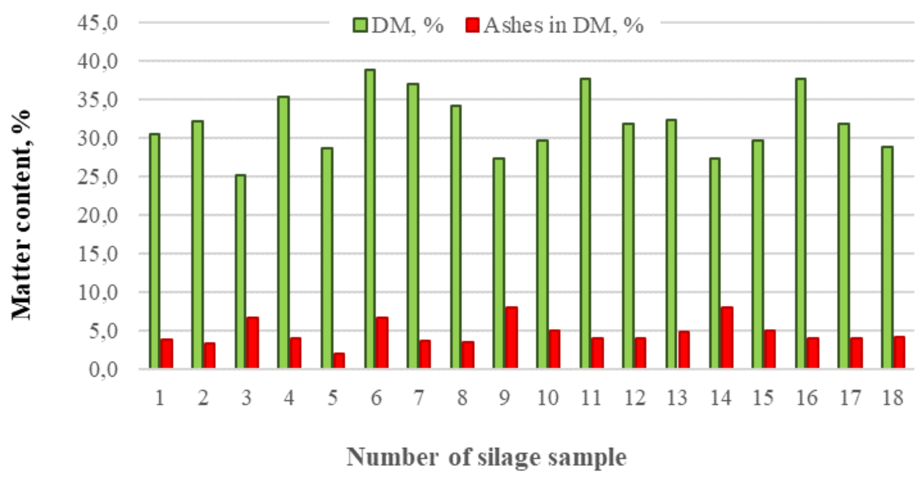

Fig. 1. **Content of dry matter and ashes in dry matter in silage used in biogas plants**

The dry matter content in silage samples was varying from 25% to 39% or was 32.0% on average. While average dry matter content in most silage samples was within a safe level (> 30%), however, there were 7 silage samples (39%) having dry matter below 30% with increased risk of effluent runoff.

The ashes content in dry matter of silage was varying from 2.1 to 10.0% or was 4.7% in average. The ashes content in 13 silages samples (72%) exceeded the average ash content 3.9% determined in fresh maize (variety Tango) biomass, harvested in Zemgale region [18], likely attributable to the variety of the crop, harvesting and pre-treatment method [7], soiling of silage, and biodegradation due to poor isolation of silage heaps or ingress of air in silage during the take-off process [9]. Biodegradation of silage can be minimised by covering of silage heaps with plastic film of high oxygen impermeability and by covering of silage heaps immediately after the take-off process.

Percentage of nutrients in the basic feedstock raw material and nitrogen to carbon (C: N) ratio is presented in Table 1.

Table 2

Average content of nutrients in raw materials in biogas plants

Raw materia2	Dry matter, %	Organic dry matter, %	$P_2 0_5$, %	Ntot, %	K_2O, %	C:N ratio
Grass silage	26.65	24.60	0.15	0.36	0.53	40
Silage	31.35	30.20	0.12	0.36	0.33	49
Cattle slurry	5.49	4.28	0.22	0.26	0.26	10
Cattle manure	26.43	22.57	0.26	0.56	0.47	23
Pig slurry	4.00	2.85	0.20	0.37	0.18	4
Poultry manure	35.47	28.53	0.74	1.51	0.76	11
Food wastes	13.40	13.10	0.11	0.25	0.10	30
Sewage sludge	13.35	10.46	0.62	0.97	0.36	6
Industrial sewage	17.99	10.29	0.31	0.54	0.07	11
Milk residues	7.33	6.18	0.21	0.45	0.20	8
Grain residues	83.50	77.32	0.38	1.18	0.59	38

The highest content of phosphorus, nitrogen and potassium content was in poultry manure and the lowest values were found in food industry wastes. The highest C:N ratio was determined in maize or grass silage and grain residues, and the lowest C:N ratio was in pig slurry, sewage sludge and milk production residues.

Liquid digestate was produced in all 22 biogas plants and was stored in lagoons usually. Average values of samples of the liquid digestates obtained after anaerobic fermentation of different primary raw materials are given in Table 3.

Table 3

Average results of analyses of liquid digestates produced from different basic raw materials

Liquid digestate	Dry matter, %	Org. matter, %	P_2O_5, %	Ntot, %	K_2O, %	$N\text{-}NH_3$, %	pH	C:N ratio
Agriculture	6.00	3.94	0.09	0.49	0.50	0.27	8.0	5
Cattle manure	4.56	3.17	0.13	0.33	0.32	0.17	8.2	6
Pig manure	9.05	6.62	0.31	0.60	0.32	0.24	8.2	6
Poultry manure	5.17	3.33	0.27	0.59	0.42	0.37	8.4	3
Food industry waste	1.60	1.34	0.08	0.23	0.10	0.13	7.0	3

The highest content of phosphorus pentoxide 0.31% and nitrogen 0.60% contains liquid digestate from pig manure followed by liquid digestate fraction from poultry manure. The lowest values of phosphorus pentoxide 0.08% and nitrogen 0.23% were determined in digestate from food industry wastes (distilling dregs).

Content of ammonium nitrogen in digestates was varying from 0.13 to 0.27%, indicating that the anaerobic fermentation process can be possibly slightly inhibited by the high (above 0.15%) ammonium content in all biogas plants, except one biogas plant processing food industry wastes (distilling dregs).

High pH values (above 8.0) were found in all liquid digestates, except of distilling dregs, also indicating a risk of possible inhibition in the anaerobic fermentation process in digesters.

Part of feedstock and all digestates had a very low carbon to nitrogen (C: N) ratio 3-6: 1, that was below the recommended values for effective fermentation process with minimal ammonium losses from substrate in fermenters and digestate in storages [14]. The carbon to nitrogen ratio in raw materials and in digestates is given in Fig. 2.

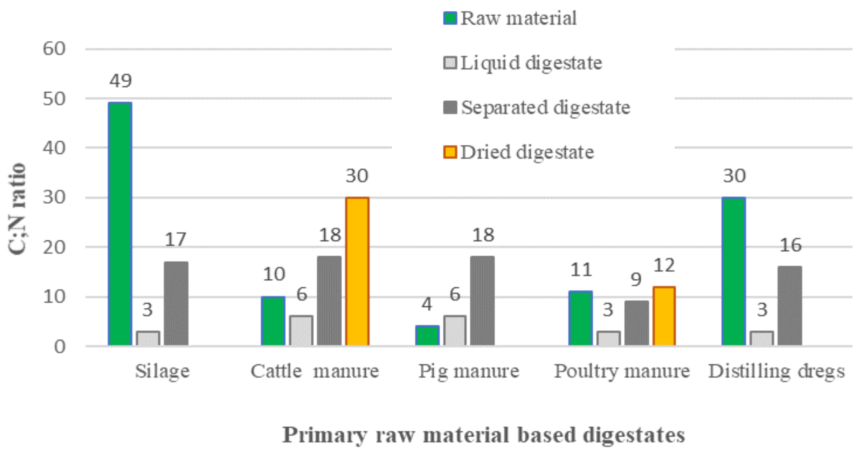

Fig. 2. **Average C:N ratio in primary raw materials and in digestates in biogas plants**

During the anaerobic process, the highest change in the C:N ratio (from 49 to 5) was determined in digestate produced from silage biomass that can be explained by the high content of easy degradable components in maize silage. Less change in the C:N ratio was be observed in digestates from cattle manure, poultry manure and distilling dregs. A slightly increased C:N ratio was observed in digestate from pig manure compared to the input pig manure due to addition of lignocellulosic materials, like grain processing residues, in fermenters. After mechanical separation of digestate the C: N ratio increases in the solid fraction as most of the nitrogen passes into the liquid fraction of the digestate. The C:N ratio sharply increases in the dried digestate compared to the undried solid fraction of digestate that can be explained by losses of gaseous ammonia during the drying process. The collection of gaseous ammonia during the digestate drying process can be recommended to improve nutrient management in biogas plants.

Conclusions

1. The dry matter content of silage ranges from 22.2% to 38.8% and was below the optimal (> 30%) in 7 or 39% biogas plants that increases the risk of silage effluent runoff. Adding of dry lignocellulosic materials, e.g., straw, or other lignocellulosic materials may increase the dry matter content in silage.
2. The ashes content in the dry matter of silage was varying from 2.1 to 8.1%, and the increase in the ash content may be due to biomass contamination and/or biodegradation processes due to insufficient oxygen barrier properties during silage storage or removal. Usage of plastic covers with high oxygen barrier properties is recommended for covering of silage heaps or bunkers.
3. The nutrient content of the raw materials differed significantly, with the highest nutrient concentrations determined in poultry manure following by pig manure. It is recommended to separate poultry or pig manure digestates to enable nutrient rich solid fraction transport away from the biogas plant so preventing overfertilization of nearby agricultural areas.
4. All produced digestates had a low carbon: nitrogen (C:N) ratio 3:1-6:1, and manure based digestates had a high pH value that poses risks for inhibition of the anaerobic fermentation process in most of the biogas plants. To minimize the influence of ammonium nitrogen, it is recommended to provide the C: N ratio of 25:1 to 35:1 for input substrate using carbon-rich additive materials, e.g., straw, leaves, reeds, deciduous wood waste and other lignocellulosic materials.
5. In the drying process of solid fraction of digestate the C: N ratio increased by 40% or 25% in the dried digestate from cattle or poultry manure respectively that can be explained by escaping of gaseous ammonium nitrogen during the drying process. Drying of the digestate in combination with gaseous nitrogen capture technologies, e.g., wet scrubbers, etc. can be strongly recommended.

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