ORIGINAL PAPER

LIVESTOCK WASTE IN THE CONTEXT OF AGRICULTURAL SUSTAINABILITY

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Abstract. *The production of biogas from animal waste is not only a way to reduce waste quantities but also to generate thermal or electrical energy in a sustainable manner, thereby contributing to environmental preservation and diversification of energy sources. Through combustion, biogas can generate electricity or heat, providing a sustainable, renewable, and environmentally friendly energy source. It was observed that manure from different animal species can exhibit varying biogas production rates, and certain types of manure can lead to higher or more consistent biogas levels. The experimental set-up recorded efficient biogas production after seven days of anaerobic digestion. The optimal mixtures were those with a higher proportion of grass, consisting for example of 40% grass, 15% pig manure, 15% cattle manure, 30% poultry manure, and 278.23 g of inoculum.*
Keywords: *biogas; animal waste; organic waste; anaerobic digestion.*

1. INTRODUCTION

Anaerobic digestion is an efficient technology for converting organic waste such as agricultural residues and manure into biogas. This technology brings numerous benefits, including better waste management, particularly in rural areas, improved environmental quality, and increased energy efficiency.

Biogas is a renewable fuel obtained through the decomposition of organic matter in the absence of oxygen. It's primarily composed of methane and carbon dioxide, along with small amounts of other gases. An important aspect is its ability to convert organic waste into a useful energy source for the community, thereby contributing to the reduction of greenhouse gas emissions and the sustainable management of waste. The production of biogas eliminates the emission of methane into the atmosphere and contributes to a net emission reduction of greenhouse gases [1, 2]. Biogas can be generated in many ways such as from plants, trees, grass, seeds, solid fruit and vegetable waste, manure from animal farms, algae, sludge, sewage, and agro-food, and even organic urban solid waste material [1, 3]. The variation in biogas composition depends on some factors namely the substrate type being digested, pH, operating temperature, organic loading rate, hydraulic retention time, and digester design [4].

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Biogas is a renewable fuel that can be produced from organic materials such as animal waste, plant residues, sewage sludge, or household waste. Biogas can be used for electricity and heat generation or as a vehicle fuel. It is a key component of organic farming, offering numerous advantages as a green, harmless, inexhaustible, and more cost-effective energy source than non-renewable conventional sources [5]. Biogas production from locally available renewable organic resources can be a good alternative because it contributes to the reduction of GHG emissions. Biogas technology provides an attractive route for the utilization of different categories of biomass for meeting energy needs [4, 6]. The suitability of biomass as a substrate to produce biogas is majorly dependent on its nutritional composition. These compositions influence the biogas yield, methane content, biodegradability, and degradation kinetics of the biomass involved. The major nutritional composition of interest in substrates includes carbohydrates, protein, and fats [4, 7]. The digestate contains most of the nutrients that enter the process, which turns it into a valuable biological fertilizer. Typical agricultural feedstocks that can be used for digestion include manure and sludge, crops, and crop residues [8, 9].

Agricultural waste is material from the processing of agricultural products, which from an economic point of view is considered to have little or no value. To obtain quality compost, it was chosen organic matter rich in carbon, such as straw, but also in nitrogen, such as leaves, weeds, or the remains of fruits and vegetables. Biogas results from the anaerobic digestion of solid/liquid waste such as cattle and pig excrements, sewage sludge, kitchen and agro-industrial wastes, or lignocellulosic biomass which is one of the most favorable sources of bioenergy [10-16]. The stability of the anaerobic digestion process is strongly influenced by the composition of the raw material used in the bioreactor. Many different types of substrates can be used as feedstock in the anaerobic digester for biogas production, including animal manure (36 %), agro-industrial waste (30 %), and municipal solid waste (34 %) [17].

Animal manure has a high nitrogen content, such as fresh goat manure (1.01%), chicken manure (1.03%), cattle manure (0.35 %) and pig manure (0.24 %) [18]. According to Mid-West Plan Service (MWPS) [19], the carbon/nitrogen (C/N) ratio for pig manure is about 6 to 8, which is too low for an anaerobic digester. In this case, it is recommended to use animal manure for biogas production in co-digestion with crop residues to maintain a balanced C/N ratio, enhance bacterial growth, and decrease the risk of ammonia inhibition and acidification [20, 21].

Biodegradable wastes are rich in lipids, cellulose, and proteins. Many scientific studies have shown that the mixing of different organic wastes for the anaerobic co-digestion process results in a better-balanced substrate. Researchers have reported significant increases in biogas production in the co-digestion process by combining carbon-rich agricultural residues with pig manure [22]. The organic mixture that provides the substrate for the anaerobic digestion process can comprise a wide variety of organic carbon sources, ranging from raw sewage sludge to municipal waste or biomass materials such as plants and crops [23].

Sousa Lima et al. published the effect of different thermal pretreatments and inoculum selection on the rate of biomethane production from sugarcane [24]. They noticed that the use of a combined inoculum consisting of anaerobic sludge and fresh bovine manure was more effective in maximizing methane production during the anaerobic digestion of sugarcane than biomass pretreatment processes [10]. The literature reports the results from the anaerobic co-digestion of the agro-food by-product with manure or wastewater, and the introduction of two or three co-substrates into the biodigester [10]. Organic wastes are rich in proteins and fats, which are important energy sources and generate considerable amounts of methane in biogas [25].

In agricultural by-products such as straw and grass, hemicellulose is predominantly xylan, and in softwood, it is mainly glucomannan. Hemicellulose is highly branched and amorphous, which makes it easier to hydrolyze than cellulose. Having the role of physical protector of cellulose, the removal of hemicellulose by pretreatment can increase the contact area between cellulose and enzymes, thus improving the rate of hydrolysis [26]. Lignocellulosic materials are often rich in carbon but contain low amounts of essential nutrients such as nitrogen, phosphorus, and trace elements [27]. A carefully chosen co-substrate, which complements the deficiencies of lignocellulosic biomass, can ensure a stable and efficient anaerobic digestion process [28].

Common feedstock categories used for biogas production include agricultural waste and residues, animal waste, aquatic waste and algae, forest residues, energy crops and the organic fraction of municipal solid waste [29], organic industrial waste and sewage sludge [30], human feces, manure, wastewater from the food industry and animal husbandry [31].

Table 1. Raw materials that can be used in the anaerobic digestion process [31, 32].

Waste	Types of waste
Agricultural waste and crop residues	Straw (wheat, canola, barley, oats, rice, rye), adulterated fodder, sugar cane residues, sugar beet or fodder beet leaves, weeds, tobacco waste, rice husks, coffee husks, peanuts, sorghum (potatoes, soybeans, beans, tomatoes), cobs and corn stalks and/or corn silage, hemp dust etc.
Animal droppings	Manure from cattle, pigs, goats and sheep, poultry manure etc.
Waste from the food industry	Oilseed meal, pomace, fruit and vegetable processing waste, fish waste, slaughterhouse waste (animal carcasses, bones, blood) etc.
Aquatic plants	Algae, sea grass, water hyacinths, water lilies and other aquatic plants.
Forest residues	Sawdust, twigs, plant bark, roots, leaves etc.

Animal manure is suitable for anaerobic digestion for several reasons: it has a high water content, which facilitates the dilution of concentrated by-products and simplifies the pumping process; they have a high buffering capacity, essential to prevent sudden fluctuations in the pH value; and contain a wide range of nutrients necessary for the development of microorganisms [33].

The principal objective of the research is to develop an optimal blend of animal waste and agro-food by-products for biogas production. Since the topic of obtaining biogas is on the top, and in the scientific specialized literature only mixtures of organic matter with animal wastes that come from a single category of animals are presented, this study aimed to choose some waste mixtures that lead to higher biogas yields than in the specialized literature, using both poultry manure, cattle manure, and pig manure in the same digester. On the other hand, the study aims to show that mixtures that contain grass, generate a larger volume of biogas than those containing wheat straw.

2. MATERIALS AND METHODS

Different categories of waste from animals were mixed in the same digester containing poultry, cattle, and pig manure, green grass, and straw. A Gas Endeavor equipment was used to obtain and measure the volume of biogas. The system used consists of a sample incubation unit (15 x 500 mL glass reactors), a gas absorption unit, and a gas volume measuring device. The mixtures in each reactor (8 experiments) are constantly stirred (20 min stirring with 10 min break, stirring speed of 100 rpm) at a constant temperature of 37°C while gas is continuously produced.

Figure 1. Anaerobic digestion – lab-scale experimental setup.

The gas obtained in each reactor passes through an individual container containing a NaOH solution that absorbs certain gas fractions (CO_2 and H_2S). The volume of the gas released from the two units is measured in the last gas flow measurement unit. The measurements obtained are then recorded and analyzed using the integrated software. The animal waste used in this study was collected from farms located in Teleorman County, while the inoculum was obtained from a wastewater treatment plant in the same county. After collection, the inoculum was stored in a sealed container, protected from light, at room temperature for later use.

Table 2. The quantities of materials required for the anaerobic co-digestion process.

	Grams [g]
Total volume	500
Useful volume	400
10% solids	40

The reactor contained the following: organic materials such as animal waste, plant residues, food waste with a concentration of 10% solids, 40 g of inoculum, and water. The inoculum was obtained from a wastewater treatment plant in Teleorman County [34]. The main components still present in urban wastewater after secondary treatment are nitrogen and very low amounts of organic carbon and phosphorus. Nitrogen, carbon, and phosphorus are the main components present in wastewater.

Table 3. Wastewater quality indicators.

Pollutant	**Concentration [mg/L]**
CBO_5	300 - 400
CCOCr	500 – 600
TSM*	350
TKN**	40
TP***	8

** TSM = total suspended matter; ** TKN = total kjeldahl nitrogen; *** TP = total phosphorus.*

Several types of organic materials with a 10% solid concentration were mixed and inoculum, an anaerobic bacteria culture was added. These mixtures were introduced into fermentation reactors with a useful volume of 400 g, aiming to evenly distribute the anaerobic bacteria throughout the substrate, thus facilitating the anaerobic co-digestion process. The raw material mixtures maintained a C/N (carbon/nitrogen) ratio between 20 and 25 g. The elemental analysis method was used to determine the total organic C and N content. The fermentation process involved continuous stirring to maintain a constant and uniform movement of the substance mixture. This ensures the even distribution of nutrients, oxygen, or other essential elements in the fermentation solution.

Table 4. Biomass composition.

No. crt.	Grass [g]	Straw [g]	Pig manure [g]	Cattle manure [g]	Poultry manure [g]	Inoculum [g]
1	20.00	4.21	32.00	11.43	12.63	319.73
2	10.00	6.32	32.00	11.43	12.63	327.62
3	30.00	2.11	32.00	11.43	12.63	311.83
4	50.00	-	24.00	17.14	12.63	296.23
5	60.00	-	20.00	17.14	12.63	290.23
6	70.00	-	16.00	17.14	12.63	284.23
7	80.00	-	12.00	17.14	12.63	278.23
8	90.00	-	8.00	17.14	12.63	272.23

Potential limitations have been considered, such as temperature, which could influence the results, even if the experimental setup remains constant, and the exhaustion of the inoculum used to accelerate the fermentation process.

The primary objective was to determine the initial biogas production moment and identify the peak production level. This experimental approach is crucial for understanding the behavior of animal manure in the biogas production process.

3. RESULTS AND DISCUSSION

On the first day of anaerobic digestion, was recorded the highest biogas volume in experiment number 6, which had the following raw material composition: 35% grass, 20% pig manure, 15% cow manure, and 30% poultry manure. This was followed by experiment number 7, which had the following raw material composition: 40% grass, 15% pig manure, 15% cow manure, and 30% poultry manure.

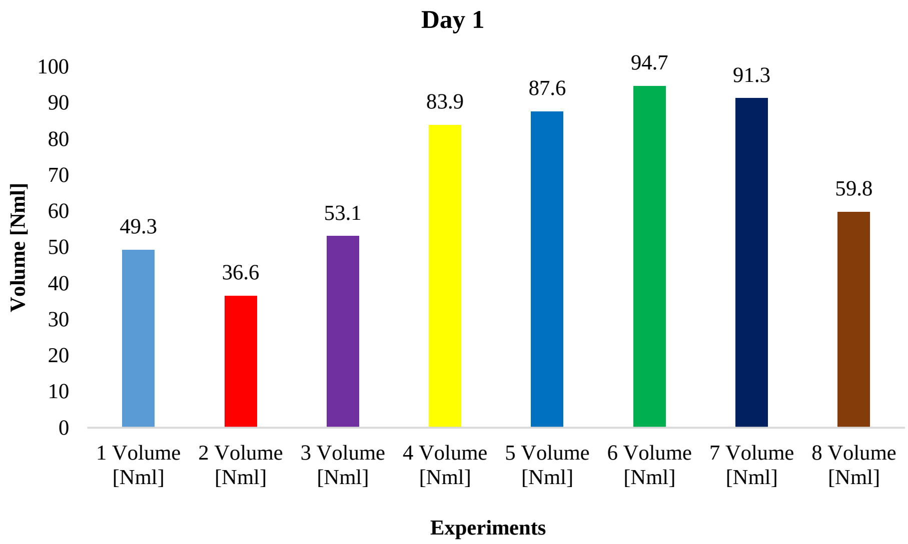

Figure 2. Results from the first day of the anaerobic digestion experiment.

Compared to the first day of biogas production, in the next days (the second day and the third day) it was observed an increase in the volume of biogas generated in all experiments. On the fourth day from the start of the experiments, the highest volumes of biogas are recorded at experiments number 4 and number 5, this fact indicating that the most effective mixtures contain grass in their composition.

Compared to the literature data [35], when it was added grass, the experiments recorded an increase in the yield of biogas generated; data have shown how the composition of the mixture influences the biogas yield and noticed that it had a positive yield.

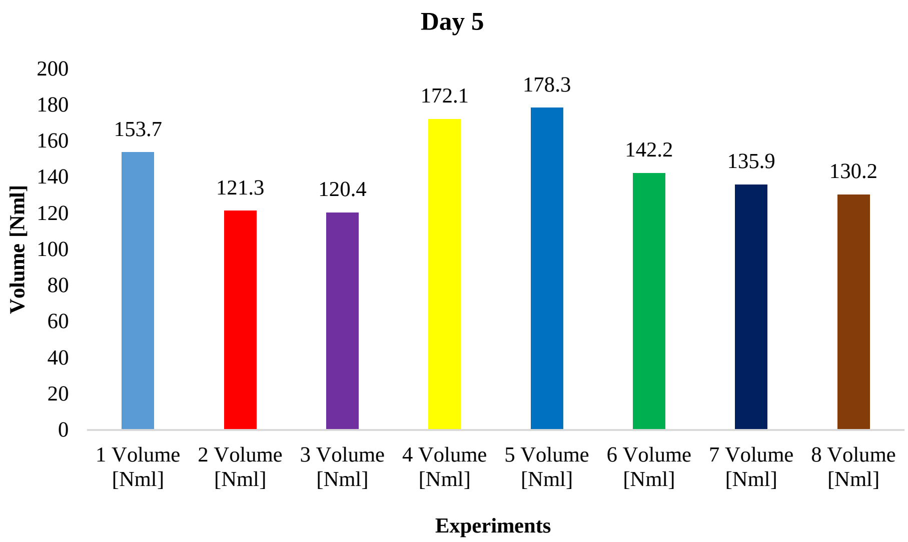

Figure 3. Results from the fifth day of the anaerobic digestion experiment.

On the fifth day of anaerobic digestion, as on the previous days, the system recorded a larger volume of biogas from mixtures containing grass. The mixtures that also included wheat straw registered a lower volume of generated biogas. The observation that the mixtures that contain grass generated a larger volume of biogas than those containing wheat straw could result from differences in the chemical composition and degradation characteristics of these materials. This can lead to more efficient breakdown and a higher production of biogas. On the other hand, wheat straw contains higher amounts of components that are more resistant to degradation. These components, such as lignin [36], may require more extensive degradation conditions or more intense microbial activity to be fully broken down. This could explain the lower volume of biogas generated in mixtures containing wheat straw. Wheat straw represents a suitable substrate for biogas production, although its lignin content slows down the degradation process. In a study conducted by Song and Zhang [37] was examined the mono-digestion and co-digestion of wheat straw, pre-treated with four concentrations of H_2O_2 (1%, 2%, 3%, and 4%) before digestion with bovine manure. They recorded a higher methane yield when wheat straw was treated with H_2O_2 and co-digested with bovine manure, whereas co-digestion of untreated wheat straw resulted in a lower yield.

The volume of generated biogas continued to increase on the seventh day, with the highest volumes still recorded in experiments no. 4 and no 5. The low biogas production could be due to a lack of water. Sadaka and Engler [38] reported that the solid content and water are crucial parameters in biogas production, directly influencing anaerobic digestion. Water facilitates the movement and growth of bacteria, aiding the transport of nutrients and reducing mass transfer limitations. An increase in the biogas production rate was observed during the first 7 days as the microbial consortium in the inoculum better adapted to the digested biomass. Following this period, there was a gradual decline in the biogas production rate, due to the depletion of the most easily biodegradable organic matter. The low rates of biogas production observed after the seventh day indicate that anaerobic digestion was largely completed within this interval.

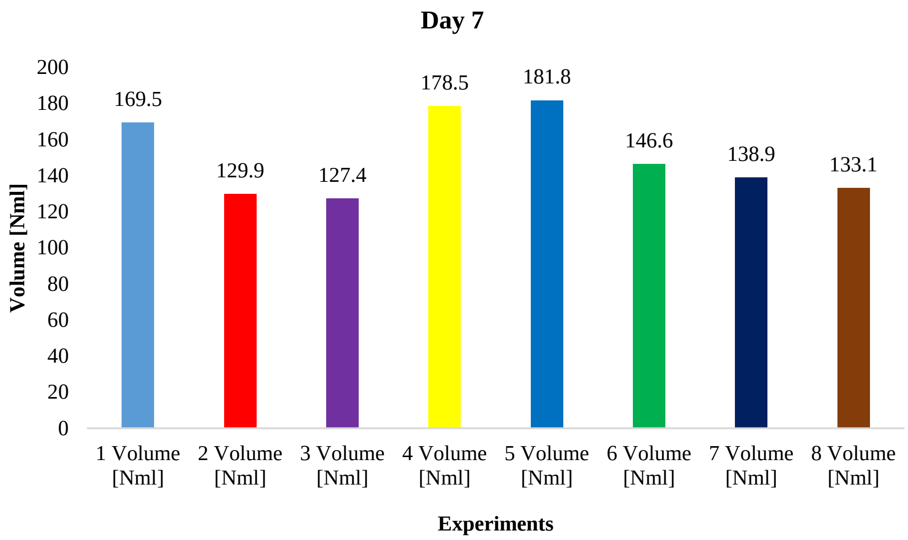

Figure 4. Results from the seventh day of the anaerobic digestion experiment.

The experiments were carefully monitored, maintaining optimal conditions of temperature, pH, and continuous substrate feeding. Anaerobic fermentation was facilitated by mixing the substrate with the inoculum, which expedited the fermentation process. The maximum level of biogas was obtained after 7 days of anaerobic digestion.

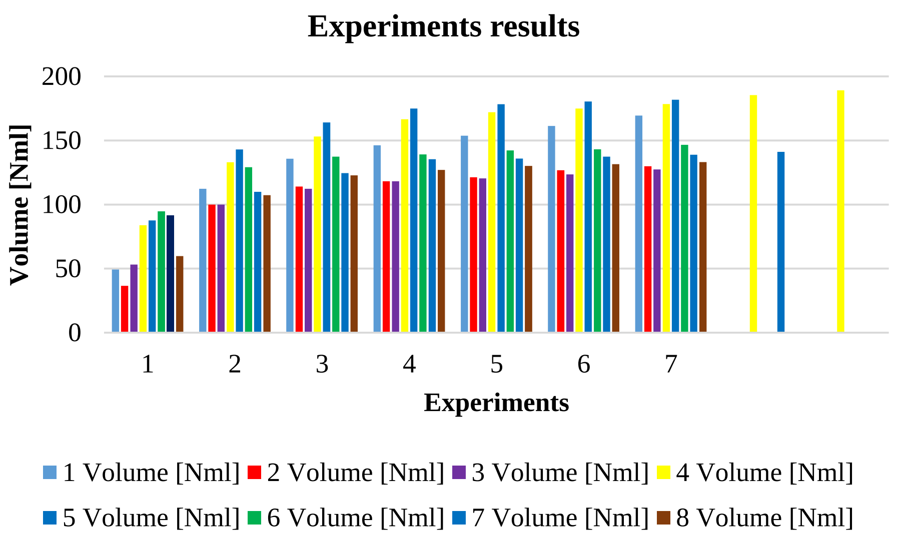

Figure 5. Biogas production results using mixtures of pig manure, poultry manure, cattle manure, green grass, potatoes and straw.

This study investigates the effects of various organic mixtures on biogas production through anaerobic digestion, highlighting the significant role of grass as a key component. Notably, experiment number 6, which consisted of 35% grass, 20% pig manure, 15% cow manure, and 30% poultry manure, achieved the highest biogas volume on the first day. This was closely followed by experiment number 7, composed of 40% grass, 15% pig manure, 15% cow manure, and 30% poultry manure. On the fifth day of anaerobic digestion, as in previous days, the system recorded a greater volume of biogas from mixtures that included grass. In contrast, mixtures containing wheat straw produced lower biogas volumes. This disparity suggests that the chemical composition and degradation characteristics of these materials play a significant role. Grass typically has a higher content of fermentable substances, such as carbohydrates and water-soluble components, making it more readily accessible to the microorganisms involved in the anaerobic digestion process. The inclusion of grass in organic mixtures significantly enhances biogas production during anaerobic digestion. Experiment number 6, which contained a substantial proportion of grass, achieved the highest biogas yield on the first day, illustrating the material's effectiveness in promoting microbial activity. The results indicate that the composition of organic mixtures directly impacts biogas yield.

The study highlights the importance of understanding the chemical composition and degradation characteristics of different organic materials. This knowledge can guide the formulation of optimal mixtures for biogas production, ultimately improving energy recovery from organic waste. By optimizing the use of grass and other organic materials in biogas production, this research contributes to more sustainable waste management practices. It underscores the potential for converting agricultural and food industry waste into renewable energy, reducing environmental impact, and promoting circular economy principles. Future studies should explore the long-term effects of varying grass ratios and investigate other organic materials that could complement grass to further enhance biogas yields. This could lead to more efficient anaerobic digestion systems and increased energy production.

4. CONCLUSIONS

Among the tested mixtures, the best yields were obtained from the experiments that included green grass in their composition. The experimental set-up recorded efficient biogas production from the initial days, reaching its peak after 7 days of anaerobic digestion. The optimal mixtures were those containing a higher quantity of grass. After 10 days of experiments, due to the depletion of organic matter resources, the biogas production stopped. Simultaneous treatment of solid and liquid organic waste in a unified process can significantly diminish environmental impact by reducing waste quantities and greenhouse gas emissions. Therefore, the anaerobic digestion process for biogas generation stands as a simple and cost-effective method for converting biomass into a greener and less polluting form of energy. Through the obtained data, a new perspective is offered by which the storage of huge amounts of waste from the food industry and agriculture is avoided, by valorizing them in the form of biogas.

The present study demonstrates that incorporating green grass into biogas mixtures enhances yield, highlighting the importance of optimizing resource use in waste management. The anaerobic digestion process proves to be an efficient and cost-effective method for converting organic waste into biogas, offering a sustainable alternative to traditional energy sources. By simultaneously treating solid and liquid organic waste, this method significantly mitigates environmental impacts, reducing both waste volumes and greenhouse gas emissions, which is crucial in the fight against climate change. The ability to transform food industry and agricultural waste into biogas presents a valuable opportunity for waste valorization, helping to address the issue of waste accumulation while providing a renewable energy source. These findings suggest that implementing anaerobic digestion processes can lead to a more circular economy, where waste is not merely disposed of but converted into valuable resources, benefiting both the environment and the energy sector.

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