NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY
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Faculty of Biotechnical Systems Engineering
Doctoral School of Biotechnical Systems Engineering

SUMMARY
PhD THESIS

THE USE OF AGRICULTURAL AND LIVESTOCK WASTE AS RAW MATERIAL FOR BIOGAS PRODUCTION

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CONTENTS

Acknowledgements

The desire to continue specialized studies in the field of Environmental Engineering through a doctoral study program is based on my work experience of over 19 years in this field, beginning at the Teleorman Environmental Protection Agency in 2005 and, since 2023, at the National Agency for Protected Natural Areas.

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INTRODUCTION

The doctoral thesis titled "Utilization of Agrozootechnical Waste as Raw Material for Biogas Production" has the primary objective of providing both theoretical and experimental foundations for solutions to address the challenges faced by society in managing animal manure and its negative environmental impacts, particularly in the context of adapting to climate change.

European environmental legislation and the funding provided by the European Union through various funding lines, both at the European and national levels, emphasize that most industrialized countries focus on integrated waste management that offers sustainable solutions for waste management and renewable energy production through "waste-to-energy" technologies.

Starting from this concept, this thesis presents feasible solutions for utilizing agrozootechnical waste as an alternative and environmentally friendly energy source. The studied energy recovery processes are based on the action of anaerobic fermentation bacteria that convert organic matter into biogas with a high methane content. From an energy efficiency perspective, this process is considered optimal as it allows the use of a wide range of organic waste while also serving as an effective method for treating it, thereby reducing environmental impact. Additionally, the residues resulting from anaerobic digestion can be used as fertilizer in agriculture.

The research topic covers subjects related to integrated waste management, the energetic valorization of biogas produced through anaerobic digestion using agrozootechnical waste as raw material, the presentation of a biogas production installation, and a series of experimental studies conducted in the laboratory using the BPC Instruments AB - Gas Endeavour biogas production facility.

The doctoral thesis is structured into 6 chapters, developed over 210 pages, including 67 figures and graphics, 46 tables, and a bibliography consisting of 269 references.

The thesis includes a synthesis of theoretical and experimental research conducted by the author on the application of animal manure resulting from zootechnical activities and agricultural waste in environmental protection, through their conversion into biogas and fertilizer for agricultural crops.

In Chapter I of the doctoral thesis titled "Objectives of the Doctoral Thesis and the Importance of the Topic," the proposed objectives, later achieved through experimental research, are presented, along with the importance of the chosen topic for its development in this doctoral thesis as part of the doctoral program.The scientific objectives pursued in the theoretical and experimental research can be grouped into two categories:

1. Literature study regarding the energy recovery of agro-zootechnical waste and the production of biogas through the anaerobic digestion process;
2. Experimental research that included: establishing the investigated raw materials (grass, green tomato leaves, potatoes, straw) and obtaining biogas on a laboratory scale using the low-capacity biogas production plant(15 500 ml glass reactors) BPC Instruments AB – Gas Endeavor, at a constant temperature of 37°C, the calculation starting from different raw material mixing recipes in order to achieve the highest biogas yield.

Chapter II of the doctoral thesis titled "Literature Review on Environmental Pollution" presents the current state of scientific research on environmental pollution. This chapter is based on a comprehensive study of the specialized literature regarding the concept of "pollution," with a particular focus on environmental pollution caused by waste. It highlights environmental issues related to the prevention and reduction of pollution effects, the economic importance of animal husbandry, waste management, and aspects of maintaining ecological balance.

Animal manure can pose a major risk to the environment. The way manure is collected, stored, handled, and its composition and quality are key factors determining the level and density of emissions. Therefore, sustainable management of agrozootechnical waste requires increasing its utilization to reduce nitrate pollution: waste should be stored on storage platforms, and composting, pelletizing, and agrozootechnical waste processing facilities should be established to produce biogas.

Chapter III of the doctoral thesis titled "Overview of Zootechnical Activities: Poultry Farms, Pig Farms, Cattle Farms" details the technological processes involved in zootechnical activities and the types of waste generated from agro-zootechnical operations.

Manure deposits represent potential sources of atmospheric emissions, including ammonia (NH_3), methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NOx), carbon dioxide (CO_2), hydrogen sulfide (H_2S), and particulate matter. Factors such as temperature, ventilation, humidity, and the composition of feed can affect ammonia levels. For instance, in pig manure, the nitrogen from urea constitutes more than 95% of the total nitrogen in urine, which quickly transforms into volatile ammonia through microbial activity. Microbial processes in soil produce nitrous oxide (N_2O) and nitrogen gas (N_2), with nitrous oxide contributing to the greenhouse effect.

In Chapter IV, titled "Study on the Treatment of Animal Waste Resulting from Zootechnical Activities," various aspects of utilizing animal waste for biogas production in agriculture are analyzed, with special attention given to environmental management.

In Chapter V, titled "Own Research on Biogas Production from Agro-Zootechnical Waste," the contributions made in the doctoral thesis are presented, focusing on the use of anaerobic digestion technology to treat agro-zootechnical waste with the aim of reducing its negative environmental impacts and producing biogas. The chapter details the process through which the experimental research was conducted, the materials and methods used for biogas production via anaerobic digestion, and the results obtained from the research using the Gas Endeavour Biogas Production System (Automatic Gas Flow Measuring System).

Chapter VI, titled "General Conclusions and Future Research Directions," provides the overall conclusions and perspectives for future research.

CHAPTER 1. THE OBJECTIVES OF THE DOCTORAL THESIS AND THE IMPORTANCE OF THE THEME

1.1 The objectives of the doctoral thesis

One of the major problems of human society at the moment is the processing and treatment of organic waste resulting from agriculture and the food industry. Obtaining food products is done with a very high energy consumption, which leads to the generation of huge amounts of organic waste.

Since the increase in the amount of waste from agriculture (grass, plant residues) and animal husbandry (dung, manure, etc.) is one of the major environmental problems, the research direction chosen for the doctoral thesis was to find an efficient alternative for the utilization of manure livestock and those from agriculture, by transforming them into biogas and organic fertilizer for agriculture.

The objectives pursued in the doctoral thesis can be grouped into two categories:

3. Literature study regarding the energy recovery of agro-zootechnical waste and the production of biogas through the anaerobic digestion process;
4. Experimental research that included: establishing the investigated raw materials (grass, green tomato leaves, potatoes, straw) and obtaining biogas on a laboratory scale using the low-capacity biogas production plant(15 500 ml glass reactors) BPC Instruments AB – Gas Endeavor, at a constant temperature of 37°C, the calculation starting from different raw material mixing recipes in order to achieve the highest biogas yield.

The ultimate goalof the doctoral thesis is represented by obtaining and developing an optimal mixture of animal manure and agro-food by-products to obtain biogas through the anaerobic digestion process.

At the same time, the anaerobic digestion process aims to reduce the level of environmental pollution with nitrogen and decrease the amount of agri-food waste by valorizing it, thus contributing to the improvement of the quality of the environment, in an ecological and sustainable manner.

1.2. The importance of the theme

The proper management of agro-zootechnical waste is made difficult by the environmental conditions, by the accelerated degradation due to enzymatic activity, due to the high water content, their treatment and storage representing significant challenges in the field of environmental protection.

The environmental problems created by waste from agriculture and animal husbandry concern the impact on water resources, on the soil, subsoil and air due to the high content of nutrients and organic waste, which can lead to water pollution and greenhouse gas emissions.

Fig.1.1. Poultry breeding farm

Fig.1.2. Pig breeding farm

Nitrogen pollution of agricultural land is a major concern for agriculture and the environment. Nitrogen is an essential element for plant growth, but used in excess can have significant negative consequences on the environment (eutrophication of water leading to the degradation of aquatic habitats, pollution of drinking water sources, greenhouse gas emissions that contribute to global warming) and on human health.

Nitrogen pollution can produce a number of negative effects on human health and can cause diseases such as: methemoglobinemia - increased methemoglobin levels in the blood (blue baby disease), respiratory problems such as asthma and bronchitis, chronic lung diseases, eye irritations and of the respiratory tract, breathing difficulties, cardiovascular diseases such as heart attack and stroke, cancer, birth defects and multiple negative effects on fetal development and lowered immune system.

Inadequate management of these wastes can also contribute to the degradation of biodiversity and the reduction of the quality of natural habitats.

Fig. 1.3. Cow breeding farm

Fig. 1.4. Agricultural waste

In this regard, energy recovery through the exploitation of biogas obtained through the process of anaerobic digestion is a feasible and sustainable solution for the production of green and renewable energy from agro-zootechnical waste and contributes tosolving environmental problems (reducing pollution of the soil on which this waste was stored, reducing water table pollution, reducing greenhouse gases).

CHAPTER 2. LITERATURE STUDY ON ENVIRONMENTAL POLLUTION

2.1. General considerations on environmental pollution

Changes in the natural and artificial environment are the consequence of natural phenomena, but - especially - of human activity, industrial civilization, etc. which has the effect of destroying the ecological balance, which in turn negatively affects human living conditions [1].

The increase in industrial production, the intensification of the movement of motor vehicles, the generation of electrical and thermal energy, various agricultural activities and the uncontrolled expansion of waste have led to the release into the air of increasing amounts of invisible particles such as carbon dioxide, nitrogen, methane, dust and other polluting agents. These emissions affect the atmosphere slowly but steadily and progressively, so that in a decade the average global temperature may rise by another degree Celsius [2].

Agriculture based on intensive exploitation, also called intensive agricultureUSEDlarge amounts of chemical fertilizers, pesticides, insecticides, which contribute to the pollution of arable land, water and the atmosphere. Herbicides and fertilizers end up in surface water and underground water and contribute to the degradation of the environment.

The contribution of the agricultural sector to climate change is becoming increasingly evident, generating increased interest in identifying ways in which agriculture can reduce greenhouse gas emissions. Sustainable agriculture represents an effective strategy not only for mitigating climate change, but also for adapting agricultural ecosystems to their effects, by increasing the resistance of crops to climate variations. This contributes to reducing soil erosion, improving soil quality and fertility, and allows crops to better absorb water during periods of drought [3].

2.2. Waste – Source of environmental pollution

Waste is one of the main sources of environmental pollution, having a significant negative impact on water, soil, air and, implicitly, on human health and biodiversity. Inefficient waste management can have disastrous long-term consequences for natural ecosystems and the quality of life on Earth.

Municipal waste management involves a complex process that includes several essential steps to ensure an efficient and sustainable system: waste collection, waste transport, waste recovery and disposal, disposal site maintenance.

There are two ways to eliminate admunicipal waste: by storage or by incineration.

In Romania, starting from 2021, the municipal waste that is produced from the sorting facilities, and that cannot be recycled or recovered, is incinerated in incineration facilities authorized for the incineration of these types of waste. At the end of 2021, 48 compliant landfills for municipal waste and one facility that also incinerates municipal waste were authorized and in operation. However, the amount of stored waste still remains high, which goes against the principles and objectives established by the European Union in the legislative package on the circular economy. This legislative package aims to reduce dependence on the final disposal of waste and promote reuse, recycling and recovery of resources. The increase in the amount of stored waste indicates a discrepancy between current practice and the objectives of sustainability and efficient management of resources promoted by the European Union [4].

According to the legislative provisions in force regarding waste storage, biodegradable waste is waste that can undergo decomposition through aerobic or anaerobic processes, such as food products (which decompose easily through the action of microorganisms), garden waste (which decompose naturally), paper or cardboard (which are biodegradable and break down under appropriate conditions).

In accordance with OG no. 92/2021 on waste storage, the amount of biodegradable waste stored must not exceed 35% of the total amount of waste produced in 1995, expressed gravimetrically.

Adequate measures will be taken to promote the reuse of products and their preparation for reuse, with the aim of prohibiting, starting from 2030, the storage of waste that can be recycled or utilized in another way. Also, by the year 2035, the total amount of municipal waste disposed of annually through landfill will have to be reduced to 10% or less of the total municipal waste generated [5].

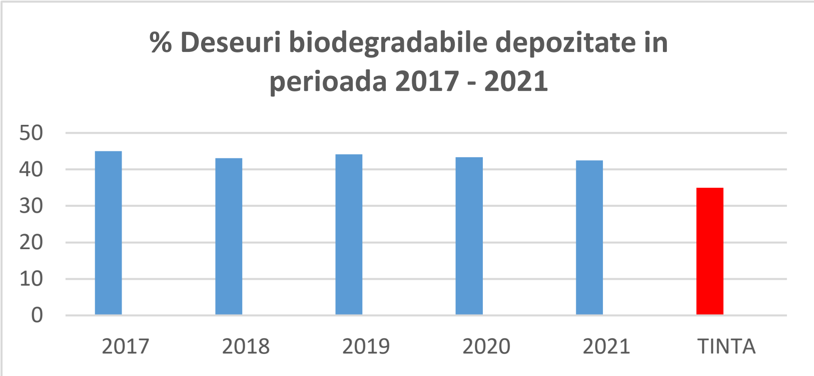

Fig. 2.1. Biodegradable waste stored in the period 2017 – 2021 [4]

In Fig. 2.1., the objective was to establish a target for reducing the amount of stored biodegradable waste. In this context, the specific target was that stored biodegradable waste should not exceed a certain percentage of the total amount of municipal waste generated in 1995, in order to align waste management with environmental and sustainability requirements. The graph shows that the objective of reducing the amount of biodegradable waste at storage was not achieved.

The excessive consumption of resources exerts considerable pressure on the environment, affecting not only Europe but the whole world. These pressures contribute to the excessive use of renewable resources, to the depletion of non-renewable resources, to large amounts of emissions of polluting substances from economic activities in the atmosphere, air and soil.

Waste management implies compliance with environmental legislation in waste management both by the business environment and by the people responsible for reducing the impact on the environment through responsible waste generation. If economic agents are obliged to adopt environmentally friendly technology, so as to minimize the negative impact on the environment and contribute to sustainable development, each citizen can significantly contribute to reducing the volume of waste generated by recycling, composting and reducing the consumption of products with excess packaging.

2.3. The impact of pollutants resulting from animal husbandry activities on the environment

2.3.1. Impact on environmental factors

In the activity of raising birds, the potential impact on environmental factors refers to ammonia emissions in the air, nitrogen and phosphorus leaks in the soil, in underground and surface waters, leaks coming from manure.

In order to be able to establish the measures to reduce or eliminate the negative impact of the activities aimed at the intensive breeding of birds on the environment, it is very important to know all the risk factors from the beginning. The forms of impact presuppose the analysis of some key aspects:

Table 2.1 Aspects - key necessary to establish the forms of impact on the environment [6]

The nature and duration of the impact	Identification of environmental aspects that may be affected. Evaluation of the impact (positive, neutral or negative). Identifying and highlighting the forms of significant impact (positive and negative). Description of the impact (eg cumulative, continuous, intermittent, occasional, temporary, short, medium or long term, direct/indirect, reversible/irreversible).
The extent, the scope and the complexity	Measuring the amount or intensity of changes in the character or quality of any aspect of the environment. Determining the geographical extent of the effects, indicating whether they will affect only a few areas, a large part of the territory or the entire area. Evaluation of the degree of change (imperceptible, slight, observable or significant).
Result	Determining whether the impact can be avoided, mitigated or remedied. Identifying forms of reversible impact. Determining whether there are available, possible or acceptable options for compensation.

2.3.2. The cumulative impact

In the case of an intensive bird breeding activity, the following potential cumulative effects must be taken into account: surface water quality, groundwater quality, metabolic gas emissions, odors, dust, noise.

2.3.3. The main types of pollution generated by the activities aimed at intensive breeding of birds

Air pollution

Table 2.2 Atmospheric emissions from intensive poultry farms

No. crt.	**Pollutant emissions**	**Poultry breeding system**
1.	Ammonia (NH3)	Bird housing, manure storage.
2.	Methane (CH4)	Bird housing, manure storage.
3.	Nitrous Oxide (N2O)	Bird housing, manure storage.
4.	NOx	Indoor heating installations.

No. crt.	Pollutant emissions	Poultry breeding system
5.	carbon dioxide (CO_2)	Bird shelter, fuel used for heating and transport, burning of vegetable waste.
6.	Odor (H_2S)	Bird shelter, storage and spreading of droppings.
7.	Dust	Food preparation and storage, production halls, manure storage and spreading
8.	Smoke/CO	Combustion of vegetable waste.

Water pollution

Table 2.3 Pollutants emitted into surface waters associated with intensive poultry farms

The origin of the waste water	Resulting pollutants
Cleaning the halls	- organic compounds - suspended particles - cleaning products
Hygienic - sanitary requirements of the staff	- organic compounds - suspended particles - cleaning products
Rainwater collected from platforms	- suspended particles

Soil pollution

After the operation of the objective, the storage of manure could constitute a source of soil pollution, following the development of the activity resulting in a relatively large amount of nitrogen and phosphorus. Manure contains varying amounts of nutrients as well as minerals and essential elements such as sulfur and magnesium.

2.4. The economic importance of Animal Husbandry

Animals are, on the one hand, an indispensable factor for agriculture, because they serve for field work, for transport, for the production of fertilizers, etc., and on the other hand, they provide society with essential materials, because they mostly provide food for humans and his clothing [7].

Thus, animal products - milk, meat, eggs are essential foods for a rational human diet, with high digestible and biological nutritional value.

Also, a series of other products of animal origin such as: wool, feathers, skins, down, furs, silk, constitute the raw materials in the light industry (confectionery, clothing and footwear industry, leather goods).

The fifth quarter represented by the by-products obtained from the slaughter of animals - slaughterhouse by-products (blood, bones, horns, hooves, intestines, glands with internal secretion) are used in different forms - in the medicine industry, in the combined feed industry under the form of different flours, for the preparation of bone glues, the extraction of industrial oil, etc. [8].

Blood (blood meal), bones (bone meal) are also used for obtaining animal charcoal, glues, extracting industrial oils, intestines in the sausage making industry, strings for instruments, etc. [9].

Working animals(equines and cattle) - they are used for transport and agricultural work.

Animals make better use of a series of coarse agricultural products and by-products (straw, hay, potatoes, etc.) which they transform into animal products with high nutritional value (meat, milk, etc.). It is estimated that man uses only 25% of the total vegetable production, the remaining 75% transformed by animals into valuable food products or raw materials needed for light industry or transformed into mechanical energy [9].

2.5. Aspects regarding maintaining the ecological balance in animal husbandry

Sustainable development involves updating the theoretical and applied knowledge of engineers in the agricultural field, regarding how to organize economic, social and environmental activities, taking into account the principles and requirements of sustainable development, by using the best performing methods and means of investigating pollution and depollution in technology, agricultural and zootechnical biotechnology.

The excessive and uncontrolled use of chemical fertilizers leads to soil acidification and pollution of the water table and surface waters. In agriculture, emissions to the atmosphere, water and soil include methane and ammonia, gases generated by enteric fermentation processes and animal manure [10].

The effects of biogas on the environmentare: limiting nitrogen leaks, reducing odor problems, reducing greenhouse gas emissions, controlled waste management.

In rural areas, where animal and household waste can be used as substrates, biogas technology plays an essential role in promoting sustainable agriculture, ensuring a balance between energy production, environmental protection, social progress and economic performance. As a result, the demand for biogas production systems has increased recently, due to its low costs and its ability to be used in approximately 70% of energy-consuming activities in rural areas [11].

Biodegradable waste, accumulated in landfills, breaks down and produces gases and leachate. If not captured, the resulting gases, which mainly contain methane, contribute significantly to the greenhouse effect [12].

The construction of a biogas plant does not pose a risk to either water source, as the biogas production process does not generate waste water. After fermentation, the digestate is processed, and the resulting water is reused in the technological process. Surplus water can be used in various applications because, after a two-stage reverse osmosis treatment, its quality becomes suitable for industrial and agricultural use [13].

If waste from agricultural crops is not collected during the winter, it decomposes, releasing nitrogen that can cause eutrophication of waters. Organic materials not used in biogas production become hazardous and pathogenic, and direct use of these materials can lead to nitrate pollution of soil and groundwater. Pig manure, which can contain heavy metals such as copper and zinc, can also pollute waters [14].

Through anaerobic fermentation and biogas production, the nutrients in the untreated garbage undergo significant transformations due to the metabolic activity of the microbial populations, which has a number of positive effects on the nutritional balance in the digesta [15].

Raw materials used for biogas production

The composition of the substrate is crucial both for the quantity and quality of the gas produced, and for the quality of the residues resulting from the digestion process (digestate). This influences the content of plant nutrients in the digestate, as well as the presence of potential contaminants such as metals, organic compounds and pathogenic microorganisms [16].

Organic wastes are rich in proteins and fats, which are important energy sources and generate considerable amounts of methane in biogas [16].

In agricultural by-products such as straw and grass, the 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 [17].

Lignocellulosic materials are often rich in carbon but contain low amounts of essential nutrients such as nitrogen, phosphorus and trace elements [18]. A carefully chosen co-substrate, which complements the deficiencies of lignocellulosic biomass, can ensure a stable and efficient anaerobic digestion process [19].

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 [20], organic industrial waste and sewage sludge [21], human feces, manure, wastewater from the food industry and animal husbandry [22].

Table 2.9. Raw materials that can be used in the anaerobic digestion process. [22, 23]

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 [24].

CHAPTER 3. PRESENTATION OF LIVESTOCK ACTIVITIES: POULTRY FARMS, PIG FARMS, COW FARMS

3.1. Aspects related to pollution in the context of the human-animal relationship

The polluting substances that enter the food chains often concentrate, and man consuming animal products, which in turn have consumed polluted plants, will suffer the most, being the end of the food chain. The polluting effects resulting from raising animals are not to be neglected either, if the technologies used do not take this aspect into account.

Pollution through agricultural activity, due to the large surfaces that it can affect, as well as the multitude of chemical substances that are worked with, the phenomenon has multiple implications. First of all, nitrogen fertilizers can be washed into rivers or groundwater, which they pollute. The waters can contain large amounts of toxic radicals: $NO3$ - $NO2$, which can be absorbed in the intestine. Pesticides and herbicides, used in excess, can have toxic effects, known or unknown, often damaging ecosystems and negatively influencing animal breeding.

The polluting effects of badly managed technologies are not to be neglected either. Many times manure, in various stages of fermentation, scattered randomly around the farms, in addition to contaminating the air and polluting the soil with its removal from cultivation for a long period, also constitutes a real danger for groundwater or surface water pollution, through the "dung must" carried with the rainwater. Taking into account the irreplaceable value of manure for maintaining and even increasing soil fertility, a solution against pollution is the arrangement of manure platforms next to each farm, for composting the manure to be used as a valuable fertilizer [25].

3.2. Technological flow

3.2.1. Technological flow of poultry farms

In poultry farming, the potential environmental impact includes ammonia emissions into the air, nitrogen and phosphorus leakage into the soil, groundwater and surface water, and leakage from animal waste. The assessment of the impact of the activities aimed at the intensive breeding of birds on the environmental factors aims to correctly determine the forms of impact. The more detailed the impact generated by the activity project is described, the greater the chances of identifying effective measures to reduce or prevent negative effects on the environment.

The environmental impact will be reduced as the poultry breeding facility becomes more modern and efficient. For this reason, it is recommended that, when the environmental impact assessment is carried out, the age of the farm should be taken into account, in order to adopt the appropriate measures, such as air filtration techniques, equipping the farm with technologies that allow reducing as much higher emissions, changing the methods of manure transfer, imposing specific conditions regarding manure storage.[26]

Fig. 3.1. Poultry farm

The technological process involves: The preparation and introduction of the bedding in the hall, consisting of rice husks, shavings or sunflower husks, spread by hand, the operation is carried out in each series, about 6 times a year, the population of the hall with day-old chicks purchased by at specialized poultry companies, a process that is carried out six times a year, feeding that is done with the help of a closed circuit installation - through an auger, watering that is done with watering lines connected to the water network in the premises and arranged between the lines of fodder, depopulation of the hall, evacuation of garbage - permanent bedding per series (straw and droppings), sanitization of the hall and machines.

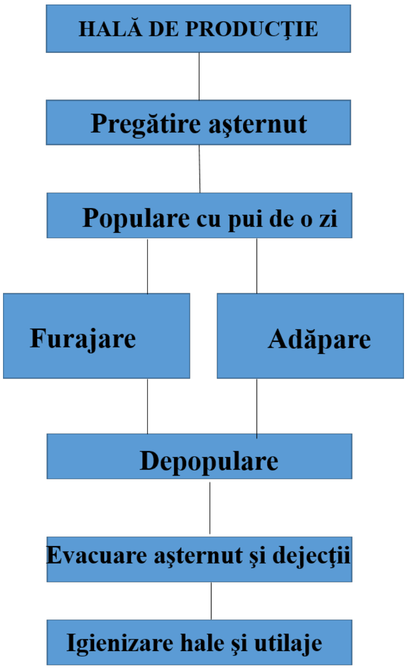

Fig. 3.2. Technological flow [6]

3.2.2. Technological flow of pig farms

Fig. 3.3. Pig rearing hall

Technological process:includes several sectors:

- Mountain sector - pregnancy
- The maternity sector
- The pig breeding sector
- The fattening sector

Waste management

The resulting waste is mainly household and similar household waste, which is stored in a container.

mANUREmixed with the washing water are taken from the collector channels of the halls to a sewage network.

Technological wastewaterthey are represented by the waters used for the sanitation of the production spaces, plus the waste resulting from the productive cycle (urine and feces).

3.2.3. Technological flow of cow farms

Fig. 3.4. Farm for raising cows

Excrement from sheltersthey are collected at the ends and discharged into end collecting channels and, through a scraper installation, they are directed to collection basins. A biogas station provides the electricity and thermal energy needed at the dairy farm.

Figure 3.5 shows the complex scheme of biomass transformation into biogas, passing through four characteristic steps.

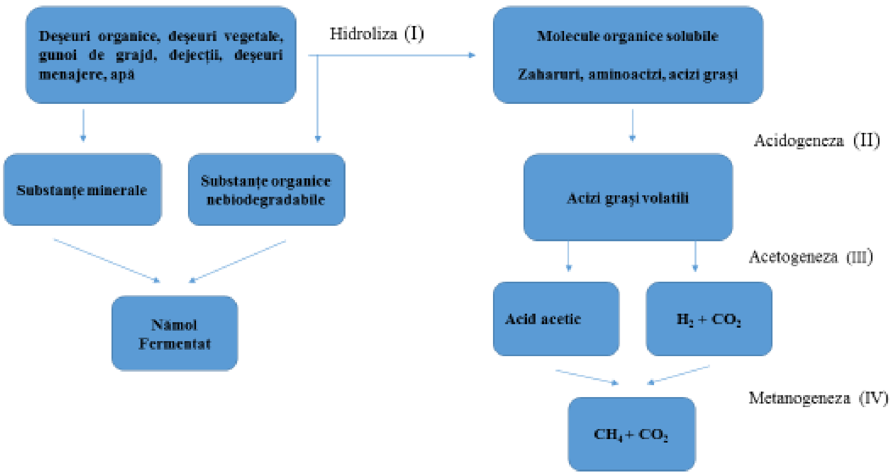

Fig. 3.5. The complex scheme for the transformation of biomass into biogas

From the metagenesis process exposed before, it can be observed that in the substrate subjected to fermentation there are the most different compounds from a chemical point of view. The presence of numerous acids is the result of the activity of the group of acidogenic bacteria, which work well at a lower pH. In stages III and IV, the task falls to methanogenic bacteria, for which the optimal pH is between 7 - 7.6.

The technological flow of the biogas station:

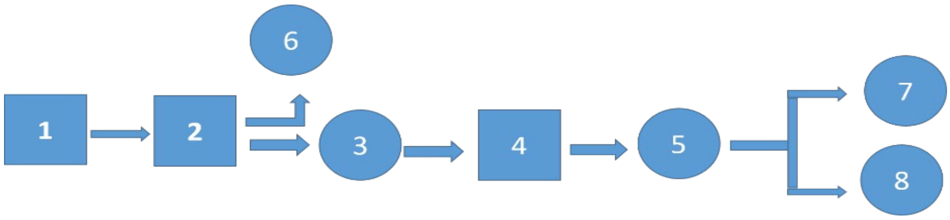

Fig. 3.6. The technological flow of the biogas station

1. supply with solid and liquid substrate 5. cogeneration
2. fermenter 6. fertilizer
3. biogas 7-8 electrical and thermal energy
4. gas analysis system

Excrement from shelters

The droppings from the shelters are collected on the ends and discharged into collecting channels and then directed to a pre-collection basin.

After obtaining the biogas, a fertilizer sludge results, which is collected in the two above-ground storage basins made of concrete.

Household waste platform

Household waste is stored on a platform fenced with brickwork and cement flooring.

In the milking room, the room for collecting the milk in the milk tank, there are concrete channels with drainage slopes to floor siphons that take the droppings and direct them to the external sewage network.

Fig. 3.7. Milking room

3.3. Literature study on agro-zootechnical waste and methods of recovery Types of waste resulting from agro-zootechnical activities

Agro-zootechnical activities result in various types of waste that can have a significant impact on the environment if not properly managed. These wastes include both organic and inorganic materials, and can come from various agricultural and animal husbandry processes.

Animal agriculture is responsible for around 20% of greenhouse gas (GHG) emissions such as nitrous oxide (N2O), methane (CH4) and fluorinated compounds[27, 28]. Globally, manure management contributes about 10% of agricultural CH4 emissions [27, 29], but in closed livestock production systems (e.g., dairies and pigs), with liquid manure management, this proportion can exceed 50% depending on the climate [27, 28]. Furthermore, the researchers estimated that the management and land application of animal manure generally accounts for 44% of total anthropogenic N2O emissions. These figures highlight the need to improve estimates of GHG emissions from proper manure management.

Agricultural residues include crop residues such as: straw, bran, vegetable residues and by-products resulting from food processing.

Forest residues include logging residues, wood processing by-products and forest management residues. There are other residues, which include organic waste from municipalities and industry.

Due to the high potential of these partially untapped resources, an increasing number of studies are investigating the use of residual biomass as feedstock for energy and/or biofuel production. In the literature, there are numerous studies aimed at estimating the energy potential from biomass and/or residual biomass at different scales, regional or national, and in different countries. Such analyzes are carried out considering all available biomass or only certain specific sources [30].

Some authors have estimated benefits related to the use of biomass as an energy source, in the sense that they reduce greenhouse gas emissions. The release/sequestration of CO2 from biomass residues was analyzed for four scenarios: uncontrolled management, biomass conversion to bioethanol as transport fuel, biogas production from agricultural residues and biomass co-combustion in power plants [30, 31].

Agricultural and livestock wastes are a serious concern in terms of their management and disposal, with much of it ending up as solid residues or being burned in the fields. They contribute to air pollution and global warming. Therefore, different methodologies have been investigated to transform these wastes into valuable resources such as chemicals, biogas, and raw materials for various industries [32].

In order to obtain biofuels, different types of biomass can be used:

- biofuels produced from raw materials such as food and feed crops (e.g. biodiesel from rapeseed oil, sunflower oil, palm oil and soybean oil, or bioethanol from corn, wheat, beet sugar, from barley and from rye);
- biofuels produced mainly from waste, residues and co-products that can be transformed using advanced technologies: from algae, from straw, from effluents from palm oil presses, from cellulosic materials of non-food origin, from lignocellulosic materials;
- biofuels produced mainly from waste, residues and co-products that can be processed using mature technologies – biofuels obtained from used cooking oil and animal fats [33].

CHAPTER 4. EXPERIMENTAL RESEARCH REGARDING THE TREATMENT OF ANIMAL EXPERIENCE RESULTING FROM LIVESTOCK ACTIVITIES

4.1. Environmental assessment of the activity of a poultry farm

The STAS 12574/1987 standard refers to atmospheric air and establishes the maximum allowed concentrations of some polluting substances in the air of protected areas.

This standard establishes the maximum allowed concentrations so that the population in unprotected areas is not affected by the harmful effects of polluting substances.

Table 4.1. Measurements performed according to STAS 12574/1987 – Standard for air quality in protected areas [34]

Date of sampling 21.11.2022	Sample code	Pollutant emission analysis		
		Ammonia (NH_3) mg/m3	**Hydrogen sulfide (H_2S) mg/m3**	**Powders in suspension mg/m3**
14.00 - 14.30	1495 - I	0.0065	SLD (<0.002)	0.051
14.30 – 15.00	1495 - I	0.0063	SLD (<0.002)	0.056
15.00 – 15.30	1495 - I	0.0059	SLD (<0.002)	0.055
Average value		**0.0062**	**SLD (<0.002)**	**0.054**
Mean value mg/mc (24 h daily average)		**0.1**	**0.008**	**0.15**
Short-term mean value mg/m LEL (30 min)		**0.3**	**0.015**	**0.5**
The method of investigation		**STAS 10812-76**	**STAS 10814-76**	**STAS 10813-76**

Wastewater samples were taken from the drainable basin from the sanitation of the poultry rearing halls, obtained using the arithmetic mean are presented in the table below.

Table 4.2. Measurements carried out according to STAS 12574/1987 – Sample of waste water from the drainable basin from the sanitation of poultry breeding halls [35]

No. Crt.	Quality indicators	UM	Methods of investigation	Values obtained	Admissible limit values according to AIM no. 132/16.05.2022 rev. In 23.04.2014
1.	pH	pH unit	SR ISO 10523/2009	7.38	**6.5 – 8.5**
2.	Suspended matter	mg/l	SR EN 872/2005	16.0	**190**
3.	Chemical oxygen consumption (CCO-Cr)	mg O_2/l	SR ISO 6060/1996	164.0	**250**

No. Crt.	Quality indicators	UM	Methods of investigation	Values obtained	Admissible limit values according to AIM no. 132/16.05.2022 rev. In 23.04.2014
4.	Biochemical oxygen consumption (CBO5)	mg O2/l	SR EN 1899-1/2003	67.2	**150**
5.	Ammoniacal nitrogen	mg/l	SR ISO 7150-1/2001	11,18	**20**
6.	Biodegradable synthetic detergents	mg/l	SR EN 903/2003	0.792	**25**
7.	Total phosphorus	mg/l	SR EN ISO 6878/2005	2,882	**5**
8.	Extractable substances with organic solvents	mg/l	SR 7587/1996	< 20 (7.2)	**15**
9.	chloride	mg/l	SR ISO 9297/2001	135.0	**500**
10.	Petroleum products	mg/l	SR 7877/2-1995	SLD (< 0.100)	**5**
11.	Sulfates (SO42-)	mg/l	EPA 472 C	136.0	**600**
12.	Temperature	ªC	Digital thermometer	19.6	**30**

It can be observed that the values fall within the maximum permissible limits, not exceeding any of the indicators.

4.2. Environmental assessment of the activity of some poultry farms in other countries

Brazil is the country that occupies the leading position in chicken meat exports and ranks third in terms of production volume. (ABPA, 2021). In 2020, Brazil produced 13.84 thousand tons of chicken meat, followed by China, which produced 14.90 thousand tons, and the United

States of America, which produced 20.38 thousand tons. The country's high competitiveness results from an adequate biosecurity system, which meets international standards for meat production, slaughter and processing, thus allowing the export of chicken meat to more than 150 countries [36].

The performance of the Brazilian chicken production chain is due to investments in genetics, nutrition and production intensification, as well as technical support provided by different sectors of the chain, mainly the slaughter and processing industries [36, 37, 38].

Given the increase in food demand, one of the biggest challenges for maintaining competitiveness in the medium and long term is the implementation of environmental sustainability practices.

In Brazilian broiler production, litter is generally treated by biological, chemical or fermentative processes, the latter being the most common [36, 37].

According to the study, considering the low cost and high nutrient content, it is recommended that the waste be used as an organic fertilizer in agriculture. Before applying to the soil, the poultry litter must be treated to minimize the occurrence of environmental problems related to biological, fermentative or chemical processes [39, 40].

4.3. Environmental assessment of the activity of a pig farm

Table 4.3. Air emissions [41]

Pollutant emissions	**Pig rearing system**
Ammonia (NH3)	Animal shelters, storage and distribution of manure
Methane (CH4)	Animal shelters, storage and treatment of dung
Nitrous Oxide (N2O)	Animal shelters, storage and distribution of manure
Nox	Space heating and combustion installations
carbon dioxide (CO2)	Animal shelters, fuel used for heating and transport, burning of waste
Odor (H2S)	Animal shelters, storage and distribution of manure
Dust	Feed preparation, feed storage, animal housing, solid manure storage and distribution
Smoke/CO	Incineration of remains

Impact on soil and surface water

The evaluation criterion used to assess the characteristics of wastewater is Normative NTPA-002/1997 regarding the conditions for the discharge of wastewater into the sewage networks of localities.

Manure spreading on land is responsible for the emissions of numerous compounds that can contaminate soil, groundwater, and surface water. Although there are techniques for treating manure, applying it directly to the field remains the most widely used method. Manure can work effectively as a fertilizer, but when applied in excess of the soil's absorption capacity and crop needs, it becomes a significant source of emissions.

4.4. Environmental assessment of the activity of a pig farm in other countries

A study conducted on four breeding farms and eight fattening pig farms located in the province of Modena, Italy, analyzed the impact categories on global warming, acidification, eutrophication, abiotic depletion and photochemical ozone formation. The greenhouse gases responsible for global warming were mainly CH4, N2O and CO2, with ammonia being the most important source of acidification. Nitrates and NH3 were the main emissions responsible for eutrophication, while P and NOx were present in a very small percentage. Consumption of crude oil and natural gas was the main source of abiotic depletion. Photochemical ozone consists of: CH4 resulting from manure fermentation, CO2 caused by the burning of fossil fuels in agricultural activities and industrial processes, ethane and propene emitted during oil extraction and hexane used in soybean oil extraction [42].

In order to reduce the impact on the environment, special attention should be paid to feed production systems, which havea relevant role in both phases and for all impact categories. This is especially true for those impact categories that consider water and air quality, because if feed is used efficiently, less nitrogen compounds enter the production system, either as fertilizers or as organic fertilizers , with reduced emissions of N2O, NH3 and NO−3.

4.5.Environmental assessment of the activity of a cow farm

The storage of unfermented manure generates a significant amount of methane. Processing them in a biogas plant allows the decomposition of manure and the burning of methane, which is then transformed into energy. This method considerably reduces the negative impact on the environment. The carbon dioxide emitted from combustion comes from carbon recently extracted by plants, not from energy sources from an earlier geological age, thus integrating into an ecological cycle. Energy production in biogas plants is considered carbon neutral.

The main characteristics of the emissions resulting from the operation of the cogeneration system are presented in the following table:

Table 4.4. Emissions resulting from the operation of the cogeneration system [43]

Pollutant emission	**Mass flow rate (g/h)**	**Gas flow (m3N/h)**	**Emission concentration (mg/Nm3)**	**Alert threshold* (mg/Nm3)**	**Intervention threshold** (mg/Nm3)**
PM10 powders	2.05	811.6	2.52	3.5	5
Co.	21.76	811.6	26.81	70	100
NOx	54.4	811.6	67	245	350
SOx	0.652	811.6	0.8	24.5	35

*70% of the limit value of the emission concentration provided by OM 462/1993 for the approval of the Technical Conditions regarding atmospheric protection and the Methodological Norms regarding the determination of atmospheric pollutant emissions produced by stationary sources
**limit value of the emission concentration provided by OM 462/1993

The obtained results show that the pollutant emissions generated by the cogeneration system comply with the provisions of Order 462/1993. Pollutant concentrations in the emission are below the alert and intervention thresholds established for this source category.

The possibility of soil pollution as a result of the activity could be the discharge of waste water, the management of waste and manure.

The production activity (breeding of dairy cows) is organized in closed production and auxiliary halls, waste water is collected through a closed sewage system of the premises, and domestic and technological waste is collected by category and eliminated/utilized accordingly.

Thanks to the existing facilities, a high level of protection is ensured for surface and underground waters. By channeling the water into a dividing system, as well as by providing grease and sludge separators for the pre-purification of waste water, the discharge of waste water from the farm platform is done in compliance with NTPA 002/2002.

Due to the existing facilities, the activity carried out within the zootechnical complex studied does not influence the quality of the soils on the site.

4.6. Environmental assessment of the activity of some cow farms in other countries

The case study of a dairy farm in Italy aimed to evaluate the different stages of reducing the potential impact on the environment. The environmental performances obtained from a conventional farm in the northern area of Italy were compared with the results obtained in a farm that adopted anaerobic digestion in the treatment of manure. The researchers found that in the anaerobic digestion scenario, the impact on the environment was significantly reduced, the most important advantage being that acidification decreased by 29%, global warming decreased by 22%, and eutrophication potential decreased by 18% [44].

In conclusion, the main problem of using digestate is the release of nitrogen into the environment, which can be reduced by applying best practices for maintaining soil quality.

4.7. Research on the impact of animal manure storage on the environment

The increase in the amount of waste from agriculture is one of the major environmental problems that humanity is facing. The process of obtaining biogas through anaerobic digestion is a concern of researchers and is considered to be the best solution in the case of manure, by transforming organic waste into green energy and organic fertilizer for agriculture. The possibility of using anaerobic digestion of manure was considered to minimize emissions and to replace the fuels used in farms with biogas. If farms applied anaerobic digestion, greenhouse gases would be reduced, and the resulting methane could be used as fuel within the farms.

The activity of intensive breeding of domestic animals has led to the appearance over time of a deficit of space necessary for the production of the quantities of fodder and the storage of animal residues resulting from the activity carried out. Thus, animal droppings result in significant amounts of nutrients in excess, which is why it is necessary to apply biowaste management measures to prevent serious consequences, such as:

- Groundwater and surface water pollution caused by nutrient runoff.
- Destruction of the soil structure and its microbiota.
- The destruction of the specific population of herbaceous plants and the formation of vegetation typical of lands with excess nutrients.
- Major risks of methane and ammonia emissions.
- existence of flies and unpleasant smells, due to the storage of manure and its spreading.
- The danger of contamination with pathogens and their spread [45].

4.7.1. The impact of the storage of animal manure and the treatment of raw materials

The main gas emissions with the effect of sera (GHG) from agriculture is due to CH4 and N2O.

In order to reduce greenhouse gases, special attention must be paid to the production of biogas, the storage of animal waste and the treatment of raw materials used in animal husbandry activities. The storage of raw material influences greenhouse gas emissions, in the sense that most of the N2O emissions can be reduced when a sealed landfill is used [46].

4.7.2. The impact of the digestate on the environment

An important point for the development of the biogas market is the fate of the digestate, which is often problematic. A proposal for a regulation on fertilizers will be submitted to the

European Commission proposing the recognition of digestate as an organic fertilizer that can be sold throughout the EU. Another strong impact on the biogas sector could be Europe's possible ban on landfilling and limiting the incineration of organic waste, as well as the significant increase in the European Union's recycling targets. This is in favor of anaerobic digestion, as it is recognized as a recycling process [47].

Through anaerobic digestion, in the absence of oxygen, organic matter is decomposed by bacteria. This is how biogas is formed, which contains methane (CH4) and carbon dioxide (CO2) with traces of other gases; and digestate, a sludge-like substance containing the waste materials.

In conclusion, the main problem of using digestate is the release of nitrogen into the environment, which can be reduced by applying best practices for maintaining soil quality.

4.7.3. Experimental research on the treatment of bedding used in poultry rearing halls

Intensive agriculture produces huge amounts of organic waste and due to the fact that it can be recycled bringing some benefits to the soil, there is currently an increasing demand for its recycling.

Livestock activities generate a large amount of organic waste, such as manure, bedding, which must be disposed of properly, withoutto pollute the soil, water and air (odors, NH3, NH4, CO2).

By composting, some of the organic matterit is mineralized into carbon dioxide, while another part is transformed into humic substances, which represent a valuable index of organic matter stabilization [48, 49].

4.7.4. Raw materials that can be used in the composting process

The composting process will have two stages: mechanical treatment (shredding the droppings until homogenization) and biological treatment (fermentation). After the manure is shredded until homogenized, it is prepared for biological treatment. This involves three phases:

- Phase 1 – the organic matter decomposes at a temperature between 25-40°C
- Phase 2 - organic matter decomposes thanks to bacteria at a temperature between 50 - 70° C
- Phase 3 – the organic matter turns into compost, at a temperature of 35-45°C

In order to obtain a quality compost, it is necessary for the organic matter to be rich in carbon, such as straw, sawdust, tree branches, but also in nitrogen, such as leaves, weeds or the remains of fruits and vegetables.

Also, humidity has a very important role, because it provides a favorable living environment for bacteria, and air contributes to the decomposition of matter by microbes.

4.8. Possibilities to reduce pollution

4.8.1. Environmental management of agro-zootechnical waste

An essential component of sustainable development is the environmental management of agro-zootechnical waste. If not properly managed, agro-zootechnical waste resulting from agricultural activities and animal husbandry activities, represents a major source of pollution.

An effective management of agro-zootechnical waste requires as a first phase the collection and proper separation of waste, which provides for the implementation of separate collection systems for organic and inorganic waste, ensuring that each type of waste is treated appropriately.

The pyramid of waste recovery consists of five levels, ordered from the most efficient and sustainable options to the least favorable.

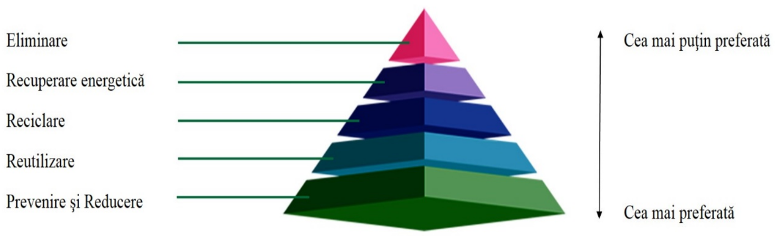

Fig. 4.4. Waste Pyramid [50]

4.8.2. Biogas - a solution for treating animal waste

The circular economy concept seeks to abandon natural resources in economic activities and aims to move towards renewable resources, eliminating waste and pollution from the system. It proposes a model in which resources are renewable, reusable and recyclable.

Fig. 4.5. Circular economy [51]

One of the major environmental problems that humanity is currently facing is the increase in the amount of waste that comes from agriculture. In order for the number of landfills to decrease, we need to turn to alternative sources of energy, with beneficial effects on the environment, such as biogas production.

Biogas is a renewable fuel that can be produced from organic matter, such as animal manure and vegetable waste, sludge from water treatment plants or household waste. Biogas can be used to produce electricity, heat or to fuel vehicles.

Animal manure has a high energy potential for obtaining biogas and is easily accessible wherever there is a farm for raising animals.

Biogas resulting from the anaerobic digestion of solid/liquid waste such as cattle and pig excrement, kitchen waste, sewage sludge, agro-industrial waste, lignocellulosic biomass is one of the most favorable sources of bioenergy [52, 53, 54, 55, 56 , 57, 58].

Biogas can greatly contribute to reducing greenhouse gas emissions. Using biogas can improve air quality and reduce greenhouse gas emissions. Biogas has been suggested as a fuel for cooking, home and water heating, crop drying, refrigeration, irrigation and electricity generation [59].

The process of obtaining biogas through anaerobic digestion is a concern of researchers and is considered to be the best solution in the case of manure, by transforming organic waste into green energy and organic fertilizer for agriculture.

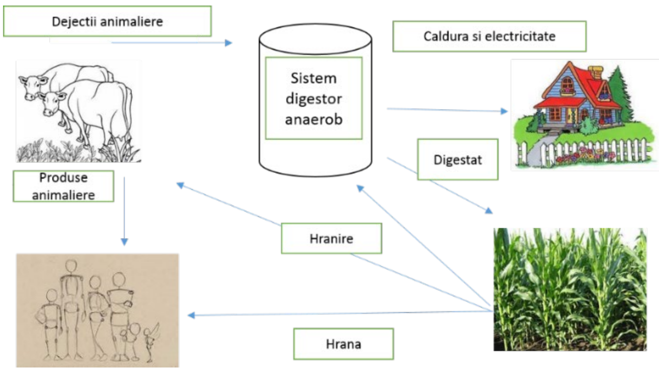

Fig. 4.6.Biogas production with various applications: fertilizer, lighting and electricity[60]

4.8.2.1. Literature study regarding the production of biogas

Animal manure is a potential source of energy, less expensive and could be used efficiently for energy production using biogas, but also for electricity production. Treating animal droppings using the anaerobic digestion process significantly reduces the negative impact that these droppings generate on the environment [59].

In the absence of air, biogas is obtained through the process of anaerobic digestion by several species of microorganisms, in four main stages, namely: hydrolysis, acidogenesis, acetogenesis and methanogenesis [61, 62]. Anaerobic digestion of biosolids involves the biological conversion of soluble organic matter dissolved into biogas, alcohols, volatile fatty acids and nitrogen-rich organic residues [63].

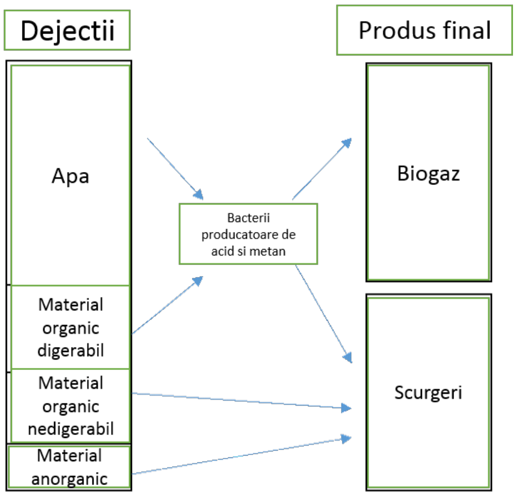

Fig. 4.7. Separation of manure in an anaerobic digester [65]

In general, a biogas production plant consists of several main components:

- the digester (the tank where the anaerobic digestion process takes place)
- the raw material supply system (feeds the digester with the raw material necessary for the anaerobic digestion process)
- the biogas evacuation system (collects and evacuates the biogas from the digester)
- biogas treatment system (releases impurities from biogas, such as hydrogen sulphide)
- the biogas combustion system (it is used for the production of electricity and thermal energy)

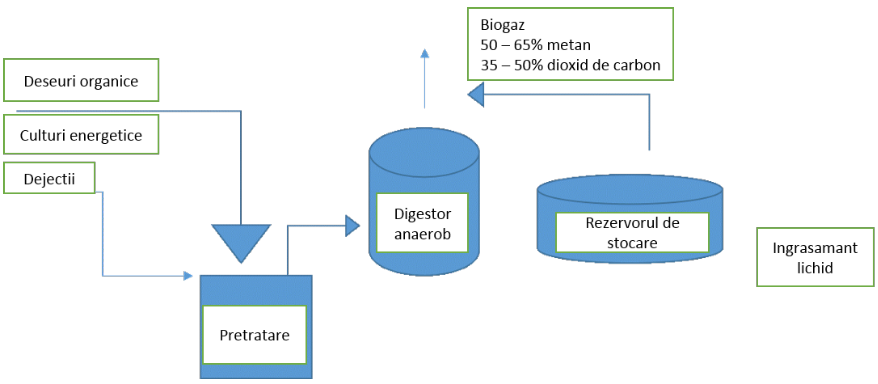

Fig. 4.8. Biogas and fertilizer production[65]

The organic mixture, which 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 plant and crop wastes [66].

In recent years, there have been significant advances in the development of biogas production technologies, advances that have led to the reduction of biogas production costs, which makesfor it to be more and more competitive with other energy sources.

Biogas has the potentialto contribute significantly to the reduction of greenhouse gas emissions and to the diversification of energy sources.

In agriculture, the use of anaerobic digestion has multiple benefits such as: reducing water pollution and the need for mineral fertilizers.

Biomass is currently considered one of the most vital sources of renewable energy, its use contributing to the reduction of global fossil fuel consumption and the achievement of carbon dioxide emission targets [67].

CHAPTER 5. OWN RESEARCH REGARDING THE OBTAINING OF BIOGAS FROM AGROZOOTEHICAL WASTE

5.1. Materials used

This researchinvestigated the potential of poultry, cattle and pig wastes for biogas production through the anaerobic digestion process.Recently, the anaerobic fermentation process of animal manure has become a promising solution for the production of biogas through anaerobic digestion. Anaerobic digestion technology is considered not only as a way to solve environmental problems, but also as a potential source of energy, while also contributing to solving economic and social problems. This research investigated the potential of poultry, cattle and pig wastes for biogas production through the anaerobic digestion process.

Since there are no research papers that use animal excrement from different animals in the same biodigester, I chose to try several variants of mixtures, containing both bird excrement, cow excrement, and pig excrement.

In this paper, the main objective of the research is the development of an optimal mixture of animal manure and agro-food by-products to obtain biogas.

We prepared and tested 27 recipes of mixtures in 3 sets, using animal droppings taken from farms located in Teleorman county. Thus, three different animal manure samples were characterized to study the anaerobic co-digestion process. The physico-chemical properties were evaluated through laboratory analyzes with the help of the WESSLING Romania SRL Environmental Protection Laboratory.

We kept the animal excrement samples at a temperature of (– 4) o C, in a closed container, protected from light. The inoculum we used to speed up the anaerobic digestion process was taken from a sewage treatment plant in Teleorman County.

We carried out the experiments using the Gas Endeavor biogas production plant, with a small capacity (15 500 ml glass reactors) and at a constant temperature of 37°C

Fig. 5.1. Gas Endeavor biogas production facility (Automatic Gas Flow Measuring

System)

With the Gas Endeavor installation, data analysis and recordingit is fully automatic.

Fig. 5.2. Optimum mixtures of animal manure and agro-food by-products to obtain biogas using Gas Endeavour

<u>Sample preparation phase</u>it consisted in the collection of samples from the site and the characterization of the organic substance by determining the content of dry substance and volatile substance. The samples were collected in the morning, to keep the biological characteristics intact and not to contaminate the samples.

<u>Recipe calculation method</u>it was made taking into account that the C/N ratio should be between 15 and 25 and that the mixture should have a humidity of at least 90%.

<u>Preparation and commissioning of the installation</u>Gas Endeavor consisted in the preparation and loading of the 15 glass reactors with substrate, according to the previously calculated mixture recipes.

After completing these phases, the installation is ready to be put into operation, and the reactors will be connected to the biogas treatment module, where the CO2 retention takes place. The monitoring and control of the installation was done with the help of a laptop, which recorded and processed the data.

Recording of experimental datait was carried out over a period of 10-15 days, during which the installation worked non-stop. The installation calculated the value of the biogas production potential for each experiment.

The experiments were carefully monitored to maintain the best conditions for the development of anaerobic bacteria in the fermentation reactor: an optimal temperature, pH, continuous supply of substrate.

The testing of the experiments with four recipes that had as a substrate begana mixture of organic materials with a concentration of 10% solids (animal waste, vegetable waste, food waste) and the rest water, I continued the experiments with 8 more recipes and then with 15 more recipes, with the same mixtures of materials, but in different proportions to see how the composition of the mixture influences the production of biogas.

5.2. Results obtained

The substrate is a mixture of organic materials with a concentration of 10% solids (animal waste, vegetable waste, food waste) and the rest water.

In order for the distribution of anaerobic bacteria to be uniform in the entire substrate, in order to achieve pranaerobic co-digestion oces, we combined more mute ssubstrates with a concentration of 10% solids with 40 g of the inoculum (which is a previously prepared anaerobic bacteria culture) and then IPUTin fermentation reactors with a useful volume of 400 g.

The first set of experiments includes four mixture recipes using as organic waste green leaves (tomatoes), wheat straw, lawn grass, potato and pig, cattle and poultry manure, in different proportions.

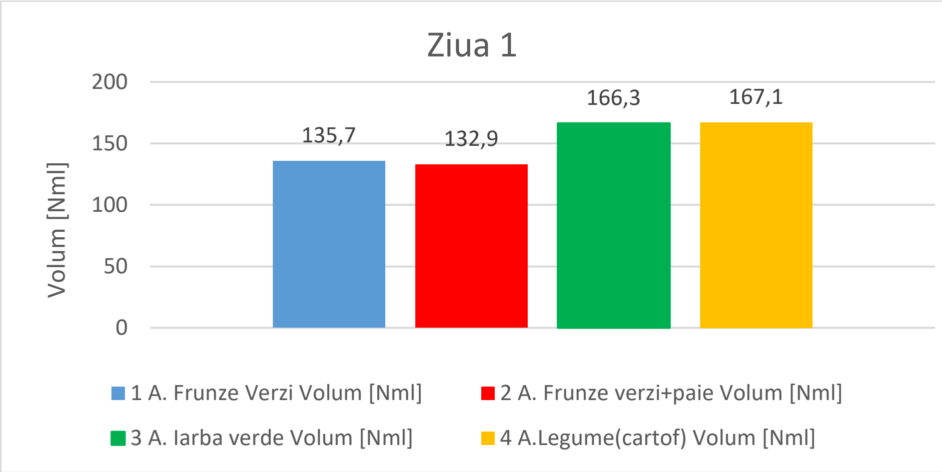

Fig. 5.3. Biogas experiment results generated, Volume [Nml] – Day 1

After the first day of biogas production, the highest yield for biogas production was obtained for two tested mixture recipes, namely: recipe no. 3 which had as organic waste green grass (lawn) 20%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and 40 g inoculum and recipe no. . 4 which had in its composition as organic waste potato 20%, pig animal waste 40%, cattle animal waste 10%, poultry animal waste 30%, water 172.29 g and inoculum 40 g. Recipes 3 and 4 generated approximately the same value of biogas flow rate.

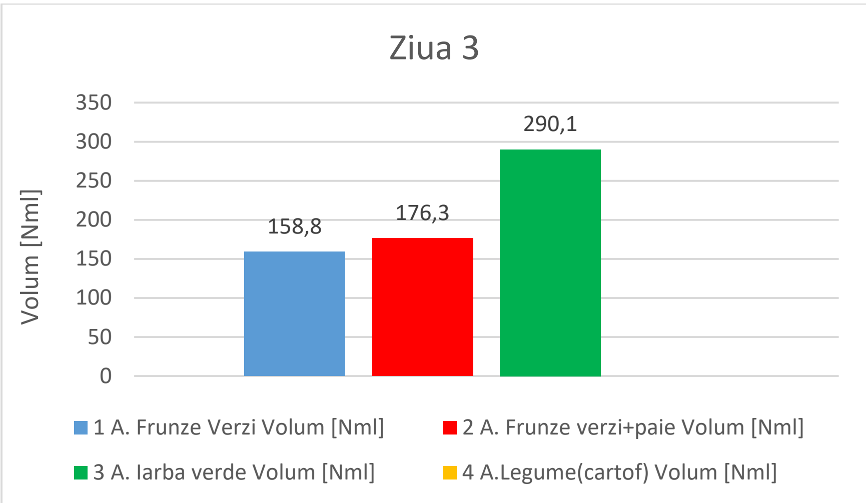

Fig. 5.6. Biogas experiment results generated, Volume [Nml] – Day 3

On the third day of anaerobic digestion, the best result for biogas generation is also achieved by mixture no. 3 which had as organic waste green grass (lawn) 20%, pig animal waste 40%, cattle animal waste 10%, poultry animal waste 30%, water 172.29 g and 40 g inoculum, this recording 290.1Volume [Nml], followed by mixture no. 2 which had in its composition green leaves (tomatoes) 10%, wheat straw 10%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and 40 g inoculum , generating biogas up to 176.3 Volume [Nml].

The recipe whichhad potato in its composition as organic waste, it no longer generated biogas.

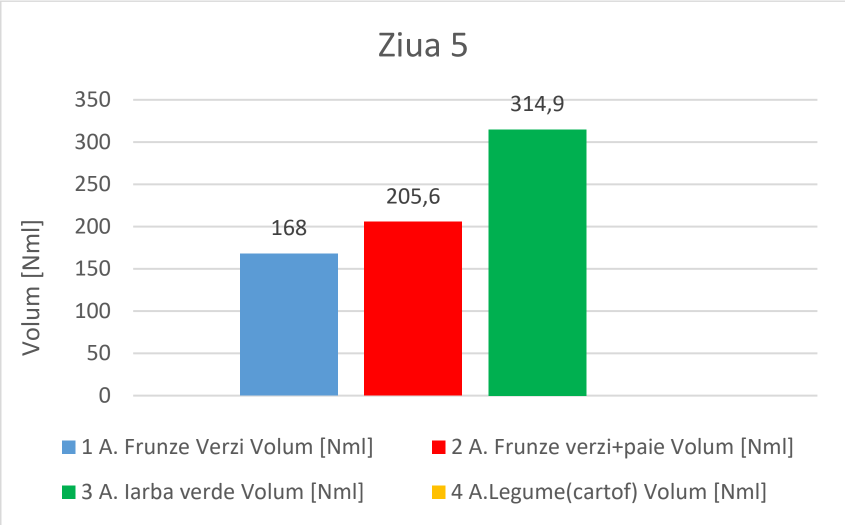

Fig. 5.4. Biogas experiment results generated, Volume [Nml] – Day 5

On the fifth day of the experiment, the biogas generation rate increases with mixture no. 3 which had as organic waste green grass (lawn) 20%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and 40 g inoculum, recording in around 350 Volume [Nml], on the other hand no increase was recorded for the other mixtures.

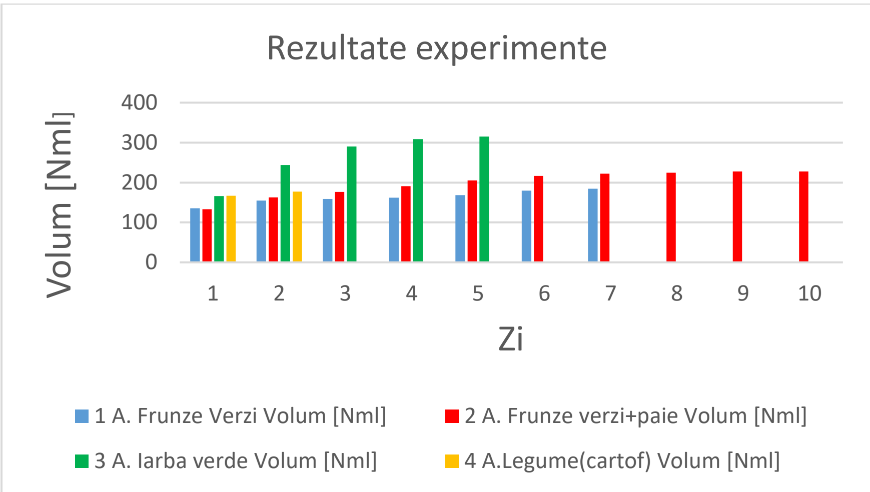

Fig. 5.5.Experimental results – Volume [Nml]

In figure 5.5. we made a centralized presentation of the experiments, from which we draw the following conclusions:

- The mixture that generated biogas for 9 days is mixture no. 2 which had in its composition green leaves (tomatoes) 10%, wheat straw 10%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and 40 g inoculum , recording 200 - 230 Volume [Nml].
- In the first five days, the highest biogas generation was given by mixture no. 3 which had as organic waste green grass (lawn) 20%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and inoculum 40 g, registering 240 - 320 Volume [Nml].
- Mixture no. 4 which had as organic waste potato 20%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and 40 g, the inoculum generated biogas only in the first two days.
- Mixture no. 1 generated biogas for seven days, recording 140 – 180 Volume [Nml].

The results were also expressed in the form of biogas flow rate generated/day

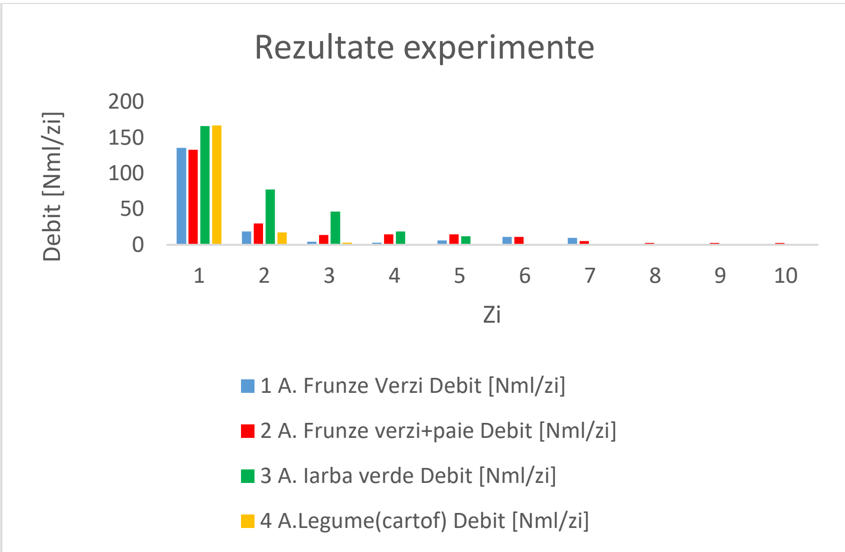

Fig. 5.6. Experimental results - Flow [Nml/day]

As can be seen from Fig. no. 5.6, the highest flow was recorded on the first day, these flows decreasing on day 2, 3, 4, 5,6, 7, remaining a small flow for mixture no. 2 which had in its composition green leaves (tomatoes) 10%, wheat straw 10%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and 40 g inoculum .

We continued the experiments, with the second set of experiments, taking animal droppings from farms located in Teleorman County, and we took the inoculum from a sewage treatment plant in Teleorman County.

Fig. 5.7.Anaerobic digestion - laboratory scale experiment[68]

We combined several types of organic materials at a concentration of 10% solids and added the inoculum, a culture of anaerobic bacteria. These mixtures were introduced into the fermentation reactors with a useful volume of 400 g, thus trying to evenly distribute the anaerobic bacteria throughout the substrate to facilitate the realization of the anaerobic co-digestion process.

The mixtures of raw materials respecteda C/N ratio between 15 and 25 and had a mixture humidity of at least 90%.

The reactor uses the technique of continuous stirring in the fermentation process in order to maintain a constant and uniform movement of the mixture of substances. Thus, the uniform distribution of nutrients, oxygen or other essential elements in the fermentation solution is ensured.

On the same mixtures previously tested, but with different proportions, I used 8 mixture recipes.

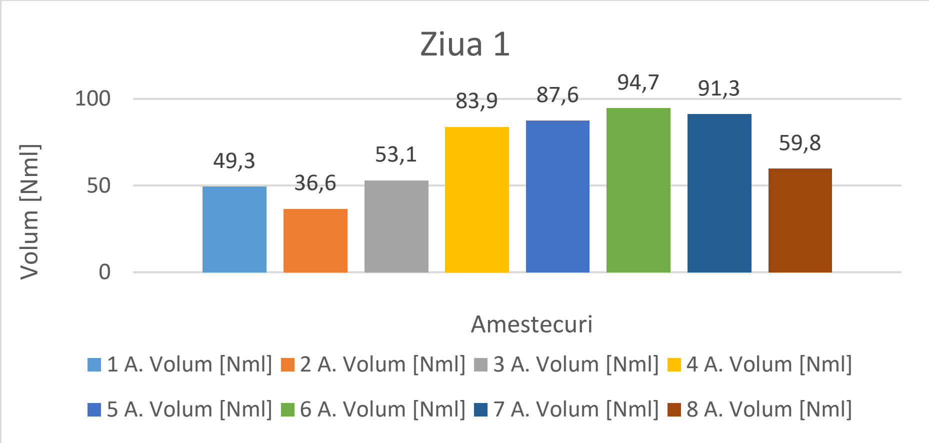

Fig. 5.8.Results of biogas experiments generated using a mixture of pig manure, poultry manure, cattle manure, straw, green grass, Volume [Nml] – Day 1

On the first day of anaerobic digestion, the installationrecorded the highest volume of biogas in experiment no. 6, which had as raw material: green grass 35%, pig droppings 20%, cattle droppings 15% and bird droppings 30%, followed by experiment no. 7, which had as raw material: green grass 40%, pig droppings 15%, cattle droppings 15% and bird droppings 30%.

On the third day of anaerobic digestion, the volume of biogas generatedis increasing in all experiments, in experiment no. 5 which had as raw material: green grass 30%, pig droppings 25%, cattle droppings 15% and bird droppings 30%, inoculum 290.23 g, being the largest volume of biogas recorded, followed by experiment no. 4 which had a mixture of green grass 25%, pig manure 30%, cattle manure 15%, poultry manure 30%, inoculum 296.23 g.

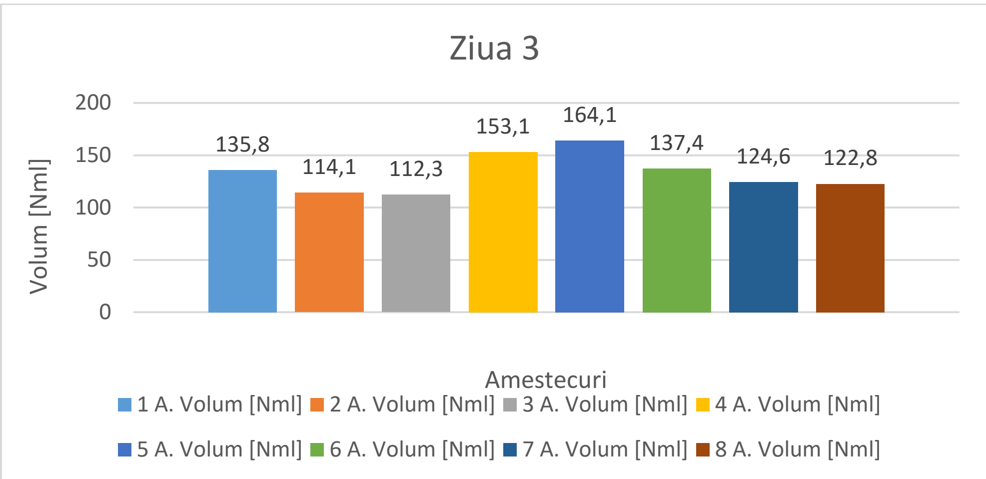

Fig. 5.18. Results of biogas experiments generated using a mixture of pig manure, poultry manure, cattle manure, straw and green grass, Volume [Nml] – Day 3

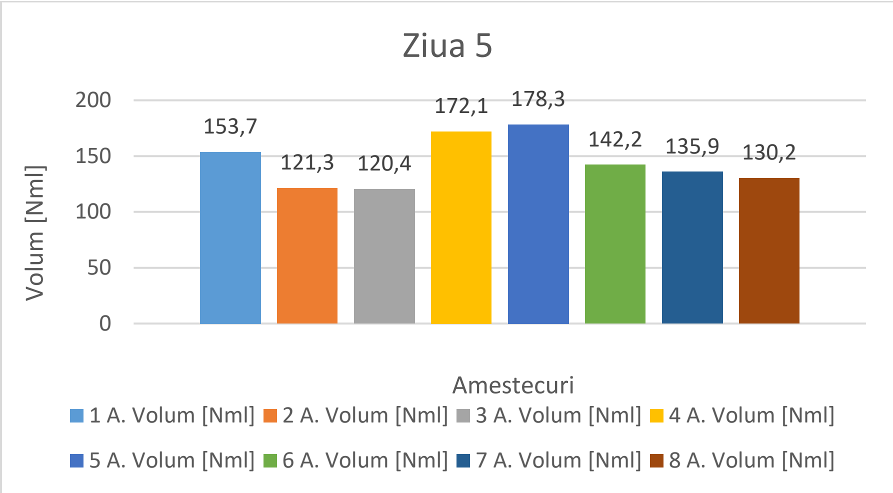

Fig. 5.9. Biogas experiment results generated, Volume [Nml] – Day 5

On the fifth day after the start of the experiments, as in the previous days, the installation registered a higher volume of biogas also for the mixtures that have green grass in their composition, the mixtures that also contain wheat straw registering a lower yield of generated biogas. The observation that mixtures containing green grass generated a higher volume of biogas than those also containing wheat straw may be the result of differences in the chemical composition and degradation characteristics of these materials. Green grass may have a higher content of fermentable substances, such as carbohydrates and other water-soluble components, which are more easily accessible to the microorganisms involved in the anaerobic digestion process. This can lead to more efficient decomposition and higher biogas production. In contrast, wheat straw contains higher amounts of components that are more resistant to degradation.

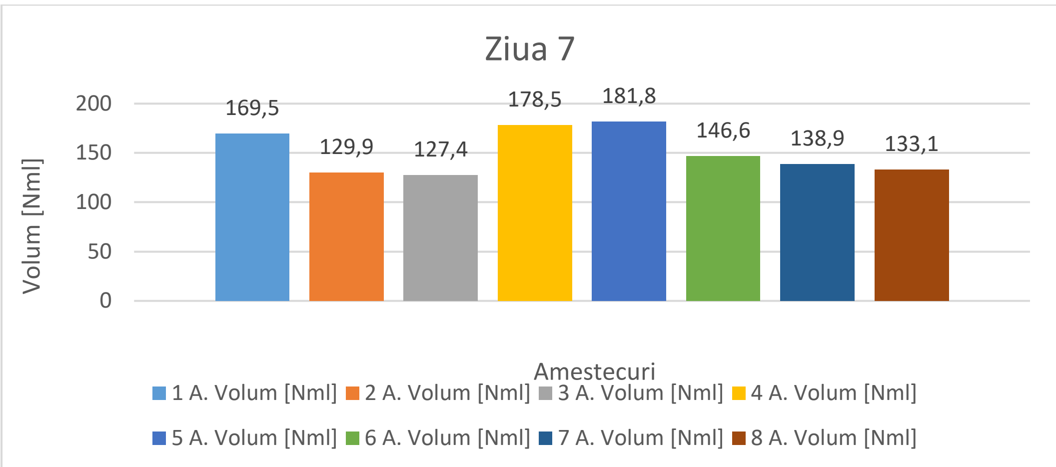

Fig. 5.10. Biogas experiment results generated, Volume [Nml] – Day 7

The volume of biogas generated continues to increase even on the seventh day of anaerobic digestion, the highest volumes of biogas generated being also recorded in experiments no. 5 and no. 4, which contain green grass in the composition.

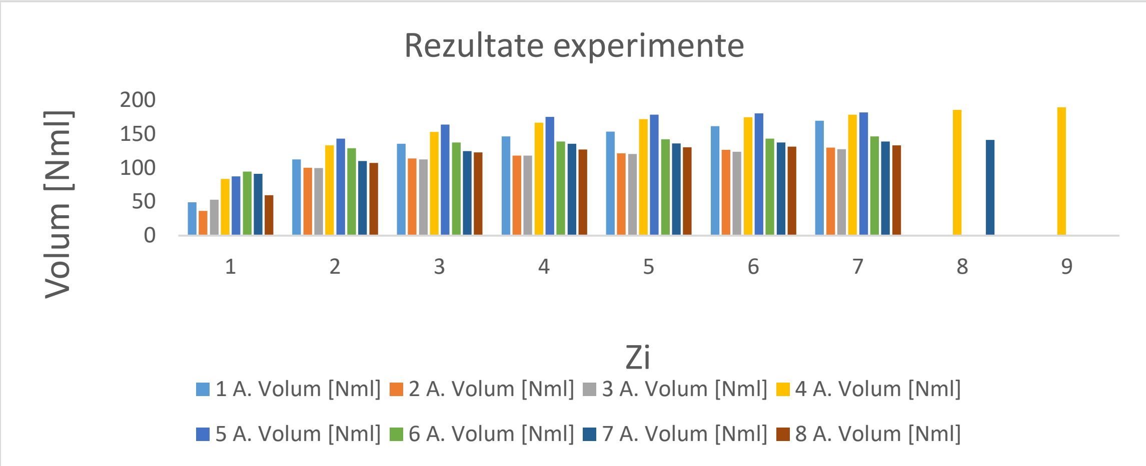

Fig. 5.11.Results of biogas experiments generated using mixtures of pig manure, poultry manure, cattle manure, green grass, straw, Volume [Nml]

In figure 5.25. we made a centralized presentation of the experiments, from which we draw the following conclusions:

- The highest volume of biogas generated 189.2 Volume [Nml] was recorded on the ninth day, by mixture no. 4 which had in its composition a mixture of green grass 25%, pig manure 30%, cattle manure 15%, poultry manure 30%, inoculum 296.23 g.
- Experiment no. 7 which consisted of a mixture of green grass 40%, pig manure 15%, cattle manure 15%, poultry manure 30%, inoculum 278.23 g, and experiment 8 which consisted of a mixture of green grass 45%, pig manure 10%, cattle manure 15%, poultry manure 30%, inoculum 272.23 g showed good results on the second day, and the volume of biogas generated increases compared to first day
- On the third day, all experiments registered an increase for all recipes, the best results being recorded in experiment no. 5, followed by experiment no. 6, respectively experiment no. 1.
- On the fifth day, biogas generation increases for all experiments, the highest increase being recorded in experiments no. 5 and 4, followed by experiments 1, 6, experiment no. 7 which consisted of a mixture of green grass 40%, pig manure 15%, cattle manure 15%, poultry manure 30%, inoculum 278.23 g and experiment 8 which consisted of a mixture of green grass 45%, pig manure 10%, cattle manure 15%, poultry manure 30%, inoculum 272.23 g,2,3.

The results were also expressed in the form of flow, the highest flow being recorded on the second day and decreasing on days 3, 4, 5, 6, 8.

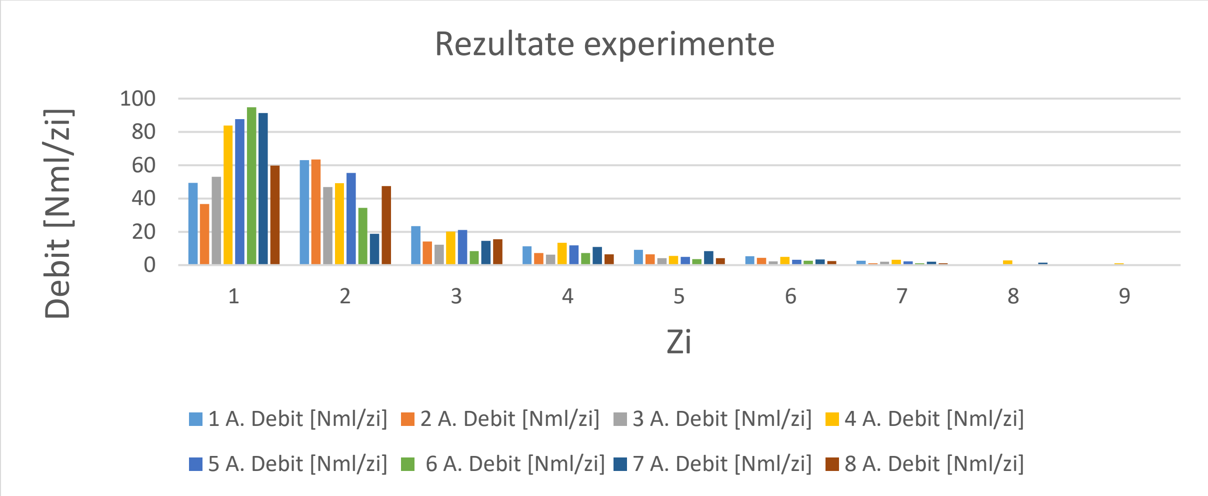

Fig. 5.12.Experimental results using mixtures of pig manure, poultry manure, cattle manure, green grass, straw - Flow rate [Nml/day]

The experiments were carefully monitored, maintaining the best conditions of temperature, pH, continuous feeding with substrate. Anaerobic fermentation was done by chewing the substrate with the inoculum, which accelerated the fermentation process.

The maximum level of biogas was obtained after 7 days of anaerobic digestion.

We continued the experiments with the third set of recipes, taking animal droppings from farms located in Teleorman county, and we took the inoculum from a sewage treatment plant in Teleorman county.

On the same mixtures previously tested, but with different proportions, we used 15 mixture recipes.

Fig. 5.13. Samples with the mixtures used in anaerobic digestion

On the first day of anaerobic digestion, experiment no. 14 generated the largest volume of biogas, which had as raw material: green grass 30 g, potatoes 30 g, straw 20 g, pig droppings 12 g, cattle droppings 17.14 g and bird droppings 12.63 g, followed by experiment no. 9, which had as raw material: green grass 45 g, potatoes 35 g, pig droppings 12 g, cattle droppings 17.14 g and bird droppings 12.63 g, then followed by experiment no. 1, which had as raw material: green grass 20 g, potatoes 20 g, pig droppings 70.39 g, cattle droppings 23.529 g and bird droppings 53.78 g and experiment no. 8, which had as raw material: green grass 40 g, potatoes 40 g, pig droppings 12 g, cattle droppings 17.14 g and bird droppings 12.63 g.

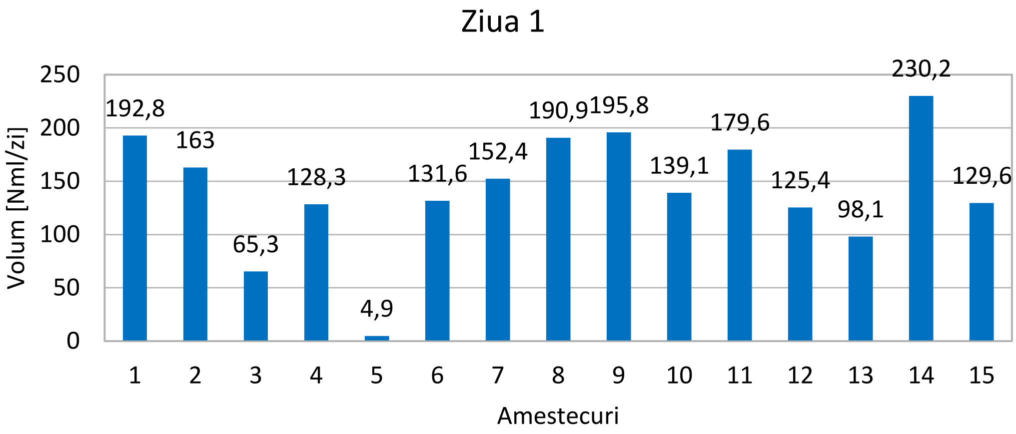

Fig. 5.14.Results of biogas experiments generated using a mixture ofpig droppings, bird droppings, cattle droppings, green grass, potatoes and straw, Volume [Nml] – Day 1

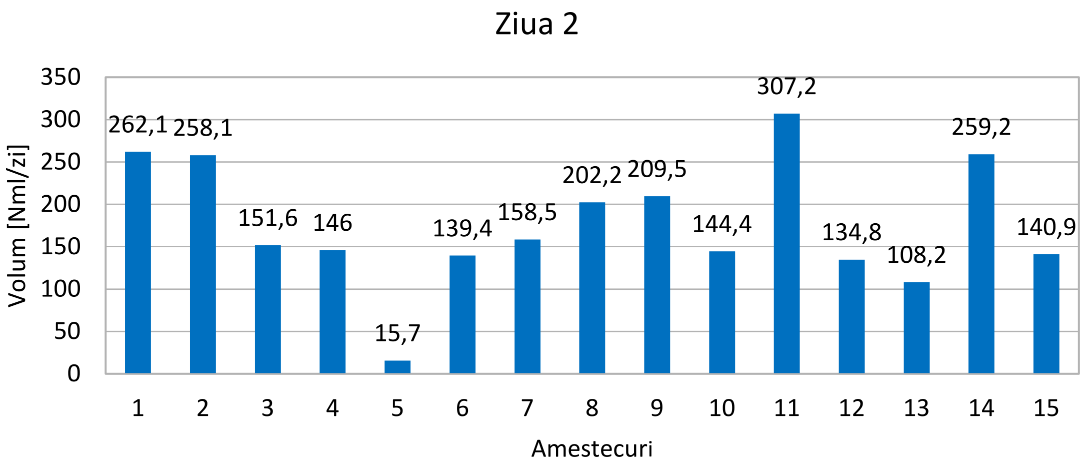

Fig. 5.15.Results of biogas experiments generated using a mixture ofpig droppings, bird droppings, cattle droppings, green grass, potatoes and straw, Volume [Nml] – Day 2

Ffrom the first day of anaerobic digestion, on the second day, an increase in the volume of biogas generated in all experiments is observed, with the highest volume of biogas being recorded in experiment no. 11 which had as raw material: green grass 20 g, potatoes 10 g, straw 10 g, pig droppings 70.39, cattle droppings 23.52 g and bird droppings 53.78 g, followed by experiments no. 1, 2 and 14.

On the fourth day of anaerobic fermentation, the volume of biogas generated continues to increase in almost all experiments, the highest volumes of biogas generated being recorded in experiments no. 11, no. 2 and no. 1, from where it can be seen that the best mixtures are those that have green grass and potatoes in their composition. Experiments no. 3, 5, 7, 8, 9 and 10 no longer generated biogas.

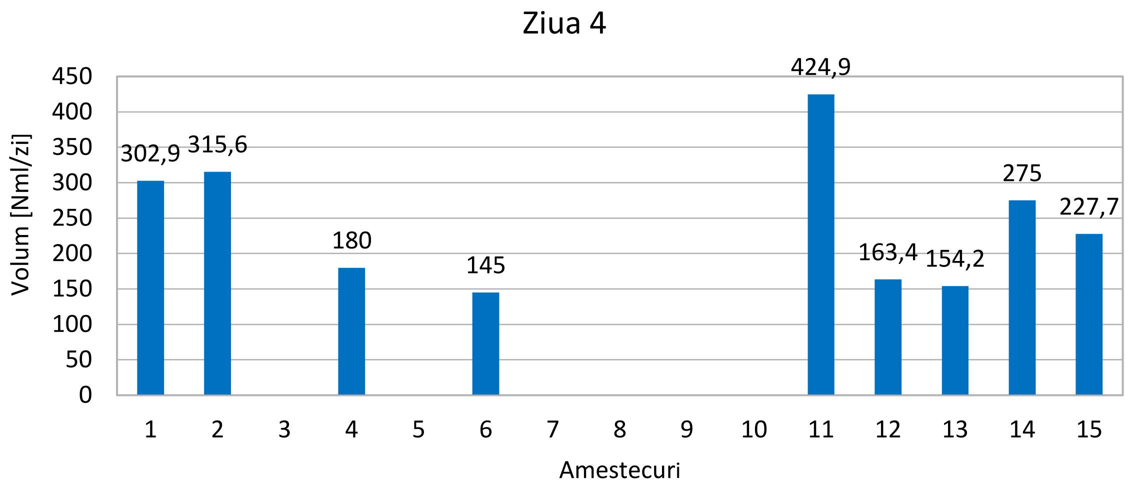

Fig. 5.16.Results of biogas experiments generated using a mixture ofpig droppings, bird droppings, cattle droppings, green grass, potatoes and straw, Volume [Nml] – Day 4

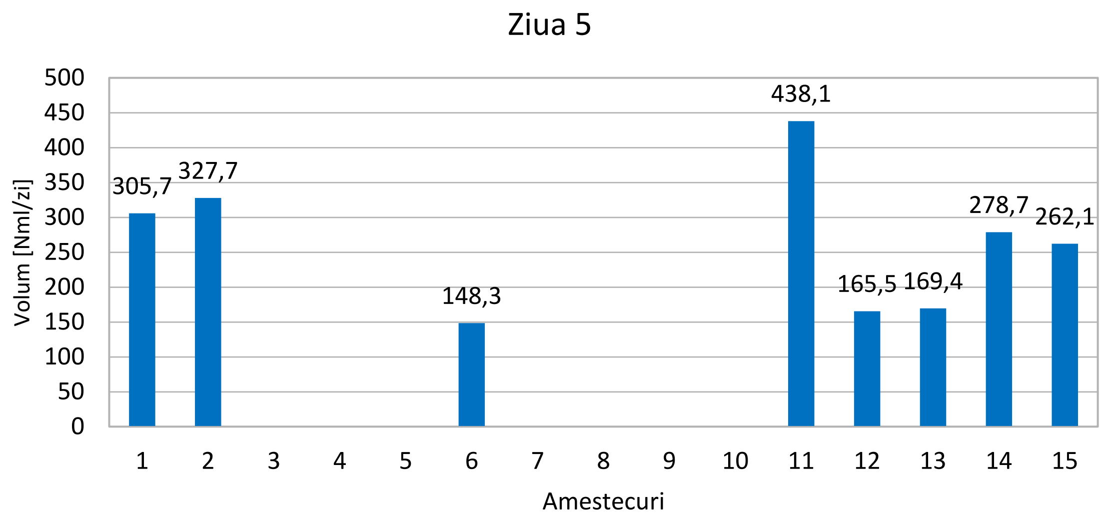

Fig. 5.17. Results of biogas experiments generated using a mixture ofpig droppings, bird droppings, cattle droppings, green grass, potatoes and straw, Volume [Nml] – Day

On the fifth day of anaerobic digestion, the highest volume of biogas generated was recorded in experiment no. 11 whichconsisted of a mixture of green grass 20 g, potatoes 10 g, wheat straw 10 g, pig manure 70.39 g, cattle manure 23.53 g, poultry manure 53.79 g, inoculum 212.29 g, the installation registering a larger volume of biogas in the mixtures that have in their composition a smaller amount of green grass and a larger amount of animal waste. Experiments no. 3, 4, 5, 7, 8, 9 and 10 no longer generated biogas.

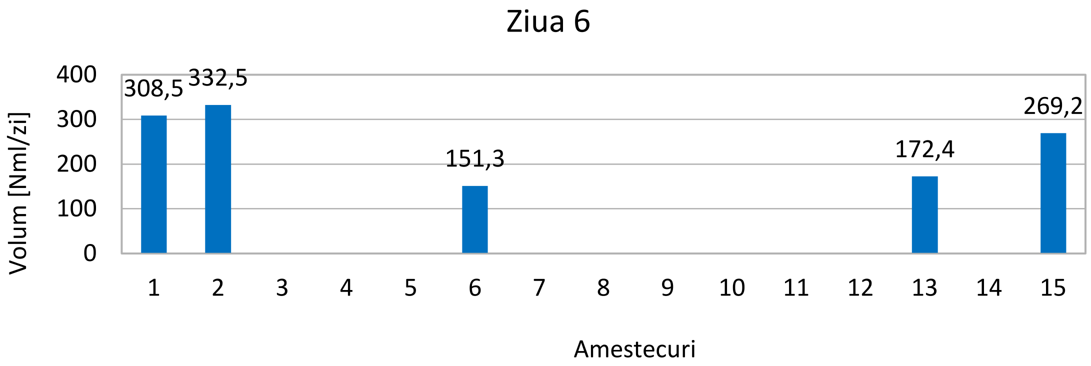

Fig. 5.33. Results of biogas experiments generated using a mixture ofpig droppings, bird droppings, cattle droppings, green grass, potatoes and straw, Volume [Nml] – Day 6

S-observed a low rate of biogas production after the fifth day of anaerobic digestion, indicating that anaerobic digestion was largely complete after this interval. The maximum level of biogas was obtained after 5 days of anaerobic digestion.

The highest volume of biogas generated was recorded in experiment no.1, followed by experiment no. 2.

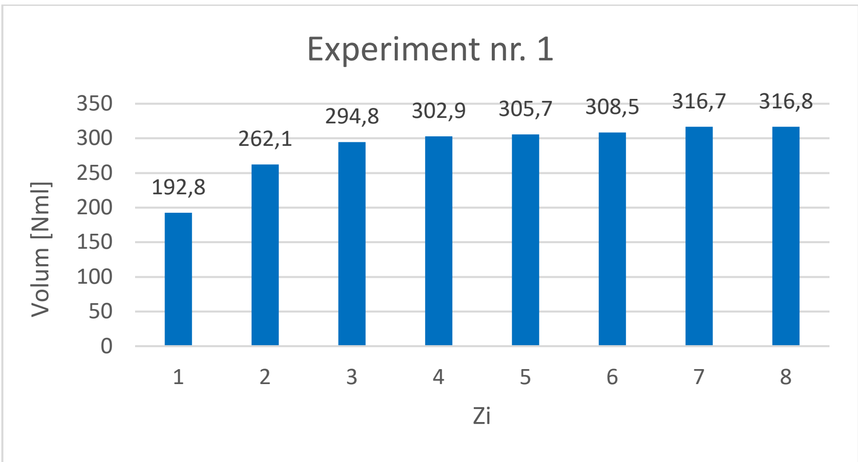

Fig. 5.18.Results of experiment no. 1 biogas generated, using a mixture ofpig droppings 70.39 g, bird droppings 53.79 g, cattle droppings 23.53 g, green grass 20 g, potatoes 20 g, Volume [Nml]

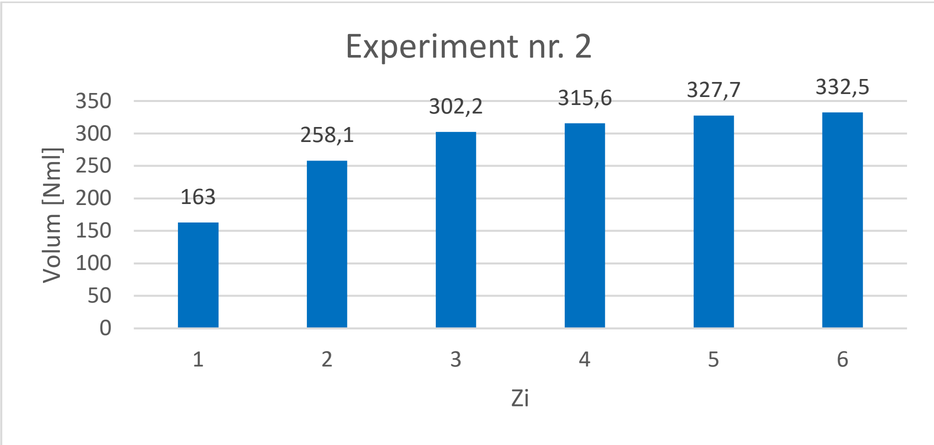

Fig. 5.19.Results of experiment no. 2 biogas generated, using a mixture ofpig droppings 70.39 g, bird droppings 53.79 g, cattle droppings 23.53 g, green grass 40 g, potatoes 10 g

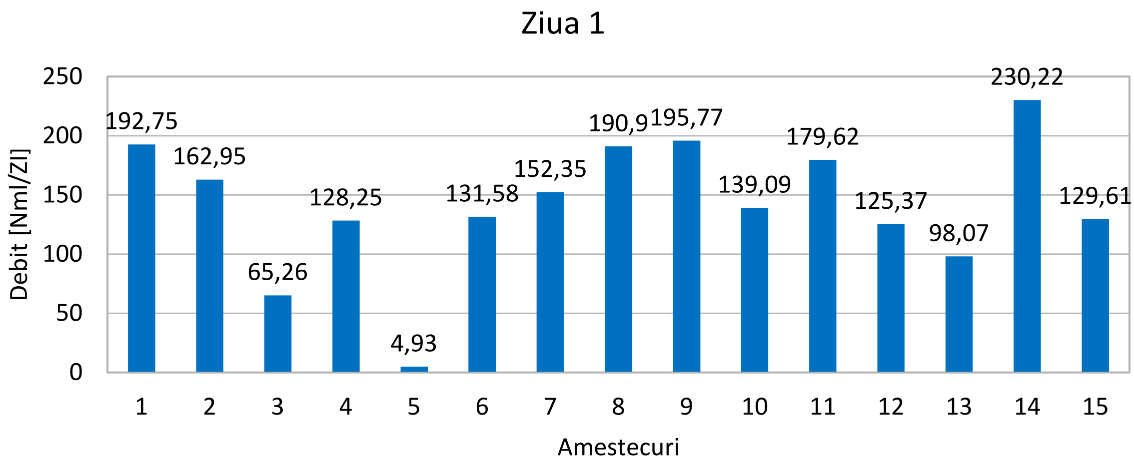

Fig. 5.20.Experimental resultsbiogas flow generated, using a mixture ofpig manure, poultry manure, cattle manure, green grass, potatoes and straw, Flow [Nml/day] – Day 1

The level of biogas generated recorded the highest flow on the first day ofanaerobic digestion, then started to decrease in the following days. The highest flow of biogas generated by experiment no. 1 was registered on the second day, having the value of 195.77 m3/day for the substrate with green grass and potatoes.

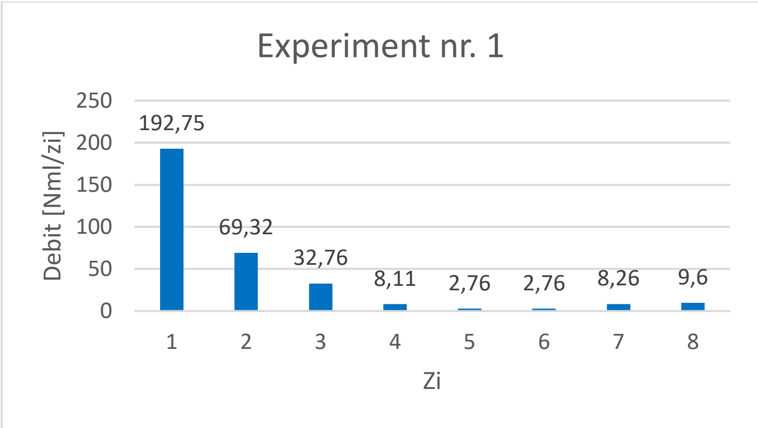

Fig. 5.21.Experimental resultsbiogas flow rate generated by experiment no. 1, using a mixture ofpig droppings 70.39 g, bird droppings 53.79 g, cattle droppings 23.53 g, green grass 20 g, potatoes 20 g, Flow [Nml/day]

Experiment no. 3 recorded the highest flow of biogas generatedhaving the value of392.21m3/day.

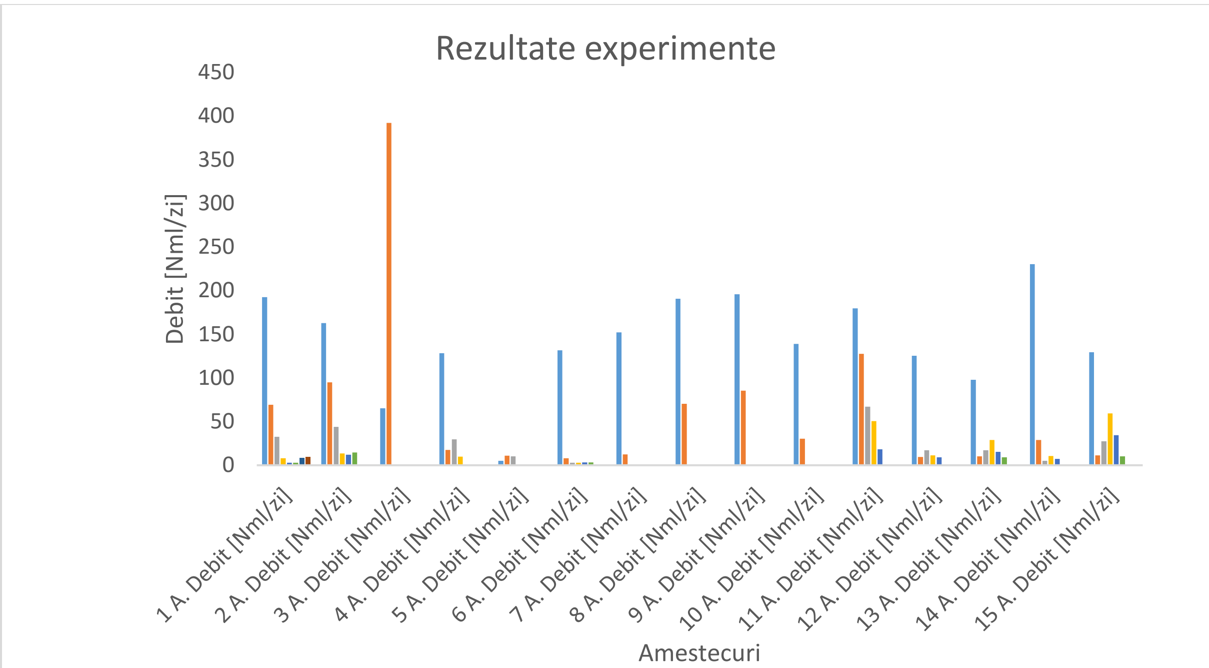

Fig. 5.22.Experimental results, using a mixture ofpig manure, poultry manure, cattle manure, green grass, potatoes and straw - Flow [Nml/day]

In figure 5.42. we made a centralized presentation of the experiments, from which we draw the following conclusions:

- Experiment no. 3 whichconsisted of a mixture of green grass 50 g, potatoes 20 g, pig manure 70.39 g, cattle manure 23.53 g, poultry manure 53.79 g, inoculum 182.29 g, a recorded the highest flow of biogas generated with the value of 392.21 m3/day.
- The mixture that generated biogas for 6 days is mixture no. 3 which consisted of a mixture of green grass 50 g, potatoes 20 g, pig manure 70.39 g, cattle manure 23.53 g, poultry manure 53.79 g, inoculum 182.29 g .
- The best yields were given by the experiments that had in their composition both green grass and animal droppings.

CHAPTER 6. GENERAL CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

6.1. General conclusions

Scientific research focused on the utilization of agro-zootechnical waste in order to obtain biogas through the anaerobic digestion process.

In this sense, we carried out experimental research on manure from poultry farms, cow farms and pig farms, in the laboratory. We used waste water with organic load generated from a sewage treatment plant.

All the objectives proposed and presented in subchapter 1.1. were fulfilled as follows:

- Literature study regarding the energy recovery of agro-zootechnical waste and the production of biogas through the anaerobic digestion process;
- Realization of three experimental sets to investigate the production of biogas using as investigated raw materials: grass, green tomato leaves, potatoes, straw, on a laboratory scale using the BPC Instruments AB - Gas Endeavor biogas production facility.

The aim of the research was to develop an optimal mixture of animal manure and agro-food by-products in order to obtain biogas.

The experimental research consisted in the preparation and testing of 27 recipes of mixtures of three sets of experiments, from farms located in Teleorman county. We kept the animal excrement samples at a temperature of (– 4) o C, in a closed container, protected from light. The inoculum we used to speed up the anaerobic digestion process was taken from a sewage treatment plant in Teleorman County.

The experiments were carried out using the Gas Endeavor biogas plant with a small capacity (15 500 ml glass reactors) and a constant temperature of 37°C.

Each set of experiments was carried out in four phases that included the collection and preparation of samples, the calculation of recipes, the preparation and commissioning of the installation and the collection and analysis of experimental data.

The first set of experiments was carried out for ten days.

The highest yield for biogas production after the first day was obtained for two tested mixture recipes, namely: recipe no. 3 which had as organic waste green grass (lawn) 20%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and 40 g inoculum and recipe no. . 4 which had in its composition as organic waste potato 20%, pig animal waste 40%, cattle animal waste 10%, poultry animal waste 30%, water 172.29 g and inoculum 40 g.

Mixture no. 1 which had in its composition green leaves (tomatoes) 20%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and 40 g inoculum and mixture no. 2 which contained green leaves (tomatoes) 10%, wheat straw 10%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172, 29 g and 40 g inoculum, had a lower yield of biogas generation compared to mixture no. 3.

The best result tested s-recorded on the second day of anaerobic fermentation for mixture no. 3 which had as organic waste green grass (lawn) 20%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and inoculum 40 g, followed by mixture no. 4 which had in its composition as organic waste potato 20%, pig animal waste 40%, cattle animal waste 10%, poultry animal waste 30%, water 172.29 g and inoculum 40 g. Even if the biogas production rate did not register a significant increase for mixture no. 4 which had in its composition as organic waste potato 20%, pig animal waste 40%, cattle animal waste 10%, poultry animal waste 30%, water 172.29 g and inoculum 40 g, for the other two mixtures we recorded a small increase, falling above 200 Volume [Nml].

On the third day, the best result for biogas generationit is also made by mixture no. 3 which had as organic waste green grass (lawn) 20%, pig animal waste 40%, cattle animal waste 10%, poultry animal waste 30%, water 172.29 g and 40 g inoculum, this recording around 300 Volume [Nml], followed by mixture no. 2 which had in its composition green leaves (tomatoes) 10%, wheat straw 10%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and 40 g inoculum , generating biogas up to approximately 200

Volume [Nml], and the mixture that had potato as organic waste in its composition did not generate biogas anymore.

Mixture no. 2 containing green leaves (tomatoes) 10%, wheat straw 10%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and 40 g inoculum and mixture no. . 1 which had in its composition green leaves (tomatoes) 20%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and inoculum 40 g, they are the only ones that still generate biogas on the seventh day.

All mixture no. 2 is the one that generated biogas on the eighth day and the ninth day, the biogas generation being over 200 Volume [Nml] and he also generated biogas for 9 days, recording 200 - 230 Volume [Nml].

In the first five days, the highest biogas generation was given by mixture no. 3 which had as organic waste green grass (lawn) 20%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and inoculum 40 g, registering 240 - 320 Volume [Nml].
The mixture that generated biogas for seven days, recording 140 – 180 Volume [Nml] was mixture no. 1 which had in its composition green leaves (tomatoes) 20%, pig manure 40%, cattle manure 10%, poultry manure 30%, water 172.29 g and inoculum 40 g.

For the second set of experiments, the same mixtures were used as in the first set, but varying the quantities of the components of the mixtures to see how the composition of the mixture influences the production of biogas. The experiment was carried out for nine days.

On the first day of anaerobic digestion, the installation recorded an increase in the volume of biogas in experiment no. 6 which had as raw material: green grass 35%, pig droppings 20%, cattle droppings 15% and bird droppings 30%, inoculum 284.23 g, followed by experiment no. 7, which had as raw material: green grass 40%, pig droppings 15%, cattle droppings 15% and bird droppings 30%, inoculum 278.23 g, followed by experiment no. 4 which had a mixture of green grass 25%, pig manure 30%, cattle manure 15%, poultry manure 30%, inoculum 296.23 g, experiment no. 5 consisted of a mixture of green grass 30%, pig manure 25%, cattle manure 15%, poultry manure 30%, inoculum 290.23 g and experiment no. 8 consisted of a mixture of green grass 45%, pig manure 10%, cattle manure 15%, poultry manure 30%, inoculum 272.23 g. The other experiments that had straw in their composition of wheat generated less biogas, registering up to 50 Volume [Nml].

On the second day of anaerobic digestion, the volume of biogas generated increased in all the experiments carried out, with the highest volume of biogas generated in experiment no. 5 which had as raw material: green grass 30%, pig droppings 25%, cattle droppings 15% and bird droppings 30%, inoculum 290.23 g, followed by experiments no. 4 which had a mixture of green grass 25%, pig manure 30%, cattle manure 15%, poultry manure 30%, inoculum 296.23 g and experiment no. 6 which had as raw material: green grass 35%, pig droppings 20%, cattle droppings 15% and bird droppings 30%, inoculum 284.23 g.

The volume of biogas generated is increasing in all experiments on the third day of anaerobic digestion, in experiment no. 5 which had as raw material: green grass 30%, pig droppings 25%, cattle droppings 15% and bird droppings 30%, inoculum 290.23 g, being the largest volume of biogas recorded, followed by experiment no. 4 which had a mixture of green grass 25%, pig manure 30%, cattle manure 15%, poultry manure 30%, inoculum 296.23 g.

On the fourth day of biogas production, the volume of biogas generated continues to increase in all experiments. the highest volumes of biogas generated were also recorded in experiments no. 5 which had as raw material: green grass 30%, pig droppings 25%, cattle droppings 15% and bird droppings 30%, inoculum 290.23 g and no. 4 which had a mixture of green grass 25%, pig manure 30%, cattle manure 15%, poultry manure 30%, inoculum 296.23 g.

The installation registered a higher volume of biogas also for the mixtures that have green grass in their composition, the mixtures that also contain wheat straw registering a lower yield of biogas generated on the fifth day.

The only experiment that still generated biogas on the ninth day of anaerobic fermentation was experiment no. 4which had a mixture of green grass 25%, pig manure 30%, cattle manure 15%, poultry manure 30%, inoculum 296.23 g, the volume of biogas generated being 189.2 Volume [Nml].

The biogas yield is given on the first day by experiment no. 7 which consisted of a mixture of green grass 40%, pig manure 15%, cattle manure 15%, poultry manure 30%, inoculum 278.23 g.

Biogas generation increases on the second day compared to the first day in experiment no. 5 which consisted of a mixture of green grass 30%, pig manure 25%, cattle manure 15%, poultry manure 30%, inoculum 290.23 g, reaching 143 Volume [Nml] biogas generated .

The third set of experiments was carried out over eight days and included 15 mixture recipes, we used the same mixtures as in the first two sets, but varying the quantities of the mixture components.

Experiment no. 14 is the onewhich generated the highest volume of biogas on the first day of fermentation and had as raw material: green grass 30 g, potatoes 30 g, straw 20 g, pig droppings 12 g, cattle droppings 17.14 g and bird droppings 12 .63 g, followed by experiment no. 9, which had as raw material: green grass 45 g, potatoes 35 g, pig droppings 12 g, cattle droppings 17.14 g and bird droppings 12.63 g, then followed by experiment no. 1, which had as raw material: green grass 20 g, potatoes 20 g, pig droppings 70.39 g, cattle droppings 23.529 g and bird droppings 53.78 g and experiment no. 8, which had as raw material: green grass 40 g, potatoes 40 g, pig droppings 12 g, cattle droppings 17.14 g and bird droppings 12.63 g.

On the second day of anaerobic digestion, all experiments were recordedan increase in the volume of biogas generated, being the largest volume of biogas recorded in experiment no. 11 which had as raw material: green grass 20 g, potatoes 10 g, straw 10 g, pig droppings 70.39 g, cattle droppings 23.52 g and bird droppings 53.78 g, followed by experiments no. 1, 2 and 14.

On the third day of obtaining biogas, the volume of biogas generatedis increasing, in experiment no. 11 whichconsisted of a mixture of green grass 20 g, potatoes 10 g, wheat straw 10 g, pig manure 70.39 g, cattle manure 23.53 g, poultry manure 53.79 g, inoculum 212.29 g, being the largest volume of biogas generated.

On the next day of anaerobic fermentation, the volume of biogas generated continues to increase in almost all experiments.

On the fifth day of anaerobic digestion, experiment no.11 recorded the highest volume of biogas generated andconsisted of a mixture of green grass 20 g, potatoes 10 g, wheat straw 10 g, pig manure 70.39 g, cattle manure 23.53 g, poultry manure 53.79 g, inoculum 212.29 g, the installation recording a larger volume of biogas in the mixtures that have in their composition a smaller amount of green grass and a larger amount of animal waste.

Starting with the sixth day of anaerobic digestion, the laboratory experimentrecorded a decrease in the volume of biogas generated, the only experiment that generated biogas in the following days being experiment no. 1 whichit consisted of a mixture of green grass 20 g, potatoes 20 g, pig manure 70.39 g, cattle manure 23.53 g, poultry manure 53.79 g, inoculum 212.29 g.

Saddlenoticeda decrease in biogas production after the fifth day of anaerobic digestion, which means that anaerobic digestion was mostly complete. The maximum level of biogas was obtained after 5 days of anaerobic digestion.

The level of biogas generatedit recorded the highest flow in the first days of anaerobic digestion, then started to decrease in the following days.

The highest flow of biogas generatedhaving the value of392.21m3/day was recorded byexperiment no. 3 whichconsisted of a mixture of green grass 50 g, potatoes 20 g, pig manure 70.39 g, cattle manure 23.53 g, poultry manure 53.79 g, inoculum 182.29 g.

All mixture no.3 is the one that generated for 6 days biogas consisting of a mixture of green grass 50 g, potatoes 20 g, pig manure 70.39 g, cattle manure 23.53 g, poultry manure 53.79 g, inoculum 182.29 g.

Among the three sets of experiments, the best yields were given by the experiments that had in their composition both green grass and animal droppings.

The installation recorded an efficient production of biogas from the first days, the maximum level being recorded after 5-7 days of anaerobic digestion, the optimal mixtures being those that have a greater amount of green grass in their composition.

These differences between mixtures containing green grass and those containing wheat straw highlight the importance of biomass composition and characteristics in the biogas production process. The detailed analysis and understanding of these differences can provide valuable information for optimizing the composition of the mixtures used in biogas production and for increasing the efficiency of the process.

6.2. Personal contributions

Some of the personal contributions brought to the process of valorization of agro-zootechnical waste as raw material in the production of biogas are the following:

- We carried out an extensive literature study that includes information about the treatment of animal waste and methods of valorization.

- Since the existing research works do not use animal droppings from several categories of animals in the same biodigester, I chose to try several variants of mixtures, which would contain bird droppings, cow droppings, but also pig droppings.

- The realization of 27 recipes, grouped in three sets of experiments, for approximately 10 days, using the Gas Endeavor biogas production facility, with a small capacity and at a constant temperature of 37°C, the proposed purpose being to determine the initial moment of biogas production and identifying the moment of reaching the maximum production level.

- To speed up the anaerobic digestion process, we used the waste water taken from a sewage treatment plant as the inoculum.

- Testing different mixture recipes that included bird droppings, cow droppings, pig droppings, but also plant waste (grass, green leaves, potatoes, straw) in order to identify materials with high biogas production potential , qualitatively and quantitatively.

- We used various compositions to see which are the optimal mixtures in obtaining biogas.

- Mixing animal manure with the inoculum is a first step in the production of biogas and ensures the efficiency of the anaerobic digestion process.
- The results of the research carried out during the doctoral training were capitalized by the elaboration and publication of 10 scientific papers in specialized journals (4 indexed BDI and 1 ISI) or in the volumes of international conferences, as author and co-author, according to the list attached at the end of the thesis .

6.3. Recommendations and future research directions

The thesis presents a series of laboratory research aimed at identifying optimal strategies for carrying out fermentation processes, with the aim of increasing the economic profitability of biogas production units. The obtained results provide valuable information about the use of agro-zootechnical waste for the production of biogas.

The present work opens new perspectives for further research, such as:

- increasing biogas production using various types of substrate, analyzed under similar experimental conditions.
- carrying out experimental studies involving the use of different concentrations of biomass as additives for fermentation.
- investigating innovative pretreatment strategies and increasing biomethane production.
- extension of physico-chemical and biological analysis methods for a detailed description of the fermentation medium and intermediate phases of the process.

The continuation of research on anaerobic fermentation processes can attract the interest of legislative structures and by attracting investments inregarding biogas production technologies, the number of specialists in this field can also increase. The adoption of such technologies only brings important benefits to the environment through a good management of agro-zootechnical waste and the production of green energy.

The promotion and implementation of biogas production facilities within farms mustbecome a priority, especially if we want to put into practice the concept of sustainable development.

LIST OF PUBLICATIONS

1. **Roxana MITROI**, Oana STOIAN, Cristina Ileana COVALIU, Dragoş MANEA, Pollutants resulting from intensive poultry farming activities and their impact on the environment, E3S Web Conferences 286, 03018 (2021) TE-RE-RD 2021.
2. Dragoş MANEA, Eugen MARIN, Gabriel GHEORGHE, Cătălin PERŞU, Roxana MITROI, Experimental research of equipment for burying in the ground the drip irrigation lines, E3S Web Conferences 286, 03011 (2021) TE-RE-RD 2021.

3. **Roxana DRÁGHICI (MITROI)**, Sorin-Ştefan BIRIŞ, Cristina Ileana COVALIU-MIERLĂ, Mihaela NIŢU, Technological flow in the poultry farms and environmental impact assessment, INTERNATIONAL SYMPOSIUM ISB-INMA TEH' 2022, 742-747.
4. **Roxana MITROI**, Cristina Ileana COVALIU-MIERLĂ, Biogas - a solution for treating animal waste resulting from zootechnical activities, accepted for publication in the Scientific Bulletin of the National University of Science and Technology POLITEHNICA BUCHAREST.
5. **Roxana MITROI**, Cristina Ileana COVALIU-MIERLĂ, Cristina-Emanuela ENĂŞCUțĂ, Grigore PSHENOVSCH, Zootechnical waste as raw material for biogas production and as fertilizer for agriculture, accepted for publication in Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering ISSN 2285-6064, volume XIII, 2024, LRE 30.
6. **Roxana MITROI**, Cristina Ileana COVALIU-MIERLĂ, Cristina-Emanuela ENĂŞCUŢĂ, Grigore PSHENOVSCH, Livestock waste in the context of agricultural sustainability, accepted for publication in the Scientific Bulletin of the National University of Science and Technology POLITEHNICA BUCHAREST.

PRESENTATIONS AT INTERNATIONAL CONFERENCES

1. TE-RE-RD 2021 – oral presentation

- Authors: Roxana Mitroi, Oana Stoian, Cristina Ileana Covaliu, Dragoş Manea;
- Title of the paper: Pollutants resulting from intensive poultry farming activities and their impact on the environment;
- Conference title: International Conference on Thermal Equipment, Renewable Energy and Rural Development TE-RE-RD 2021;
- Period: June 10 – 11, 2021;
- Location: Polytechnic University of Bucharest

2. ISB – INMA TEH' 2022 – oral presentation

- Authors: Mitroi R., Biriş S.Ş, Covaliu - Mierlă IC, Niţu M.;
- Title of the paper: Technological flow in the poultry farms and environmental impact assessment

- Conference title: International Symposium ISB-INMA TEH Agricultural and Mechanical Engineering;

- Period: 06 – 07 October 2022;

- Location: Polytechnic University of Bucharest

3. ISB – INMA TEH' 2023 – oral presentation

- Authors: Mitroi R., Covaliu – Mierlă IC, Paraschiv G., Biriş S.Ş;

- Title of the paper: Biogas - a solution for treating animal waste resulting from zootechnical activities

- Conference title: International Symposium ISB-INMA TEH Technologies and Technical Systems in Agriculture, Food Industry and Environment;

- Period: 05 – 06 October 2023;

- Location: Polytechnic University of Bucharest

4. A4LIFE_ 2024 – oral presentation

- Authors: Mitroi R., Covaliu – Mierlă IC, Enăşcuță C. E, PSHENOVSCH G.;

- Title of the paper: Zootechnical waste as raw material for biogas production and as fertilizer for agriculture

- Conference title: International Conference "Agriculture for Life, Life for Agriculture";

- Period: 06 – 08 June 2024;

- Location: University of Agronomic Sciences and Veterinary Medicine from Bucharest

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