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SUSTAINABLE NUTRITIONAL SOLUTIONS FOR ANIMAL PRODUCTION: OPTIMISING NUTRITION TO REDUCE POLLUTION

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Abstract

The contribution of animal production to environmental pollution is a pressing global issue. This study aims to evaluate the chemical composition of selected feeds and explore the relationship between feed composition and pollutant emissions generated by animals. Chemical analyses of 10 feed samples assessed parameters such as protein, cellulose, fat, and nitrogen-free extractive contents. The goal was to identify some connection with pollutant emissions and propose nutritional strategies to reduce emissions, improve nutrient utilisation, and promote the sustainable management of animal resources. The results revealed potential links between feed composition and different emissions from animals with considerable environmental impact. High-protein feeds were associated with elevated nitrogen residues, while feeds with greater digestibility showed potential for reduced pollutant emissions. Future efforts should focus on adjusting feed composition and integrating optimised feed formulations to support a sustainable approach to animal nutrition, and reducing pollution from livestock production systems, benefiting both the environment and public health.

***Key words**: environment, feed composition, livestock, pollution.*

INTRODUCTION

Industrial and technological developments, needed to support a growing population, have generated different pollutants, adversely impacting ecosystems. The destabilisation of the natural environments often results from antropogenic activities, whether conscious or inadvertent, which introduce disruptive factors that interact with various ecosystem components. Agriculture, particularly animal production, considerably contributes to environmental pollution through greenhouse gas emissions or manure rich in nitrogen and phosphorus, which degrade soil and water quality (U.S. EPA, 2019; Ukaogo et al., 2020). Due to their dynamic behaviour, bioaccumulation potential, and inherent toxicity, pollutants pose a serious threat to all environmental elements. Consequently, phased monitoring of their impact, along the trophic cycle – from soil and agricultural crops to organisms and animal–derived products – is required for understanding and mitigating their cumulative effects (Matei et al., 2024b). Recent changes in pollution levels and population consumption trends, characterised by an increasing demand for animal products, underscore the close connection between animal husbandry and the environment. This dynamic highlight the importance of producing safe (Postolache et al., 2020; Lăpușneanu et al., 2025), high-quality outputs while ensuring animal welfare and implementing effective strategies to minimize pollution's environmental impact and preserve ecological balance (Mitchell, 2007). Pollution stemming from animal production has become a major concern, particularly due to intensive practices and diversification of production methods. While the interaction between animals and the environment is unavoidable (Postolache et al., 2015), animal husbandry paradoxically represents a major source of pollution, contributing through waste, gaseous emissions, and chemical residues from current treatment practices applied to livestock (Dumitraș, 2008).

The polluting potential of animal waste is determined by the substances present in manure, which, when exceeding the environment's tolerance levels, contribute to its gradual degradation. According to the U.S. EPA (2019), excess phosphorus and nitrogen in animal manure are among the primary factors negatively affecting the environment. Among the residual constituents, Neumeier & Mitloehner (2013) emphasise emissions with considerable environmental impacts, including greenhouse gases, hydrogen sulphide, ammonia, or volatile organic compounds. In practice, ammonia, methane, and nitrous oxide are the principal pollutants linked to animal production; these pollutants have direct implications for climate change, air quality, and water pollution. Methane (CH_4) has been classified as a main pollutant due to its major contribution to the greenhouse effect and global warming (IPCC, 2013). Other gases contributing to the greenhouse effect are carbon dioxide (CO_2), nitrous oxide (N_2O), and fluorinated gases (U.S. EPA, 2019; IPCC, 2014). From a nutritional perspective, the feed administered to animals directly influences their health and productivity (Rațu et al., 2021). The ideal functioning of the animal body and its production performance are closely tied to the energy density of the feed, the balance of nutrients, and their biologically active components assimilated from the feed (Coșman et al., 2018). Research on feed efficiency has demonstrated that factors such as dry matter digestibility, protein and fat content, and feed safety are determinants for nutrient absorption (Liu et al., 2018; Gallo et al., 2020; Pu et al., 2021; Mwaniki et al., 2021). The chemical and biological characteristics of feeds, such as digestibility and nutrient composition, are essential for optimizing growth, minimizing overfeeding, and reducing environmental impact. A balanced diet, associated with feed availability and nutritional profile knowledge, contributes to reducing waste, reducing polluting emissions (Neumeier & Mitloehner, 2013) and limiting economic losses. However, while well-formulated feeds enhance animal health and productivity, they can also serve as vectors for contaminants, impacting both animal health and the environment (Matei & Pop, 2022; Lăpușneanu et al., 2024). Contaminants such as mineral oil hydrocarbons (MOSH/MOAH), pesticides, or heavy metals can interfere with animal health and affect the ecosystem's balance (Ciobanu et al., 2020; Boișteanu et al., 2024). A serious concern is the transfer of these pollutants from feed to animals and, subsequently, to products intended for human consumption (Matei et al., 2024a). Different studies (Jaspers et al., 2014; Ali et al., 2019) highlighted the mechanisms of pollutant bioaccumulation and transfer, underscoring the pivotal role of feed composition and nutritional management in mitigating their impact on health and the environment.

In this context, the work aims to analyze the chemical composition of certain feeds and investigate the connections between it and polluting emissions linked to animal production. The main objective is to identify sustainable nutritional solutions and to create strategies that contribute to reducing the environmental impact by improving nutrition and resource efficiency. These initiatives are intended to provide a deeper understanding of the role of animal production in pollution and to support the implementation of sustainable farm practices, with positive effects on both the environment and public health.

MATERIALS AND METHODS

The analyses carried out aimed to determine the raw chemical composition of the feeds while establishing their relationship with the polluting emissions associated with animal production. The investigations aimed to assess the impact of technological conditions on the pollution linked to animal production and to identify solutions for optimizing nutrition and promoting the efficient use of available resources.

Sample Collection

The research material was represented by 10 samples of animal feed collected from a livestock farm. These samples included different types of feed, such as fresh, dried, preserved, concentrated, and mixed. The samples were collected following the SR EN ISO 6497:2005 standard and the provisions of Regulation (EC) 152/2009–Annex I to make sure they were accurate and fair. The final samples weighed between 1.5 and 3.0 kg and were prepared for analysis following the rules to keep the integrity of chemical composition. The way the samples were prepared followed the guidelines outlined in SR EN ISO 6498:2012 and the provisions of Regulation (EC) 152/2009–Annex II.

Sample Processing

To determine the crude chemical composition, the samples were dried, ground, and homogenized using methods that preserved the integrity of the compounds and prevented the denaturation of essential components. Bulk forages were initially manually cut to 1-2 cm sizes, while fresh and pickled feed were pre-dried at 60ºC, to reach 8-12% moisture content. Afterward, all the samples were ground into a fine powder using the Grindomix GM 200 lab mill. For the concentrated feed samples, they were directly ground into a fine powder using the same Grindomix GM 200 mill.

Chemical Analysis

Chemical analyses were done according to standardized and internationally recognized methods, with literature additional adaptations (Matei & Pop, 2023). The crude chemical composition was performed using the modified Weende method, as described in Annex III of Regulations (EC) 152/2009. These analyses followed the methods set by national and international standards for each constituent: SR ISO 6496:2001; SR EN ISO 6540:2021; SR ISO 712:2010 (moisture); SR EN ISO 2171:2010 (ash); SR EN ISO 5983-1:2006/AC:2019 (crude protein); SR ISO 6492:2001/AC:2016 (ether extract/fats); SR EN ISO 6865:2002/AC:2017 (crude fiber).

Processing and Data Interpretation

The quality of the analyses was ensured by using reference standards for equipment calibration and method validation. Data reproducibility was confirmed through replicate analyses for each sample, verifying the consistency of the results. For statistical processing, primary estimators of position (mean) and variation (standard deviation, coefficient of variation) were calculated. The interpretation of the results was achieved by correlating them according to the type of samples and the selected variables, being discussed by referring to literatura data.

RESULTS AND DISCUSSIONS

In this study, feed samples were analyzed to determine their raw chemical composition, such as the content of organic and inorganic substances; Table 1 summarizes the average results on crude chemical composition. The results were compared with reference values reported in the literature and contextualized with finding from previous similar research.

To investigate the relationship between the chemical composition of feed and the potential for polluting emissions from animal production, the study hypothesized that a balanced ration – defined as a mixture of feeds rich in energy substances, with a moderate protein and cellulose content – can optimize the utilization of nutritional resources and reducing the polluting impact, by improving feeding efficiency and reducing emissions of environmentally harmful gases.

The ration includes the essential parameters that influence the nutritional balance of animal nutrition, based on various feed sources with different nutritional profiles (dry matter DM, ash, crude protein CP, ether extract EE, crude fiber CF, non-nitrogenous extractive substances NES). These parameters are analyzed through the coefficient of variation (CV, %), which reflects the variability of each nutrient and provides insights into their consistency across the ration (Figure 1).

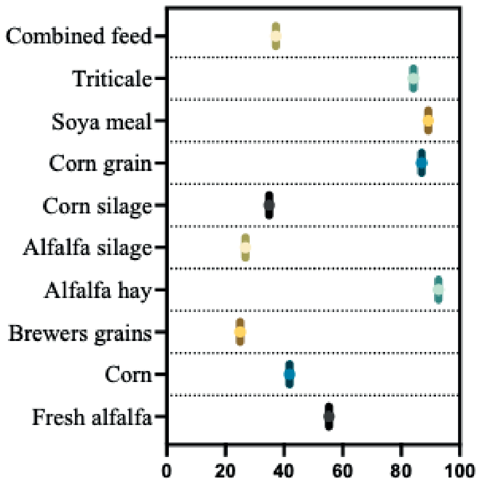

Figure 1. Dry matter content of feed (%) – the main source of nutrients available to animals

The ration is formulated using a mix of green feeds, wet roughage and hay, each adding different content of CP, NES and CF (Figure 2). Soybean meal, its high crude protein content (54.58% DM) is an important contributor to the protein intake of the ration. Meanwhile, corn grain, rich in NES (81.72% DM), fulfills the energy and growth requirements of the animals. Additionally, hay, silage and brewer's grains supply considerable amounts of CF, important for maintaining an optimal digestive process in livestock.

Table 1. Average data and variability of chemical composition of feeds

Sample	Mean	DM[1]	Ash	OM[2]	EE[3]	CP[4]	CF[5]	NES[6]	NES / CF
		%	% DM						
Fresh alfalfa	$\bar{x}\pm s_{\bar{x}}$	55.32±0.02	13.16±0.07	86.82±0.06	2.35±0.13	28.59±0.07	21.74±0.15	34.14±0.12	1.57
	CV (%)	0.11	1.22	-	12.77	0.59	1.59	0.84	-
Corn	$\bar{x}\pm s_{\bar{x}}$	41.89±0.02	2.84±0.06	97.14±0.06	2.54±0.16	7.92±0.06	19.63±0.05	67.05±0.26	3.42
	CV (%)	0.10	5.38	-	14.66	1.74	0.62	0.88	-
Brewer's grains	$\bar{x}\pm s_{\bar{x}}$	24.99±0.05	4.02±0.03	95.95±0.03	8.97±0.17	34.14±0.03	15.14±0.12	37.70±0.18	2.49
	CV (%)	0.01	2.07	-	4.27	0.24	1.90	1.08	-
Alfalfa hay	$\bar{x}\pm s_{\bar{x}}$	92.71±0.02	13.22±0.09	86.75±0.09	1.81±0.07	21.92±0.10	28.22±0.11	34.80±0.08	1.23
	CV (%)	0.70	1.67	-	8.78	1.08	0.88	0.57	-
Alfalfa silage	$\bar{x}\pm s_{\bar{x}}$	26.85±0.02	13.52±0.14	86.45±0.14	2.04±0.06	14.07±0.06	36.16±0.10	34.18±0.21	0.95
	CV (%)	0.07	2.40	-	7.38	0.99	0.62	1.39	-
Corn silage	$\bar{x}\pm s_{\bar{x}}$	34.92±0.01	3.31±0.03	96.67±0.03	3.63±0.09	8.77±0.10	18.42±0.09	65.85±0.21	3.57
	CV (%)	0.06	2.40	-	5.71	2.63	1.14	0.72	-
Corn grain	$\bar{x}\pm s_{\bar{x}}$	86.95±0.07	1.32±0.01	98.66±0.01	4.30±0.07	10.66±0.13	1.98±0.03	81.72±0.16	41.27
	CV (%)	1.34	2.08	-	3.91	2.73	3.53	0.44	-
Soya meal	$\bar{x}\pm s_{\bar{x}}$	89.26±0.03	7.28±0.01	92.70±0.08	1.22±0.07	54.58±0.11	3.83±0.07	33.07±0.19	8.63
	CV (%)	0.79	0.34	-	13.90	0.47	4.53	1.33	-
Triticale	$\bar{x}\pm s_{\bar{x}}$	84.14±0.01	2.25±0.02	97.73±0.03	1.63±0.12	15.37±0.04	3.06±0.04	77.67±0.11	25.38
	CV (%)	0.19	2.81	-	17.46	0.65	3.42	0.34	-
Combined feed	$\bar{x}\pm s_{\bar{x}}$	37.16±0.01	4.31±0.04	95.66±0.04	2.92±0.07	10.10±0.07	18.35±0.04	64.29±0.12	3.5
	CV (%)	0.05	2.21	-	5.96	1.61	0.48	0.41	-

[1]DM=dry matter; [2]OM=organic matter; [3]EE=ether extract; [4]CP=crude protein; [5]CF=crude fiber; [6]NES=non-nitrogenous extractives substances.

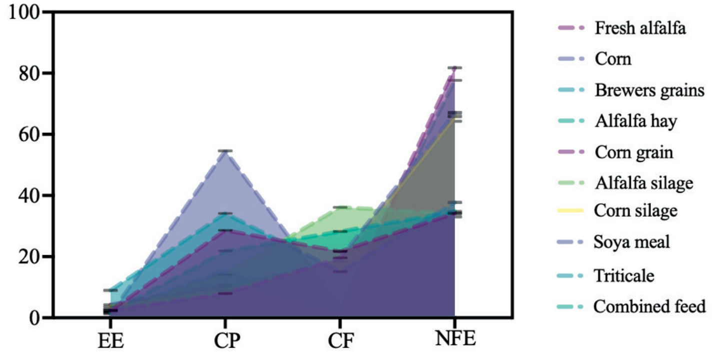

Figure 2. Organic matter (% DM) content in the analyzed feeds

The impact of feed chemical composition on pollution, particularly through greenhouse gas emissions, requires a detailed understanding of how the chemical components influence digestibility and methane production in the rumen; some of feed compounds directly affect the digestion rate and retention time within the digestive tract. More easily digestible feeds can help reduce greenhouse gas emissions, while feeds rich in insoluble fiber tend to increase the

volume of solid manure, complicating its management and heightening the risk of environmental pollution.
A key indicator in this context is the NES/CF ratio, indicating the fraction of fermentable carbohydrates in the diet. Feeds with increased NES/CF ratio allow easily metabolizable carbohydrates, stimulating propionic fermentation in the rumen, a reduction of producing methane in comparison to other fermentation types, helping to reduce methane emissions.
Based on the analyses carried out, most of the feeds in the evaluated ration exhibit a moderate NES/CF ratio. Feeds such as brewer's grains, green corn, corn silage, and combined feed show an optimal balance between NES and CF, making them highly digestible and associated with lower methane emissions than more fibrous feeds. These options not only contribute to reduced air pollution, but also have a lower ecological footprint, making them ideal for sustainable animal production.
Highly concentrated feeds, including corn, triticale, or soybean meal which contain NES have high digestibility and therefore low methane yield. However, their extensive use increase production costs and contribute to secondary forms of pollution, such as those associated with intensive agricultural practices (Matei et al., 2024b).
The assessed ration also contained low NES/CF ration feeds like alfalfa hay (1.23), green alfalfa (1.57) or alfalfa semi-silage (0.95). These fibrous feeds are generally less digestible and should be fed in limited quantities in order to reduce methane emissions. It is suggested to combine them with concentrated feeds to maintain dietary balance. Overall, less directly metabolizable energy sources (soybean meal or hay) for ruminal microbes are associated with anaerobic fermentation and thus with enhanced emissions of methane. In contrast, more easily digestible high-NES feeds, such as corn grain or corn silage, have the potential to limit potentially polluting discharges.
In particular, the protein content among the chemical constituents of feed contributes to soil pollution. High-protein diets carry the risk of higher environmental contamination, because excess proteins are wasted and excreted in the form of nitrogen, leading to soil and water contamination by nitrate leaching. Achieving an optimal balance between crude protein CP and non-nitrogenous extractives NES is essential to reduce this impact. Feeds rich in CP can result in higher ammonia emissions in urine and faeces, exacerbating nitrogen pollution, especially when protein intake exceeds the animal's nutritional needs. Analysis of the feeds included in the ration reveals important variations in CP content (Figure 3), which can directly affect nitrogen excretion levels and the environmental impact of animal production.

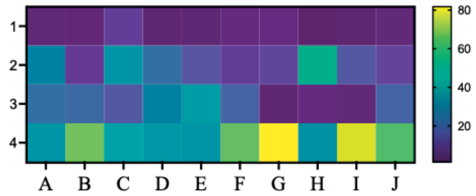

Figure 3. Variability in organic matter (% DM) contribution across the feeds included in the ration
(1 - EE; 2 - CP; 3 - CF; 4 - NES; A - Fresh alfalfa; B - Corn; C - Brewers grains; D - Alfalfa hay; E - Corn grain; F - Alfalfa silage; G - Corn silage; H - Soya meal; I - Triticale; J - Combined feed)

Feeds such as green alfalfa, alfalfa hay, green corn, brewer's grains, corn silage, grain corn or triticale have a moderate protein content (1.25-13.33% DM), suggesting a low impact on nitrogen excretion. The high NES content in some of these forages such as green corn, corn silage, grain corn, triticale, contributes to maintaining an adequate nutritional balance, reducing the risk of exceeding the protein requirements of the animals. In contrast, soybean meal, with its high protein content (54.58% DM), can favor nitrogen excretion if not used efficiently, especially in animals with limited capacity to fully metabolize the proteins in their diet. However, this effect depends on the amount used in the ration, as well as in the main nutritional composition of the combined feed.
Previous studies (Ferket et al., 2002; Burkholder et al., 2007) have repeatedly emphasized the importance of efficient animal nutrition management to reduce the impact of environmental pollution. Carter & Kim (2013) pointed out the connection between animal feeding and environmental deterioration, associating suboptimal rations with higher rates of nitrogen and phosphorus discharge from manure. They concluded that excess nutrients provided in animals rations are not fully

assimilated for productivity, often contributing to nutrient pollution. These findings align with our observations, which indicate that the types of feed included in the analyzed ration have a considerable influence on nitrogen excretion level, especially in relation to their protein content and NES/CF ratio.

Some of feeds included in the analyzed ration presented a moderate NES/CF ratio, having a higher digestibility. These characteristics align with previous findings, which suggest that, adopting a balanced and well-formulated diet is sufficient to reduce nitrogen and phosphorus pollution. In contrast, feeds with a low NES/CF ratio, such as hays, are richer in insoluble fiber, which can lead to an increase in the volume of solid manure and thereby contribute to soil pollution. This effect is consistent with the studies of Hristov et al. (2006) who identified a direct link between excessive feed administration and soil pollution with nitrogen and phosphorus through their research on the quantitative control of potentially polluting nutrients in manure.

Chemical composition analysis of the studied ration showed that the protein content in the ration is also a remarkable contributor to soil pollution. High protein feeds like soybean meal can lead to nitrogen pollution as documented by studies carried out by Ferket et al. (2002); Knowlton et al. (2004) which demonstrated that excessive protein intake in the ration can lead to increased ammonia emissions. Furthermore, this protein surplus may disrupt nutritional balance of the ration, reducing the efficiency of nutrient conversion and causing important nutrient losses to the environment.

Regarding pollution reduction strategies, research has shown that the most effective practices involve optimizing rations to reduce nutrient waste. Sofia et al. (2020) pointed out that environmental pollution reduction must be accompanied by measures to increase the production efficiency and adopt ecological approaches. In this context, the integration of feeds with high digestibility and a balanced protein and cellulose content into rations can contribute to achieving these objectives. Also, as part of pollution reduction strategies, biotechnologies and the use of feed additives can be promising solutions to improve feed utilization and reduce the ecological impact of animal production.

CONCLUSIONS

The feed chemical composition influences both the efficiency of animal digestion and the environmental release of pollutants. Feeds high in crude fiber promote intense fermentation in the rumen, leading to increased emissions of methane and other greenhouse gases. Conversely, feeds rich in non-nitrogen extractives substances, like corn grain or corn silage, provide a quick source of energy, helping to reduce methane production. However, an unbalanced intake of crude protein, without proper alignment with NES levels can result in nitrogen losses through feces and urine, exacerbating pollution from nitrogen compounds. Achieving a balanced feed ration is essential to minimize the environmental impact, requiring the use of highly digestible feeds with an optimal ratio of crude fiber, crude protein, and non-nitrogenous extractives substances.

Reducing the environmental pollution caused by animal production through optimized animal nutrition and feed composition is achievable by targeted nutritional strategies that ensure the efficient use of feed resources.

These strategies include formulating balanced rations tailored to animal requirements, by such means reducing nitrogen and phosphorus excretions. These rations should incorporate highly digestible feeds, reducing waste and improving feed conversion efficiency into animal products. Additionally, the use of feed enzymes and other feed additives can enhance nutrient digestion and absorption of nutrients, while feed processing technologies like grinding and pelleting, improve nutrient availability and minimize lossed. To maximize effectiveness, these nutritional strategies should align with proper livestock management and optimized nutrient flows on the farm. These measures can be implemented as part of European and global initiatives aimed at pollution reduction, fostering more sustainable and efficient animal production to meet growing consumer demands.

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