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Environmental safety aspects of using the digestate from an agricultural biogas plant

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Abstract. This review aims to summarize research findings and provide an up-to-date assessment of the current state of knowledge on the environmental safety of digestate, including its effects on soil, crop yields and animal health. Topics covered include the potential benefits and drawbacks of using digestate as a fertilizer. In recent years, the biogas industry in Europe has experienced significant growth. Many countries are actively promoting biogas production as a means to reduce greenhouse gas emissions and achieve renewable energy targets. As a result, there has been a corresponding increase in the production of digestate remaining after the anaerobic digestion of organic waste. Digestate is a source of growing concern due to its potential adverse effects on the environment, specifically concerning soil quality and the risk of nutrient runoff. A number of studies have been conducted in European countries to assess the safety of digestate for the environment and identify ways to reduce its negative impact.

Keywords: environmental safety, digestate, agricultural biogas plants, nutrients.

INTRODUCTION

Anaerobic digestion is often considered as the most promising way to recover energy from materials with high concentrations of organic matter (Bernat et al., 2008). Biogas is an energy source produced by anaerobic digestion of organic matter, typically contains about 40–70% of methane. Due to its high energy value, methane can be considered as an energy source for heat or electricity production (Montusiewicz, 2008). Biogas plants not only produce renewable energy, but also produce digestate, which is a so-called by-product (Fig. 1).

The digestate is the solid and liquid residue from the anaerobic digestion process of bio-waste, residues, dedicated crops and natural fertilizers. Biogas plant digestate can be used as fertilizer in agriculture due to its high nutrients content (Möller, Müller, 2012; Liu et al., 2021). Lamolinara et al. (2022) indicate that the use of digestate as a biofertilizer due to its nutrient content is one of the most promising applications to minimize and avoid direct and indirect impacts on the environment and human health, and to improve the economic viability of biogas production systems. A study in Switzerland showed that digestate can be used as a fertilizer, but with caution to avoid excessive use that can lead to environmental pollution, as a result of the runoff of fertilizer components (Lohri et al., 2017).

It is worth noting that there may be risks associated with the use of natural fertilizers like parasitological contamination, the presence of heavy metals or the presence and content of antibiotics (Patyra et al., 2023) – in this publication authors describing manure as a natural fertilizer. Natural fertilizers are originally produced directly from animal farms. Patyra et al. (2023) have the same concerns refer for: microbiological and parasitological contamination, the presence of heavy metals and presence of chemical substances excreted from the organism of animals in these fertilizers, including antibiotics and their metabolites. Their use may have a negative impact on animal and human health and also on the environment by increasing development of antibiotic resistance of pathogenic microorganisms, affecting adversely microbiota of the digestive tract in animals and humans. Currently, there are no regulations for processing, laboratory testing for microbial and parasitological contamination, the presence of heavy metals, or the presence and content of antibiotics for the application of natural fertilizers to cropland and farmland, and there is no global standard process for the safe handling of digestate (Eraky et al., 2022). A further studies in this area are needed to find limits for that kind of contaminations. But in the subject of other risks connected to applications of digestate we can prevent or reduce greenhouse gas emissions into the air or avoid nitrogen losses by planning the timing

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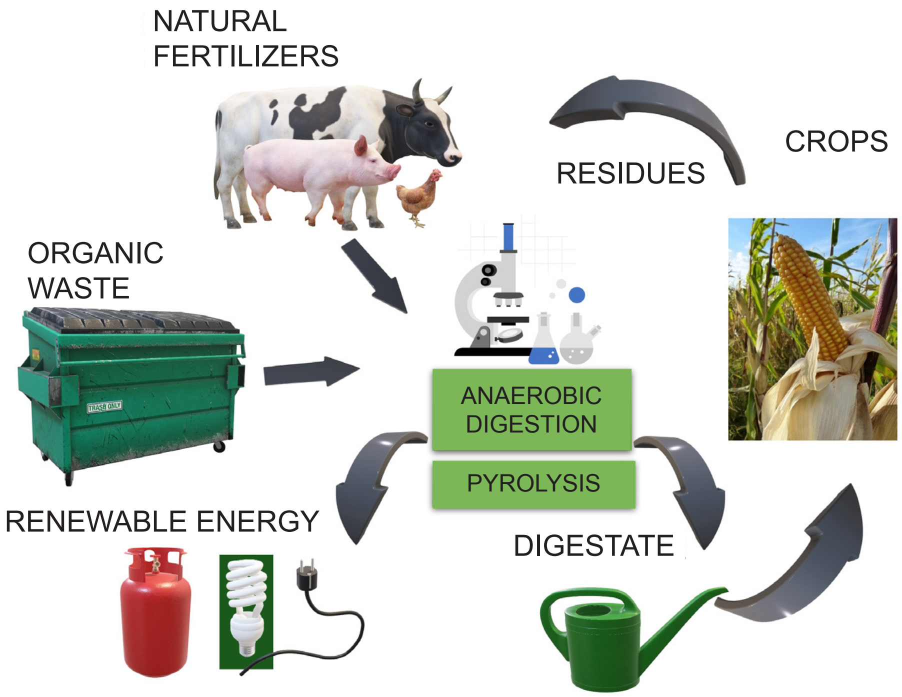

Figure 1. Close loop digestate diagram.
Source: Own elaboration

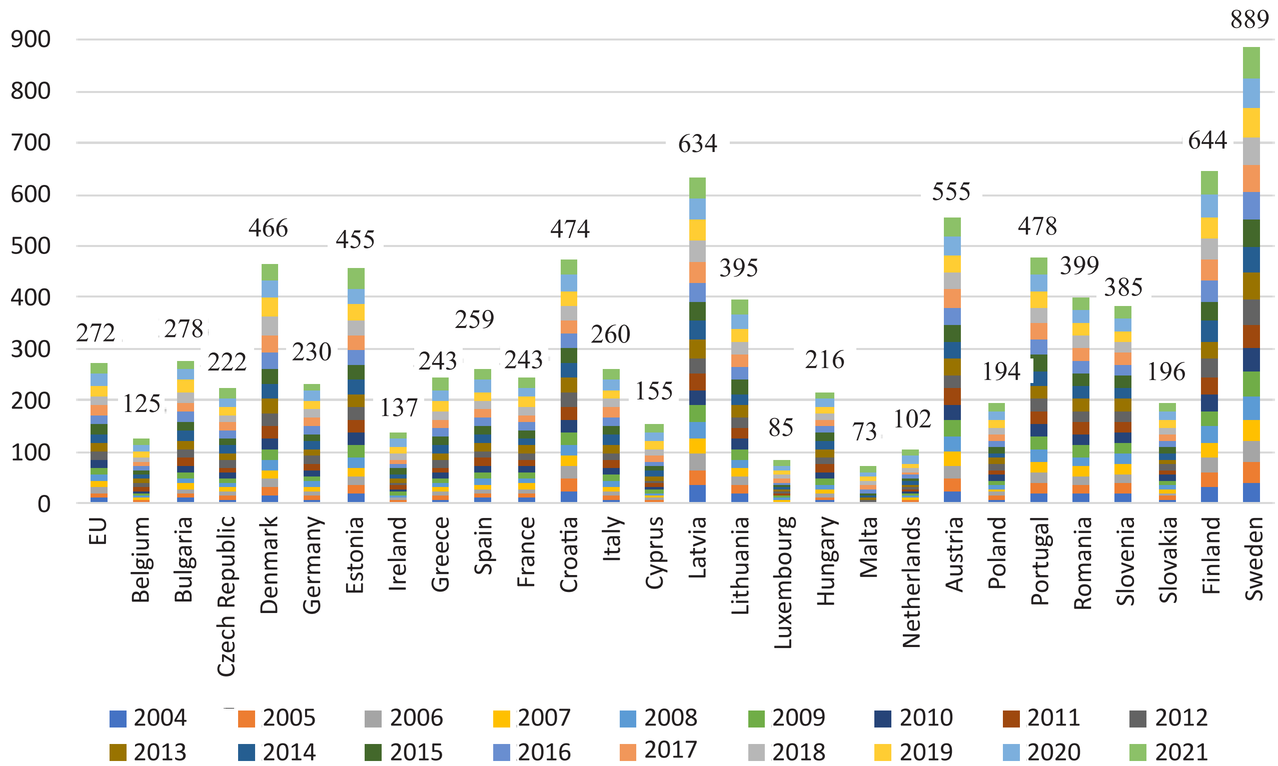

Figure 2. Average gross of share of energy from renewable sources in 2004-2021 in Europe (% of gross finally energy consumption).
Source: Eurostat (online data 24.08.2023). Result until 2002 are based on the methodology included in Directive 2009/28/EC, while results for 2021 are based on Directive (EU) 2018/2001

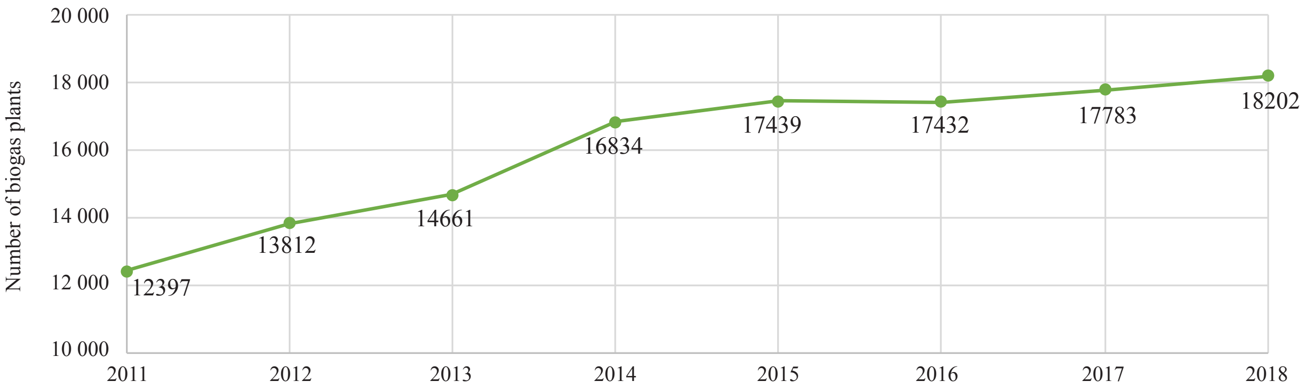

Figure 3. Development of the total number of biogas plants in Europe in years 2011–2018.
Source: EBA 2020.

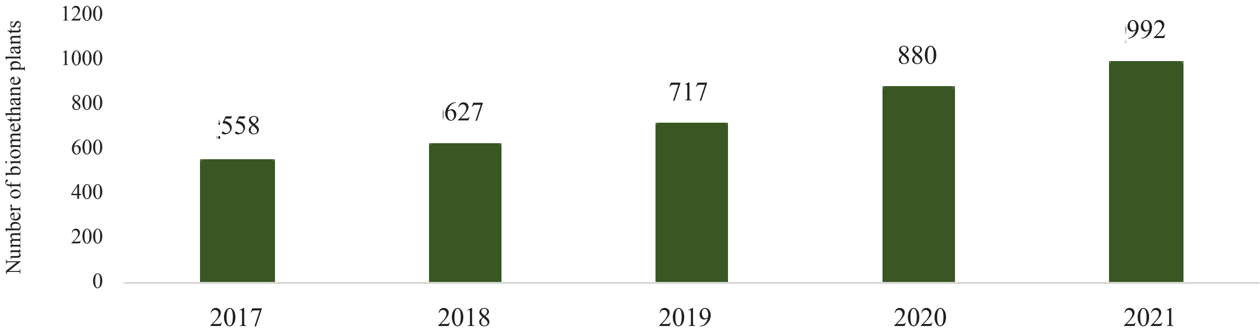

Figure 4. Number of biometane plants in Europe in 2017–2021.
Source: Jens et al., 2021.

of the application of it (Al Seadi, Lukehurst, 2012). Factors to pay attention, to when evaluating the safety aspects of the application of manure and digestate from agricultural biogas plants, are its impact on soil fertility and pathogens, the aspect of newly formed pollutants, metals and nitrogen and phosphorus management, and greenhouse gas emissions. The application of good agri-environmental practice is a mandatory element here.

Over the past seventeen years, there has been a significant increase in the share of energy derived from various renewable sources, including biogas plants (Fig. 2). This trend illustrates the growing popularity and importance of renewable energy sources since 2004.

Among various renewable energy sources, we can include biogas plants and biomethane plants. The production of biogas and biomethane has increased in Europe in recent years, and with this comes an increase in the production of digestate (Fig. 3, 4).

From 2017 to 2021, Europe has witnessed a remarkable surge in the number of biomethane plants, signaling a profound commitment to sustainable energy solutions. This period of rapid growth reflects a collective effort towards harnessing the potential of biomethane as a clean and renewable resource. The increasing numbers of biomethane plants across the continent highlight a strategic response to environmental challenges, showcasing a tangible shift towards greener energy alternatives.

In recent years, the use of agriculture biogas plants has become increasingly popular as a sustainable alternative to energy production (Fig. 5).

In recent years, there has been a notable evolution in the field of biogas production, specifically within agricultural biogas plants. This dynamic shift has seen a transformative progression towards biomethane production, marking a pivotal moment in sustainable energy practices. The increasing emphasis on harnessing biomethane from agricultural waste showcases a commitment to cleaner and more efficient energy sources. Illustrating this remarkable transition, a diagram depicting the share of biomethane plants in Europe offers a visual testament to the region's dedication to renewable energy. The diagram reveals a compelling narrative of growth, with biomethane produc-

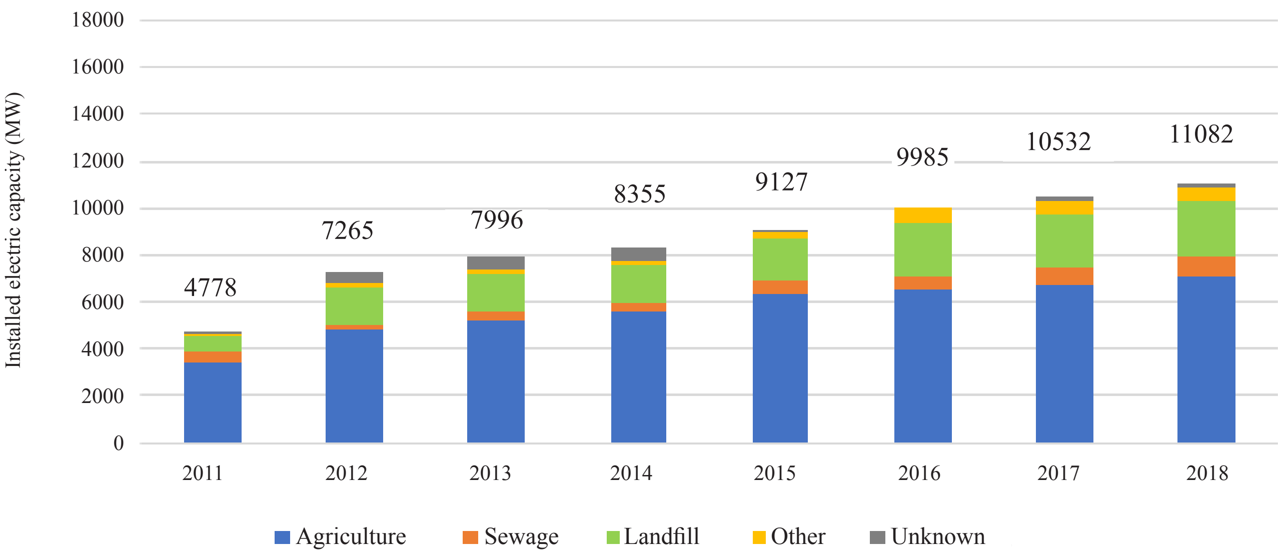

Figure 5. Increase of installed electric capacity of biogas plants by feedstock in Europe in 2011–2018.
Source: EBA 2020.

tion gaining prominence and contributing significantly to the overall energy landscape. This shift not only reflects a commitment to environmental stewardship but also underscores the economic viability and technological advancements driving the expansion of biomethane as a pivotal player in the renewable energy sector. In Europe, by far the largest share of biomethane plants is recorded in France and Germany – a total of 56% (Fig. 6).

Although biogas plant digestate is used as a fertilizer in agriculture, there are concerns about its potential impact on soil and water quality (Lohri et al., 2017). To ensure the environmental safety of the digestate, biogas plant operators can take a number of measures. One of the most important measures is to properly manage the storage and handling of the digestate. Storage should be designed to prevent leaks or spills (Al Seadi, Lukehurst, 2012; Regulation 1774/2002/WE, Regulation 1069/2009/WE).

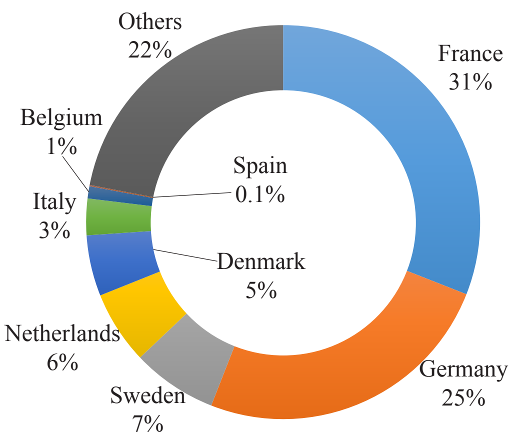

Figure 6. Share of biomethane plants in Europe.
Source: Jens et al., 2021

In the last a few years we can observe that more EU regulations concerned agriculture (European Green Deal, REACH, Circular Economy Action Plan, Farm2Fork, Mission Soil Health & Food and Bioeconomy strategies) are related to innovative development of market new soil improvers and fertilizers. Digestate from biogas plants is that kind of product, but in direction to its varied substrates, from with one is produced, needs deeper analysis about his environment safety. That is why the following hypothesis was made: the digestate from agricultural biogas plants is safe for the environment and the life and health of humans and animals through its proper storage and handling.

The literature on the environmental safety of biogas plant digestate from agricultural biogas plants suggests that the answer to the hypothesis is not clear. Although digestate from agricultural biogas plants can be a valuable source of fertilizer nutrients and organic matter for agricultural soils, its environmental safety depends on several factors, such as the composition of the feedstock, processing technology and timing of application. There are also potential risks associated with the accumulation of heavy metals and fertilizer components, soil salinization and groundwater contamination. According to many authors, the use of digestate for fertilizer purposes contributes to improving the physical and chemical properties of the soil, thereby maintaining soil fertility (Kalina et al., 2003; Gellings et al., 2004; Garg et al., 2005; Węglarzy, Stekla, 2009; Teliga et al., 2011; Makadi et al., 2012; Möller, Müller, 2012; Cukrowski et al., 2013; Bachmann et al., 2016; Gulyás et al., 2016; Ronewicz et al., 2016; Koszel et al., 2017; Risberg et al., 2017; Czekała, 2019; Peng, Pivato, 2019; Robles-Aguliar et al., 2019; Slepetiene et al., 2020). However, the use of digestate may be associated with the introduction of heavy metals, weed seeds and various organic pollutants into the soil (Gellings et al., 2004; Odlare et al., 2008; Govasmark et al., 2011; Kupper et al., 2014). Rules for the storage, transport, use and marketing, at the EU level, of animal by-products and derivatives that cannot be destined for human consumption are dealt with in Regulations (EC) No. 1069/2009 and (EU) 142/2011, conditioning the marketing of products resulting from the processing of manure (and guano) by subjecting them to a heat treatment process (at 70 °C for at least 60 minutes). Internal national regulations may include the use of other standardized process parameters if they will reduce the viability of endogenous indicator organisms (e.g. *Enterococcus faecalis*, heat-resistant viruses such as parvoviruses and parasites, and *Ascaris* sp. eggs, *Escherichia coli* bacteria, *Enterococcaceae* and *Salmonella* spp.).

MATERIAL AND METHODS

The paper conducted a systematic review of recent data related to the use of digestate and environmental safety. Authors reviewed 89 papers, including legal regulations. Articles were grouped on those treated about direct experiments and those which one were literature revue and others (like legal regulations). Key words were: “digestate”, “biogas plant”, “fertilizations”, “environmental safety”, “agriculture biogas plant”, “agriculture fertilizations”, “fertilizers environmental risk”. The data collected as a result of the review was synthesized to identify trends, knowledge gaps and emerging patterns in the field of the use of digestate, taking into account its impact on the environment.

RESULTS

The literature highlights a key implication: the imperative for additional research to ascertain the optimal conditions for the safe and efficient use of digestate, addressing factors like soil salinity and groundwater contamination. Developing appropriate guidelines and management practices to minimize these risks is essential. Furthermore, evaluating the effectiveness of various processing technologies is necessary to mitigate potential risks and maximize the benefits of digestate utilization.

The literature emphasizes the importance of appropriate regulation and monitoring of the use of digestate Lamolinara et al. (2022). This means adopting clear regulations and standards for the production, transportation and use of digestate to minimize environmental and health risks. Regular monitoring of the quality and quantity of the digestate used can also help ensure that it is used in safe and optimal amounts (Reuland et al., 2021).

Smol and Szołdrowska (2021) summarized in their study that in order to use waste-based fertilizers, it is necessary to analyze the physical and chemical composition of the waste, especially for the content of heavy metals, which are harmful to soil and plants. As long as they are used in accordance with current regulations and manufacturers’ recommendations, they bring environmental, economic and social benefits.

Yan et al. (2023) showed in their study that, with the exception of biochar, the fertilizers and soil additives tested, i.e., digestate, compost, commercial fertilizer, and biocarbon surrounded by digestate, had positive effects on plants. Biochar encapsulated with digestate was of comparable importance to compost in improving the soil’s immune system against pathogen infection, and also accelerated the nitrification process and inhibited the denitrification process.

A study by Zilio et al. (2022) shows that the use of highly stable digestate can be a good strategy for producing bio-based fertilizer with similar performance to synthetic fertilizer, without environmental risks.

The literature reports presented here deal with digestate of varying composition and substrate source, and thus varying content of potential sources of environmental pollution (heavy metals, etc.). Nevertheless, they have been found to be below the recommended threshold levels set by the country or federation (Kuusik et al., 2017). In addition, the solid fraction of the digestate was shown to have a positive effect on all groups of soil microorganisms, and the liquid fraction is only slightly beneficial for bacteria and negatively affects mycorrhizal and saprophytic fungi (van Midden et al., 2023). In a study by Kuusik et al. (2017) the digestate in its basic form (without separation into fractions) was shown to negatively affects the jumping rodents, nematodes and earthworms living on the surface of the mulch, although the impact is smaller for organisms living in deeper soil layers. The negative impact of digestate on soil organisms is due to a combination of factors, including: (i) lack of carbon supplied to support growth, (ii) toxicity due to ammonia and contaminant content, and (iii) changes in habitat conditions due to changes in soil pH Efforts have been made to address these concerns, making it use considered use.

Panuccio et al., (2021) declared that the benefits of manure from natural sources depended mainly on soil properties, rather than on the quantity and quality of organic material used, but the highest amount of organic matter, microbial biomass (MBC), fungi, bacteria and cation exchange capacity were observed in pH-neutral soil; all these properties increased the most over time, both in the presence of solid and liquid fractions.

There are concerns about the presence of hazardous compounds in digestate based on animal, industrial or household waste, such as antibiotics (Widyasari-Mehta et al., 2016), hormones (Congilosi, Aga, 2021), pesticides (Govasmark et al., 2011), phenols (Levén et al., 2012). No biodegradation of BPA was observed in the Limam et al.

(2013) study. According to Weithmann et al. (2018) and Porterfield et al. (2023), plastics can be present in many food waste composts and digestates and can be transferred to agricultural soils. Research by Piveteau et al. (2022) describes the microorganisms that may be present in digestate and their potential health risks.

A study by Zilio et al. (2022) indicates that mesoorganisms living close to the soil surface are at risk of being negatively impacted, they can regenerate due to rapid generation time, but can also have a positive impact in the long term due to changes in soil properties caused by the digestate. However, the authors point out that much more research is needed in this area to make scientifically sound generalizations. An extensive analysis of literature studies conducted by Zilio et al. (2022) found no significant changes in earthworm abundance after application of digestate. At the same time, they pointed out that digestate can be stabilized by composting, reducing its toxicity and negative environmental impacts, such as the loss of fertilizer components during application and positively influencing soil microorganisms. A study by Patyra et al. (2023) showed that the level of antibiotic contamination, mainly in manure, can reach several hundred milligrams per kilogram. The introduction of manure into soils, particularly cropland and grassland, can also pose a threat to ecosystems, in the form of potential leakage of antibiotic residues into groundwater, which can lead to changes in soil microbial populations.

Digestate is an example of recycling processed agricultural residues and biomass, which returns to nature's original cycle, and its composition can be stabilized through composting, reducing its toxicity and negative environmental impacts, such as losses of fertilizer components, which can positively affect soil microorganisms (Kuusik et al., 2017).

Several studies have evaluated the impact of the application of digestate on soil and water quality. A study by Barłóg et al. (2020) found that the application of digestate to soil led to an increase in nitrogen, potassium and phosphorus concentrations, which can lead to the risk of eutrophication of water bodies. In addition to its use as a fertilizer, the digestate has been studied for its valorization potential with respect to elements and their chemical forms (Wang, Lee, 2021).

In summary, digestate can be used responsibly and sustainably without negative environmental impacts. Al Seadi and Lukehurst (2012) pointed out that when using digestate as a fertilizer, it is necessary to examine its quality – starting with the composition of the feedstock delivered to the biogas plant where the digestate is produced. This approach is optimal in terms of achieving maximum environmental and economic benefits, while ensuring sustainability and environmental safety. Management of the quality of the digestate used as fertilizer should be integrated into the overall national policy for environmental protection and management of fertilizer components. Good examples of this can be found in countries such as Austria, Canada (Ontario), Denmark, Germany, the Netherlands, Sweden, Switzerland and the United Kingdom. Adequate national regulatory frameworks for quality management and certification of digestate enhance its use as a fertilizer in a safe and sustainable manner.

SUMMARY

The use of digestate as fertilizer should be done in accordance with local regulations and best practices. The amount of digestate applied should be based on the fertilizer nutrient requirements of the crop. This ensures that crops can absorb the fertilizer nutrients in the digestate and minimizes the risk of fertilizer nutrient runoff into nearby water sources. Application of the digestate should also be properly timed to avoid application during heavy rainfall or when the soil is water-saturated. In conclusion, the environmental safety of biogas plant digestate can be achieved through proper management, handling and application. By taking these measures, biogas plant operators can produce renewable energy while minimizing environmental impacts. Available data suggest that the environmental safety of biogas plant digestate is highly dependent on factors such as its composition, application rate and management practices (Lohri et al., 2017). However, there are some concerns about the impact of digestate on soil and water quality, although it also offers potential benefits as a resource for bioremediation and bioenergy production.

To ensure the safe and effective use of digestate, the following recommendations can be made:

– Further research is needed to identify optimal processing technologies and timing for the use of digestate, based on the characteristics of the feedstock and specific environmental conditions. These studies should also assess the potential risks associated with the use of digestate.

– Collaboration among various stakeholders, including biogas plant operators, farmers, regulators and researchers, is necessary to develop effective policies and practices for the safe and efficient use of digestate.

– Policy development should focus on regulating the production, transportation and use of digestate to minimize environmental and health risks. Clear regulations and standards should be established for the production and transportation of digestate, with regular monitoring of the quality and quantity of digestate used to ensure its safe and effective use.

Based on the literature review, the environmental safety of biogas plant digestate is a complex issue that requires further research and policy development to ensure safe and effective use. While digestate has the potential to improve soil quality and reduce greenhouse gas emissions, there are also potential environmental and health risks associated with its use.

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