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BIOGAS SLURRY AS FERTILIZER: A BRIEF REVIEW

Megha Vishwakarma[1]*, Rajul Soni[2], Indra Raj Yadav[3] and Hradesh Patel[2]
[1]Shri Vaishnav Vidyapeeth Vishwavidyalaya, Shri Vaishnav Institute of Agriculture, Indore, (M.P.), India
[2]Medicaps University, Indore, (M.P.), India
[3]Rajmata Vijyaraje Scindia Krishi Vishwavidyalaya Indore, (M.P.), India
*Corresponding Author E-mail: meghavishwakarma007@gmail.com

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ABSTRACT

The global population is projected to reach 10.6 billion by 2050, significantly increasing the demand for food and subsequently, fertilizers, which have historically contributed to substantial crop yield enhancements. However, reliance on mineral fertilizers alone poses challenges, as they provide limited macronutrients and often lack essential micronutrients necessary for sustainable agriculture. This review highlights the potential of biogas slurry as an effective nutrient source. Biogas slurry, characterized by a high nitrogen content and beneficial bioactive compounds, can enhance soil fertility and promote crop growth. The findings suggest that sole or integrating biogas slurry with mineral fertilizers improves nutrient availability and soil health, resulting in increased crop yields across various staple crops. This paper underscores the importance of biogas slurry in achieving sustainable agricultural practices and addresses the need for balanced nutrient management to optimize both crop production and soil properties.

***Keywords* :** Biogas slurry, fertilizer, C:N ratio

Introduction

The global population is projected to rise from 7.75 billion in 2020 to between 8.9 and 10.6 billion by 2050 (World Bank, 2022). A significant portion of this population relies on fertilizers to ensure food security, as fertilizers are essential for maximizing crop yields. It is estimated that fertilizer application contributed to at least a 50% increase in crop yields during the 20th century (Yousaf, 2017). Mineral fertilizers are commonly used worldwide to address nutrient deficiencies in soils (Crawford and Jayne, 2010) and play a crucial role in maintaining the short-term productivity of agro-ecosystems (Ansari *et al.*, 2017). However, typical mineral fertilizers often provide only a limited range of macronutrients primarily N, P, K, S and fall short in supplying other essential macro- and micronutrients (Asaye *et al.*, 2022). A balanced application of these nutrients is vital for achieving high crop yields and ensuring overall system productivity (Shil *et al.*, 2016).

Uses of organic manures enhances the physical, chemical, and biological properties of soil while also giving plants nutrients (Choudhary *et al.*, 2022). Application of organic manures release nutrients slowly due to slow decomposition, and store nutrients for a longer time in the soil providing a prolonged residual effect. They also increase microbial population, which in turn results in initial immobilization of soluble N in microbial cells and prevents losses. However, the nutrient content of organic manure is relatively low, and it has a low ability to release nutrients quickly enough to meet crop requirements (Iqbal *et al.*, 2019). In India, farmyard manure (FYM) is the predominant organic fertilizer used (Kalappanavar and Gali, 2018), supplying key nutrients such as N, P, K, Ca, Mg and S essential for plant growth (Tadesse *et al.*, 2013). However, the quality of FYM produced through traditional methods tends to be poor due to nutrient losses during preparation and low nutrient content (Reddy *et al.*, 2015). Consequently, inadequate management and application of FYM can lead to insufficient replenishment of soil nutrients, thereby reducing soil productivity. Sole reliance on organic manure may also fail to achieve the desired increase in crop yields (Warners, 2014). Combining organic and mineral inputs has been recommended as an effective management practice for smallholder farms in tropical regions, where the availability of either type of input is often inadequate. Both are necessary for maintaining soil fertility and sustaining crop production over the long term (Vanlauwe, 2001).

Biogas slurry, a byproduct of anaerobic digestion, can be applied directly to crops or used in composting with other organic materials. The nutrient composition of biogas slurry varies based on the original substrate, type of digester and anaerobic process used (Groot *et al.*, 2013). Typically, biogas slurry consists of 93% water and 7% dry matter, which includes 4.5% organic matter and 2.5% inorganic matter (Kumar *et al.*, 2015).

The total nitrogen concentration in farmyard manure (FYM) can be as much as 30% lower than that found in biogas slurry (Möller *et al.*, 2008). Nitrogen digestates typically contain a high percentage of ammonium relative to total nitrogen (Abubaker *et al.*, 2012; Möller and Müller, 2012; Wentzl and Joergensen, 2016). Research by Chen (2017) indicates that the NH_4-N concentration in biogas slurry can comprise 77–93% of the total nitrogen, highlighting the nitrogen levels in the slurry. Ammonium nitrogen (NH_4-N) is a mineral form of nitrogen readily available for plant uptake or easily converted into plant-accessible nitrate, which promotes enhanced plant growth (Pitts *et al.*, 2019). Additionally, the presence of ammonium nitrogen can stimulate soil priming effects, encouraging microbial activity and nutrient cycling (Bernal and Kirchmann, 1992; Gunnarsson *et al.*, 2010). Müller (2008) highlighted that ammonia concentration in the slurry could increase from 43% to 53% of total nitrogen because of the digestion process. Jared *et al.*, (2017) reiterated that the elevated nitrogen levels in biogas slurry are due to the conversion of organic compounds during anaerobic decomposition into readily available ammonium nitrogen, positioning bio-slurry as a superior organic fertilizer compared to other organic amendments.

The C:N ratio affects nitrogen mineralization. At low C:N ratios (below 20:1), microorganisms quickly convert organic nitrogen into inorganic forms, while higher C ratios hinder this process (Stefaniuk *et al.*, 2015; Bengtsson *et al.*, 2013). Digestates derived from highly degradable feedstocks, such as cereal grains and poultry or pig manures from concentrate-rich diets, typically exhibit elevated NH_4^+-N to total N ratios and narrow C:N ratios (Emmerling *et al.*, 2007 and Moller and Muller, 2012). The combination of biogas slurry and synthetic fertilizers enhances C transformation in crops, leading to yield increases of 6.5%, 8.9%, 15.2%, and 15.9% for cotton, wheat, maize, and rice, respectively (Sandeep Kumar).

Bioslurry generally has pH values in the alkaline range (Bonten *et al.*, 2014 and Niyungeko *et al.*, 2018). During anaerobic digestion of manure, organic solids are converted into volatile fatty acids (VFAs). Initially, this accumulation of organic acids causes a drop in pH. However, manure has a sufficient buffering capacity to limit this decrease. Next, methanogenic microorganisms convert the VFAs into methane, as long as the pH stays above approximately 6.5. As these acids are metabolized, the pH of the effluent rises due to the consumption of protons during the methanogenesis process (Möller and Müller, 2012). As a result, bio-slurry typically has pH values greater than 7.

The availability of phosphorus (P) is enhanced by increased pH, which shifts the equilibrium towards the formation of phosphates (HPO_4^{2-} and PO_4^{3-}) (Moller and Muller, 2012). However, Gungor *et al.* (2007) found that higher pH levels in BGS promote the formation of struvite ($MgNH_4PO_4{\cdot}6H_2O$) and hydroxylapatite ($Ca_5(PO_4)2OH$), which can reduce P solubility in BGS and impact the phosphorus available to plants during their growth period. Additionally, Svensson *et al.* (2004) pointed out that BGS typically has low phosphorus content, which is insufficient for most crops, and recommended the use of mineral supplementary P to prevent deficiencies. Additionally, digestates contain bioactive substances like phytohormones (such as gibberellins and indoleacetic acid), nucleic acids, monosaccharides, free amino acids, vitamins, and fulvic acid, which can promote plant growth and enhance tolerance to biotic and abiotic stresses (Liu *et al.*, 2009; Yu *et al.*, 2010). This study reviews the use of biogas slurry as a nutrient source for crop production and its impact on improving soil properties.

Effect of biogas slurry on yield

Extensive research has explored the effects of biogas slurry on crop yields, revealing significant benefits across various studies. Khan *et al.* (2018) demonstrated that a combination of 50% bioorganic growth stimulant (BGS) and 50% chemical fertilizer led to a 20% increase in both cob and biomass yields of baby corn, along with nearly doubling the protein content and a 41% increase in total sugar content compared to controls. Similarly, Jiaxiang *et al.* (2018) found that applying biogas slurry fertilizer at a 5% rate significantly boosted the growth of ornamental lettuce, resulting in increases in plant height (12.66% to 16.75%), leaf area (19.97% to 42.03%), and fresh weight (43.96%). Ferdous *et al.* (2020) reported that mixing 5 t ha^{-1} of biogas slurry with chemical fertilizers resulted in 20–24% higher maize grain yields. Głowacka *et al.* (2020) noted that the application of biogas digestate at 60 m³ ha^{-1} raised switchgrass yields to 5.15 t ha^{-1}, comparable to mineral fertilization, while lower rates yielded 4.30 t ha^{-1}. This digestate's value is attributed to its improved nitrogen availability, as anaerobic digestion alters the C:N ratio, enhancing nitrogen mineralization and plant assimilation. High application rates of biogas slurry, such as 480 m³ ha^{-1} for rice and 9.00–11.25 m³ ha^{-1} for wheat, led to yield increases of 8.9% and 15.7%, respectively (Tang *et al.*, 2019). Lu *et al.* (2012) found a 24% increase in rice yield with biogas slurry compared to no fertilization. Further studies indicated that integrating digestate with chemical fertilizers enhanced tomato yields by up to 26.29% (Li *et al.*, 2023). In a comparative analysis, Shaheb (2017) showed that bioslurry outperformed chemical fertilizers for boro rice production, yielding 5.06 t ha^{-1} with 5 t ha^{-1} of cow dung slurry. Zheng *et al.* (2019) found that a 20% biogas slurry application provided stable nutrients for tomatoes, improving growth metrics over inorganic treatments. For oilseed rape, Wu *et al.* (2011) reported that applying biogas slurry at 112,500 kg hm^{-2} resulted in yields 157.5% higher than controls and 38.26% greater than those treated with chemical fertilizers.

Table 1 : Effect of biogas slurry on crop yield

	Crops	**Recommended treatment**	**Key results**	**References**
1.	Cucumber	BGS 30 t ha^{-1} with 100% dosage or 75% RDF	Maximum yield 195.20 and 193.89 t ha^{-1} found in 30 t ha^{-1} + 100% RDF or 75% RDF	Yamika *et al.* (2019)
2.	Carrot	7.8 t bio slurry manure ha^{-1}	Increased yields by 8.8% in season 1 and 23.5% in season 2 compared to the control.	Jeptoo *et al.*, 2017
3.	*Camellia oleifera Abel*	30 kg $plant^{-1}$ $year^{-1}$	Fruit yield increased by 40.1% over control	You *et al.* (2019)
4.	*Lolium Multiflorum*	37.5 kg ha^{-1} chemical synthetic fertilizer + 100.5 t ha^{-1} BS,	Yield increased 7.64%, 7.99%, and 6.96% in first season and 4.71%, 23.60%, and 17.70% in second season at I, II and III cutting compared to chemical synthetic fertilizer (CSF)	Xu *et al.* 2021
5.	Baby corn	50% BGS + 50% chemical fertilizer	Gave fresh cob yield 60%, green fodder yield (35.32 vs 24.47 t ha^{-1}), higher protein content (6.45 vs 13.25%)	Khan *et al.*, 2017
6.	Peanut	30% BS–TN (total N) plus 70% chemical fertilizer –TN	Yield increased by 366.98% over control	Zheng *et al.*, 2017
7.	Rice–Wheat	480 m^3 BGS ha^{-1} for rice 9.00–11.25 m^3 BGS ha^{-1} for wheat	Yield of rice increased by 8.9% and wheat by 15.7% over conventional fertilization, respectively	Tang *et al.*, 2019
8.	Wheat- Maize	50% biogas slurry substitution	Yield of wheat increased by 55% and maize by 89.17% over control	Tang *et al.*, 2022
9.	Cabbage	RDF + 5 t ha^{-1} poultry litter bio-slurry (after digestion)	Yield increased by 366.98% over control	Shahariar *et al.*, 2013
10.	Wheat	BGS 50% + CF 50%	Yield increased by 145.32% over control	Hussain *et al.* 2019
11.	Maize	70 kg of slurry N ha^{-1}	Yield increased by 56.10% over control	Islam *et al.* 2010
12.	Maize and wheat	Biogas slurry	Wheat yield increased by 23.47% and maize yield by 15.46%, respectively.	Du *et al.*2018
13.	Tomato	NPK (14:14:14) fertilizer with 90 kg N ha^{-1} and 90 kg N ha^{-1} of digestate	26.29% and 10.78% higher than that in the chemical fertilizer treatment under field and greenhouse conditions, respectively.	Li *et al.* 2023
14.	Okra	Bio slurry 600 kg ha^{-1} + N (50%)	No. of fruits per plant increased by 168% over control	Shahbaz *et al.*, 2013
16.	Pea	PGPR and BGS (800 kg ha^{-1})	Enhanced fresh weight of pods by 88.43% over control	Muslim *et al.*, 2013

17.	Kale *(Brassica oleracea L.)*	100% Bio-slurry	The highest leaf fresh weight 333.63% and fresh biomass 483.05% over control	Haile and Ayalew, 2020
18.	Spinach and Chilli	50% RD of N from chemical fertilizer and 50% liquid slurry	Yield increased by 34.07% for spinach and 39.78 chilli over liquid slurry	Muhmood *et al.*, 2014
19.	Capsicum spp.	495 m^3/hm^2 BGS	Increased plant height 113% and fruit bearing population 98.8% over control	Wang *et al.*, 2024
20.	Maize	Chemical fertilizer + cow dung biogas slurry (5 t h^{-1}) or poultry biogas slurry (3 t h^{-1})	20–24% higher grain yield	Ferdous *et al.*, 2020
21.	Rainfed maize *(Zea mays L.)*	100% N by BGS	Increased grain yield 124.42 per cent over control	Gurjar *et al.*, 2023
22.	Cabbage	10 t ha^{-1} BGS	Yield increased by 75.5% over control	Nasir *et al.*, 2015
23.	Cabbage	Application of inorganic fertilizer (Recommended dose) + Biogas slurry compost at 8ton ha^{-1}	66.7 %	Debebe *et al.*, 2016
24.	Tomato	T3 1 biogas slurry + 2 water (v/v),.	The highest yield occurred in T3 and its yield per plant was 2.74% higher than that of CK.	Liu *et al.*, 2012
25.	Maize	25% BS +75% CF	Grain yield (4.90 vs 7.09 t ha^{-1}) compare to control	Kebede *et al.*, 2023

Du *et al.* (2018) noted that combining biochar with biogas slurry enhanced wheat yield by 8.46% and maize yield by 18%. Shahariar *et al.* (2013) achieved the highest cabbage head yield (97.6 t ha^{-1}) using 5 t ha^{-1} of poultry litter bio-slurry, surpassing the control by 366%. Hussain *et al.* (2019) observed that equal application of biogas slurry and chemical fertilizers improved various growth parameters. Maqbool *et al.* (2014) highlighted that a 50% nitrogen source from chemical fertilizers combined with biogas slurry substantially increased okra yield. Haile *et al.* (2018) found that the sole use of liquid bio-slurry produced the highest leaf fresh weight, attributed to optimal nutrient availability. Slurry significantly enhanced soil nutrient levels and crop yields, maintaining productivity in intensive rotations (Tang *et al.*, 2022).

Muhmood (2014) indicated that combining liquid slurry with chemical fertilizers achieved comparable yields for spinach and chili to those from chemical fertilizers alone. Further research highlighted the potential for maximizing yields in maize-wheat rotations with 226 kg N ha^{-1} using 38% biogas slurry (Rahaman *et al.*, 2021). Chen *et al.* (2020) suggested that rice yields could be sustained with a 50% biogas slurry replacement at 270 kg N ha^{-1}.

Musse *et al.* (2020) noted that liquid biogas slurry and nitrogen applications significantly impacted soil and crop parameters, with a 120% increase in cation exchange capacity (CEC) and a total pod yield of 14.3 t ha^{-1}. Nasir *et al.* (2010) compared biogas slurry and chemical fertilizers on maize yields, finding that chemical fertilizers produced the highest average yield of 5.34 t/ha, while biogas slurry at 20 and 40 t/ha yielded 4.02 t/ha and 4.52 t/ha, respectively. In a follow-up, Nasir (2015) reported that bioslurry-treated plots retained 15% more organic matter and nutrients than those treated with commercial fertilizers.

Xu *et al.* (2019) indicated that moderate applications (165.1 t ha^{-1}) of biogas slurry positively affected rice and rape yields, soil fertility, and bacterial diversity compared to inorganic treatments. Chen *et al.* (2017) highlighted that ammonium nitrogen in biogas slurry constitutes 77–93% of total nitrogen, underscoring its critical role in plant nutrition. They noted that mineral nitrogen fertilizers could be partially or completely replaced by biogas slurry without compromising yields or nitrogen efficiency in *Z. aquatica* plants. In Nepal, Karki (2006) found that applying slurry compost at 10 t/ha increased maize yields by 23% over controls, while liquid bioslurry at the same rate resulted in a 10% increase, and full chemical fertilizers yielded 8% more than controls. Fashaho (2020) reported that applying bioslurry at rates of 12 and 18 t/ha in medium-altitude sites and 10 and 15 t/ha in high-altitude sites significantly increased grain yields, with results of 7.8–8.0 t/ha in medium altitudes and 6.9–7.3 t/ha in high altitudes at a significance level of $P < 0.05$.

Effect of biogas slurry on soil chemical properties

The application of biogas slurry (BGS) has shown clear benefits for soil properties, including increases in organic matter content, porosity, and reductions in bulk density. Khan *et al.* (2017) indicated that using BGS in conjunction with chemical fertilizers at a 1:1 ratio can serve as an effective soil amendment, providing both short-term and long-term advantages in crop production and soil improvement. Malav *et al*., (2015) confirmed that applying BGS at a rate of 7 t ha^{-1} effectively reduced bulk density while enhancing soil porosity. Additionally, BGS application increased the availability of essential nutrients such as nitrogen (from 0.24% to 1.21%), phosphorus (from 0.35% to 6.39%), and potassium (from 0.51% to 2.06%) in the topsoil (0-15 cm). He concluded that incorporating biogas slurry with 50% chemical fertilizers could yield significant benefits for both immediate and sustained soil health and productivity.

Feng *et al.* (2024) reported that applying BGS at a rate of 150 t ha^{-1} significantly boosted soil organic carbon (SOC), total nitrogen (TN), available phosphorus (AP), and available potassium (AK) by 45.93%, 39.52%, 174.73%, and 161.54%, respectively. Similarly, Wang (2024) discovered that pretreating degraded soils with biogas slurry improved total nitrogen (0.15–0.32 g/kg), total phosphorus (0.13–0.75 g/kg), available phosphorus (102.62–190.68 mg/kg), available potassium (78.94–140.31 mg/kg), and organic carbon content (0.67–3.32 g/kg). This treatment also had a positive impact on the diversity and distribution of soil bacteria and fungi. Lai *et al.* (2018) noted that maintaining the application of swine manure biogas slurry over three years at concentrations between 546.25 and 626.00 × 10^3 kg/hm^2 significantly increased soil levels of available potassium, phosphorus, and alkaline hydrolyzable nitrogen, while also mitigating the risk of soil acidification. Gupta *et al.* (2023) found that applying BGS at 6 Mg ha^{-1} compensated for a substantial portion of nitrogen (75%) and phosphorus (50%) typically supplied by recommended chemical fertilizers. The use of BGS also enriched the soil with organic carbon and DTPA-extractable micronutrients (Fe, Mn, Zn, and Cu), significantly improving the balances of nitrogen, phosphorus, and potassium.

Tang *et al.* (2022) found that applying a combination of 50% chemical fertilizer and 50% biogas slurry reduced soil bulk density while increasing water-holding capacity and the mean weight diameter of water-stable aggregates. All fertilization treatments improved organic carbon and available nutrients (nitrogen, potassium, and phosphorus) compared to the control, with the BSCF treatment showing the most significant enhancements. Additionally, microbial community composition BSCF resulting in the highest diversity and most balanced bacterial and fungal assemblages at the phylum level. You *et al.* (2019) evaluated the utilization of ammonium nitrogen in biogas slurry and found that over 90% of the applied ammonium nitrogen could be absorbed by the soil, indicating an immediate increase in available nitrogen levels. Fertilization with biogas slurry notably enhanced the concentrations of available nitrogen, phosphorus, and potassium, leading to improved yields of *C. oleifera*. Niyungeko (2019) highlighted the short-term benefits of biogas slurry as a nutrient source, providing ammonium (NH_4^+–N), nitrate (NO_3^-–N), and Olsen phosphorus. The study identified inorganic orthophosphates and orthophosphate monoesters as the main phosphorus forms in biogas slurry. The rise in inorganic orthophosphates after application is due to the mineralization of organic phosphorus, while orthophosphate monoesters are associated with stable organic matter, such as inositol phosphates, which degrade more slowly.

Effect of biogas slurry on microbial properties

Malav *et al.* (2015) found that using a combination of 50% N from biogas slurry (BGS) and 50% from RDF significantly increased SMBC compared to chemical fertilizers and controls. The integrated use of organic and inorganic materials offers a balanced supply of both nutrients and carbon. Additionally, enzyme activities (protease, acid phosphatase, dehydrogenase, and urease) were highest with 100% nitrogen from BGS, measuring 116.4, 217.7, 56.2, and 74.8 µg, respectively. Further investigations by Du *et al.* (2018) found that both biochar and biogas slurry applications led to increased total nitrogen and organic matter content in the soil, while also enhancing soil aggregation, microbial biomass, and actinomycete populations. They noted that BGS not only lowered soil pH but also boosted urease and protease activities, further contributing to a healthier soil ecosystem. Moreover, Du *et al.* (2018) highlighted that BGS, rich in polysaccharides and humic acids, effectively reduced soil pH and improved its buffering capacity. The nutrient density of biogas slurry promotes microbial growth by enriching the soil with various nutrients and bioactive compounds, which in turn enhances enzyme activity and fosters beneficial physiological and biochemical changes in the soil.

Xu *et al.* (2019) found that biogas slurry (BS) was more effective than chemical fertilizers in promoting agricultural soil sustainability, particularly with the rate of 165.1 and 182.1 t ha^{-1}. This was attributed to improved nutrient content, increased soil pH, and enhanced soil crumb structure formation. Additionally, the introduction of biogas slurry may alter bacterial communities differently than chemical fertilizers and control treatments, due to its higher carbon content and distinct carbon composition, leading to shifts in microbial community structure (Abubaker *et al*., 2013). Shi (2023) noted that, when compared to chemical fertilizers alone, the combination of biogas slurry and chemical fertilizer rapidly increases nutrient levels such as ammonium and total phosphorus in paddy water while also enriching the organic matter content. This enrichment helps regulate the microbial communities in the rhizosphere.

Further supporting this, Tang *et al*. (2021) reported that BGS significantly elevates both labile and recalcitrant organic carbon levels compared to chemical fertilizers. Their network analyses revealed that BGS fosters a more complex bacterial community, whereas chemical fertilizers promote greater complexity within fungal communities. This suggests that BGS plays a vital role in soil organic carbon (SOC) cycling, enhancing SOC stocks and improving straw decomposition in systems that return straw to the soil. Tang (2022) also noted that the application of biogas slurry 50% combined with chemical fertilizers 50% results in the highest diversity and most balanced assemblages of bacteria and fungi at the phylum level. He emphasized that BGS and chemical fertilizers provide a rich array of nutrients and energy resources, leading to notable increases in the relative abundance of actinomycetes in treated soils. However, Pezzolla *et al*. (2015) found that applying a digestate equivalent to liquid digestate led to an increase in gram-negative bacteria, which decreased the fungal-to-bacterial (F) ratio. These fast-growing bacteria are more capable of utilizing the readily available carbon in liquid digestate, while the limited complex carbon content poses challenges for fungal growth.

Zhang *et al*. (2021) conducted a three-year field experiment that demonstrated the application of biogas slurry (BGS) combined with chemical fertilizers significantly improves soil nutrient availability and increases bacterial community diversity, while simultaneously reducing fungal diversity. Their findings revealed that as the ratio of biogas slurry to chemical fertilizer increased, soil organic carbon (SOC) and dissolved organic carbon (DOC) levels initially rose before subsequently declining. This suggests that a balanced application specifically a 50% replacement of chemical fertilizers with biogas slurry optimally enhances soil organic matter content. Wang (2024) reported that soil pretreatment with biogas slurry dosage of 495 m^3/hm^2 and 990 m^3/hm^2 increased total nitrogen (0.15–0.32 g/kg), total phosphorus (0.13–0.75 g/kg), available phosphorus (102.62–190.68 mg/kg), available potassium (78.94–140.31 mg/kg), and organic carbon content (0.67–3.32 g/kg). These changes also significantly influenced the population, diversity, and distribution of both soil bacteria and fungi.

In conclusion, the rising global population demands innovative agricultural solutions, and integrating biogas slurry with traditional fertilizers offers a compelling strategy. This combination not only enhances nutrient availability and soil health but also significantly boosts crop yields compared to chemical fertilizers alone. The high nitrogen content and improved microbial activity from biogas slurry promote both immediate productivity and long-term sustainability in farming systems. Embracing biogas slurry as a key nutrient source is essential for meeting food security challenges while supporting environmentally responsible practices. Future research should focus on optimizing these methods for broader agricultural applications.

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