Forage Res., **51**(1) : pp. 24-28 (2025) **http://forageresearch.in**

INSIGHT OF BIOGAS SLURRY AS ORGANIC FERTILIZER AND ITS SCOPE IN FODDER CROPS PRODUCTION

GULAB PANDOVE*[1], NIRMAL SINGH[2], AMANDEEP SINGH SIDHU[1] AND AMAN PREET[1]

[1]School of Organic Farming, Punjab Agricultural University, Ludhiana-141 004 (Punjab), India
[2]Department of Microbiology, Punjab Agricultural University, Ludhiana-141 004 (Punjab), India
(e-mail: gpandove@pau.edu)

(Received: 2 June 2025; Accepted: 29 June 2025)

SUMMARY

Biogas slurry is a by-product of anaerobic digestion, it can act as a valuable organic fertilizer as it is enriched with essential plant nutrients and beneficial microorganisms. It can serve as an efficient soil conditioner, enhance fertility, improve crop productivity, and support eco-friendly farming practices. The application of biogas slurry improves soil structure by increasing aeration, water retention, and nutrient availability, thereby fostering healthier plant growth. Since the slurry undergoes anaerobic decomposition, it reduces unpleasant odours and suppresses harmful pathogens, making it a safer alternative to raw manure. The microbial population in biogas slurry includes nitrogen-fixing bacteria, phosphate-solubilizing microbes, and plant growth-promoting bacteria, along with various enzyme-producing organisms that contribute to organic matter breakdown and nutrient release. Additionally, biogas slurry has been observed to exhibit antifungal properties, which can aid in controlling plant pathogens and enhancing crop resistance. This review will focus on the following aspects: microbiome of biogas slurry, Physico-chemical properties of biogas slurry, Impact of biogas slurry on crop productivity and quality, application method of biogas slurry, Impact of biogas slurry on soil health, pest disease resistance and antifungal potential of biogas slurry. The insight gained from the litrature reviewd herein will further assist the scientific community in exploring the potential of biogas slurry across a range of forage crops.

Key words: Beneficial microorganisms, biogas slurry, enzymes, nitrogen-fixing bacteria, pathogens

The residual slurry produces from the anaerobic digestion (AD) of biogas feedstocks, such as livestock manure is referred to as biogas slurry (BGS). BGS is abundant in nutrients and bioactive compounds playing a crucial role in fostering diverse microbial communities, enhancing nutrient utilization efficiency, and contributing to overall soil and plant health (Ferdous *et al.*, 2020). It is regarded as a valuable agricultural waste resource capable of modulating soil microbial communities, enhancing the nutrient uptake efficiency of crops and fostering plant-soil interactions. Consequently, its application led to increased crop productivity (Wang *et al.*, 2023). Singh *et al.*, (2020) have highlighted the positive impact of biogas slurry on soil fertility, nutrient availability, and crop yields, attributing these benefits to its nutrient composition and organic nature. Kalamdhad and Kumar (2021) also elucidated the treatment processes and significance of biogas slurry fertilizers in sustainable agricultural practices, emphasizing its role in nutrient recycling and soil enrichment. Further, characterization of the slurry enabled a thorough evaluation of its nutrient profile, optimizing its utilization in agricultural applications (Yadav *et al.*, 2023).

Microbiome of biogas slurry

Biogas slurry (BGS) presents numerous benefits as an organic fertilizer that includes the enhancement of soil nutrient profiles and bioavailability of nutrients to plants. It also improves soil structure, increased water holding capacity, and elevated cation exchange capacity. Additionally, BGS fostered soil microbiota, notably nitrogen-fixing bacteria and phosphate-solubilizing bacteria (PSBs), thereby contributing to overall soil health and fertility (Kumar *et al.*, 2015). Zhao *et al.*, (2013) identified 18 operational taxonomic units (OTUs) in biogas slurry compost were affiliated with nine bacterial genera, predominantly *Bacillus* sp. and *Carnobacterium* sp. Application of high concentration of biogas slurry significantly enhanced the relative abundance of *Candidatus Solibacter*, *Roseiflexus* sp., and *Gaiella* sp. Jin *et al.*, (2021) reported that Fresh Biogas Slurry (FBS), Aged Biogas Slurry (ABS) influences on soil bacteria. Specifically, the FBS treatment displayed the highest bacterial count (178.7×10^7 g^{-1}), followed by the ABS treatment (177.7×10^7 g^{-1}). Zhang *et al.*, (2021) reported that the combined application of biogas slurry with chemical fertilizer leds to a notable enrichment of Proteobacteria, Acidobacteria, Planctomycetes, Rokubacteria, and Ascomycota, whereas, Chloroflexi, Bacteroidetes, Crenarchaeota, Basidiomycota, and Glomeromycota were depleted. Rao *et al.*, (2019) observed bacterial count of 30.67 x 10^5 CFU g^{-1} soil , actinomycetes count of 53.33×10^4 CFU g^{-1} soil and fungi count of 24.33×10^3 CFU g^{-1} at harvest stage of chickpea with the application of 100% Recommended dose of phosphorus (RDP) through BGD + Microbial Consortium soil.

Physico-chemical properties of biogas slurry

Biogas slurry can act as organic source of macro and micro nutrients. Biogas slurry produced after anaerobic digestion, exhibited pH of 7.13 and higher nutrient content (Wentzel *et al.,* 2015). It has been reported that biogas slurry contained abundant essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), and trace elements like calcium (Ca), zinc (Zn), nickel (Ni), iron (Fe), sodium (Na), boron (B), cobalt (Co), chromium (Cr), and cadmium (Cd) (Gupta, 2007). Furthermore, it contains organic nitrogen, mineral elements, and bioactive substances such as hormones, humic acids, and vitamins (Liu *et al.,* 2008). Similarly, Xu *et al.*, (2021) observed 1.9% organic matter content, 80% moisture content, 0.23% total nitrogen, 0.05% total phosphorus, 0.32% total potassium and 7.7 pH. Yu *et al.*, (2010) reported the nutrient content of biogas slurry and found 0.069 g L^{-1} of total N, 0.048 g L^{-1} of total P, 0.34 mg L^{-1} of total K, 159mg L^{-1} of NH_4^+-N, 6.51 at 25^0C dS m^{-1}, 491 mg L^{-1} of COD_{Cr}, 110 mg kg^{-1} of Na, 36 mg kg^{-1} of mg, 25 mg kg^{-1} of Ca, whereas Ti, Mn, Fe, Zn, Rb, Sr, Ba, Al exhibited less than 1 mg kg^{-1} and simultaneously observed 0.71 g L^{-1} of total N, 15.5 g L^{-1} of total P, 2.1 mg L^{-1} of total K, 1250 mg L^{-1} of NH_4^+-N, 30.3 at 25^0C dS m^{-1}, 25400 mg L^{-1} of COD_{Cr}, 1074 mg kg^{-1} of Na, 434 mg kg^{-1} of Mg , 2 mg kg^{-1} of Al, 526 mg kg^{-1} of Ca, 4.6 mg kg^{-1} of Ti, 10 mg kg^{-1} of Mn , 23 mg kg^{-1} of Fe, 8.5 mg kg^{-1} of Zn, , 4.8 mg kg^{-1} of Rb , 7.3mg kg^{-1} of Sr, 4.3 mg kg^{-1} of Ba in concentrated biogas slurry. Zhao *et al.,* (2013) assessed the physico-chemical properties of biogas slurry and revealed 967.89 mg L^{-1} total nitrogen, 218.48 mg L^{-1} total phosphorus, 3.42 mg L^{-1} total potassium, 90.68 mg L^{-1} total moisture content, and a pH of 8.5.

Impact of biogas slurry on crop productivity and quality

Biogas slurry (BS) derived from anaerobically digested animal waste is recognized as a valuable source of plant nutrients, making it a nutrient-enriched organic fertilizer for enhancing crop production (Abubaker *et al.,* 2013; Ozores-Hampton *et al.*, 2011 and Win *et al.,* 2014). Xu *et al.*, (2021) reported that the italian ryegrass treated with a combination of 37.5 kg ha^{-1} chemical synthetic fertilizer and 100.5 t ha^{-1} of BS demonstrated the highest fresh weight during various harvest intervals in the first growth season with improvements of 7.64%, 7.99%, and 6.96% compared to treatment with 112.4 kg ha^{-1} of chemical synthetic fertilizer at the first, second, and third cuttings respectively. Lina *et al.*, (2011) found that application of biogas slurry to rice fields resulted in comparable or slightly higher yields compared to using chemical fertilizers. In addition, the application of biogas slurry as a nitrogen fertilizer stimulated maize fodder growth, the optimal growth was achieved with an application rate of approximately 70 kg of slurry N per hectare (Islam *et al.,* 2010). Jin *et al.*, (2021) reported both Fresh Biogas Slurry (FBS) and Aged Biogas Slurry (ABS) contributed to an increased tomato yield. Further, the application of Biogas Slurry (20 tonnes per hectare) significantly improved wheat yield and various parameters such as plant height, cob yield, thousand grain weight (Hussain *et al.*, 2019). Islam *et al.,* (2010) concluded that the application of biogas slurry improved both the production and quality of maize fodder. Similarly, Wu *et al.,* (2013) reported that the use of biogas slurry on oilseed rape led to increased levels of protein, iron, manganese, copper, and zinc in rapeseed, along with higher yield. Xu *et al.,* (2019) demonstrated that the incorporation of biogas slurry at a moderate dosage (165.1 t $ha^{"1}$) had positive impacts on rice and rape yields, soil fertility and bacterial diversity, Tiwari *et al.,* (2000) revealed that the application of wheat straw nodes at 7.5 t $ha^{"1}$ alongside biogas slurry and 50 kg N $ha^{"1}$ resulted in a significant increase in grain yield compared to using 50 kg N alone. This combined application also demonstrated comparable yields to those achieved with 100 kg N $ha^{"1}$. Muhmood *et al.,* (2014) indicated that the highest yield of spinach (56.0 t ha^{-1} for two cuttings) and chili (3.06 t ha^{-1}) was achieved using chemical fertilizers, comparable to the results where half of the recommended dose (RD) of nitrogen was supplied from chemical fertilizers and the other half from liquid biogas slurry. Haque *et al.,* (2018) asessed the impact of combined biogas slurry applications from cow dung and poultry manure on a wheat-rice cropping system and observed a 3.1–11.7% increase in total system productivity compared to the use of chemical fertilizers alone. Tang *et al.,* (2019) reported that applying slurry at a rate of 480 m^3 ha^{-1} for wheat and 9–11.25 m^3 ha^{-1} for rice enhanced grain yields by 8.9% and 15.7% for rice and wheat, respectively. The application of biogas slurry derived from cow dung (5 t ha^{-1}) or poultry manure (3 t ha^{-1}), in conjunction with chemical fertilizers, led to a 20–24% increase in grain yield and a 22–23% higher gross return (Ferdous *et al.,* 2020).

Application method of biogas slurry

Biogas slurry (BGS) can be utilized in various forms: as a foliar spray on crops, as a diluted liquid applied to roots, or in a dry composted form, often combined with irrigation techniques to ensure adequate water supply to crop plants (Warnars and Oppenoorth, 2014). Zhao *et al.,* (2013) advised using BGS as compost in agricultural applications rather than applying it directly. Zhao *et al.,* (2007) explored the impact of varying concentrations of biogas slurry (BGS) sprayed on chili peppers, specifically focusing on the leaves' surface and found that the application of 50% concentration spraying slurry resulted in a significant maximization of chili pepper yield, achieving a maximum increase of 25.42% compared to the control group.

Impact of biogas slurry on soil health

Biogas slurry apart from nutrients also contain organic matter that has the capacity to augment the soil carbon pool, mitigate soil degradation risks, and enhance overall soil quality (Zilio *et al.,* 2022). As per reports, application of biogas slurry led to an increase in the abundance of bacteria involved in nitrogen (N) cycling within the soil of annual ryegrass, with the source of soil carbon (C) being a critical determinant affecting bacterial community composition (Zhang *et al.,* 2017). Liang *et al.,* (2023) reported that soil organic carbon (SOC) content from both bottom applications and topdressings of biogas slurry saw significant increments ranging from 9.92% to 15.52% and 13.02% to 18.26%, respectively throughout the full fruiting period. Biogas slurry is rich in nutrients offering the potential to decrease the dependency on chemical fertilizers in agriculture (Liang *et al.,* 2023). El-Badawy *et al.,* (2017) reported the highest dehydrogenase (DHA) activity (201.5 µg TPF g^{-1} rhizosphere soil day^{-1}), total bacterial count (17.2 x 10^6 CFU g^{-1} soil), and nitrogenase activity (44.5 nmole C_2H_4 g^{-1} rhizosphere soil h^{-1}), for the treatment where plants received 10 m^3 biogas slurry (BS) and 30 kg P_2O_5 per fed as rock phosphate (RP) for the Xera cultivar. Rao *et al.,* (2019) reported higher urease activity, dehydrogenase, acid phosphatase, alkaline phosphatase through recommended dose of phosphorus (RDP), biogas digestate (BGD) and a microbial consortium, with values recorded at 75.30, 73.40, and 72.80 (µg NH^{4+} g^{-1} 2 h^{-1}), 41.00, 38.67, and 36.00 (µg TPF g^{-1} d^{-1}), 27.71, 26.20, and 25.40 (µg PNP g^{-1} h^{-1}), 43.37, 41.65, and 40.89 (µg PNP g^{-1} h^{-1}) respectively during the vegetative, reproductive, and harvest stages, respectively.

Pest disease resistance and antifungal potential of Biogas slurry

The application of biogas slurry demonstrated an effective repellent effect on adult brown rice plant hoppers (Huang *et al.,* 2014). Biogas slurry exhibited potent antimicrobial and insecticidal properties, effectively eliminating pathogenic bacteria and insect eggs. This activity can be attributed to its elevated ammonium content, consortia of beneficial microorganisms, hydrolytic enzymes, phytohormones, and bioactive compounds (Du *et al.,* 2018). Furthermore, biogas slurry demonstrated inhibitory effects against six distinct phytopathogens, including *Botrytis cinerea*, *Pythium* spp. causing chili root rot, and *Colletotrichum* spp. responsible for cucumber anthracnose. Previous studies have also reported that biogas slurry supplementation significantly suppressed the mycelial proliferation and zoospore germination of *Phytophthora capsici*, thereby mitigating disease incidence (Cao *et al.,* 2014).

The suppressive effect of biogas slurry on the mycelial growth of four phytopathogens under *in vitro* conditions with a particularly pronounced effect on *Botrytis cinerea* and *Aspergillus sonali*. The inhibition percentages were 51.10% for *Botrytis cinerea*, 46.20% for *Aspergillus sonali*, 17.60% for *Fusarium oxysporum* f. sp. *melonis* (FOM), and 11.00% for *Sclerotinia sclerotiorum* (SS) respectively (Yu *et al.*, 2014). Ma *et al.,* (2011) also reported that the inhibitory effect of both types of biogas slurry (BS) (from pig manure and cow manure) on five strawberry plant pathogens demonstrated significant variability and observed growth inhibition rate of 73-

87% for *F. oxysporum* f. sp. *fragariae*, *Glomerella cingulata*, and *Verticillium dahliae*. In contrast, *Phytophthora capsici* exhibited a growth inhibition rate of 38%, while no inhibitory effect was detected for *Pythium aphanidermatum*.

CONCLUSION

Biogas slurry serves as a reservoir of beneficial microbes, including nitrogen-fixing bacteria, phosphate-solubilizing bacteria, and plant growth-promoting microorganisms, which contribute to soil fertility and plant health. The microbial diversity within the slurry plays a crucial role in organic matter decomposition, nutrient mineralization, and enzymatic activities, which enhance nutrient availability. Additionally, biogas slurry exhibits antifungal and antibacterial properties, suppressing phytopathogens, thereby reducing disease incidence in crops. The incorporation of biogas slurry in agricultural systems not only enriches the soil microbiome but also promotes biological control of plant diseases, reducing reliance on chemical pesticides. Further research on microbial interactions within biogas slurry could unlock its full potential in sustainable and organic farming practices. Considering its promising attributes, the potential of biogas slurry can be further harnessed for the cultivation of various forage crops.

REFERENCES

Abubaker, J., H. Cederlund, V. Arthurson and M. Pell, 2013: Bacterial community structure and microbial activity in different soils amended with biogas residues and cattle slurry. *Appl. Soil Ecol.*, **72**: 171-180.

Cao, Y., Z. Chang, J. Wang, Y. Ma, H. Yang and G. Fu, 2014: Potential use of anaerobically digested manure slurry to suppress *Phytophthora* root rot of chili pepper. *Sci. Hortic.*, **168**: 124-131

Du, Z., Y. Xiao, X. Qi, Y. Liu, X. Fan and Z. Li, 2018: Peanut-shell biochar and biogas slurry improve soil properties in the North China Plain: a four-year field study. *Sci. Rep.*, UK **8**: 13724.

El-Badawy, E. S. H., 2017: Response of snap bean to biogas slurry combined with either rock phosphate or super phosphate fertilizers. *Ann. Agric. Sci. Moshtohor,* **55**(2): 261-270.

Ferdous, Z., H. Ullah, A. Datta, A. Attia, A. Rakshit, and S. H. Molla, 2020: Application of biogas slurry in combination with chemical fertilizer enhances grain yield and profitability of maize (Zea mays L.). *Commun. Soil Sci. Plant*, **51**(19): 2501-2510.

Gupta, M. K., 2007: Handbook of Organic Farming and Biofertilizers. ABD Publishers, Jaipur, India.

Haque, M. A., M. Jahiruddin, M. S. Islam, M. M. Rahman and M. A. Saleque, 2018: Effect of bioslurry on the yield of wheat and rice in the wheat–rice cropping system. *Agric. Res.*, **7**: 432-442.

Huang, L., R. Lou, Y. Xu, J. Li and Y. Zhu, 2014: Preliminary study on insect repellent and disease control effect of biogas fertilizer on rice. *China Biogas,* **32**: 79-82.

Hussain, S., M. Rasheed, C. Y. Long, A. Altaf, A. Masoom, I. Ahmad, Z. Rui and S. S. Hussain, 2019: Impact of biogas slurry as a nutrient source on wheat (Triticum aestivum L.) production and soil health. *Spec. J. Agric. Sci.*, **5**(4): 15-22.

Islam, M. R., S. M. E. Rahman, M. M. Rahman, D. H. Oh and C. S. Ra, 2010: The effects of biogas slurry on the production and quality of maize fodder. *Turk. J. Agric. For.*, **34**(1): 91-99.

Jin, Z., R. Sun, L. Ping, C. A. Zhang, M. Ying and S. Ding, 2021: Evaluating the key factors of soil fertility and tomato yield with fresh and aged biogas slurry addition through greenhouse experiment. *Biomass Convers. Biorefin.*, **13**(6): 5073-5084.

Kalamdhad, A. S. and S. S. Kumar, 2021: Biogas slurry management: treatment processes, application, and significance in sustainable agriculture. *Environ. Prog. Sustain. Energy,* **40**(6): e13555.

Kumar, S., L. C. Malav and A. S. Khan, 2015: Resource utilization of biogas slurry for better yield and nutritional quality of baby corn. *Int. J. Ext. Res.*, **2**: 42-46.

Liang, X., H. Wang, C. Wang, Z. Yao, X. Qiu, H. Ju and J. Wang, 2023: Disentangling the impact of biogas slurry topdressing as a replacement for chemical fertilizers on soil bacterial and fungal community composition, functional characteristics, and co-occurrence networks. *Environ. Res.*, **238**: 117256.

Lina, J., W. Qiang, C. D. Jiang, Q. Aifen, F. J. Shiming, Rong and W. Jiamei, 2011 : Effects of paddy field disposal of biogas slurry on rice production, soil quality, and environmental safety. *J. Agro-Environ. Sci.*, **30**(7): 1328-1336.

Liu, W. K., L. F. Du and Q. C. Yang, 2008: Biogas slurry added amino acids decreased nitrate concentrations of lettuce in sand culture. *Acta Agric. Scand. Sect. B Soil Plant Sci.*, **58**: 15.

Ma, Y. M., H. L. Li, Z. Z. Chang, Y. D. Xu and J. Y. Zhang, 2011: Biological control effect and mechanism of biogas slurry on plant disease I. A primary study of growth inhibition effects and mechanism on plant pathogen fungi. *J. Agro-Environ. Sci.*, **30**(2): 366-374.

Min Xu, Yang Xian, Jun Wu, Yunfu Gu, Gang Yang, Xiaohong Zhang, Hong Peng, Xiaoyu Yu, Yinlong Xiao and Li Li 2019: Effect of biogas slurry addition on soil properties, yields,and bacterial composition in the rice-rape rotation ecosystem over 3 years. *Journal of Soils and Sediments. https://doi.org/10.1007/s11368-019-02258-x*.

Muhmood, A., S. Javid, Z. A. Ahmad, A. Majeed and R. A. Rafique, 2014: Integrated use of bioslurry and chemical fertilizers for vegetable production. *Pak. J. Agric. Sci.,* **51**(3).

Ozores-Hampton, M., P. A. Stansly and T. P. Salame, 2011: Soil chemical, physical, and biological properties of a sandy soil subjected to long-term organic amendments. *J. Sustain. Agric.,* **35**: 243-259.

Rao, G. V., C. S. Rao, P. V. Subbaiah and M. S. Rekha, 2019: Effect of biogas digest on the microbial population and enzymatic activity of soil under chickpea cultivation. *J. Res.,* ANGRAU **47**(4): 26-37.

Singh, A. D., A. Upadhyay, S. Shrivastava and V. Vivekanand, 2020: Life-cycle assessment of sewage sludge-based large-scale biogas plant. *Bioresour. Technol.,* **309**: 123373.

Tang, Y., G. Wen, P. Li, C. Dai and J. Han, 2019: Effects of biogas slurry application on crop production and soil properties in a rice-wheat rotation on coastal reclaimed farmland. *Water Air Soil Pollut.,* **230**: 1-13.

Tiwari, V. N., K. N. Tiwari and R. M. Upadhyay, 2000: Effect of crop residues and biogas slurry incorporation in wheat on yield and soil fertility. *J. Indian Soc. Soil Sci.,* **48**(3): 515-520.

Wang, Z., I. A. Sanusi, J. Wang, X. Ye, E. B. G. Kana, A. O. Olaniran and H. Shao, 2023: Developments and prospects of farmland application of biogas slurry in China-A review. *Microorg.,* **11**(11): 2675.

Warnars, L. and H. Oppenoorth, 2014: A study on bioslurry results and uses. *no. March, K. Atkinson, Ed,* 20.

Wentzel, S., R. Schmidt, H. P. Piepho, U. Semmlerbusch and R. G. Joergensen, 2015: Response of soil fertility indices to long-term application of biogas and raw slurry under organic farming. *Appl. Soil Ecol.,* **96**: 99-107.

Win, A. T., K. Toyota, K. T. Win, T. Motobayashi, T. Ookawa, T. Hirasawa, D. Chen and J. Lu, 2014: Effect of biogas slurry application on CH4 and N2O emissions, Cu and Zn uptakes by whole crop rice in a paddy field in Japan. *Soil Sci. Plant Nutr.,* **60**: 411-422.

Wu, J., Q. Yang, G. Yang, F. Shen, X. H. Zhang and Y. Z. Zhang, 2013: Effects of biogas slurry on yield and quality of oil-seed rape. *J. Plant Nutr.,* **36**(13): 2084-2098.

Xu, W., Y. Zhu, X. Wang, L. Ji, H. Wang, L. Yao and C. Lin, 2021: The effect of biogas slurry application on biomass production and forage quality of *Lolium multiflorum. Sustainability,* **13**(7): 3605.

Yadav, R., S. Sudhishri, M. Khanna, K. Lal, A. Dass, H. L. Kushwaha, K. Bandyopadhyay, A. Dey, A. Kushwah and R. H. Nag, 2023: Temporal characterization of biogas slurry: a pre-requisite for sustainable nutrigation in crop production. *Front. Sustain. Food Syst.,* **7**: 1234472.

Yu, F. B., X. D. Li, S. W. Ali, C. F. Song, S. D. Shan and L. P. Luo, 2014: Use of biogas slurry for enhancing control of phytopathogens. *Pol. J. Environ.,* **23**(2).

Yu, F. B., X. P. Luo, C. F. Song, M. X. Zhang and S. D. Shan, 2010: Concentrated biogas slurry enhanced soil fertility and tomato quality. *Acta Agric. Scand. Sect. B–Soil Plant Sci.,* **60**(3) : 262-268.

Zhang, H., S. Li, X. Zheng, J. Zhang, N. Bai, H. Zhang and W. Lv, 2021: Effects of biogas slurry combined with chemical fertilizer on soil bacterial and fungal community composition in a paddy field. *Front. Microbiol.,* **12**: 655515.

Zhang, H., L. Sun, G. Qi, S. Chen and X. Zhao, 2017: Microbial community composition is related to soil biological and chemical properties and bacterial wilt outbreak. *Sci. Rep.,* **7**(1): 343.

Zhao, S., R. Guangxin and Y. G. Yang, 2007: Effect of Spraying Biogas Slurry on Capsicum. *Actaa Gricu Lturae Borea Liocci Denta Lis Sinice.,* **16**(3): 202-203.

Zhao, H. Y., J. Li, J. J. Liu, Y. C. Lü, X. F. Wang and Z. J. Cui, 2013: Microbial community dynamics during biogas slurry and cow manure compost. *J. Integr. Agric.,* **12**(6): 1087-1097.

Zilio, M., A. Pigoli, B. Rizzi, A. Herrera, F. Tambone, G. Geromel, E. Meers, G. Schoumans, A. Giordano and F. Adani, 2022: Using highly stabilized digestate and digestate-derived ammonium sulphate to replace synthetic fertilizers: The effects on soil, environment, and crop production. *Sci. Total Environ.,* **815**: 152919.