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New developments in manufacturing and uses of liquid fertilizers

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Abstract

Liquid fertilizers in agriculture have the potential to meet expanding food demands while lessening their negative effects on the environment. This research looks at the creation and use of liquid fertilizers, emphasizing its advantages for nutrient availability, soil health and the decrease of synthetic inputs. Additionally, it looks into bio-liquid fertilizers created from organic waste and augmented with beneficial microbial populations, slow- and controlled-release fertilizers, and nano-liquid fertilizers for the best nutrient absorption. These developments might improve the effectiveness of fertilizer distribution, lessen pollution, soil degradation and support sustainable agriculture. For crop productivity, nutrient utilization, efficiency and sustainability, the integration of liquid fertilizers with precision agriculture technology and cutting-edge application methods including fertigation, foliar spraying and soil injection is being investigated. Future research objectives include increasing production capacity, methodically examining long-term environmental safety and developing customized nutrient delivery techniques to maximize liquid fertilizers' contribution to environmental cleaning and global food security.

Keywords: Liquid fertilizers, Nutrient availability, Sustainable agriculture, Environmental safety and Targeted nutrient delivery.

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1. Introduction

One of primary needs is food. The current population growth is contributing to the rise in the demand for food. Meeting food demand depends much on the fertilizer industry. Agro-technology applies numerous technologies and approaches to improve profitability, productivity and efficiency in agriculture. Modern agriculture has a novel approach in liquid fertilizers, which improve nutrient availability and soil health to maximize agricultural methods. Plants, for best growth, need nitrogen (N), phosphorous (P), potassium (K), organic carbon (C) and other macronutrients. Several forms of liquid fertilizers meet plant nutritional needs [1]. Acid hydrolysis and compositional change are examples of advanced processing processes that provide consistent fertilizer formulation and production. These kinds of formulations are offered to raise the amount of essential nutrients; they are designed to provide greater amounts of essential nutrients, with a primary focus on amino acids, which are necessary to promote effective plant metabolic processes [2]. Liquid fertilizers help the environment by decreasing greenhouse gas emissions and the need for chemical fertilizers and the associated environmental effects. They are also crucial for recycling the vital nutrients found in waste products. Liquid fertilizers improve nitrogen delivery, reduce waste and improve application efficiency when used with foliar and fertigation methods [3]. Liquid fertilizers are another consistently accessible source of recycling. These concepts not only support waste management systems that transform biowaste into useful resources, but they also support agriculture. Additionally, using ecologically friendly alternatives to synthetic fertilizers reduces agriculture expenses [4]. Precision agriculture is an advancement in agricultural technology in which these fertilizers help reduce the impact on the environment by using resources more efficiently via the use of modern farming technologies [5]. Processed liquid digestates' microbiological safety guarantees that their usage in agriculture won't put in danger the health of people or plants. The use of liquid fertilizers is crucial for improving plant health and soil fertility. As a result, digestate-based liquid fertilizers provide a workable and efficient way to address both economic and environmental issues in contemporary farming [6]. Liquid fertilizers are fulfilling plant nutrient needs by their targeted applications, which include nitrogen-based liquid fertilizers, phosphorous-based liquid fertilizers, potassium-based liquid fertilizers and micronutrient-based liquid fertilizers [7].

Due to high CO_2 emissions and poor usage efficiency, ammonium nitrate (NH_4NO_3) can cause energy and environment problem but it is important for protein synthesis and for the development of plant [8]. Although, some phosphorus based liquid fertilizers can cause eutrophication and cost high energy but they promote root development. Liquid fertilizers based on potassium, such as potassium nitrate, improve disease resistance and drought resilience, but excessive application may cause excess of salt in the soil. Micronutrient-based liquid fertilizers address specific soil deficiencies and improve crop quality by enriching soil with trace elements such as manganese, iron,

and zinc. Developments in liquid fertilizer technology are essential to sustainable agriculture because they provide energy-efficient solutions while meeting food demands in a green way [9].

Synthetic fertilizer overuse has significant hazards including nutritional imbalances, soil degradation, and environmental pollution. Leaching, denitrification, and heavy metal pollutants in these fertilizers help to contaminate soil, water, and the atmosphere. Moreover, extended usage of these fertilizers lowers soil organic matter levels and raises soil acidity, thus deplete important nutrients. Disruption of soil microbial populations exacerbates these problems by limiting nutrient availability and therefore compromising beneficial plant-microbe interactions. Reducing chemical fertilizers and using sustainable technologies such as nanotechnology can helps to improve the soil [10].

2. New development in liquid fertilizers

2.1 Slow-release liquid fertilizers

Slow-release fertilizers have a characteristic of constant, under control nitrogen supply (Fig.1 and Table 1). Slow-release formulations may be created by encasing liquid fertilizers in a semi-permeable polymer or resin matrix [11]. The rate at which nutrients reach the surrounding environment is regulated by this barrier based on temperature, moisture content, and microbial activity. Over time, the encapsulating material gradually degrades, making it easier to release nutrients in a controlled manner [12]. These slow-release formulations were developed to enhance nutrient delivery to plants, boost agricultural yields, lower environmental consequences while keeping economic viability. Although advanced materials and synthetic polymers help to increase continuous nutrient delivery, semipermeable coatings are employed to slow down nutrient breakdown and release [13].

2.2 Controlled-release fertilizers

In order to improve nutrient delivery to plants, increase agricultural yields, minimize environmental effects, and maintain economic viability, these controlled-release formulations were created. Semipermeable coatings are employed to reduce nutrient breakdown and release, despite the fact that synthetic polymers and sophisticated materials improve prolonged nutrition delivery [14]. CRFs are products that contain water-soluble nutrients whose release into the soil is controlled by a coating placed on the fertilizer [15].

Controlled-release liquid fertilizers are more effective than granular fertilizers due to their fast absorption, even distribution, and protection against fertilizer burn (Fig. 2). They help the environment by reducing losses related to leaching or fixation, therefore avoiding environmental pollution [16].

Techniques of CRFs encapsulation consist of pan and rotary drum coating, fluidized bed coating, spray drying, and in situ polymerization. Regarding coating consistency, equipment needs and scalability, every technique offers unique benefits and constraints [16].

2.3 Nano liquid fertilizers

Nanotechnology finds one of its most significant applications in nano-fertilizers, which enhance the nutrient absorption capacity of plants [17]. New nanofertilizers have emerged using organic nanoparticles such as lignin, lipids, urea, starch, chitosan, cellulose, zeolites, polymers and others. These materials have antipathogenic properties that add value to agricultural production, in addition to their direct use as nutritional supplements. To ensure sustainable use and minimize any potential toxic or adverse consequences, it is crucial to look at their long-term interactions with crops and the environment [18].

Among organic materials that could be used instead of chemical fertilizers are crop leftovers, vermicompost, farm yard manure and nano fertilizers. IFFCO responded by launching liquid nano-urea fertilizer. Farm yard manure, vermicompost, crop leftovers and nano fertilizers are a few organic alternatives one may use for chemical fertilizers [19]. IFFCO responded with liquid Nano-urea fertilizer, a nanotechnology-based alternative for urea fertilizer that provides the nitrogen the crop requires at all phases of growth. Because the nanoparticles in nanostructured fertilizers are tiny (1–100 nm), they have a vast surface area, intense reactivity and high-water solubility [20]. While nanotechnology-based solutions act as an alternative to urea fertilizer by providing the crop with nitrogen as needed throughout its growth stages, they also reduce production costs and the potential negative consequences of over-application, thereby supporting agricultural sustainability by reducing application frequency. Also, they improve crop yield, quality and fertilizer response characteristics along with nutrient use efficiency [21]. Reduced size of nanoparticles (1–100 nm) results in high surface area, great reactivity and high-water solubility nano-structured fertilizers have. By means of nutrient usage efficiency, they also enhance crop yield, quality, and fertilizer response characteristics; thus, they reduce production costs and the probable negative effects of overdose, so fostering agricultural sustainability [22]. Nanoparticles' fertilizer environmental impact and toxicity—including phytotoxicity and soil contamination—demand further research on biodegradability and long-term effects. To ensure sustainability and lower negative consequences, long-term soil investigations, risk analyses and life cycle evaluations are required. High production costs and scaling problems limit adoption; consequently, affordable manufacturing methods and alliances are needed for general use [23].

2.4 Bio liquid fertilizers

Among the microorganisms used as biofertilizers are Alcaligenes, Bacillus, Azotobacter, Pseudomonas, mycorrhizal fungus, Penicillium, Chaetomium and Trichoderma as they improve plant development. Agro-industrial wastes include plant and animal wastes as well as other useable substrates for biofertilizer manufacture [24]. Biological liquid fertilizers improve soil condition and reduce environmental pollution through microorganisms released from food waste such as eggshells, coffee grounds, and banana peels. While yeast functions as a bio-stimulant and biopesticide, coffee grinds have bacteria like Pseudomonas, Fusarium and Trichoderma that help fight off diseases. These nutrients enhance sustainability by means of waste conversion and reduced environmental impact, improved soil structure and decreased need for chemical fertilizers, therefore promoting plant development [25].

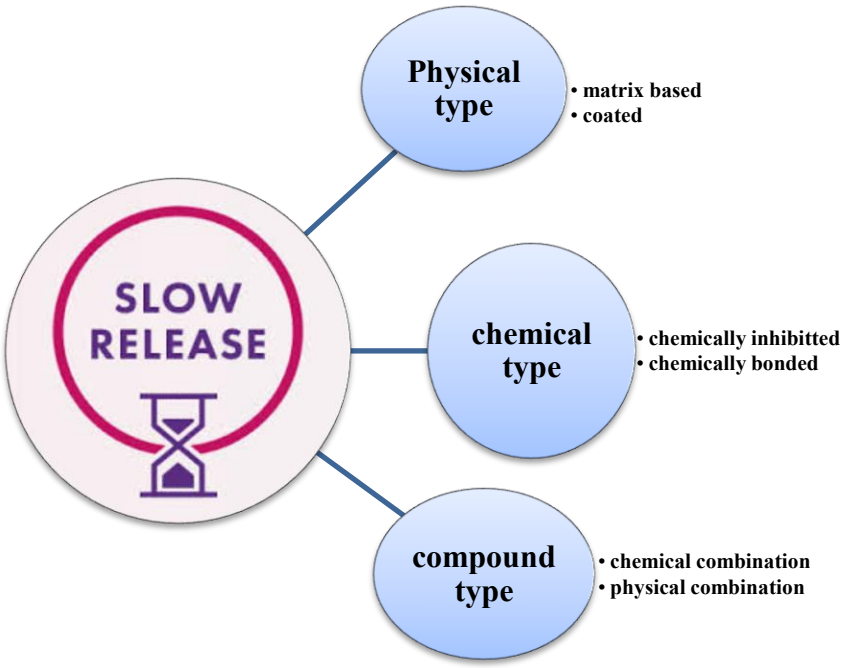

Figure 1: A classification of slow-release fertilizers

Table 1: Slow-release liquid fertilizers

Product Name	Manufacturer	Type	Details
Nitroform	-	Urea-formaldehyde derivative	A slow-release nitrogen source, utilized for efficient nitrogen delivery over time.
Greens Plus	-	Liquid fertilizer (gradual release)	Features a formulation designed for gradual nutrient release to optimize plant growth.
Urea-formaldehyde (UF)	-	Liquid fertilizer (gradual release)	A widely used nitrogen source in fertilizers, offering slow, sustained nutrient release.
IBDU	-	Iso butylidene di urea	A slow-release nitrogen source designed for extended nutrient availability to plants.
Sierraform	ICL	Fertilizer	A product line by ICL, known for incorporating controlled-release technology for improved nutrient efficiency.
Nutriq Technology	Agro-Liquid	Fertilizer technology	A fertilizer technology focused on gradual nutrient release for sustained plant nutrition.
N-Code	Hexion	Fertilizer technology	A slow-release nitrogen technology designed to optimize nitrogen utilization in plants.

Table 2: Controlled-release liquid fertilizers

Product Name	Manufacturer	Type	Details
Multi-cote™	Haifa Group	CRF	Designed for use in nurseries and decorative horticulture, offering gradual nutrient release to optimize plant growth.
Multi-cote Agri / Multigro™	Haifa Group	CRF	Tailored for agriculture and horticulture, providing sustained nutrient delivery for improved crop productivity.
Multi-cote™ Turf / Multigreen™	Haifa Group	Controlled-release turf fertilizers	Specially formulated for turfgrass, ensuring steady nutrient availability for healthy and vigorous turf growth.
Cote-N™	Haifa Group	Controlled-release nitrogen	A controlled-release nitrogen product for arable crops, promoting efficient nitrogen use and minimizing leaching.
Multi-cote Micro™	Haifa Group	Controlled-release fertilizers (Ca, Mg, Zn, B)	Provides controlled release of micronutrients such as calcium, magnesium, zinc, and boron to support plant development.
Osmocote	ICL	CRF	Known for its reliable controlled-release formulation, supporting nutrient release over extended periods for various plant types.
Agro-cote	ICL	CRF	Offers a consistent release of nutrients for agricultural applications, designed to enhance crop yield and quality.
Basa-cote	Compo	CRF	A controlled-release fertilizer solution that promotes efficient nutrient delivery to plants, enhancing overall plant health.
Master-cote	Master-blend International	CRF	A product line providing controlled nutrient release to support healthy plant growth across various applications.

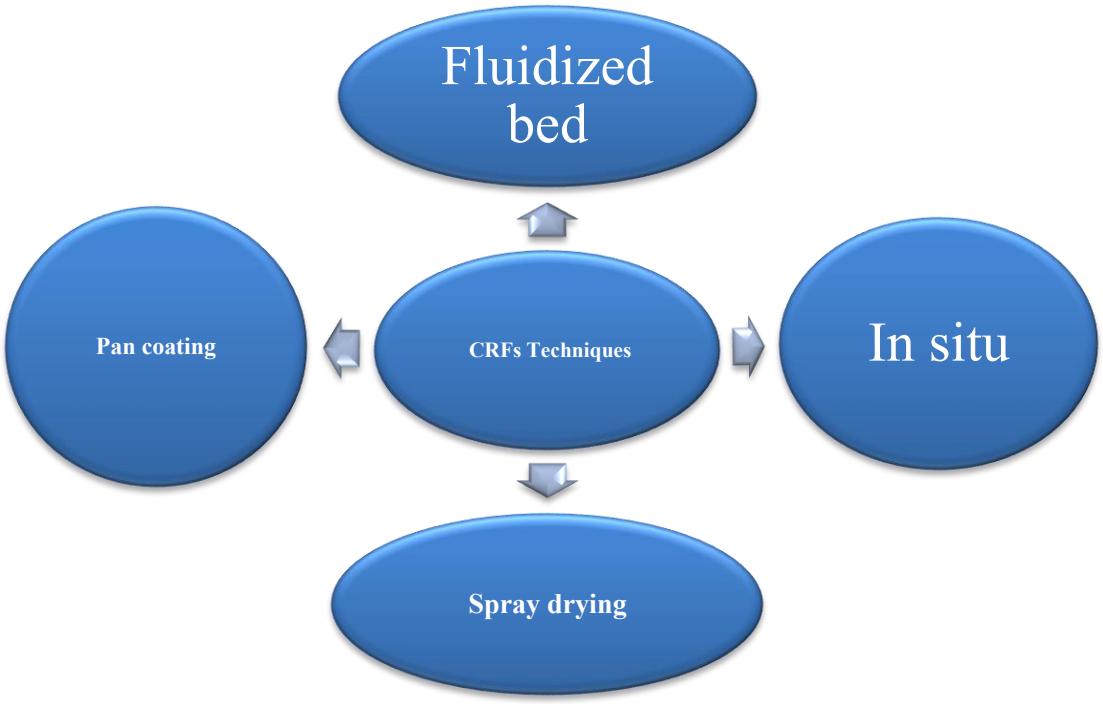

Figure 2: Commercial methods for producing CRFs

Because of other factors not explored in the lab, liquid biofertilizer may react badly when applied from the lab to the big scale. These qualities have to be considered when manufacturing liquid biofertilizers fit for different soil kinds and climatic circumstances. Liquid biofertilizers also present another problem as they may be energy-intensive and need different or more sophisticated tools for broad use. Thus, it is important to make liquid biofertilizers in a way that is low-cost or compatible with existing equipment [26].

3. Benefits of liquid fertilizers

3.1 Improved crop yield

Liquid fertilizers increase crop yields, but they are easy to apply, provide easily absorbed nutrients, and are less affected by weather. Their high nutrient content and low production cost increase efficiency. Their ability to absorb micronutrients, pesticides, and herbicides also accelerate their growth. In addition to being less expensive than solid fertilizers, liquid fertilizers are suitable for a variety of soil types, especially alkaline ones, as they reduce fertilizer stickiness [27].

3.2 Reduced environmental pollution

The use of synthetic fertilizers and pesticides in agricultural areas without sufficient research will cause various types of environmental and health problems. We must practice sustainable and eco-friendly agriculture to protect both our crops and the environment. Reducing the use of harmful fertilizers and pesticides will reduce the frequency of these problems. Rich in micro and macronutrients, liquid fertilizer contains growth-promoting chemicals such as auxin, gibberellin, and beneficial bacteria that stimulate plant growth and immunity [28].

3.3 Increased nutrient efficiency

Liquid fertilizers provide nutrients in forms that are easily absorbed by plants. Slow-release fertilizers increase sustainability and efficiency by reducing nutrient losses due to volatilization and leaching. Liquid formulations provide useful application, minimizing waste and enhancing yields. Moreover, its topical use enhances nutritional absorption and may augment disease resistance [29].

3.4 Improved soil health

Liquid fertilizers enhance soil health by supplying nutrients that promote microbial activity, create soil structure, and ensure efficient nutrient cycling. They enhance root development and water retention by forming soil aggregates, boosting enzyme activity required for nutrient conversions, and fostering beneficial microbial communities. Liquid fertilizers improve the availability of nitrogen, phosphorus, and potassium, reducing soil degradation and encouraging ecologically friendly agricultural practices. Their use is essential for improving root growth and nutrient absorption as well as long-term soil production [30].

4. Application of liquid fertilizers

4.1 Agriculture

Liquid fertilizers have many benefits in the agricultural environment, and there are many ways to apply them to suit different soil types and crops. Fertilizers combine fertilizer with irrigation to ensure a continuous supply of nutrients for large-scale crops, orchards, and vineyards. Broadcast spraying is best for pre-planting or early growth stages because it can cover large areas quickly. While banding distributes fertilizer across crop rows, reducing weed competition and helping row crops like corn and wheat, foliar treatments target plant leaves directly for rapid nutrient uptake. For deep-rooted crops, injection methods reduce nitrogen loss by delivering fertilizer directly to the soil. Spot therapy targets plants that are deficient, particularly in orchards and vineyards. These techniques address a range of agricultural needs, promote sustainable practices, and increase yields [31].

4.2 Horticulture

The application of liquid fertilizers in horticulture provides an efficient and sustainable nitrogen delivery technology that enhances organic farming practices. By providing readily available minerals to increase soil fertility, natural liquid fertilizers can help complement soil revitalization measures and mulching and composting techniques. They contribute to the conservation of biodiversity by promoting healthy plant growth, reducing the need for chemical treatments and creating an environment that is conducive to the growth of beneficial insects and companion plants. Liquid fertilizers can help control pests and diseases by increasing plant resistance and reducing susceptibility to them. Their careful use for nitrogen management, combined with natural fertilizers such as compost, ensures balanced nutrient levels in the soil without endangering the environment. Finally, environmentally friendly techniques like drip irrigation, which maximizes water use and delivers essential nutrients directly to plant roots, can easily incorporate liquid fertilizers, conserving resources and enhancing ecosystem resilience [32].

4.3 Turf management

Effective liquid fertilizers turf management depends on consideration of environmental parameters, turfgrass needs and type of soil. Although nitrogen (N) is essential for growth, it leaches easily and must be supplied frequently, especially in sandy soils that require less. High-demanding grasses like hybrid Bermuda grass benefit greatly from a monthly nitrogen treatment of one pound per 1,000 square feet. Avoid overfertilization since it causes thatch growth, increased water demand, root degeneration and disease and pest issues, more frequent doses than in clay soils retaining nutrients. In order to address nutritional deficits and preserve equilibrium during Hawaii's year-round growing season, consistent fertilization guided by soil testing is necessary. Appropriate treatment and timing provide vigorous, healthy grass while also lowering maintenance concerns [33].

4.4 Environmental remediation

Liquid fertilizers are essential for environmental remediation because they increase soil fertility, stimulate plant growth, and facilitate phytoremediation and bioremediation processes. They revitalize nutrient-deficient soils, promote the proliferation of plants capable of sequestering pollutants, and support the microbial populations crucial for decomposing toxins. Moreover, liquid fertilizers facilitate reforestation and the rehabilitation of

aquatic habitats by promoting plant growth and enhancing nitrogen cycling [34].

5. Future Direction and Research Needs

The key to the future of liquid fertilizers is sustainability, efficiency, and environmental friendliness. Researchers are investigating methods to deliver nutrients precisely where plants need them, nanotechnology (using small particles), and biofertilizers (using beneficial bacteria). Additionally, they are aiming to integrate liquid fertilizers with precision agriculture, which uses technology to target fertilizer usage. The objective is to develop environmentally friendly fertilizers that are very effective [35]. Using more organic waste such as seaweed or biogas plant waste which is rich with benefits for plants is one major concept. Particularly from seaweed, researchers are also developing better bio-stimulants plant boosters to enable crops to flourish larger and better. Certain businesses are even developing unique fertilizers, such as DewEco, which make use of natural components to assist in difficult growing environments. Additionally growing in popularity are organic-mineral fertilizers, which combine vital minerals with organic matter such as plant and algae extracts [4]. Research has shown that combining liquid and solid fertilizers may significantly improve crop quality and yields. Additionally, slow-release fertilizers which are derived from materials like wood ash, may aid in the more efficient delivery of nutrients. In order to lessen our reliance on chemical fertilizers, protect the environment and ensure that there is enough food for everyone, scientists are also developing new sustainable methods of producing fertilizers and developing unique formulas [36]. Most likely, the basic advantages that have driven liquid fertilizers to their present degree of use will always be there. Research advances are also helping to reduce the drawbacks of low nutrient content, high raw material prices and poor product quality issues that have historically hampered liquid fertilizer manufacturers. As such, fluid fertilizers are expected to become progressively more important in the future.

6.Conclusions

In conclusion, this study provided a detailed overview of various aspects of liquid fertilizers which are important parts of modern agriculture, offering a sustainable and efficient means of increasing crop output and soil health but reducing the environmental impacts. Liquid fertilizers address problems like nutrient loss, soil deterioration and resource inefficiency. Some technologies like slow -release system, control release formulation, nano technology and biofertilizers also deals with environmental problems. There are so many applications in horticulture, agriculture, grass management and in environmental cleanup. Uses of bio-stimulants and organic waste are the best solution for an ecofriendly environment. Further research is needed for development and to address the production scalability, biodegradability and long-term impacts of environment, as well as to optimize nutrient delivery systems and improve compatibility with precision agriculture. By embracing these innovations, liquid fertilizers can support a healthier environment, sustainable farming practices and also enhance the food security globally.

References

[1] P. Isyanto. (2024). Optimizing Fertilizer Distribution Performance, In Supporting Food Security Programs. International Journal. 5(10): 5533-5548.

[2] F. Monlau, C. Sambusiti, E. Ficara, A. Aboulkas, A. Barakat, H. Carrère. (2015). New opportunities for agricultural digestate valorization: current situation and perspectives. Energy & Environmental Science. 8(9): 2600-2621.

[3] D. Skrzypczak, K. Trzaska, M. Mironiuk, K. Mikula, G. Izydorczyk, X. Polomska, J. Wiśniewski, K. Mielko, K. Moustakas, K. Chojnacka. (2024). Recent innovations in fertilization with treated digestate from food waste to recover nutrients for arid agricultural fields. Environmental Science and Pollution Research. 31(29): 41563-41585.

[4] R. Pajura, A. Masłoń, J. Czarnota. (2023). The use of waste to produce liquid fertilizers in terms of sustainable development and energy consumption in the fertilizer industry—A case study from Poland. Energies. 16(4): 1747.

[5] B. Lamolinara, A. Pérez-Martínez, E. Guardado-Yordi, C.G. Fiallos, K. Diéguez-Santana, G.J. Ruiz-Mercado. (2022). Anaerobic digestate management, environmental impacts, and techno-economic challenges. Waste Management. 140: 14-30.

[6] S. Agarwal, S. Darbar, S. Saha, R.P. Singh. (2023). Microbiological digestion of agricultural biomass: prospects and challenges in generating clean and green energy. Agriculture Waste Management and Bioresource: The Circular Economy Perspective. 105-130.

[7] B. Sniatala, T.A. Kurniawan, D. Sobotka, J. Makinia, M.H.D. Othman. (2023). Macro-nutrients recovery from liquid waste as a sustainable resource for production of recovered mineral fertilizer: Uncovering alternative options to sustain global food security cost-effectively. Science of the Total Environment. 856: 159283.

[8] S.A. Siddiqui, D. Pleissner, A. Pentjuss, J. Gołaszewski, A. Karwowska, E. Dace, M. Pahmeyer, S. Van Miert, L. Frooninckx, L. Broeckx. (2023). Biological nitrogen recirculation to food protein–A review. Cleaner and Circular Bioeconomy. 6: 100056.

[9] A.D. Ray. (2021). A Comparative Study of Phosphorus Based Fertilisers' Performance: An Assessment on Plant Growth Parameters and Soil Health Using Lolium Perenne. Bangor University (United Kingdom): pp.

[10] F. Amin, M.I. Jilani. (2024). Environmental, Microbiological and Chemical Implications of Fertilizers use in soils: A review. International Journal of Chemical and Biochemical Sciences. 25(18): 56-73.

[11] M.E. Abd El-Aziz, D.M. Salama, S.M. Morsi, A.M. Youssef, M. El-Sakhawy. (2022). Development of polymer composites and encapsulation technology for slow-release fertilizers. Reviews in Chemical Engineering. 38(5): 603-616.

[12] E. Priya, S. Sarkar, P.K. Maji. (2024). A review on slow-release fertilizer: Nutrient release mechanism

and agricultural sustainability. Journal of Environmental Chemical Engineering. 113211.

[13] D. Shanmugavel, I. Rusyn, O. Solorza-Feria, S.-K. Kamaraj. (2023). Sustainable SMART fertilizers in agriculture systems: A review on fundamentals to in-field applications. Science of The Total Environment. 904: 166729.

[14] M. Rajan, S. Shahena, V. Chandran, L. Mathew, Controlled release of fertilizers—concept, reality, and mechanism. In *Controlled release fertilizers for sustainable agriculture*, Elsevier: 2021; pp 41-56.

[15] H. Jariwala, R.M. Santos, J.D. Lauzon, A. Dutta, Y. Wai Chiang. (2022). Controlled release fertilizers (CRFs) for climate-smart agriculture practices: a comprehensive review on release mechanism, materials, methods of preparation, and effect on environmental parameters. Environmental Science and Pollution Research. 29(36): 53967-53995.

[16] S. Moradi, A. Babapoor, S. Ghanbarlou, M.Y. Kalashgarani, I. Salahshoori, A. Seyfaee. (2024). Toward a new generation of fertilizers with the approach of controlled-release fertilizers: a review. Journal of Coatings Technology and Research. 21(1): 31-54.

[17] A. Kahlel, A. Ghidan, T. Al-Antary, I. Alshomali, H. Asoufi. (2020). Effects of nanotechnology liquid fertilizers on certain vegetative growth of broad bean (Vicia faba L.). Fresen. Environ. Bull. 29(6): 4763-4768.

[18] A. Batool, M. Nazir, S.M. Zargar. (2024). Nano-pesticides and nano-fertilizers from natural (plant/animal) wastes. Biocatalysis and Agricultural Biotechnology. 60: 103265.

[19] B. Verma, P. Pramanik, D. Bhaduri, Organic fertilizers for sustainable soil and environmental management. In *Nutrient dynamics for sustainable crop production*, Springer: 2019; pp 289-313.

[20] S. Babu, R. Singh, D. Yadav, S.S. Rathore, R. Raj, R. Avasthe, S. Yadav, A. Das, V. Yadav, B. Yadav. (2022). Nanofertilizers for agricultural and environmental sustainability. Chemosphere. 292: 133451.

[21] J. Tyagi, S. Ahmad, M. Malik. (2022). Nitrogenous fertilizers: Impact on environment sustainability, mitigation strategies, and challenges. International Journal of Environmental Science and Technology. 19(11): 11649-11672.

[22] K. Lakshman, M. Chandrakala, P. Prasad, G. Babu, T. Srinivas, N. Naik, A. Korah. (2022). Liquid nano-urea: an emerging nano fertilizer substitute for conventional urea. Chronicle of Bioresource Management. 6(Jun, 2): 54-59.

[23] S.K. Soni, S. Dogra, A. Sharma, B. Thakur, J. Yadav, A. Kapil, R. Soni. (2024). Nanotechnology in Agriculture: Enhancing Crop Productivity with Sustainable Nano-Fertilizers and Nano-Biofertilizers. Journal of Soil Science and Plant Nutrition. 1-34.

[24] G. Uzah, F. Ire, C. Ogugbue. Optimization and Production of Liquid Biofertilizer from Agro-Wastes using Microbial Cells.

[25] A.A. Ayob, N.H. Hamzah, S.N.S. Rosli, N.A. Bakar. (2025). Production of Bioorganic Liquid Fertilizer from Food Waste for Chilli Plants. Multidisciplinary Applied Research and Innovation. 6(1): 139-146.

[26] R. Negi, N. Yadav, A.N. Yadav. (2025). Microbial biofertilizers: A paradigm shift towards agricultural sustainability. Biologia. 1-26.

[27] B. Sadriddinovich. (2022). Benefits Of Liquid Fertilizers In Agriculture. Scientific Impulse. 1(5): 1843-1850.

[28] P. Maity, R. Rijal, A. Kumar. (2020). Application of liquid manures on growth of various crops: A review. International Journal of Current Microbiology and Applied Sciences. 11: 1601-11.

[29] S. Sajar, A. Setiawan, A.T. Anzani In *Analysis Of Liquid Organic Fertilizer Azolla SP And Chicken Manure On the Growth and Yield of Shallot Plants*, The International Conference on Education, Social Sciences and Technology (ICESST), 2024; 2024; pp 133-143.

[30] Y. Xing, X. Zhang, X. Wang. (2024). Enhancing soil health and crop yields through water-fertilizer coupling technology. Frontiers in Sustainable Food Systems. 8: 1494819.

[31] N. Stamate, O. Ranta, A. Ghețe, O. Marian, C. Bogdan, A.M. Irimie. (2024). Equipment and Systems for The Application of Liquid Fertilizers in Field Crops-News and Perspectives. Agricultura. 128(3-4).

[32] S. Kumar, R. Singh. Manures and Manuring in Horticultural Crops. Inclusive Fundamental of Horticulture. 163.

[33] H. Liu, M. Pessarakli, H. Luo, N. Menchyk, C.M. Baldwin, D.H. Taylor. (2021). Turfgrass nitrogen management: A review. Handbook of plant and crop physiology. 343-385.

[34] T.B. Singh, A. Ali, M. Prasad, A. Yadav, P. Shrivastav, D. Goyal, P.K. Dantu. (2020). Role of organic fertilizers in improving soil fertility. Contaminants in agriculture: sources, impacts and management. 61-77.

[35] B. Sharma, S. Tiwari, K.C. Kumawat, M. Cardinale. (2023). Nano-biofertilizers as bio-emerging strategies for sustainable agriculture development: Potentiality and their limitations. Science of The Total Environment. 860: 160476.

[36] M. Rashid, Q. Hussain, K.S. Khan, M.I. Alwabel, R. Hayat, M. Akmal, S.S. Ijaz, S. Alvi. (2021). Carbon-based slow-release fertilizers for efficient nutrient management: synthesis, applications, and future research needs. Journal of Soil Science and Plant Nutrition. 21: 1144-1169.