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AGRI JOURNAL WORLD
VOLUME 4 ISSUE 8 AUGUST, 2024

SMART FERTILIZERS FOR SUSTAINABLE AGRICULTURE

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ABSTRACT

The global population's increasing food demand necessitates enhanced sustainable crop production. Fertilizer application is crucial for improving crop yield and soil fertility, but conventional methods can lead to nutrient loss through leaching, volatilization, and eutrophication, reducing nutrient use efficiency. Next-generation smart fertilizers, designed with innovative formulations, aim to maximize agricultural production while minimizing environmental impact. These advanced fertilizers include controlled-release fertilizers, nano-fertilizers, bioformulations, and IoT-based nutrient management practices. Their adoption is essential to meet global food needs and reduce environmental harm.

KEYWORDS: Bioformulations, Controlled release fertilizer, Nano fertilizer, Nutrient use efficiency

INTRODUCTION

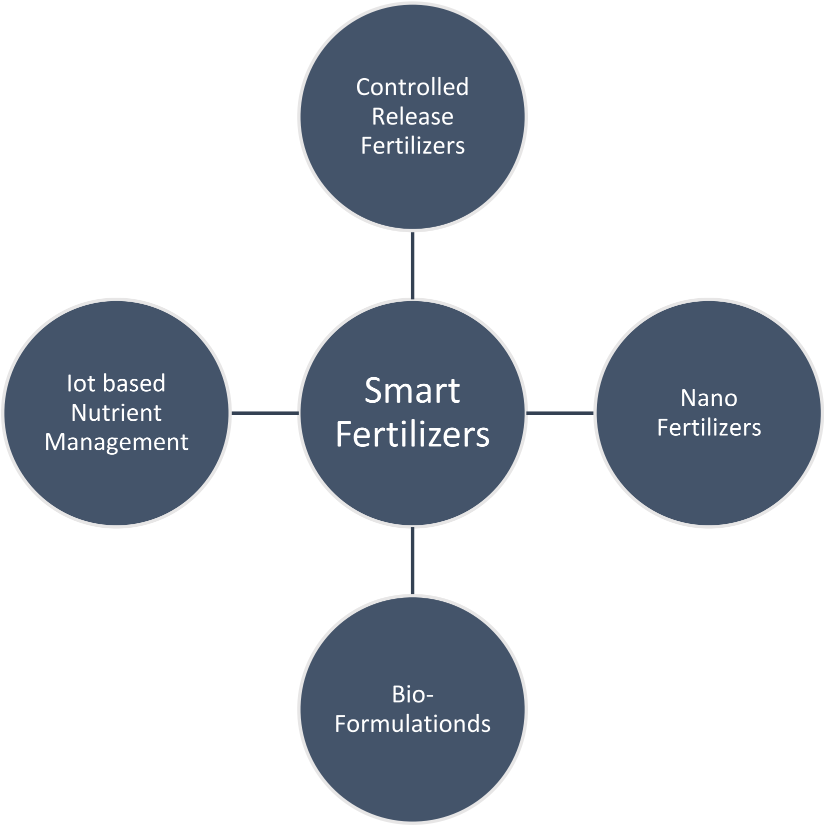
Agriculture confronts the challenge of ensuring food security for the escalating global population without endangering environmental security as demand for the world's food systems amplifies in the upcoming decades. The primary channel for food supply, agriculture, necessitates immediate support for enhancing crop productivity. Potential strategies include employing high-yield varieties and optimizing irrigation and fertilization methods. Fertilizer application is a critical agricultural management practice for increasing crop yield and improving soil fertility by augmenting the supply of fertilizers and soil amendments (Aryal et al., 2021). Although fertilizers are designed to improve nutrient use efficiency, several pathways of losses can significantly reduce their effectiveness. These losses include leaching, denitrification, microbial immobilization, fixation, and runoff. As a result, a substantial amount of nitrogen (40-70%), phosphorus (80-90%), potassium (50-70%), and micronutrients (more than 95%) are lost in the environment, leading to pollution (Kanjana, 2017). These losses have detrimental consequences on the environment globally, such as the contamination of groundwater from leached nutrients and reduced efficiency of applied fertilizers. New generation smart fertilizers, with innovative formulations, are designed to maximize agricultural production while minimizing environmental harm. These advanced fertilizers represent a modern approach to agricultural methods that emphasize precision, sustainability, and environmental responsibility (Kanjana., 2017). To meet the expanding global demand for food while minimizing the environmental impact of farming, these advancements are imperative.

Smart fertilizers involve the precise dosage and timing of fertilizer application using advanced technologies, to optimize crop yield and minimize agrochemical usage. By accurately monitoring the environment, these tools can help create and promote the use of sustainable fertilizers. Conventional fertilizer practices can lead to poor nutrient management and loss of nutrients through leaching, but smart fertilizers offer a more advantageous alternative (Vejan et al., 2021). These next-generation fertilizers aim to address the limitations of conventional fertilizers and support environmentally responsible and productive agriculture. Among the various types of smart fertilizers, controlled-release, nano-fertilizers, bioformulation fertilizers and IoT-based fertilizer applications are notable innovations that can enhance nutrient use efficiency and sustainably improve crop yield. According to Raimodi et al. (2021), smart fertilizers are defined as "any single or composed nanomaterial, multicomponent, and/or bioformulation containing one or more nutrients that can adapt the timing of nutrient release to the plant nutrient demand via physical, chemical, and/or biological processes, thereby improving crop growth and development and reducing environmental impact when compared to conventional fertilizers".

TYPES OF SMART FERTILIZERS

Controlled release fertilizer

Controlled-release fertilizers (CRFs), which are sometimes referred to as coated or encapsulated fertilizers, can be described as "a granular fertilizer coated with polymer/resin/coating materials that delay the nutrient release from the fertilizer core and extend its availability significantly longer than traditionally available nutrient fertilizer" (Trenkel et al., 2010). CRFs, as described by Shaviv (2005), are fertilizers in which the factors governing the rate, pattern, and duration of release are known and controllable during their preparation. In contrast, slow-release fertilizers release nutrients at a slower rate than conventional fertilizers, but the rate, pattern, and duration of release are not well controlled. Common examples of slow-release fertilizers include microbially decomposed N products, such as urea-formaldehyde, and coated or encapsulated products, classified as controlled-release fertilizers (Trenkel, 1997). The European Standardization Committee (CEN) Task Force has established criteria for controlled-release fertilizers, specifying that the rate of nutrient release must be slower than that of conventional fertilizers. Specifically, no more than 15% of the nutrients should be released within 24 hours, no more than 75% within 28 days, and at least 75% within the stated release time.



Nano fertilizers

Nano-fertilizers are available in both powder and liquid forms and involve the engineering, design, and application of nanoparticles. These fertilizers are defined as products in the nanometer range that provide nutrients to crops. Nanoparticle-based fertilizers are a type of fertilizer that delivers nutrients precisely for optimal plant growth. These fertilizers can be administered either in real-time to the rhizosphere or through foliar sprays. They are designed with small size, high surface area, and reactivity to enhance the solubility, diffusion, and availability of nutrients to plants. By doing so, they increase crop productivity by utilizing unavailable plant nutrients in the rhizosphere. Nano-fertilizers improve nutrient release kinetics and plant uptake efficiency, resulting in benefits such as higher crop yields, reduced nutrient loss to the environment, and improved nutritional content and shelf life. The use of nano-fertilizers can help reduce the risk of eutrophication and subsequent degradation of natural resources.

Bioformulations and Biostimulants

Bioformulations are fertilizers that include active or dormant microorganisms, including bacteria and fungi, which can affect growth and nutrition (Tayade et al., 2022). These microbial preparations comprise beneficial microorganisms that possess the ability to fix, solubilize, or mobilize plant nutrients, thereby enhancing plant growth and crop yield. Plant bio-stimulants are substances or materials, other than nutrients and pesticides, that can influence physiological processes in plants when applied to plants, seeds, or growing substrates in specific formulations. Bio-stimulants can have direct hormonal effects on plants, which can lead to benefits such as increased root growth, improved root efficiency and enhanced nutrient uptake. These effects can be particularly useful when transitioning from chemical to organic fertilization regimes. The primary categories of bio-stimulants encompass humic substances, protein hydrolysate and amino acid stimulants, seaweed extract, and PGPR. Bio-stimulants refer to natural or synthetic compounds that may be administered to seeds, plants, and soil, to enhance vital and structural processes in plants, ultimately leading to increased tolerance to adverse environmental conditions, higher seed and grain yield, and improved quality. Bio-stimulants are effective in reducing the necessity for fertilizers. They are capable of enhancing nutrient efficiency, abiotic stress tolerance, and crop quality traits, even in small concentrations, regardless of the nutrient content of the substances. On the other hand, biofertilizers and bio-stimulants have an indirect impact on nutrient availability, as they do not directly provide nutrients. Instead, they consist of live microbial formulations or compounds that facilitate the acquisition and absorption of essential nutrients.

Internet of Things (IoT) based nutrient management

The utilization of the Internet of Things (IoT) in agriculture presents significant potential for real-time monitoring of soil temperature, nutrient requirements and moisture levels. By doing so, farmers can gain valuable insights into the availability of soil nutrients, enabling site-specific nutrient management practices that conserve resources and minimize environmental pollution. IoT systems can also be utilized for automated fertilizer delivery through drones and smart irrigation systems, which can increase nutrient and water use efficiency. Furthermore, IoT technologies allow farmers to remotely monitor and manage their farms, enabling timely interventions and improving overall farm management. Overall, the integration of IoT into farming practices can contribute to sustainable nutrient management and enhance sustainable agricultural productivity.

CONCLUSION

In the realm of Indian agriculture, considerable technological advancements are currently being made. Although the use of smart fertilizers has been developed, their application in agriculture remains limited. When contrasted with conventional fertilizers, smart fertilizers exhibit several notable advantages. The integration of smart fertilization techniques allows for the decrease of application losses, the reduction of the amount of fertilizer required, and the alignment of nutrient availability with crop demand. Smart fertilizers are essential for enhancing nutrient use efficiency, protecting the environment, achieving long-term cost savings, promoting sustainable productivity, reducing greenhouse gas emissions, improving soil health, and enhancing climate resilience. In summary, smart fertilizers represent a significant breakthrough in agricultural technology, offering a multitude of benefits. The adoption of smart fertilizers is a crucial step in the direction of more efficient and sustainable agricultural practices

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How to Cite:

Suvana, S., Neethu, N., Debarup, D., Gobinath, R., and Girija, V. (2024). Smart fertilizers for sustainable agriculture. Leaves and Dew Publication, New Delhi 110059. *Agri Journal World*, 4(8):28-32.

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