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Nitrogen Fertilization: A Key Element for Sustainable Crop Production

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Nitrogen (N) is one of the most crucial nutrients for plant growth and development. It plays an essential role in the formation of amino acids, proteins, and enzymes that support vital functions such as photosynthesis and energy transfer in plants. Nitrogen fertilization has long been recognized as a cornerstone of modern agricultural practices, as it significantly contributes to crop productivity. Various studies have shown that the application of nitrogen fertilizers is directly linked to enhanced crop yields, with farmers worldwide relying on them to meet growing food demands.

Over the past few decades, a strong correlation has been observed between nitrogen fertilizer usage and global food grain production. This relationship underscores the critical role of nitrogen in feeding a growing global population. However, while nitrogen fertilizers such as urea remain indispensable for crop production, challenges regarding their efficiency and environmental impacts persist.

The Dominance of Urea in Nitrogen Fertilization

Urea is the most widely used nitrogenous fertilizer in agriculture, thanks to its high nitrogen content (46%), affordability, ease of storage, and availability. Farmers across the world prefer urea because it meets their nitrogen needs effectively. However, despite its popularity, urea has a major downside: low nitrogen use efficiency (NUE). On average, only 30-50% of the nitrogen applied through urea is taken up by plants, with the remainder lost to the environment through processes such as volatilization, leaching, denitrification, and runoff (Ladha et al., 2005).

These inefficiencies not only result in economic losses for farmers but also have serious environmental consequences. Nitrogen lost to the atmosphere as ammonia contributes to air pollution, while nitrogen leached into groundwater can lead to water contamination. Moreover, nitrous oxide, a potent greenhouse gas, is released during denitrification, further exacerbating

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climate change. These challenges highlight the urgent need to improve the NUE of nitrogen fertilizers.

Addressing Nitrogen Losses: The Role of Urease and Nitrification Inhibitors

In recent years, significant efforts have been made to enhance the efficiency of nitrogen fertilizers and minimize their environmental impacts. One approach involves the use of urease and nitrification inhibitors, which slow down the processes that lead to nitrogen loss. Urease inhibitors work by reducing the rate at which urea is broken down into ammonia, thereby minimizing volatilization losses. Similarly, nitrification inhibitors slow the conversion of ammonium into nitrate, which is prone to leaching and denitrification.

While these inhibitors have shown promise in improving nitrogen use efficiency, their widespread adoption is hindered by high costs, limited availability, and concerns about potential phytotoxic effects. As a result, there is a growing interest in developing more cost-effective and environmentally friendly alternatives that can enhance nitrogen retention in soils without negative side effects.

Coated Urea: A Breakthrough in Fertilizer Efficiency

One of the most promising innovations in nitrogen fertilizer technology is the development of coated urea. By coating urea granules with various materials, researchers aim to create a controlled-release system that delivers nitrogen to plants more gradually, reducing losses and improving NUE. Compared to regular urea, coated urea has been shown to increase crop yields and minimize environmental pollution.

Several types of coatings have been explored, including polymers, sulfur, and bio-based materials. However, these options often come with challenges, such as high production costs and potential risks to the environment. This has prompted scientists to seek out indigenous, low-cost coating materials that can offer the benefits of slow-release nitrogen without the drawbacks associated with conventional coatings.

Neem Oil-Coated Urea: A Popular Solution in India

One successful example of a low-cost coated urea is neem oil-coated urea (NOCU), which is widely used in India. Neem oil, extracted from the seeds of the neem tree (Azadirachta indica), has long been known for its antibacterial, antifungal, and insecticidal properties. When applied as a coating for urea, neem oil acts as a natural urease inhibitor, slowing the breakdown of urea and reducing nitrogen losses through volatilization.

The use of NOCU has been shown to improve nitrogen uptake by crops, enhance yields, and reduce environmental pollution compared to regular urea. Its relatively low production cost makes it an accessible option for farmers, particularly in developing countries where access to expensive fertilizers is limited. Despite its advantages, there is still room for further innovation

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in the development of more efficient coated urea fertilizers.

The Potential of Pine Oleoresin-Coated Urea (POR-CU)

In a bid to explore new, cost-effective coating materials, researchers have recently turned their attention to pine oleoresin (POR) as a potential solution. POR is a natural resin obtained from pine trees (Pinus roxburghii) and is composed of various organic acids, including levopimaric acid, palustric acid, abietic acid, and neoabietic acid. These acids have antimicrobial properties, making POR an interesting candidate for inhibiting urease activity and reducing nitrogen volatilization (Kundu et al., 2013).

Pine oleoresin-coated urea (POR-CU) works by creating a physical barrier around the urea granules, which slows the release of nitrogen into the soil. Additionally, the antimicrobial properties of POR inhibit the activity of urease-producing microorganisms, further reducing nitrogen losses. Laboratory studies and field experiment have shown that POR-CU can improve nitrogen availability to plants while reducing environmental impacts (Kundu, et. Al., 2016; Vassanda Coumar et. al., 2024).

Conclusion

Nitrogen is an essential nutrient for plant growth, but its inefficient use in agriculture has led to significant environmental and economic challenges. Innovations in fertilizer technology, such as coated urea, offer a promising solution for improving nitrogen use efficiency and reducing nitrogen losses. Neem oil-coated urea has already proven to be an effective and affordable option for farmers, particularly in India.

Pine oleoresin-coated urea (POR-CU) represents a new frontier in fertilizer development, offering the potential for even greater improvements in nitrogen use efficiency. Its natural origin, low cost, and ability to reduce nitrogen volatilization make it an attractive option for sustainable agriculture. However, further research and field testing are necessary to fully realize its potential and ensure its adoption on a larger scale.

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