

Article title	Development of fertilizers for enhanced nitrogen use efficiency – Trends and perspectives
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Abstract	<p>Despite nitrogen (N) being the most important crop nutrient, its use as fertilizer is associated with high losses. Such losses pollute the environment and increase greenhouse gas production and other environmental events associated with high ammonia volatilization and nitrous oxide emission. They also cause soil nitrate leaching and run-off that pollute surface and underground waters, with human health implications. The net outcomes for the plant are reduced N uptake and crop productivity that, together, increase the costs associated with fertilization of agricultural lands and dampen farmers' confidence in the efficacy and profitability of fertilizers. To address these problems, enhanced efficiency fertilizers (EEFs) are continuously being developed to regulate the release of N from fertilizers, allowing for improved uptake and utilization by plants, thereby lowering losses and increasing crop productivity per unit of fertilizer. The EEFs are classified based on whether they are inorganic- bio- or organic-coated; their mode of action on different N forms, including urease activity and nitrification inhibition; and the technologies involved in their development, such as targeted compositing of multiple nutrients and nanotechnology. This review is a critical revisit of the materials and processes utilized to coat or formulate enhanced efficiency N-fertilizers for reducing N losses, including their shortcomings, advances made to address such shortcomings, and effects on mitigating N losses and/or enhancing plant uptake. We provide perspectives that could assist in further improving promising and potentially effective and affordable coating or formulation systems for scalable improvements that allow for reducing the rate of N-fertilizer input in crop production. It is especially critical to develop multi-nutrient fertilizers that provide balanced nutrition to plants and humans, while improving N use efficiency and mitigating N-fertilizer effects on human and environmental health.</p>
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