The Potential of Nano-Fertilizers

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Latest News

November 2019, NEW DELHI (ICIS) -- India's IFFCO is looking to produce a new 'nano' technology based on nitrogen fertilizer, according to the company's managing director. Uday Shankar Awasthi said to ICIS the new product would be produced at the firm's Kalol plant in Ahmedabad by March 2021. The company plans to produce 25m bottles/year, the executive said. Each bottle of 500 millilitres will be able to replace a 45-kg bags of urea, Awasthi added. If successful, the product has the potential to reduce the use of urea fertilizer in India by 50%, as well as raise crop output. India's current urea consumption is at around 30m tonnes, with the fertilizer often being overused by farmers as it is the least expensive. Urea market participants said that if IFFCO is able to pull off the plan it would be "trail blazing" for the global urea market. "Our aim is to reduce the use of urea [in India] by 50%. Right now, you need 100kg of urea per acre of land. In this case, farmers could use one bottle of the nano-fertilizer and one bag of urea for each acre," said Awasthi. The company is testing the product in more than 15,000 locations around India. "The nano-fertilizer is being tested in all kinds of soil and climate, from Adaman to Ladakh and Arunachal to Kutch. We are sure it will be successful. It is already showing 23% higher growth in crop mass in the first 15 days [when compared with urea]," said Awasthi. Awasthi said IFFCO does not plan to ask the government for subsidies on sale of the nano-fertilizer, which would reduce the government's subsidy burden by almost half if the product is successful, he said. Urea is heavily subsidised in India. "This will also reduce fossil fuel emissions, any water contamination and increase soil health. The farmer also does not need to carry a heavy load and it will also reduce subsidy payments by half, which is the biggest problem of the country," said Awasthi. Subsidy payments are always delayed by the government. The Fertilizer Association of India (FAI) estimates subsidy arrears close to Rs600bn ($8.4bn) by April 2020, compared with Rs337bn at present. Awasthi said the nano-fertilizer will be priced 10% lower than a bag of urea in India, with a bottle costing Rs240 compared to the current price of a bag of urea which is at Rs266. Headquarterd in New-Delhi, the Indian Farmers Fertiliser Cooperative Limited (IFFCO) has a net worth $2.3bn, is one of the world's biggest co-operative societies with around 35,000 member cooperatives reaching over 50m Indian farmers. ($1 = Rs71.60) Few years from now, fertilisers could turn from commodities to knowledge chemicals.

Introduction

The use of nano-materials in agriculture as nano-fertilizers, nano-pesticides, or nano-enabled sensors to increase crop yield is gaining increasing interest. Engineered nanomaterials (ENMs) can improve crop productivity by influencing fertilizer nutrient availability in soil and uptake by plants. These materials can suppress crop diseases by directly acting on pathogens through a variety of mechanisms, including the generation of reactive oxygen species (ROS). ENMs may also suppress disease indirectly by improving crop nutrition and enhancing plant defense pathways. Efficient use of ENMs may complement or replace conventional fertilizers and pesticides, subsequently reducing the environmental impact of agricultural practices.

Wasteful Practices

Traditionally, fertilisers are applied to crops by either spraying or broadcasting. These are extremely wasteful practices. It has been estimated that 40-70% of Nitrogen, 80-90% of Phosphorous and 50-90% of Potassium content of the applied fertilisers do not reach the targeted area of the plants and are lost to the environment. The net result is a low bioavailability to the plants and increased contamination of soil and groundwater. There are many ways by which the nutrients are lost in the environment, among them – wind drift, surface runoff, leaching, photolytic and microbial degradation and hydrolysis by soil moisture. The poor utilisation of nutrients leads to overuse of fertilisers, which further increases the losses to the environment in a self-destructive cycle.

Nano-technology

Nano-technology can be used to affect a slow and controlled release of the nutrients to plants. Nanostructures, due to their high surface area to volume ratio, have a tremendous potential to deliver nutrients to specific target sites. Deploying nanostructures as carriers, nutrients can be released in a slow controlled fashion, thereby significantly improving their uptake efficiency. Surfaces of nanostructures can be modified to hold the nutrients more strongly and help in slow and regulated release. There are several ways in which nutrients can be loaded on to nanostructures. The nutrients maybe absorbed on the nanoparticles or attached by means of ligands. Another technique is to encapsulate the nutrients in a nanoparticulate polymeric shell. The nutrients may also be entrapped in polymeric nanostructures. Alternatively, the nutrients themselves could be synthesised as nanoparticles.

Nano-fertilisers

Crop nutrition and yield depend greatly on availability of essential elements. 27 Several long-term field studies have shown that 30 to 50% of crop yield can be attributed to nutrient input from commercial fertilizers. Considering the advantages of ENMs, these nutrients can be supplied in nanosized forms to improve release and enhance efficiency

The efficacy of conventional fertilizers is inherently limited by the low availability in soil of many nutrients required by plants. This may be caused by inefficient delivery to the target and underutilization by the crop at the target endpoint. Notably, over the past four decades the nutrient use efficiency of the most important elements required by plants, including nitrogen (N), phosphorus (P) and potassium (K), has remained low: 30–35%, 18-20%, and 35–40%, respectively. Inefficiencies in nutrient delivery to and use by plants ensures that growers add excessive amounts, subsequently leading to environmental contamination from emissions, leaching, and run-off. Several studies have reported that nano-enabled fertilizers have the potential to increase efficiency of nutrient delivery to plants. If this potential could be optimized, the economic and environmental benefits could be dramatic. Accordingly, the intended use of ENMs as nano-fertilizers is targeted at increasing nutrient use efficiency, decreasing immobilization of nutrients, and reducing agricultural waste and run-off of nutrients through leaching and volatilization. Since plants require different nutrients to different degrees, ENM products (similar to conventional products) can be classified into macro- and micro-nutrient nano-fertilizers.

Macronutrient nano-fertilizers

Macronutrient nano-fertilizers provide nutrients required by plants in relatively large amounts, and include N, P, K, Ca, Mg and S. It has been estimated that by 2050, the global demand for macronutrient fertilizers will increase to 263 Mt. The high surface area and penetrability of ENMs make them potentially more efficient products in terms of nutrient use relative to conventional fertilizers. In this regard, controlled or slow release of macronutrients such as N has been achieved from materials such as nano-enabled urea coated zeolite chips and urea-modified hydroxyapatite (HA). Kottegoda et al. demonstrated the efficacy of a nanocomposite of urea-modified hydroxyapatite encapsulated under pressure into Gliricidia sepium. The nanocomposite yielded a biphasic pattern, with initial rapid release of N followed by subsequent slow release over 60 days. On day 60, in a sandy soil (pH 7) the nanocomposite released ~78% more N than the commercial fertilizer. This temporal release pattern could effectively enhance N uptake efficiency in amended plants, thereby significantly improving plant yield compared to conventional fertilizer. The above study demonstrates a promising nanotechnology-based macronutrient formulation that optimizes nutrient dosage through slow and sustainable release of N over time. Notably, a follow up laboratory and field trial by the authors revealed efficient slow release of N, which can be correlated with significant increase in rice yield, even at 50% lower concentration than the conventional urea. The nanocomposites were synthesized from urea–hydroxyapatite nanohybrid (6 : 1) with carbonyl and amine functional groups that are implicated in the effective slow release of N. Although the resultant crop yield increase is impressive, the authors did not account for the additional P and Ca in the urea–HA nanocomposite. This is important given that $Ca(OH)_2$ and H_3PO_4 were used as precursors of the HA. Note that the authors did apply P separately to the apparently P-deficient soil. However, it is likely that this P would be more susceptible to fixation in soil, relative to the P in the nanoformulation that was likely released in a controlled fashion similar to the N. Thus, together with Ca, the P in the formulation with controlled release is more likely to have contributed to plant growth than P added directly to the soil.

Micronutrients

Conventional fertilisers do not possess all the nutrients essential for plant growth. With nanotechnology, it is possible to customise fertilisers to deliver special micronutrients on demand, in tiny accurate dosages. Nano fertilisers can be engineered to address a specific nutritional deficiency in plants. Zinc and Copper are among the most commonly required micronutrients that are not provided by conventional fertilisers. Nanoparticles of Titanium Dioxide have been reported to enhance nitrogen fixation and promote photosynthesis. Cerium Oxide nanoparticles are also most sought after for crop improvement and nutritional benefits. Noble material nanoparticles, especially Silver have been found to provide many benefits. In addition to promoting plant growth, nano-technology can also be used to enhance the nutritional levels of plants for human well-being; a case in point is the Selenium enrichment of plants to satisfy human requirements.

Risks

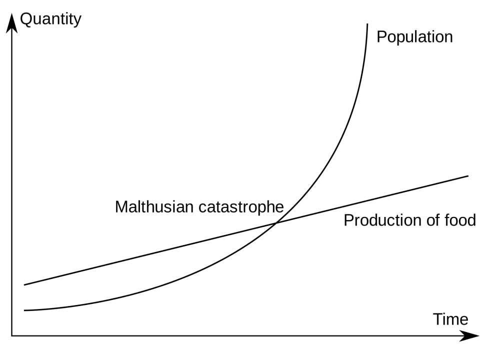
The risks of nanoparticles to human health and safety are yet to be fully understood. Since the size of nanoparticles is similar to biological molecules like antibodies and proteins, it is suspected that they will easily enter humans and animals through oral, respiratory and intradermal routes and interfere in the functioning of vital organs. The line separating deficiency and toxicity is thin, and the possibility of metallic nutrients accumulating in plants and entering the food-chain cannot be ruled out. Much work needs to be done on the characterisation of nanoparticles. Protocols on their handling and application needs to be established.

Conclusions

Collectively, the evidence provided in this review[1)] strongly indicate that nanotechnology has immense potential to improve the efficacy of agrochemical delivery and utilization by crops. As a result of extensive research on plant exposure to nanoparticles, it is clear that ENMs can have detrimental effects at higher concentrations. However, lower dose applications of select ENMs under specific conditions will yield beneficial effects, including enhanced delivery of nutrients, antimicrobial and disease suppression, and insecticidal and herbicidal applications. One very significant development associated with ENMs is that they can significantly reduce the amount of metals/agrichemicals being released into the environment, when compared to conventional formulations. ENM-based soil or foliar fertilization can be achieved through macro- and micronutrient amendments; whereas, the suppression of plant pathogens in infected systems can be attributed to in vivo generation of ROS and activation of antioxidant enzymes by ENMs and other secondary metabolites. Enhanced nutrition through nano-fertilizers could promote inherent plant defense and systemic resistance pathways. Notably, studies often compare ENM effects against untreated controls, with claims of positive outcomes. It is important that all assessment of ENM effects on plants as nano-fertilizers or nano-pesticides involve the corresponding conventional equivalents. Also, in all cases, a cost–benefit analysis of the use of ENMs should be conducted. Without such comparisons, accurate claims of the efficacy and cost effectiveness of nano-enabled agrochemicals cannot be made. Given the small profit margin associated with agriculture/food production, novel strategies will have to be equally effective to conventional approaches, both in terms of economics and efficacy. If developed and applied properly, nano-enabled agricultural approaches such as those described in this review will be a critical component in achieving and sustaining global food security and safety.

Epilogue

The Haber-Bosch process of 1909 for synthesis of Ammonia is regarded by many as the most significant invention of 20th Century for fundamentally altering the Nitrogen Cycle and laying to rest the Malthusian spectre (see graph).
But hundred years after that epic invention, chemical fertilisers are not being looked upon kindly by many environmentalists. Rampant overuse of fertilisers have degraded large swathes of arable land. Meanwhile as population continues to burgeon, food security is a cause of growing concern. Nano technology offers an alternative method of delivering nutrients to plant cells in a more efficient and sustainable manner. Nano-fertilisers bring a new level of precision to agriculture and significantly increase farm output while preserving soil health. However, there are health risks that need to be carefully evaluated before we embrace this technology wholeheartedly.



Reference

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