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Nanotechnology for Crop Nutrient Management

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Nanotechnology is an emerging science related to understanding and control of matter with dimensions between 1 and 100 nanometers. Several literatures reported across the globe highlight the potentials of nanotechnology applications in revolutionizing biological sciences sector, which includes agricultural sciences also. Nanofertilizers form one major example of nanotechnology applications in agriculture. They are fertilizer materials (nanoscale) aimed to supply nutrients to crops in a much more controlled manner as compared to conventional fertilizers thus reducing the chances of nutrient losses and environmental pollution. However, despite the numerous advantages, usage of nanomaterials as fertilizers are associated with certain environmental and toxicity concerns, which must be addressed and resolved before promoting nanofertilizers for sustainable crop nutrient management.

Introduction

The term "Nanotechnology", often abbreviated as "Nanotech", was defined for the first time by Norio Taniguchi, Tokyo Science University in 1974. The word "nano" derives its origin from Greek word meaning dwarf. Nanotechnology is the science concerned with the study of matter at atomic and molecular level. Characteristics of matter at nanoscale (1-100 nanometers) are novel and unique from those at macroscale. This will be brought about primarily by the decreased size and altered interaction pattern of the molecules. Understanding and controlling matter on a scale of 1-100 nanometers will enable the development of novel applications.

Synthesis of Nanomaterials

Nanomaterials can be prepared by different approaches: top-down and bottom-up approaches (Figure 1).

The Top-Down approach involves subdivision of a larger solid (bulk) into smaller portions (nanoparticles). In nature, these methods are neither inexpensive nor quick to manufacture; they are also inefficient for large-scale production. In the top-down approach, various methods such as milling/attrition, chemical methods, photo-lithography, electron beam lithography, X-ray lithography, etc. are utilised.

The Bottom-Up methodology is based on the incremental addition of atoms and molecules. It involves the condensation of atoms/molecules in gas phase or solution phase, allowing them to grow to nanoscale proportions. In this method, nanoparticle fabrication costs are drastically reduced. Sol-gel processing, chemical vapour deposition, plasma spraying synthesis, and molecular condensation are some of the methods used in bottom-up approach (Tarafdar and Adhikari, 2015).

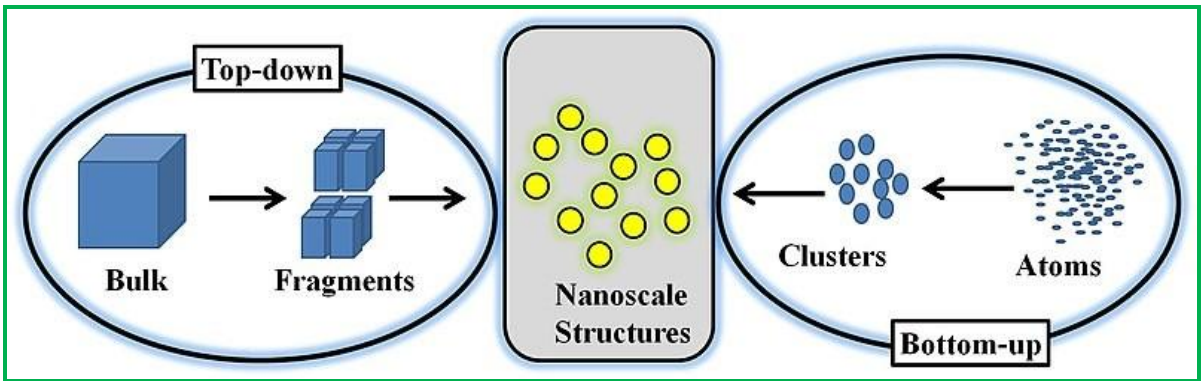

Figure 1. Approaches for nanomaterials synthesis

Nanotechnology Applications for Crop Nutrient Management

Nano-Fertilizers

Nano-fertilizers are synthesized from conventional fertilizer materials with the help of a nanotechnology, in other words they are the modified form of traditional fertilizers. The nutrients in nano-fertilizers can be encapsulated within nanoporous materials or delivered as nanoscale-sized particles or emulsions. These are mainly intended for targeted delivery, slow and sustained release of nano-fertilizer products in response to environment conditions and biological demand which thus help to increase nutrients use efficiency, reduce soil toxicity, minimise the potential negative effects of overdosing, and lower the cost of frequent application.

Engineered Nanoparticles

Engineered nanoparticles, in today's modern world, are widely being used in medicine, cosmetics, energy, agriculture sectors and thus gradually becoming an essential part of daily life. They are manufactured and designed in a unique way with the aim to have specific shape, size and properties. Engineered nanoparticles, according to the USEPA, are generally of four types viz., carbon-based materials, metal-based materials, composites and dendrimers, out of which, nanoparticles of metal oxide are the most popular ones utilized in a variety of applications. Engineered nanoparticles have the ability to increase the solubility of otherwise insoluble chemical compounds, often found with high nutrient content by altering mainly their size, shape (to nanoscale range) through several approaches (physical/chemical/biological) and thus are found to be advantageous for improving nutrient use efficiency in agriculture.

Nanosensor

A nanodevice or nanosensor is any manufactured device whose dimensions range from 1 to 100 nanometers and whose properties take advantage of the uniqueproperties of nanoscale materials. With the emergence of nanotechnology, in recent years, various industries, scientific fields have become interested in nanosensors. These nanosensors linked to GPS if distributed throughout the field can be used for real-time monitoring of soil conditions governing soil and also crop health. Nanoparticle-impregnated nanosensors can be utilised to determine the crop nutrient status. Thus, the information provided by these sensors are very crucial for deciding the appropriate time and quantity of inputs (fertilizers, plant protection measures) use and also optimal planting and harvesting times of crops, based on environmental conditions. Thus all this information may effectively be utilized in overall crop management for maximising yield, while minimising use of resource inputs.

Nanofertilizers v/s Conventional Fertilizers

- Nanofertilizers outperform conventional synthetic fertilizers due to their increased solubility and diffusion.
- However, unlike chemical fertilizers, which release nutrients rapidly and unpredictably, nanofertilizers are reported to nourish crops gradually and in a controlled manner.
- Nanofertilizers are more efficient in nutrient absorption and nutrient use, since the nutrient losses (such as leaching, volatilization) associated with them are much lower.
- Because of lower nutrient losses, nanofertilizers provide lower risk of environmental pollution.
- Nanoparticles can pass through plasmodesmata within a plant, resulting in efficient delivery of nutrients to sink sites.

Several studies reported that nano-materials used as fertilizers in various types of crops viz., sunflower, common bean, maize etc. increased germination and seedling growth, physiological activities such as nitrogen metabolism, photosynthetic activity, positive changes in gene expression,protein level, andthus indicated their potential use for increasing overall crop performance.

Challenges

Despite the numerous advantages of sustainable crop production, usage of nanomaterials as fertilizers are associated withcertain concerns. These environmental and toxicity issues associated must be addressed and resolved. The nanoparticles are often synthesised using a variety of hazardous chemical processes that have adverse effects on the environment. According to reports, nanoparticles also crossed the biological barrier and entered cells and organs. Nanoparticle characteristics, such as size, shape, solubility, exposure, dosage concentrations, etc., may pose a threat to human health. Thus, prior to their commercial use, there is a need for extensive research on the interaction of nanoparticles with living organisms. Legislation and risk management related to nanofertilizers usage continue to pose the most significant barrier for promoting nanofertilizers for sustainable agriculture.

Conclusion

Nanofertilizers show potential to be a significant technology in environmental protection, since they can be applied in smaller quantities than conventional fertilisers, and their higher nutrient use efficiency is associated with reduced losses through leaching, runoff and also gas emissions into the atmosphere. However, considering the environmental and toxicity concerns, future of nanofertilizers for sustainable crop nutrient management is dependent upon effective legislation, development of novel nanofertilizer products, and risk management.

References

1. Tarafdar, J. C., and Adhikari, T. (2015). Nanotechnology in soil science. *Soil Science: An Introduction., Chapter: Nanotechnology in Soil Science*, 775-807.