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Nanotechnology and agriculture

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Introduction

Agricultural scientists are facing a wide spectrum of challenges such as stagnation in crop yields, low nutrient use efficiency, declining soil organic matter, multi-nutrient deficiencies, climate change, shrinking arable land and water availability and shortage of labour besides exodus of people from farming. In spite of immense constraints faced, we need to attain a sustainable growth in agriculture at the rate of 4% to meet the food security challenges. To address these problems, there is a need to explore one of the frontier technologies such as 'Nanotechnology' to precisely detect and deliver the correct quantity of nutrients and pesticides that promote productivity while ensuring environmental safety and higher use efficiency. The nanotechnology can be exploited in the value chain of entire agriculture production system. Nanotechnology is emerging as the sixth revolutionary technology in the current era after the Industrial Revolution of Mid 1700s, Nuclear Energy Revolution of the 1940s, The Green Revolution of 1960s, Information Technology Revolution of 1980s and Biotechnology Revolution of the 1990s. It is now emerging and fast growing field of science which is being exploited over a wide range of disciplines such as agriculture, physics, chemistry, biology, material science, electronics, medicine, energy, environment and health sectors. A nanomaterial is one billionth of a meter. Nanoscale ranges from 1 and 100 nanometers. Nanoscale materials show unusual physical, chemical and biological properties, which are completely distinct from their bulk materials and individual molecules[2]. These unique properties find its novel applications in all the fields.

Nanoscale materials and Applications

Nano-fertilizers for crop growth and nutrition

Nano-fertilizer technology is very innovative but scantily reported in the literature. However, some of the reports and patents strongly suggest that there is a vast scope for the formulation of nano-fertilizers. Significant increase in yields has been observed due to foliar application of nanoparticles as fertilizer. It was shown that 640 mg ha^{-1} foliar application (40 ppm concentration) of nanophosphorus gave 80 kg ha^{-1} P equivalent yield of clusterbean and pearl millet under arid environment. Currently, research is underway to develop nano-composites to supply all the required essential nutrients in suitable proportion through smart delivery system. Preliminary results suggest that balanced fertilization may be achieved through nanotechnology.

Indeed the metabolic assimilation within the plant biomass of the metals, e.g., micronutrients, applied as Nano-formulations through soil-borne and foliar application or otherwise needs to be ascertained. Further, the Nano-composites being contemplated to supply all the nutrients in right proportions through the "Smart" delivery systems also needs to be examined closely. Fertilizers encapsulated in nanoparticles will increase the uptake of nutrients. Nanomaterials have potential contributions in slow release of fertilizers. Nanocoatings, or surface coatings of nanomaterials, on fertilizer particles hold the material more strongly from the plant due to higher surface tension than conventional surfaces. Moreover, nanocoatings provide surface protection for larger particles.

Nanoparticles in plant growth enhancement

With the goal to promote its use for agricultural applications, nanomaterials (NM) can be effectively used in plant germination and growth. The application of carbon nanotubes as regulators of seed germination and plant growth. They have shown that multiwalled carbon nanotubes (MWCNTs) have the ability to enhance the growth of tobacco cell culture by 55-64% when compared to control at a wide range of concentrations from 5-500 µg/ml. At low concentrations, activated carbon enhanced cell growth while at higher concentrations it intensely inhibited the cellular growth. Carbon nanotubes (CNTs) can regulate cell division and plant growth by a unique molecular mechanism that is related to the activation of water channels (aquaporins) and major gene regulators of cell division and extension. They have highlighted the novel positive effects of MWCNTs at the cellular level and have provided an understanding of the complex mechanism underlying the enhancement of plant growth. However, to consider the possible use of carbon nanoparticles in agriculture, the consequences of the introduction of carbon nanotubes into the environment have to be thoroughly investigated. CNTs penetrate into the hard coat of germinating tomato seeds and enhanced growth due to increased water uptake.

Nanotechnology in plant protection

Potential applications of nanotechnology in crop protection include controlled release of encapsulated pesticide, fertilizer and other agrochemicals in protection against pests and pathogens, early detection of plant disease and pollutants including pesticide residues by using nanosensors. The potential applications of nanomaterials in crop protection, helps in the development of efficient and potential approaches for the management of plant pathogens. As an efficient and potential modern approach, nanotechnological formulations are used in management of agriculturally important pathogens. Nanoencapsulation of insecticides, fungicides or nematicides will help in producing a formulation which offers effective control of pests while preventing accumulation of residues in soil. In order to protect the active ingredient from degradation and to increase persistence, a nanotechnology approach of "controlled release of the active ingredient" may be used to improve effectiveness of the formulation that may greatly decrease amount of pesticide input and associated environmental hazards. Nanopesticides defines as any formulation that intentionally includes elements in the nm size range and/or claims novel properties associated with these small size range, it would appear that some nanopesticides have already been on the market for several years. Nanopesticides encompass a great variety of products and cannot be considered as a single category. Nanopesticides can consist of organic ingredients (e.g., a.i., polymers) and/or inorganic ingredients (e.g., metal oxides) in various forms (e.g., particles and micelles).

Going green with nanomaterials

With the potential adverse effects of agro-chemicals on human health and ecosystem the us e of green technology to prevent the environmental damage has become major concern by research community. Green synthesis reduces the use of hazardous substances during the synthesis and protects the environment. Nanotechnology is an important contribution to green chemistry; it helps in development of microscopic and submicroscopic devices with less cost and provides huge savings in materials.

Limitations and issues

Nanotechnology has a significant role to play in agriculture, food processing, food packaging, food security and water purification. But it may pose negative effects on the environment, ecosystem, and humans. The potential risks associated with releasing nanomaterials into the environment (soil and water organisms) are still unclear by scientists. Recent findings showed the potential harmful effects of nanomaterials on the digestive systems of a beneficial soil organism-earthworm. The increased safety concerns over application of nanomaterials in food and agriculture.

Conclusion

Nanotechnology applications have the potential to change agricultural production by allowing better management and conservation of inputs to plant production. Researchers in nanotechnology can do a lot to benefit society through applications in agriculture and food systems. Nanotechnology holds the promise of controlled delivery of agrochemicals to improve disease resistance, plant growth enhancement and nutrient utilization. Nanoencapsulation shows the benefit of more efficient and targeted use of pesticides, herbicides and insecticides in environment friendly greener way. Nanotechnology in conjunction with biotechnology has significantly extended the applicability of nanomaterials in crop protection and production. Even though the toxicity of nanomaterials has not yet clearly understood, it plays a significant role in crop protection because of its unique physical and chemical properties. The application of nanomaterials is relatively new in the field of agriculture and it needs further research investigations. Barring the miniscule limitations, nanomaterials have a tremendous potential in making crop protection methodologies cost effective and environmental friendly.

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