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NANOTECHNOLOGY AND ITS APPLICATIONS IN AGRICULTURE: OVERVIEW AND FUTURE PROSPECTS

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Abstract

Our lives are being continuously transformed on account of a plethora of technological advancements. One such area is that of nanotechnology which is having a greater impact on a variety of industries, especially agriculture and allied fields. Nanomaterials are utilized in agriculture for a variety of purposes. The goal of this research is to give a broad overview of nanotechnology's numerous applications in agriculture. Precision agriculture, smart agriculture, plant growth, crop monitoring, and phytopathogen identification are all topics we explore. We not only give an overview of these uses, but we also discuss the future potential for nanotechnology in agriculture. We are convinced that this research is critical for researchers and government bodies.

Introduction

Considered to be one of the largely growing fields of the twenty-first century, Nanotechnology holds immense potential to completely revamp various sectors. The widespread impact of Nanotechnology can be seen in the way it has transformed our routine lives, our society the ecology as well as industrial systems (Thangadurai et al. 2020). One of the key offspring's of nanotechnology are nanomaterials which are based on reducing material sizes to a nanometer scale by altering the material's physical, chemical, and biological (Jeevanandam et al. 2018). Having a vast surface area and a size range 1 to 100 nm the unique property of nanomaterials provide innovative solutions across multiple fields (Nile et al. 2020). Agriculture is one such sector where nanotechnology has various applications due to its multidisciplinary nature combining engineering, chemistry, biology, physics, and materials science, all of which are key aspects of technological innovations (Bayda et al. 2020). By increasing productivity of crops, fostering food processing, and enhancing food security levels the applications of nanotechnology in agriculture becomes pivotal (Khan et al. 2019). Considered to be the backbone of India, agriculture is being largely benefitted by the critical nanotechnology applications in a similar context (Shang et al. 2019).

The applications of nanotechnology in agriculture are wide-ranging, encompassing the various facets which have an impact on the various agricultural products which are developed by employing nanotechnology. It includes aspects such as; product cost, product efficacy, its endorsement from the agricultural community, evaluation of its risks, market demand, ecological implications, and margin of profit associated with the same (Kah and Kookana 2020). As predicted by economists, subject matter experts and researchers, varied challenges such as population explosion, shrinking land mass, increased investments in pesticides and fertilizers, pest management and ecological concerns are expected to affect the agriculture sector in the coming years (Pingali et al. 2019). All these challenges can be largely overcome by the applications of nanotechnology specifically in boosting the nutritional value of the produce and increasing productivity of crops. In this context a crucial role is played in the use of nanomaterials across multiple levels right from water management to the controlled delivery of fertilizers and nutrients (Usman et al. 2020). The multifaceted uses of nanotechnology in agriculture are elaborated in subsequent sections (He et al. 2019).

Precision Farming

Also known as precision agriculture, precision farming is centered on the extensive use of information technology, applied to enhance crop productivity and simultaneously lowering inputs (Shang et al. 2019). Monitoring the environmental conditions and controlled delivery of fertilizers are key aspects of precision farming which uses "geosynchronous positioning systems" (GPS), "geographical information systems" (GIS) and "remote sensing" (RS) mechanisms, to track ecological factors (Finger et al. 2019). An ecological balance is struck by the applications of precision farming which provides the soil and crops with precise nutrients and chemicals ensuring optimal health (Saiz-Rubio and Rovira-Mas 2020). To facilitate precision agriculture, RS technology gathers and effectively analyses related data by segregating the agriculture land into district management zones by using GPS and GIS technology in an optimal manner (Georgi et al. 2018). The segregation of zones is based on various dimensions such as; the type of soil, extent of pest infestation, soil pH levels, availability of nutrients, moisture content, weather forecast, fertility requirements, hybrid responses, and crop characteristics (Vallentin et al. 2019). By using land records, the land information can be accessed where the former provides insights into characteristics of crops, cropping practices of the regions, soil survey maps, field boundaries, irrigation system, and roads nearby (Georgi et al. 2018). Farmers are equipped with real-time data by the GIS-GPS integration and the same can enable them in resource optimization and effective utilization (Oshunsanya and Aliku 2016). By applying the appropriate resources to the soil and plant, precision farming plays a pivotal role in minimizing the ecological impact of contaminants, toxic materials, and waste from agriculture (Shafi et al. 2019).

Smart Cultivation

In the light of smart farming the extensive use of nanomaterials, principally Nano sensors, are quite effectively in real-time monitoring of plant growth and subsequent crop output. By incorporating ecofriendly approaches and energy-efficient techniques, nanosensors can transform traditional methods into smart farming systems for agricultural sustainability (Pramanik et al. 2020). Monitoring soil pH levels, humidity, nutritional requirements, pest identification, and pesticide residues are facilitated by Nano sensors in the context of smart farming. A host of benefits are associated with the application of nanosensors in smart farming. The highly sensitive nanosensors have the ability to "detect substances in very low quantities, making them more helpful for smart farming". The smart delivery of various fertilizers (e.g. nitrogen, phosphorus, and potassium) is achieved by adopting a "nanoclay hybrid" method. As opposed to conventional fertilizers, nanoclay systems enable a regulated fertilizer and nutrient release into the overall system of plants ((Shang et al. 2019; Guha et al. 2020). As a result, better farming decisions to increase agricultural productivity is achieved by the use of smart sensors which provide fast, accurate and reliable information to farmers adopting precision farming practices (Saiz-Rubio and Rovira-Mas 2020).

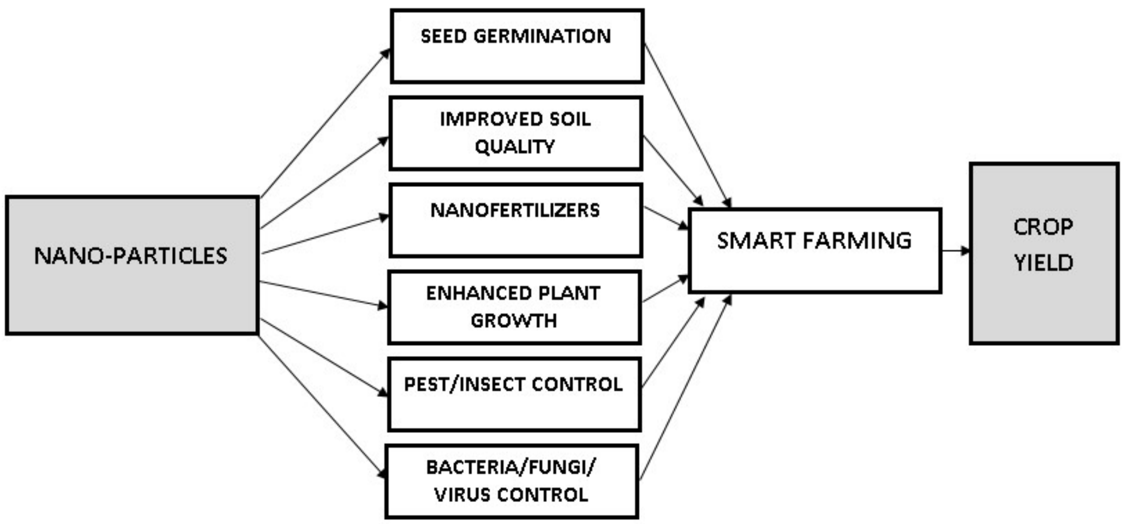

Fig. 1 Applications of Nano-particles in Smart Farming. Source: Guo et al. 2018

Delivering Agrochemicals

Various forms of "nanoformulations" like "nanocarriers", "nanocapsules", "nanofibers", "nanocomposites", "nanogels", and "nanoemulsions" are used to distribute various chemicals into various regions of the plant system and are effectively utilized in farming practices (Martinez-Ballesta et al. 2018). Distinctive qualities are offered by the use of nanomaterials which enable them to store and transport substances in a regulated manner. Consequently, this enhances plant growth, increases crop yield, provides plant protection, and reduces environmental toxins. Nanoformulations utilizing nanoscale delivery vehicles have shown improvements in terms of biodegradability, stability, and biocompatibility (Iavicoli et al., 2017).

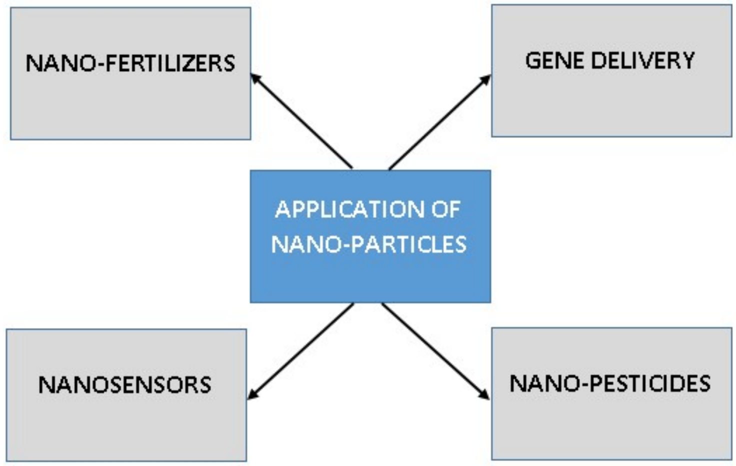

Fig 2. Applications of Nano-particles in plant growth. Source: Pramanik 2020

Tracking Crop Health and Environmental Stress through Field Sensing Systems

As discussed in the previous section, monitoring plant growth and increasing real-time productivity is one of the significant applications of nanotechnology. By employing nanosensors coupled with a mechanism of field sensing the aforementioned application is effectively implemented. The sensors provide real-time insights into crop management by monitoring in situ factors such as soil pH, moisture content, soil humidity, soil fertility, plant development, nutrient availability, insects, pests, weeds, disease-causing microorganisms, and environmental temperature (Saiz-Rubio and Rovira-Mas 2020). Wireless nanosensors can be placed strategically throughout the field collect real-time data to reduce pesticide, herbicide, and insecticide use while increasing crop production. The appropriate quantities are provided in a regulated manner using information-technology signals (Shang et al 2019).

Plant Pathogen Detection and Improving Resistant Traits

Biological-recognition element coated nanomaterials (DNA/antibody/proteins/enzymes) are used to detect plant pathogens. Nanosensors critical for detecting pathogenic bacteria in plant and soil ecosystems (Kumar and Arora 2020). Metal nanoparticles are used to control plant diseases, pests, and insects. Silver and are copper nanoparticles have been found to have antimicrobial activity targeting diseases in plants (Ramezani et al. 2019). Researchers are also working on developing recombinant DNA technology to develop varieties that are resistant to plant diseases and stress. (Parmar et al. 2017). Carbon nanotubes, nanocarriers, and nanofiber materials are nanodelivery vehicles that transfer genes to plants to produce novel features that can withstand environmental stress and illness (Jeevanandam et al. 2018).

Nanotechnology in Agriculture: Future Prospects

One of the key potential application of nanomaterials is to facilitate the transport of biochemical and fertilizers into plant mechanisms. In this regards the aspects of "nanocarriers", "nanocomposites", "nanotubes", "nanofibers", and "nanoclays" shall play a pivotal role (Kalia et al. 2020). Considered to be an ideal solution for precision farming real-time monitoring through nanosensors holds immense potentials for future applications. In the context of the same, precision farming operations can be enhanced by adopting wireless field sensing mechanisms to facilitate effective monitoring and provide real-time data to boost precision farming activities (Shafi et al. 2019). Looking at the challenges posed by climate change nanotechnology can be utilized to help plants grow better by improving the process of photosynthesis. Through research in chemistry substances can be developed which can be possibly be applied to leaves and roots to help plants utilize more sunlight. As a result group yields photosynthesis can be increased and energy from the sun can be actually transformed into chemical energy which can be later stored in plants. However, one of the major challenges of this application is the efficacy of the entire process of converting sunlight into chemical energy. If the efficacy of the process is achieved, then it can work wonders in boosting productivity of various crops and at the same time also ensure environmental sustainability (Shang et al. 2019).

Conclusion

Modern nanotechnology applications in sectors such as precision agriculture, nanosensors detection, and smart farming can leverage smart gadgets to transform the agricultural industry. Nanotechnology in agriculture finds applications in various areas, including fertilizer distribution, pesticide and herbicide reduction, chemical administration through carriers, as well as plant pathogen detection and management. By utilizing nanosensor-based methods in precision agriculture, the supply of nutrients is regulated and nanosensors can help to release nanomaterials by detecting plant-based infections in the field. The smart farming system offers agricultural production data based on crop requirements, and the chemicals are released by nanosensors into the plant system. Nanotechnology will thus aid precision agriculture and smart farming in the near future to improve plant growth, biomass, and crop output.

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