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Nanotechnology in Sustainable Agriculture – A review

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ABSTRACT

There is a sharp decline in Indian agricultural production from 3.6% in 1985- 1995 to nearly 2% in 1995-2005. To reach the goal of 4% increment in agricultural production we must use sustainable agricultural practices keeping in view of the environment. Nanotechnology is emerged as a new solution which counters the growing harmful consequences of conventional farming techniques that neither increase the output nor bring the environment back to its original position. Nanotechnology uses different particle sizes varying from 1-100 nanometres and can deliver the nutrients precisely. The different applications of nanotechnology in agriculture like nano fertilizers, nano pesticides etc are gaining interest amongst farmers and scientists. This has the potential in reducing the chemical fertilizers and pesticides, in minimising nutrient loss via leaching and to enhance the yields through precise nutrient management, Nanotechnology is also utilised at various phases of agricultural practices like packaging, processing, storing, and agricultural goods transit. Food security, agriculture, and natural resources are important areas to focus on for sustainability, susceptibility, and human existence on this planet. Following the implementation of sustainable agriculture, the nanotechnology in agricultural fertilizers and pesticides is an encouraging and alternative solution to pest control and nutrient management. This paper gives brief information about how nanotechnology works and helps to overcome the problems related to agriculture.

Key words: *Nanotechnology, Sustainability, Environment, Agriculture.*

Introduction

At present, as nearly 58% of the Indian population depends on agriculture and further the population of India would surpass China in 2030, it becomes imperative to improve agricultural production as it is a key sector that supplies raw materials to various industries (Mukhopadhyay, 2014; Hegde, 2023). To counter all these situations, we need to use some innovative agricultural techniques that boost food grain production while simultaneously preserving fertility of soil. In the current scenario of agriculture, it is inconceivable to increase food grains production without using chemical fertilizers and pesticides. However, all of these have the potential to decline soil productivity, contaminate groundwater, provide resistance to the insect pests etc. Thus, it is very important to maintain the harmony between the environment and ecosystems along the food chain and agricultural food production (Prasad *et al.*, 2017). Moreover, due to urbanization, agricultural land is declining rapidly. To cope with all these situations farmers have adopted the conventional method of farming, which involves the usage of heavy doses of fertilizers along with insecticides and pesticides (Dixit *et al.*, 2015). This method has not only increased the cost of cultivation but also has led to increased resistance to pests and has degraded

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soil productivity and fertility. To overcome this technological fatigue there is a need to increase the production in a sustainable manner. By following sustainable agriculture concept, we can maximize the production by meeting the present demands while preserving the resources for future generations, Nanotechnology is one of the advanced and promising approach which maintains the health of agricultural land without any adverse effects (Gibney *et al.,* 2015). Further, green nanotechnology which includes nano fertilizers, nano pesticides, nano char, nanohydrogels are very safe, and eco-friendly, and has the potential to reduce the emission of greenhouse gases like methane (methane released from paddy fields) by controlling nutrient and pesticide uptake (Prasad *et al.,* 2017). Nanotechnology is used in various areas viz., Nano formulations in fertilizers and pesticides; use of nano sensors in identifying disease and chemical residues in crop production; nanodevices in plants genetic engineering; plant disease diagnosis; poultry production and animal breeding and post-harvest management practices. There is no doubt that the sustainable growth of agriculture depends on inclusion of various techniques viz., crop rotation, soil conservation, mixed farming, nanotechnology etc., The application of nanotechnology in agriculture requires the adoption of effective governance and partnership with key management and integration, as well as the participation of all stakeholders. The uses of nanotechnology have been thoroughly explored in the parts that follow.

Nanotechnology in Agriculture

Nanotechnology deals with substances that range in size from 1 to 100 nm, have higher reactivity, improved bioavailability and bioactivity. Adhesion effectsand surface impacts of nanoparticles are responsible for its huge potential in the agriculture industry and is receiving increased attention. Due to these abilities nanotechnology is used in several sectors of agriculture as genetic manipulators in crops, nano fertilizers, nano biosensors, nano pesticides, nano char, nanohydrogels, gio humus, soil remediation, soil treatment. The prime concern of using nanotechnology in agriculture is to increase resource use efficiency and thereby increase crop production and yield (Prasad, 2017).

As nano fertilizers

Fertilizers are indeed very important for the growth of plant. Mineral fertiliser application is a major management method that plays a vital role in increasing crop production and, as a result, sustaining sufficient food and feed supplies across the world (Chaudhary *et al.,* 2017). Nanotechnology, which uses nanoparticles with a size of less than 100 nm, may provide a once-in-a-lifetime chance to generate concentrated sources of plant nutrients with greater absorption rates, higher usage efficacy, and lower losses (Kumar *et al.,* 2021). Nano-fertilizers are made by encapsulating plant nutrients in nanomaterials, thinly coating plant nutrients with nanomaterials, and distributing them as nano-sized emulsions (Kumar *et al.*, 2021) have the capacity to improve crop production with less ecotoxicitycity and it can also monitor the uptake of nutrients and pesticides for sustainable development of agriculture (Gruere *et al.,* 2011; Mukhopadhyay, 2014). Nano fertilizers increase the nutrient use efficiency of wheat (Mehta *et al.*, 2019). There are different nanoparticles synthesized from aluminium, zinc, magnetite, zinc oxide etc which are involved in different plant functions like seed germination, root development of species like cucumber, corn, lettuce, rape seed and radish (Lin and Xing, 2007).

Commonly used Nano fertilizers

Nano-based slow-release fertilizers offer enormous promise for improving nutrient utilization efficiency (Kumar *et al.*, 2021). Nano fertilizers have the potential to manage nutrient release, supply the proper amount of nutrients required by crops in an appropriate proportion, and improve yield while maintaining environmental safety (De Rosa *et al.,* 2010). Some of the Nano fertilizers used in agriculture are Nano Nitrogen, Nano Zinc and Nano Copper. Dwairi (1998) proposed that urea-impregnated zeolite can be utilized as a slow fertilizer because of the gradual and consistent release of N from nano zeolite. Although zinc is a micronutrient but is very essential to plants to complete their metabolic reactions. Further, it also protects the crop from oxidative stress resulting from various biotic and abiotic stresses. It also has a role to play in the synthesis of chlorophyll, carbohydrates, and auxin (IAA) formation from tryptophan (Dimkpa *et al*., 2015). Under zinc deficiency, the yield of crops and quality of the produce are significantly reduced. When Nano copper is applied copper nanoparticles are able to travel across the cell membranes and accumulate in the cells and also accumulate in shoots more rapidly than bulk particles of copper. The overall absorption into the shoots was nearly three times larger for the NPs, according to the results (Rico *et al*., 2011). Nano nitrogen, which is based on nanotechnology principles, offers a fresh approach to weaning farmers off urea. The nanoscale benefits of nitrogen particles must be harnessed in order to properly meet crops' nitrogen requirements (Kumar *et al.,* 2021). Precision and targeted management of nitrogen by foliar spray of nano nitrogen lowers urea losses, improves nutrient absorption efficiency, manages water, soil, and air pollution challenges. Applying nano nitrogen at a dosage of nano urea @ 3ml per litre of water at flower initiation stage and 15 days after the first nano urea application stimulates crop response, meets nutritional requirements, and increased the yield of the crop (Saitheja *et al*., 2022).

To control plant pest

The control of pests is difficult these days due to the increased acquisition of resistance in pests against insecticides. The green methods of extracting chemicals from plants are gaining importance due to their minimal impact on the environment as well as because of their efficacy in controlling pests. Lettuce and tomato fields are more frequently prone to fusarium wilt due to hibernating nature of fungus in soil for a long time and thus leads to resistant races of pest (Nuruzzaman *et al.,* 2016). Nanomaterials have been evolved as an alternate method to overcome the fungus. Green peach aphid is effectively controlled by nanoparticles of magnesium oxide (MgO) under greenhouse conditions (Ghidan *et al.,* 2018). The successful extraction of nanomaterials like MgO, ZnO, CuO, Mg $(OH)_2$ from aqueous forms of plants like peels of *Punica granatum,Olea europaea, Chamaemelum nobile* flowers (Ghidan *et al.,* 2017). All these have excellent properties for controlling green peach aphids. After performing experiments in different conditions, it is proved that there is no accumulation of metals in the plants. There is increasing attention to developing nanoparticles by combining biotechnology and nanotechnology to limit the accumulation of environmentally hazardous particles such as chemical insecticides and pesticides.

Nanoparticles as insecticides, pesticides, and plant protectants

There is increasing significance of nanoparticles in insecticide application due to effective control of pests and insects without getting resistance against it. Different methods like precipitation and chemical reduction are there for the synthesis of copper oxide nanoparticles (CuO) (Ghidan *et al*., 2016). Lemon juice (Mohan *et al.,* 2015) was used as a bio-reductant and biocompatible polyvinyl pyrrolidone (PVP) was used as a stabilizer to make cupric oxide nanoparticles (CuONPs). For the synthesis of ZnO NP, the green method of extraction from plants like leaves of *Solanumnigrum* (Ramesh *et al.,* 2015), *Olea europaea*, *Azadirachta indica* (Elumalai and Velmurugan, 2015) have been widely used. Mg $(OH)_2$ NPs are also synthesized from extracts of plants like Neem leaves, citrus leaf extract, gum of Acasia, *Brassica oleracea* and peels of *Punica granatum* (Ghidan *et al*., 2016). In the agricultural sector, experiments are going on to improve the efficiency of fertilizers and pesticides by nanotech methods and the nano vectors are expected to replace the bacterial and viral vectors in genetically modified plants and genes with high efficiency in the near future (Bhattacharyya *et al.,* 2016).

Nanotechnology in crop improvement

Nanotechnology has attracted many scientists to think differently. It has been able to change the genetic structure of the crops, which would not have been possible otherwise using mutation breeding. A nanotechnology research project in Thailand aimed to alter the atomic characteristics of indigenous rice cultivars, including the well-known jasmine rice. Their goal is to eliminate the debate about genetically modified organisms (GMOs), as nano biotech assists agriculture in overcoming the GMO debate and progressing to the next stage –atomically modified organisms (AMOs). Scientists used nanotechnology to shift the purple colour of the cultivar's stems and leaves to green. The research group's scientists have stated that dealing with jasmine rice would be their next goal. They want to develop a modified jasmine cultivar that will be photo-insensitive and can be grown all year, with dwarf stems and better grain colour (Prasanna, 2007).

It is relatively safe to use nanoparticles in seeds before sowing, because some metabolic, physiological and morphological changes occur before the production of biomass or reproductive growth of the plant. In seed-intensive crops, higher initial vigour, leaf growth and good germination help suppress weeds and improve biomass. Nanoparticles have been found to improve germination (Khodakovskaya *et al*., 2009) and yield (Prasad *et al*., 2012) in various crops, with some encouraging and positive outcomes. Lu *et al.,* (2002) have shown that the combination of nano-TiO2 and SiO2 can improve some parameters that promote growth and, in fact, accelerate their germination. TiO2 nanoparticles have also been shown to improve the germination ability of spinach (*Spinacia oleracea*) seeds and plant growth (Zhang *et al*., 2005 and Hong *et al*., 2005) reported that nanomaterial TiO2 can promote photosynthesis and nitrogen metabolism, thus enhancing the growth of spinach at a suitable concentration. It can be clearly seen in different studies that nanoparticles will affect the germination, growth and yield of different crops.

Nanoparticles in recycling agricultural wastes

Nanotechnology is also used in agriculture, especially in the cotton industry, to reduce waste (Peters *et al*., 2016). Some of the cellulose or fibres are thrown as waste or utilized for low-value items like cotton balls, yarns, and cotton batting, when cotton is turned into textile or garments (De Oliveira *et al*., 2014). Using newly designed solvents and an electrospinning process, researchers have created 100 nanometre fibres that can be used as an absorbent fertilizer or pesticide (Mukhopadhyay *et al*., 2014). These high-performance absorbents can be used in specific applications when and where they are needed (Lang, 2003).

Around 200 billion tonnes of biomass are expected to be produced in a year, with 90% of that amount going towards Lignocellulosic biomass (LCB) materials, which indicates the potential for the use of renewable fuels to increase. The primary polymeric components of LCB materials are cellulose (35-60%) and hemicellulose (15-30%), which form a network with lignin (15–20%) and render the lignocellulosic structure refractory, Pre-treatment techniques must be employed to the LCB available for further sugar extraction, The procedures used in nanobiotechnology involve the use of nanoparticles that may readily pierce the cell walls of LCB and mix with biomass. Nanoparticles can be used in pretreatment and enzyme/biocatalyst hydrolysis during the LCB conversion process to liberate sugars (Singhvi *et al*., 2021).

Conclusion

Nanotechnology has emerged as a potential solution for managing plant diseases and transforming sustainable agriculture. Various nanomaterials, such as nano fertilizers, nano sensors, and nano pesticides, offer the promise of increased agricultural yield, reduced pesticide usage, and improved water efficiency. Nanoencapsulation technology enables eco-friendly and targeted application of insecticides and pesticides, benefiting postharvest preservation and disease prevention. Moreover, nanotechnology finds applications in tissue engineering, drug delivery, and medical diagnostics. However, it is crucial to consider the potential risks to human health and the environment before widespread implementation. Rigorous research is necessary to ensure the safety of nanomaterials in agriculture. Despite the advantages and disadvantages, further study can lead to a comprehensive understanding and effective utilization of nanotechnology for sustainable agriculture, ultimately contributing to food security goals.

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