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Nanotechnology and Agriculture: A review

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Nanotechnology is the most developing branch of science, it is thought that application of nanotechnology in agriculture will make this sector sustainable and profitable, by reducing the use of fertilizers, pesticides and by enhancing the crop productivity. In other words we can say that application of nanotechnology in agriculture will increase food and nutritional security. However, the main issue related with the application of nanoparticles in agriculture is their toxicity. It is therefore recommended for research organizations to provide research funds to establish safety standards and to develop new techniques for the toxic free synthesis of nanoparticles. Indian council of agriculture research (ICAR) has started a programme to study the effect of nanotechnology in agriculture. The ICAR- nanotechnology scheme has major themes such as synthesis of nano-particles for agriculture use, diagnostic kits for easy and quick identification of disease and pests, nano agri-inputs for enhanced use efficiencies, precision water management, and stabilization of organic matter in soil, nano food systems and bio safety besides establishing the policy frame work. Green synthesis and microbial synthesis of nanomaterial for agriculture use is very important as they are naturally encapsulated with mother protein, therefore more stable and safer to biological systems. The review presents here discuss applications of nanoparticles in agriculture. This review also features out the potential hazardous effects of nanoparticles on microbes and environment.

Keywords: Carbon nanotubes, Nanoparticles, Agriculture, Microbes.

Food crisis is a global problem, especially for developing countries. Even though India is agriculture based country but it also suffers from food crisis. There are reports which clearly show that India is facing a steady decline in its GDP. India had made a record of producing 241 million tones of crop production in 2010-2011(www.business-standard.com/india/ news/ india-achieves-241-mn-tonne-food grain production-in-fy11/141436/on; accessed on 29/ 02/ 2012). Our population is increasing day by day while our capacity to produce grains is not increasing in the same way, which suggests that we should enhance our production. It is believed that nanotechnology increase the production and limit the disease attack and thus would be able to provide food to all.

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Nanotechnology is a branch of science which deals with various aspects of research and technology. A joint committee of the British Royal Society and the Royal Academy of Engineering defined nanotechnology as the design, characterization, production, and application of structures, devices and systems by controlling shape and size at nanometer scale (Uskokovic, V, 2008). Nanoparticles are ultrafine particles whose size is greater than 1nm and smaller than 100 nm. There are many types of nanoparticles like Natural nanoparticle, incidental naoparticles, quantum dots, organic polymers etc.

Nanotechnology deals with the matter at nanoscale (1-100 nm) dimensions. These materials when reduced to the nanoscale show some properties which are different from what they exhibit on a macro scale, enabling unique applications. Nanoscience has brought revolution in different fields by helping develop processes and products that are hardly possible to evolve through conventional methods. The nanotechnology aided applications have the potential to change agricultural production by allowing better management and conservation of inputs of plant and animal production. A survey by Salamanca–Buentella et al. (2005) predicted several nanotechnology applications for agricultural production for developing countries within next 10 years. These included - (i) Nanoforms zeolites for slow release and efficient dosage of water and fertilizers for plants; drugs for livestock; nanocapsules and herbicide delivery (ii) Nanosensors for soil quality and for plant health monitoring; nanosensors for pest's detection (iii) Nanomagnets for removal of soil contaminants and (iv) Nanoparticles for new pesticides, insecticides, and insect repellents.

It is believed that nanotechnology would be able to manage food and nutritional security, that's why many large scale investments from global food corporations and many government societies from all over the world are investing in this branch (Roco, 2005; Sandler and Kay, 2006; Scrinis and Lyon, 2007).Crop productivity, soil health, disease management, water supply storage of food are the primary requirements for food storage, that can be full fill by nanotechnology (Kalpana Sastry et al., 2011).Some new Innovations are being made in agriculture sector, such as development of nanoseed within built pesticide effect. Nano encapsulation is also a nanotechnology based technique which has the potential to change nutritional composition, flavor etc., according to consumers requirement and physiological requirements. Presently nanotechnogical intervention in agriculture focuses on three functional improvements (Observatory NANO, 2010).

1. Increased efficacy (with high solubility, stability and effectiveness)
2. Controlled release (in response to certain stimuli) and
3. Targeted delivery of fertilizers, plant growth regulators and biocides such as fungicides, herbicides and pesticides.

Some nanotechnology based agriculture products that are under development age are:

- Nano- clay capsule containing biocontrol agents and growth enhancing enzymes that are designed for the slow release of active ingredients. Examples are pyrethroids such as y -cyhalothrin and ~-cypermethrin (Wang et a1. 2007) and others like *Artemisia arborescens* L essential oil (Lai et a1. 2006)...
- Nano-formulations (nanodispersions / nanoemulsions) of herbicide designed to attack the seed coating of weeds and prevent weed germination.
- Nanotechnology-enabled devices like stand-alone nano sensors linked into a GPS system for real-time monitoring of soil conditions and crop growth. Precision farming, with the help of smart sensors, will permit enhanced productivity in agriculture by providing accurate information, thus helping farmers and land managers in taking appropriate decisions.
- Nanoscale devices could be used for early disease detection and helping us to take preventive action. Nanotechnology will help in developing fertilizer and pesticide delivery systems which would be able to respond to environmental changes.Syngenta have obtained a patent for a nano pesticide called "gutbuster" microcapsules that contain pesticides engineered to break open in the alkaline conditions of an insect's stomach. Such nano-encapsulation techniques not only provide in-built pesticides for crops - in some ways similar to genetically modified Bt insecticidal crops -but also in-built switches to control the release and subsequent availability of pesticides (Scrinis and Lyons, 2007).
- By combining together Nanotechnology and Biotechnology a potent new tool would be produce that can manipulate genes and even produce new organism. For example, nanobiotechnologies enable nanoparticles, nanofibres and nanocapsules to carry foreign DNA and chemicals that modify genes (Torney ET a1. 2007). In addition to the reengineering of existing plants, novel plant varieties may be developed using synthetic biology; a new branch of techno science that draws on the techniques of genetic engineering, nanotechnology and informatics (Lyons, 2010).

Nanotechnological Inventions will, therefore, enable development of novel agricultural chemicals, seeds, livestock, unknown plant growth promoting organisms, high-end use of agricultural water resources, high-precision farming systems etc., that will permit real time monitoring and management of farm operations.

Agriculture and nanoparticles

Numerous studies have reported the effects of nanoparticles on crops. But most of the experiments have been conducted in controlled conditions.

One study done by Khodakvskaya, 2009, found that carbon nanotubes enhance tomato seed germination and growth rate.CNTs were able to penetrate the thick seed coat and support water uptake inside seeds, a process which can enhance seed germination and growth of tomato seedlings. Lin and Xing 2007 found that suspension of MWCNTs have positive effect on the seed germination and root growth of radish (*Raphanus sativus*), rape (*Brassica napus*), rye grass (*Lolium perenne*), lettuce (*Lactuca sativa*), corn (*Zea mays*) and cucumber (*Cucumis sativus*).

$Ti0_2$ NPs have been found to accelerating spinach growth (Zheng et a1. 2005; Hong et a1. 2005; Gao et a1. 2006; Xuming et ai. 2008). $Ti0_2$ NP also improved plant growth by enhanced nitrogen metabolism (Yang ET a1. 2006). They also found that TiO_2 nanoparticle have the capacity to increase nitrogen matabolism. In 2005 Watts and yang conducted an experiment on corn (*Zea mays*), cucumber (*Cucumis sativus*), soybean (*Glycine max*), carrot (*Daucus carota*) and cabbage (*Brassica oleracea*) with ALNPs and found that they reduce the elongation of roots of the plants and retard the plant growth. CNTs enhanced root elongation in onion and cucumber and nanotubes sheets were formed by both fCNTs and CNTs on cucumber root surface; however none entered into the roots. Cabbage and carrot were not affected by either form of CNTs. Root elongation in lettuce was inhibited with fCNTs and tomato was found to be most sensitive for CNTs with significant root length reduction. Reports by Nair et a1. (2010). ZnO NPs showed no negative effects on seed germination and root growth of zucchini seeds in hydroponic solution (Stampoulis et a1., 2009) whereas the seed germination of rye grass and corn was inhibited by Zn NPs (35 nm) and ZnO NPs (15-25 nm) respectively (Lin and Xing,2007).

Root growth of radish and rape incubated in Zn NP suspension was significantly inhibited (Stampoulis et a1. 2009). They also found that ZnO NPs entered the root tissue of ryegrass which suggests that new nutrient delivery systems that exploit the nanoscale porous domains on plant surfaces can be developed (De Rosa et al., 2010).

In present time Nanoparticles made from Ag, Au, Si, Zn, Si etc are being tested as carrier for the delivery of pesticide, herbicide and fertilizers. Silicon nanoparticle is being tested for the delivery of avermectin and validamycin pesticides (Li et al., 2006; Liu et al 2006). Si nanoparticles have been reported to posse's insecticidal properties (Popat et al, 2012). Park et al, 2006 have found that when we apply composites of Si- Ag they found that it has potential to control various plant diseases.

Effects of ENPs on microorganisms

The main problem associated with the use of nanoparticles is their harmful effects which they leave after their applications. The exact toxic mechanism of ENPs is not completely known, the possible mechanisms through which they impart toxicology may include membranes disruption, proteins oxidation, genotoxicity, interruption of energy transfer pathway , reactive oxygen species (ROS) formation, toxin release etc. (Klaine *et al*.,2008).

Researches have found that ENPs like C_{60} aggregates inhibited *Escherichia coli* and *Bacillus subtilis* (Fortner et al., 2005), and fullerene water suspensions (FWS) possess strong antibacterial activity and are more toxic to B. *subtilis* (Lyon *et al*., 2006). Metals like Ag, Au, Fe; Ti, Fe, Co-Zn-Fe etc have been found to be toxic against soil bacteria (Dinesh *et al*., 2012).

Silver nanoparticle was found to be toxic to E. *coli* and *Staphylococcus aureus* (Rai *et al*., 2009) and B. *subtilis* (Suresh *et al*., 2010). Silver nanoparticles biosynthesized by fungi possess potent activity against fungal and bacterial strains like *Aspergillus niger*, *Staphylococcus* sp., E. *coli* and *Bacillus* sp (Jaidev & Narasimha, 2010).

Water suspensions of nanosized $Ti0_2$, $Si0_2$ and ZnO were found to possess antibacterial activity, antibacterial activity increases with particle concentration (Adams *et al* 2006). ZnO, $A1_2$and $Ti0_2$ NPs were found toxic to the nematode *Caenorhabditis elegans* inhibiting their growth especially the reproductive capacity (Wang *et al* 2008). Similarly, oxides of Zn, Cu and Ti NPs have been reported to be toxic to the micro algae *Pseudokirchneriella subcapitata* (Aruoja *et a1*. 2009). Studies have shown that nanoparticles cause brain damage in fish and other aquatic species (Oberdorster, 2004; Oberdorster *et a1*. 2007). Thus, from the studies conducted *in vitro* clearly shows that *ENPs* are hazardous to both micro-and macro-fauna. In view of this problem researchers are trying to use these nanoparticles as carriers for delivery of the chemical fertilizers and pesticides to crops (De Rosa et a1. 2010). It is important for us that we should set some standards for manufacturing, disposal and applications of these nanoparticles.

Environmental issues

Evidences suggests that nanoparticles have the ability to pose serious health, safety and environmental hazardous (Rocco and Bainbridge, 2001).ENPs which enter in our food either through crop application of nanoparticles, through packaging materials, as food additive have various nutritional, health and safety problems. Reports have indicated that ENPs can accumulate in plants and through plants they can find their way to humans, animals, microbial systems, aquatic system and soil (Nowack and Bucheli, 2007). Presently we have a very little knowledge about the impacts of nanoparticles on human health and environment but experiments conducted in laboratory have confirmed their toxicity against microorganisms. Still there is a lot to investigate about the health effects of foods that contain ENPs, or of workers handling nonmaterials.

The main problem associated with exposure of nanoparticles is that they may enter into the body through inhalation, digestion, skin etc. From there they found their way to circulatory system, into the lungs and may also cross the blood brain barrier (Scrinis 2006b).

In view of the growing importance of nanotechnologies the European Commission asked the independent experts of the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) to make scientific methodologies to access the potential hazardous associated with nanotechnology applications. SCENIHR 2005 gave a report saying that the present methodologies require some modifications in order to deal with hazardous effects associated with nanotechnology. Equipments for routine measurements of free NPs in various media are not adequate. The available facilities to determine the fate of NPs in environment are not adequate. They also report that very little is known about physiology of nanoparticles

Presently, International Organization for Standardization (ISO) and the Organization for Economic Cooperation and Development (OECD) are seriously engaged in nanotechnology issues and have made a technical committee to develop international standards for nanotechnology (OECD, 2011). This technical committee, ISOI TC 229, is working to develop standards for terminology and nomenclature, metrology and instrumentation, including:

The OECD has established a Working Party on Manufactured Nanomaterials (WPMN) that is engaged in a variety of projects. The main working point of this agency includes:

- Database development on environmental health and safety (EHS) research
- To develop protocols for the manufacturing of nonmaterial's
- Testing of nonmaterial product manufactured to heck weather it is safe or not.
- Develop a protocol regarding the manufacture and testing of nonmaterials.

EPA is actively working on this issue. The WPMN has made a list of manufactured nanoscale materials for environmental health and safety testing, including fullerenes (C 60), carbon nanotubes (single-and multi-walled), Ag-, Fe-, Ti-, AI-, Ce-, Zn-, Si-NPs, carbon black, polystyrene, dendrimers and nanoclays.(M. Anandarajn et al., 2011).

CONCLUSION

Nanotechnology is an emerging branch of science with profound realized potential and outcome. It can be used as a powerful tool for the management of abiotic and biotic stresses, food and nutritional security, to increase yield of crop plants. However if not handled carefully the process and products formed by nanotechnology may pose hazardous effects on health and environment. Hence we should maintain a strategy for using this science efficiently. Some government policies should also be formed to utilize this science.

Controlled and wishful use of nanotechnology has a tremendous potential of improving agriculture sector.

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