ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Sustainable Agriculture Based On Nanotechnology.

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ABSTRACT

Nanotechnology is science of manipulating materials at nano-scale. Among the latest technological advancements, nanotechnology occupies a central position. It has many applications in all stages of production, processing, storing, packaging and transport of agricultural products. The reduced use of herbicides, pesticides and fertilizers with increased efficiency, controlled release and targeted delivery will lead to precision farming. Dream of automated, centrally controlled agriculture can become reality now. Modern agriculture is need of hour because conventional agricultural will not be able to feed an ever increasing population with changing climate, depleting resources and shrinking landscape. This paper thoroughly reviews on various nanomaterials that are used as fertilizers and pesticides that help plants to grow ecofriendly. This article also provides an overview of current and potential applications of nanotechnology in agriculture and sustainability.

Keywords: Nanotechnology, nanofertilizers, nanopesticides, plant growth, sustainability

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ISSN: 0975-8585

INTRODUCTION

Agriculture is always the backbone of many developing countries. It does not only fill the people abdomen but also it is the part of economy. According to 2014-2015 censuses, India's population is almost equal to 1,270,272,105 (1.27 billion), which is really a huge number. In concern of providing food to such a big population there has to be a new technology giving more yield in short period. In that manner, nature is complex which will have imbalances which directly affects plants and crops and indirectly animals and human.

In according to this, other factors which affect agriculture are deficiencies in macro and micro nutrient content, population explosion, industrialization, depletion of water source, difference in soil condition, and erosion of top soil. In agriculture the main reason to use fertilizer is to give full-fledged macro and micro nutrients which usually soil lacks. 35-40% of the crop productivity depends upon fertilizer, but some of the fertilizer affects the plant growth directly. To overcome all these drawbacks a smarter way i.e., nanotechnology can be one of the source. Since fertilizers are the main concern, developing nano based fertilizer would be a new technology in this field. Fertilizers are sprayed in many ways either to soil or through leaves, even to aquatic environments; these inorganic fertilizers are supplied in order to provide three main components, nitrogen, phosphorous and potassium in equal ratios [1]. It increases the Nutrient use efficiency (NUE) by 3 times and it also provides stress tolerating ability. Irrespective of the type of crop it can be used, it will be the complete bio source increasing the eco friendly nature, builds carbon uptake, improves soil aggregation. Since these nano fertilizers contain nutrients, growth promoters encapsulated in nano scale polymers, they will also have a slow and a targeted efficient release. Nanotechnology is gathering information of atom in nano scale range, with considering the physical, catalytic, magnetic, optical properties [2]. However, the concentration of usage chronically exposes soil microbes and micro fauna, as well as the plants themselves, to level of chemical reactivity that may be toxic [3]. When comparing to chemical fertilizers requirement and cost, nano fertilizers are economically cheap and are required in lesser amount. For years farmers have found that nitrogen uptake is the main reason for improper yield.

Agriculture is the largest interface between humans and the environment, and is a major cause of climate change and ecosystem degradation. In particular, fertilizer use leads to fundamental changes in the pools Fertilizer utilization to supplement soil nutrients, to promote plant growth and to increase crop productivity and food quality is prevalent in modern agriculture. As a result, crop production and global food security are highly dependent on fertilizers input to agricultural lands [4] . Pesticides use has dramatic consequences both in developed and developing countries [5].Sustainable agriculture aims at long term maintenance of natural resources and agricultural productivity with minimal adverse impact on the environment [6].

SYSTEMS FOR SUSTAINABLE INTENSIFICATION IN AGRICULTURE

Sustainable intensification is a concept related to a production system aiming to increase the yield without adverse environmental impact while cultivating the same agricultural area [7]. This paradigm provides a framework to evaluate the selection of the best combination of approaches to agricultural production considering the influence of the current biophysical, social, cultural, and economic situation [8]. In this context, novel nanomaterials based on the use of inorganic, polymeric, and lipid nanoparticles, synthesized by exploiting different techniques (e.g., emulsification, ionic gelation, polymerization, oxydoreduction, etc) have been developed to increase productivity (**Figure 1A**). They can find application, as an example, for the development of intelligent nanosystems for the immobilization of nutrients and their release in soil. Such systems have the advantage to minimize leaching, while improving the uptake of nutrients by plants, and to mitigate eutrophication by reducing the transfer of nitrogen to groundwater.

Furthermore, itis noteworthy to mention that nanomaterials could also be exploited to improve structure and function of pesticides by increasing solubility, enhancing resistance against hydrolysis and photodecomposition, and/or by providing a more specific and controlled-release toward target organisms[9].[10].

Systems to Improve the Quality of the Soil Hydrogels, nanoclays, and nanozeolites have been reported to enhance the water-holding capacity of soil [11], hence acting as a slow release source of water, reducing the hydric shortage periods during crop season (**Figure 1B**). Applications of such systems are

ISSN: 0975-8585

favorable for both agricultural purposes and reforestation of degraded areas. Organic e.g., such as polymer and carbon nanotubes and inorganic e.g., such as nano metals and metal oxides nanomaterials have also been used to absorb environmental contaminants [12], increasing soil remediation capacity and reducing times and costs of the treatments. Nanomaterials as Agents to Stimulate Plant Growth Carbon nanotubes and nanoparticles of Au, SiO2, ZnO, and TiO2 can contribute to ameliorate development of plants (**Figure 1C**), by enhancing elemental uptake and use of nutrients[13].

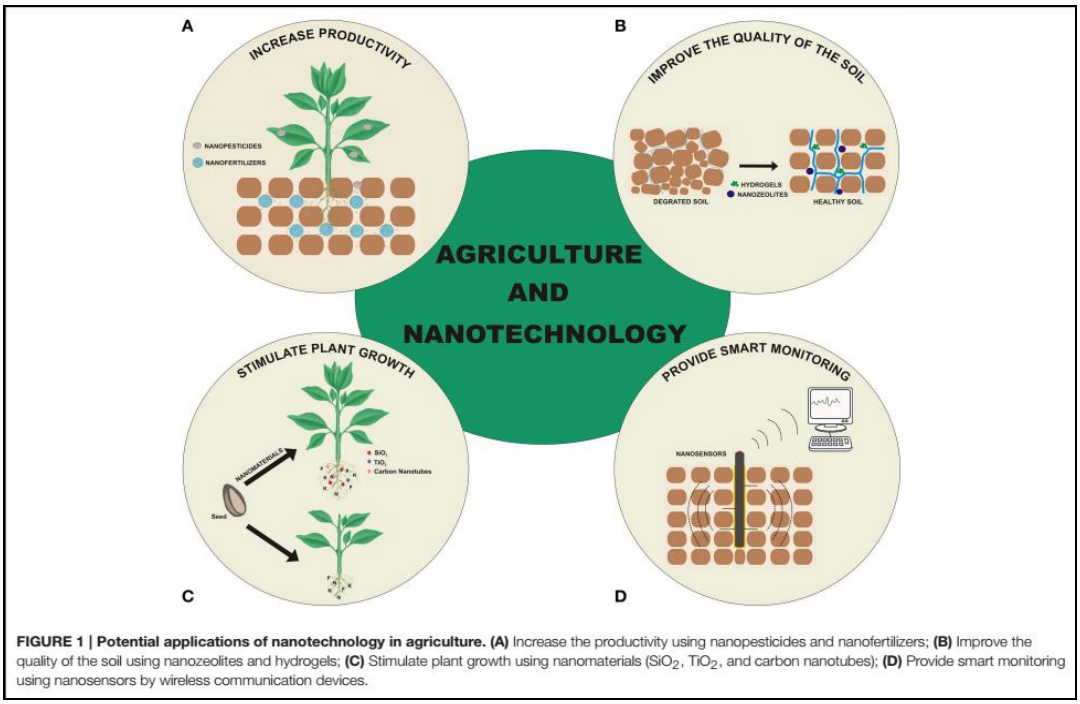

FIGURE 1 | Potential applications of nanotechnology in agriculture. (A) Increase the productivity using nanopesticides and nanofertilizers; **(B)** Improve the quality of the soil using nanozeolites and hydrogels; **(C)** Stimulate plant growth using nanomaterials (SiO_2, TiO_2, and carbon nanotubes); **(D)** Provide smart monitoring using nanosensors by wireless communication devices.

Figure 1 | Potential applications of nanotechnology in agriculture. (A) Increase the productivity using nanopesticides and nanofertilizers; (B) Improve the quality of the soil using nanozeolites and hydrogels; (C) Stimulate plant growth using nanomaterials (SiO2, TiO2, and carbon nanotubes); (D) Provide smart monitoring using nanosensors by wireless communication devices.

However, the real impact of nanomaterials on plants depends on their composition, concentration, size, surface charge, and physical chemical properties, besides the susceptibility of the plant species [14-15]. The development of new protocols and the use of different analytical techniques (such as microscopy, magnetic resonance imaging, and fluorescence spectroscopy) could considerably contribute to understand the interactions between plants and nanomaterials.

NANO FERTILIZERS

Fertilizers play an important role where the ancient chemical fertilizers are replaced with nano and bio fertilizers with their efficiency and environment friendly nature. Primary use of adding is fast uptake of nutrients from the soil and giving better, faster yield.

The symbiotic exchange between soil and the plant system is very efficient. Table1.provides an overview of the most relevant agricultural nanotechnology applications. When the same is applied in slow and efficient way all the required nutrients is taken up by the plant and restores the required and efficient energy in it for which the yield increases drastically. When fertilizers are in the form of encapsulated this can be achieved. Main element Nitrogen is needed in abundant and uptake of this itself causes many problems to the plants. Fig.2 Shows the nutrients from nanofertilizers releases with plant demands{www.cell.com) A different type of fertilizers for different crop problems is reviewed.

ISSN: 0975-8585

Table1.An overview of the most relevant agricultural nanotechnology applications.[16]

	Definition	Example
Crop production		
Plant protection products	Nanocapsules, nanoparticles, nanoemulsions and viral capsids as smart delivery systems of active ingredients for disease and pest control in plants	Neem oil (Azadirachta indica) nanoemulsion as larvicidal agent (VIT University, IN)
Fertilizers	Nanocapsules, nanoparticles and viral capsids for the enhancement of nutrients absorption by plants and the delivery of nutrients to specific sites	Macronutrient Fertilizers Coated with Zinc Oxide Nanoparticles (University of Adelaide, AU CSIRO Land and Water, AU Kansas State University, US)
Soil improvement		
Water/liquid retention	Nanomaterials, e.g. zeolites and nano-clays, for water or liquid agrochemicals retention in the soil for their slow release to the plants	Soil-enhancer product, based on a nano-clay component, for water retention and release (Geohumus-Frankfurt, DE)
Water purification		
Water purification and pollutant remediation	Nanomaterials, e.g. nano-clays, filtering and binding to a variety of toxic substances, including pesticides, to be removed from the environment	Filters coated with TiO2 nanoparticles for the photocatalytic degradation of agrochemicals in contaminated waters (University of Ulster, UK)
Diagnostic		
Nanosensors and diagnostic devices	Nanomaterials and nanostructures (e.g. electrochemically active carbon nanotubes, nanofibers and fullerenes) that are highly sensitive bio-chemical sensors to closely monitor environmental conditions, plant health and growth	Pesticide detection with a liposome-based nano-biosensor (University of Crete, GR)
Plant breeding		
Plant genetic modification	Nanoparticles carrying DNA or RNA to be delivered to plant cells for their genetic transformation or to trigger defence responses, activated by pathogens.	Mesoporus silica nanoparticles transporting DNA to transform plant cells (Iowa State university, US)
Nanomaterials from plant		
Nanoparticles from plants	Production of nanomaterials through the use of engineered plants or microbes and through the processing of waste agricultural products	Nanofibres from wheat straw and soy hulls for bio-nanocomposite production (Canadian Universities and Ontario Ministry of Agriculture, Food and Rural Affairs, CA)

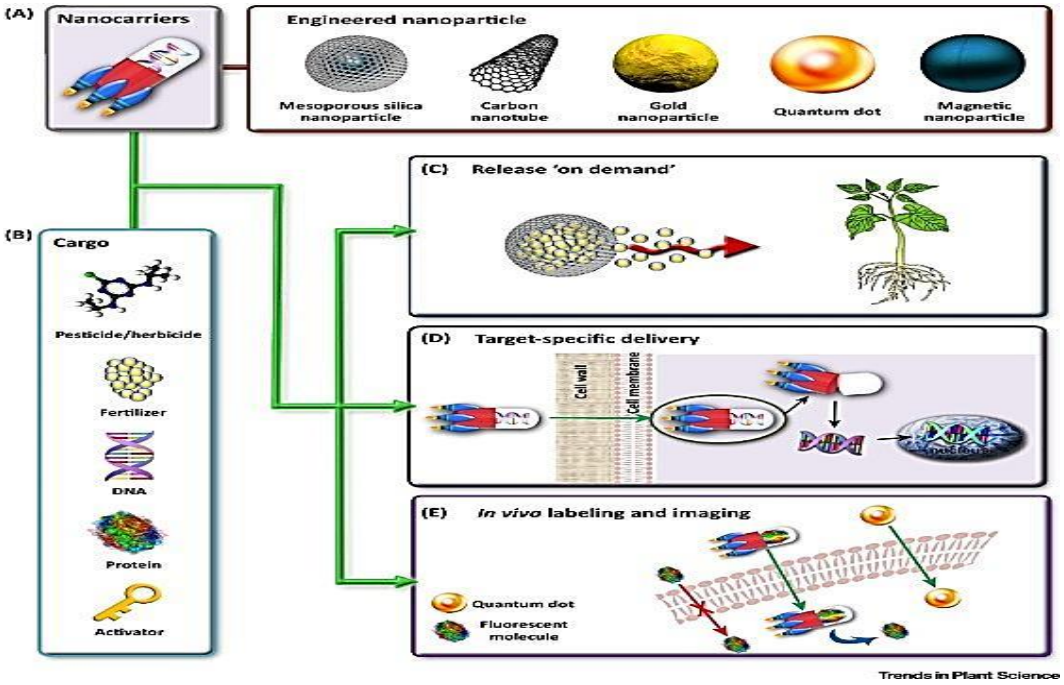

Figure.2 Shows the nutrients from nanofertilizers releases with plant demands{www.cell.com)

Nitrogen fertilizers[18]

There are ways where N is being lost in the atmosphere, and those processes include volatization, denitrification, leaching, and run off. There is a. error in applying this N fertilizer to the crop, in fact continuous applying of these to the pre plants will not benefit in optimum utilization of the entire amount added. When the plants are harvested, they take away the nutrients which are present in the soil, therefore it is necessary to replace it by a readily available fertilizer to constantly make the nutrients available to the plants. The element required in abundant, nitrogen (N), is essential for plant growth and animal nutrition and is the nutrient taken up in largest amount by all plants. Source ofnitrogen include ammonia, diammonium phosphate, ammonium nitrate, ammonium sulphate, calcium cyanamide, calcium nitrate, sodium nitrate and urea. Its widely used because it is easily available, rapid action. This element's role in the environment is complex. When coming to Nitrogen fertilizers, slow release of the same will be plant beneficiary. This is because a farmer can fertilize less often by providing the nutrients slowly and steadily. There was an attempt to increase the uptake of nitrogen with the application of 25 kg Mg Oha-1 which increased the positive uptake.[18]

Potash fertilizers

Potash fertilizer taken by the plants as K+ forming no organic compound in the plant, helps in photosynthesis process, controlling water storage and stomata opening in leaves. For the slow release of potash fertilizer, polyacrylamide based coating of pellets were used. Potash and clay was mixed together and dried for an hour, this was coated with a tooth paste for proper attachment of the polymer. This polymer was dipped in polyacrylamide polymer.The study showed the difference of dissolution with and without the coating, when the potash used is less the release is also slowed down and the release can also be maintained with less water [19]. Since the main cash crop of India and Srilanka is rice, there were studies done on rice using nano potash fertilizer as the source of potassium in rice, which resulted in increase number of grains per panicle and also the amount compared to muriate of potash was less. There are studies conducted for wheat and corn with nano coating fertilizer and slow release of the same to crops has increased the yield rate, and also effective recovery of N fertilizer [20].

Nano porous Zeolite

They usually help in slow release of the fertilizer to the plant, this way of doing makes the plant to grab entire amount of nutrients from the fertilizer supplied rather than the minimal uptake. Since it has larger surface area many molecules can fit into it and get released whenever the plant requires [21] Zeolite (Clinoptilolite) was made nano sized particles with ball mill. 1 g of this was taken in a centrifuge and stirred with 1.5M 50 ml of calcium sulphate solution for 8 hours, filtered and washed with de-ionized water, air dried. Solid: liquid ratio was maintained up to 1: 10 for synthesis purpose. [22]. Nitrogen fertilizers are very important but due to its high solubility nature it causes severe damage to the pants and the surroundings therefore a nano porous zeolite was used with urea and there was considerable increase in the uptake of nitrogen efficient urea with controlled release [23]. Aluminium zeolites are also used because they are highly porous and allow the retention of the soil. These zeolites help the dry soil also to retain all the moisture content and help to grab nutrients from the soil [24].

Zinc Nano Fertilizer

Micro nutrient, zinc has a serious deficient crisis in the world. The amount of zinc intake through daily food is very less therefore by utilizing zinc based fertilizer there are least chances of indirect supply to human. For the same nano particles can be used to coat zinc in order to get a diffused and soluble zinc [25]. When the pH increases solubility of zinc decreases [26]. Equal ratios between surface area and size of nano particles should be carefully designed If not, total solubility of the zinc will be affected. This is shown taking ratio of Nano ZnO and bulk ZnO available on whole [27].

Nano Herbicide

In a field to consider there are unwanted plants grown along with the desired plant crops and those are called weeds. To kill these weeds, herbicides are used but conventional herbicide when sprayed has a chance of getting affected to the good crops too by this there can be huge loss in the crop yield. By using Nano herbicide which is 1-100nm range will try to mingle with the soil particle and try to destroy the entire weed

kingdom from their roots by not affecting other good crops. Since the nano particles are target specific they can be used to kill the weeds and destroy it to get better yield [24]. Also there are works carried out for the controlled release of the herbicide limiting the damage caused by it to human. More widely used herbicide include triazine, herbicidesametryn and atrazine were nano encapsulated to get 84% effiecient release to the plants [28]. Adsorptive stripping voltammetry process was developed to detect herbicide fenclorim with carbon nanotubes at pH 4.0 with the adsorption techniques on the electrodes [29]. Atrazine is the widely used herbicide in order to kill the weeds and unwanted grass growing near the crops, continuous use of herbicides makes soil loose all the nutrients and make them resistant to the plants, therefore application of modified silver with nano particles and carboxy methyl cellulose makes degradation of herbicide easier [30]

Nano Pesticide

Pesticide contains four different sub categories which will act on different target objects but action is the same either completely destroy or making plant resistant. Those categories include herbicide acting on unwanted weeds and grasses, insecticide on various insects, fungicides for few molds, algae and disinfectants for the control of bacteria and making them not to spread. So preparing this pesticide in the form of a shell or in a closed envelope will make it a slow and efficient release, soil run off rate can be decreased, increase solubility [31]. An emulsion coating of pesticide was developed, with the proper mixing of oil and water, a water insoluble , β-cypermethrin was developed and compared with uncoated product for stability and effectiveness in spraying [32] . Another spodopteralitoralis, an important pest which affects major plant kingdom developing its resistivity to almost all the pesticides was effectively controlled against hydrophobic nano silica coated tomato and it showed positive response of destroying the pests at 300-350 ppm respectively [33] . When citric acid molecules were combined with multi walled carbon nano tubes certain pesticides like Zineb and Mancozeb are trapped in aqueous solution which led to encapsulated pesticide which led to a serious threat for a particular fungi type *Alternaria alternate* fungi [34]

NANO-NUTRIENT

Fertilizer play pivotal role in the agriculture production up to 35 to 40% of the productivity. To enhance nutrient use efficiency and overcome the chronic problem of eutrophication, might be a best alternative. Attempts have been made to synthesize nanofertilizer particulary for zinc in order to regulate the release of nutrients depending on the requirements of the crops, and it is also reported that nanonutrients are more efficient than ordinary fertilizer [35]. Nano fertilizer technology is very innovative and scanty reported literature is available in the scientific journals. However, some of the reports and patented products strongly suggest that there is a vast scope for the formulation of nano-fertilizers. An enhanced production has been observed by foliar application of nano particles as fertilizer [36].

PRECISION FARMING

Nanotechnology supports the application of information technologies applied to the management of commercial agriculture. Precision farming's enabling technologies include satellite positioning systems, geographic information systems, and remote sensing devices. By connecting global positioning systems with satellite imaging of fields, farm managers could remotely detect crop pests or evidence of drought. Information about these conditions would trigger an automatic adjustment of pesticide applications or irrigation levels. Dispersed throughout fields, a network of sensors would relay detailed data about crops and the soil. These sensors would need to have nanoscale sensitivity to monitor conditions, such as the presence of plant viruses or the level of soil nutrients. Other forms of nanotechnology may directly alter agricultural practices. Nanoparticles or nanocapsules could provide a more efficient means to distribute pesticides and fertilizers, reducing the quantities of these chemicals introduced into the environment [35]. Livestock may be identified and tracked through commerce using implanted nanochips. Nanoparticles may deliver growth hormone or vaccines to livestock, or DNA for genetic engineering of plants.

FOOD PROCESSING

Nanotechnology may be used in agriculture and food production in the form of nanosensors for monitoring crop growth and pest control by early identification of animal or plant diseases. These nanosensors can help enhance production and improve food safety. The sensors function as external monitoring devices

and do not end up in the food itself. Nanomaterials can also be introduced in or on the food itself. The effectiveness of pesticides may be improved if very small amounts are enclosed in hollow capsules with a diameter in the nanometer range which can be designed to open only when triggered by the presence of the pest to be controlled [37]. Nanopesticide residues on the food and from animal feed and veterinary medicine may end up inside the stomach but what happens then is not clear.

PROS AND CONS OF NANOTECHNOLOGY IN AGRICULTURE

Nanotechnology provides new agrochemical agents and new delivery mechanisms to improve crop productivity, and it promises to reduce pesticide use. Nanotechnology can boost agricultural production, and its applications include: 1) nanoformulations of agrochemicals for applying pesticides and fertilizers for crop improvement; 2) the application of nanosensors/nanobiosensors in crop protection for the identification of diseases and residues of agrochemicals; 3)nanodevices for the genetic manipulation of plants; 4) plant disease diagnostics; 5) animal health, animal breeding, poultry production; and 6) postharvest management. Precision farming techniques could be used to further improve crop yields but not damage soil and water, reduce nitrogen loss due to leaching and emissions, as well as enhance nutrients long-term incorporation by soil microorganisms.

The Catchy term 'Nanotechnology' also pose some risks and problem towards the health and also towards environment. When considering risk and safety interm of the same will be relevant to only certain area. The initial studies performed for nano materials have caused serious health hazards and also showed toxic effects, also when entered into human body caused tissue damage reaching all the vital organs. Another emerging technique is utilizing silver nano particles for the delivery of fertilizers to plants because of their antimicrobial properties, but studies have considered that it poses serious threat to ecosystem causing membrane damage, reducing the annual growth of grass, depletion photosynthesis in alga (chlamydomonasreinnardtii). Silver nano particles are usually difficult to recover, some plant species tends to use this nano particle maximum and accumulates in its tissue exceeding the limit. Soybean an important cash crop in most of the country was produced using manufactured nano materials with fossil fuel equipment that will allow NNM to locally deposit on the crop. With routine waste water treatment plants, Results were impacts on plant - microbe interaction affecting N2 fixing symbiosis for which some metals are sensitive.

Nanotechnology may transform the entire food industry, changing the way food is produced, processed, packaged, transported, and consumed. Nanotechnology has the prospective to modernize the agricultural research and development with new tools for the molecular treatment of diseases, rapid disease detection, enhancing the ability of plants to absorb nutrients etc. Smart sensors and smart delivery systems will help the agricultural industry combat viruses and other crop pathogens. In the near future nano structured catalysts will be available which will increase the efficiency of pesticides and herbicides, allowing lower doses to be used. Nanotechnology will also protect the environment indirectly through the use of alternative (renewable) energy supplies, and filters or catalysts to reduce pollution and clean-up existing pollutants. Technology may address the challenges of growing demands for healthy and nutritionally balanced food.

However, creating a bio economy is a challenging and complex process involving the convergence of different branches of science. In the agricultural sector, nanotech research and development is likely to facilitate and frame the next stage of development of genetically modified crops, animal production inputs, chemical pesticides and precision farming techniques.While nano-chemical pesticides are already in use, other applications are still in their early stages, and it may many years before they are commercialized. These applications are largely intended to address some of the limitations and challenges facing large-scale, chemical and capital intensive farming systems.

Zinc, magnesium and Titanium are playing direct or indirect role in the photosynthesis process. The photosynthate leaches in the soil through plant root. In the rhizosphere, root exudation is a key process for carbon transfer into the soil, influencing the role of soil microbial communities in the decomposition of organic matter and in native nutrient cycling [38]. Root exudates are the substances released by roots and may affect growth and activity of soil microorganisms in the rhizosphere [39]. Root exudates act as a chemo-attractants to attract microbes towards root and have been shown to increase the mass and activity of soil microbes and fauna found in the rhizosphere [40]. Nanotechnology is one of the most important tools in modern science yet only a few attempts have been made to apply these advances for increasing crop productivity. It is possible to

develop microorganisms as bionanofactories for synthesis of agriculturally important particles. These nanoparticles offer an excellent scope in developing efficient source of plant nutrients, for enhancing biomass production through increased plant metabolic activities, utilization of native nutrients by promoting microbial activities.

CONCLUSIONS

Nanotechnology will have large impact on rural development. Synthetic biology can revolutionize food production threatening traditional methods of agriculture. It is necessary to create international standards for nanotechnology and in addition special international organizations in the area of nanotechnologies to reduce national differences in assessing of nanotechnologies and risk governance practices. Nanotechnology can pose significant risks to food production, food distribution and healthcare systems that are poorly understood that are particularly important to a small country that can ill afford to mount the research effort required to manage the risks that are likely to emerge with the accelerating global development of nanotechnology. For these purposes it is necessary to create the research infrastructure for toxicology and risk assessment. In aspects of nanotechnology study courses it is necessary to define what kind of skills and knowledge are needed in a small, agricultural country to take advantage of nanotechnology and to manage risks that are likely to emerge with increasing commercialization of nanotechnology. Ultimately, nanotechnology innovations may enable the agricultural industry to precisely control and improve production by reducing the disease incidence and increasing the nutrient availability.

ACKNOWLEDGEMENTS

I would like to acknowledge Prof. Vijaya Bhaskara Raju, Director of GITAM Institute of Technology, GITAM University Bengaluru Campus, India and Prof. R. Venkatanadh, Research Coordinator, GITAM University, Bengaluru for their constant encouragement to finish this work.

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