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Nanotechnology – Scope in Precision Agriculture – A Review

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ABSTRACT: *There is a growing demand for healthy and safe food strategy against an increasing risk of biotic factors such as disease, and threats to agricultural and food production from changing global climate condition. Nanotechnology is a new discipline and developed innovative tools to revolutionize the agricultural and food industry through diagnosis and treatment of diseases, enhancing the ability of plants to absorb nutrients, combat microbial and pest infections, increase the efficiency of biocides, reduce pollution and clean-up existing pollutants. Nanotechnology, too, is likely to have wide applications in agriculture, opening enormous new opportunities such as the fabrication of nano-sensors for protecting food from pathogens and pests, new tools for molecular and cell biology (including more efficient techniques for gene delivery for genetic engineering), and molecular nano-machines and devices. Nano-technogy could be utilized to produce metabolically more absorbing fertilizers like nano-rockphospate, nano coated urea, nano potassium, efficient micronutrient supplement materials like nano-zinc powder, nano magnesium dust compounds, nano copper powder etc. As per as instrumentation side is concerned, carbon metal based nano-particle could be combined with sensors and utilized in precision agriculture. Speed, accuracy and range of sensors could be improved if they are utilized with nano-particles. The use of these target-specific nano-particles can reduce the damage to non-target plant tissues and the amount of chemicals released into the environment. With precise precaution, the usage of few nano particles like clay based nano composite, nano-composite KU2-2601 plastic film etc., have a tremendous scope in climate smart agriculture and hence sustainability. The use of nanotechnology in agriculture has begun, and will continue to develop with significant effects on different areas of agriculture and the food industry. The potential of nanotechnology in agriculture is large, but a few issues are still to be addressed, such as increasing the scale of production processes and lowering costs, as well as risk assessment issues. In this respect, particularly attractive are nano-particles derived from biopolymers such as proteins and carbohydrates with low impact on human health and the environment. For instance, the potential of starch-based nano-particles as nontoxic and sustainable delivery systems for agro-chemicals and biostimulants is being extensively investigated. Nanomaterials and nanostructures with unique chemical, physical, and mechanical properties – e.g. electrochemically active carbon nanotubes, nanofibers and fullerenes – have been recently developed and applied for highly sensitive bio-chemical sensors. These nanosensors have also relevant implications for application in agriculture, in particular for soil analysis, easy bio-chemical sensing and control, water management and delivery, pesticide and nutrient delivery. In recent years, agricultural waste products have attracted attention as source of renewable raw materials to be processed in substitution of fossil resources for several different applications as well as a raw material for nanomaterial production. If these are addressed, nanotechnology in the near future be able to help plants to cope with whatever devastating environmental changes may occur globally or locally.*

INTRODUCTION

The word Nanotechnology has originated from a Greek word which means "dwarf" and nanometer is one billionth of a meter (1 nm = 10^{-9} meter). The nano-scale is not just another step toward miniaturization but a qualitatively new scale (Kundu, 2014). The new behavior of matter at nano-scale is dominated by quantum mechanics, material confinement, large interfacial volume fraction and other unique properties, phenomenon and process. At nano-scale, physics, chemistry and biology converge towards the same principles and tools.

NANOTECHNOLOGY – DEFINING IN RELATION TO AGRICULTURE

Nanotechnology is defined as the understanding and control of matter at dimensions of roughly 1-100 nm, where unique physical properties make novel applications possible. Nanotechnology is sometimes referred to as a *general-purpose technology*. That's

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because in its advanced form it will have significant impact on almost all industries and all areas of society. It will offer better built, longer lasting, cleaner, safer, and smarter products for the home, for communications, for medicine, for transportation, for agriculture, and for industry in general. Nanotechnology is not a set of particular techniques, devices, or products, but the set of capabilities that we will have when our technology comes near the limits set by atomic physics (Storrs, 2006). The burgeoning applications of nanotechnology in agriculture will continue to rely on the problem-solving ability of the material and are unlikely to adhere very rigidly to the upper limit of 100 nm. This is because nanotechnology for agricultural applications will have to address the large-scale inherent imperfections and complexities of farm production systems (eg, extremely low input use efficiency), that might require nanomaterials with flexible dimensions, which nevertheless perform tasks efficiently in agricultural production systems. This is in contrast with nanomaterials that might be working well in well-knit factory-based production systems (Siddhartha, 2014).

SCOPE AND APPLICATIONS OF NANOTECHNOLOGY IN AGRICULTURE

Nanotechnology applications in agriculture can be successful if natural processes are simulated in greater scientific sophistication/articulation for successful implementation. For example, the goal might be to make soils more capable in order to improve efficient nutrient use for greater productivity and better environmental security. Nutrient management with nanotechnology must rely on two important parameters, i.e., ions must be present in plant-available forms in the soil system, and since nutrient transport in soil-plant systems relies on ion exchange (eg, NH_4^+ $H_2PO_4^-$ HPO_4^{2-}, PO_4^{3-}, Zn^{2+}), adsorption-desorption (eg, phosphorus nutrients) and solubility-precipitation (eg, iron) reactions, nanomaterials must facilitate processes that would ensure availability of nutrients to plants in the rate and manner that plants demand. Since clay minerals control these reactions, they could be used as receptacles. Nanofabricated materials containing plant nutrients can be used in aqueous suspension and hydrogel forms, so as to enable hazard-free application, easy storage, and a convenient delivery system. Similarly, application of zerovalent iron nanoparticles and even nanoparticles from iron rust could be harnessed for remediation of soils contaminated with pesticides, heavy metals, and radionuclides, given the high adsorption affinity these nanomaterials have for organic compounds and heavy metals. Iron nanoparticles also have excellent soil binding properties, similar to those of calcium carbonate nanoparticles, which help in formation of soil microaggregates and macroaggregates (Liu and Lal, 2012).

Further opportunities for applying nanotechnology in agriculture lie in the areas of genetic improvement of plants (Eapen and D'Souza, 2005; Kuzma, 2007), delivery of genes and drug molecules to specific sites at the cellular level in plants and animals (Maysinger, 2007), and nanoarray-based technologies for gene expression in plants to overcome stress and development of sensors and protocols for its application in precision farming, management of natural resources, early detection of pathogens and contaminants in food products, smart delivery systems for agrochemicals like fertilizers and pesticides, and integration of smart systems for food processing, packaging, and monitoring of agricultural and food system security. With nanofertilizers emerging as alternatives to conventional fertilizers, buildup of nutrients in soils and thereby eutrophication and contamination of drinking water may be eliminated (Siddhartha, 2014). Overdependence on supplementary irrigation, vulnerability to climate, and poor input and energy conversion are the three dominant issues in the current agricultural production system, and nanotechnology could possibly reduce their impact. Also, it has been observed that nanoremediation could be effective not only in reducing the overall costs of cleaning up large contaminated sites, but also in decreasing clean-up time by eliminating the need for treatment and disposal of contaminated soil and reducing some contaminant concentrations to near zero, all in situ.

PRECISION AGRICULTURE – NANOTECHNOLOGY

Precision agriculture has been a long-desired goal to maximize output (i.e., crop yields) while minimizing input (i.e., fertilizers, pesticides, herbicides etc.) through monitoring environmental variables and applying targeted action. Precision agriculture makes use of computers, global satellite positioning systems, and remote sensing devices to measure highly localized environmental conditions thus determining whether crops are growing at maximum efficiency or precisely identifying the nature and location of problems. By using centralized data to determine soil conditions and plant development, seeding, fertilizer, chemical and water use can be fine-tuned to lower production costs and potentially increase production – all benefiting the farmer. Precision farming can also help to reduce agricultural waste and thus keep environmental pollution to a minimum. Although not fully implemented yet, tiny sensors and monitoring systems enabled by nanotechnology will have a large impact on future precision farming methodologies (Singh, 2014).

One of the major roles for nanotechnology-enabled devices will be the increased use of autonomous sensors linked into a GPS system for real-time monitoring. These nanosensors could be distributed throughout the field where they can monitor soil conditions and crop growth. The union of biotechnology and nanotechnology in sensors will create equipment of increased sensitivity, allowing an earlier response to environmental changes (Singh, 2014). For example:

- Nanosensors utilizing carbon nanotubes or nano-cantilevers are small enough to trap and measure individual proteins or even small molecules.
- Nanoparticles or nanosurfaces can be engineered to trigger an electrical or chemical signal in the presence of a contaminant such as bacteria.
- Other nanosensors work by triggering an enzymatic reaction or by using nanoengineered materials.
- Ultimately, precision farming with the help of smart sensors, will allow enhanced productivity in agriculture by providing accurate information, thus helping farmers to make better decisions.

NANO-SENSORS IN AGRICULTURE

Removal of harmful contaminants from the soil and waste water should be preceded by methods to determine the presence of these toxic chemicals. Biosensors, incorporated with new technologies in molecular biology, microfluidics and nanomaterials, have diverse applications in agricultural production, food processing and environmental monitoring for in-field, on-line and real-time detection of pesticides, pathogens, toxic materials, proteins, antibiotics, odors creating bacteria, microbes, etc. in soil, air, water, food, plants and animals (Singh, 2014). Biosensors are devices that exploit the ability of biological reactions to specifically detect target analytes. The world's first biosensor to measure activity of soil microorganisms was developed in 2004 by the Research Center of Advanced Bionics (RCAB) of the National Institute of Advanced Industrial Science & Technology (AIST), Japan. The biosensor is capable of forecasting the possible occurrence of soil diseases. The basic principle of spoil diagnosis with the biosensor is to estimate the relative activity of favorable and unfavorable microbes in the soil determined on the basis of differential oxygen consumption in their respiration. It is feasible, therefore, to predict beforehand, whether or not there will be an outbreak of soil disease in the tested soil. The biosensor thus offers an innovative technique of diagnosing soil condition based on numerical data. Researchers have developed inexpensive sensors based on wireless nanotechnology which are composed of micro machined MEMS (Micro Electro Mechanical Systems) cantilever beams coated with a water sensitive nanopolymer for moisture detection. Nanotechnology based MEMS sensors are capable of not only sensing but also reacting to changes in the environment through use of microelectronic circuits (Madou, 1997). A simple, cheap optical sensor for detecting and quantifying the presence of pesticides in water and humic acid was reported by De Stefano *et al.* (2005). Microorganisms produce a range of characteristic volatile compounds.

Microorganisms produce a range of characteristic volatile compounds that may be useful as well as harmful to human beings. Food products, especially dairy and bakery products are ideal for the rapid growth of a wide range of microorganisms. Bacteria are a major contributor to food rotting which is often indicated by a foul odour. Rapid detection biosensors, by detecting foul odors, can minimize the need for food processing units to perform lengthy microbial teats and immunoassays on materials suspected to be carrying food borne pathogens. With an increase in the detection of food borne illness, the need for rapid and sensitive methods for detection of pathogens has become increasingly important. A disposable electrochemical immunosensor for detection of vibrio parahaemolyticus (VP) based on the screen-printed electrode (SPE) coated with agarose/Nano-Au membrane and horseradish peroxidase (HRP) labeled VP antibody (HR-anti-VP) has been developed by Zhao *et al.* (2007). Scientists in the University of Denmark have created two tiny devices, which they have leveraged to detect a range of contaminants, from molecules to whole bacteria, in food and water. Researchers at Purdue University also say that Nanocantilevers could be crucial in designing a new class of ultra-small sensors for the quick detection of viruses, bacteria and other pathogens. Electronic pathogen detectors (also called Electronic nose) identify the odorant, estimate the concentration of the odorant and find characteristic properties of the odor as might be perceived by the human nose. The heart of any electronic nose is the gas sensor that detects the odor producing gas. These gas sensors contain nanostructures like nanowires whose resistance changes when a certain gas is allowed to pass over it. This change in resistance causes a change in the current flowing through a closed circuit.

NANOFABRICATIONS IN AGRICULTURE

Nanofabrication could be defined as the design and manufacture of devices that measure dimensions in nanometers. Conventionally, nanofabrication can proceed by scaling down integrated circuit fabrication involving removal of one atom at a time to obtain the desired structure (top-down approach) or by a more sophisticated hypothetical scheme involving assembly of a structure atom-by-atom (bottom-up approach). Nanomaterials for application in farming could be fabricated by combining the top-down and bottom-up methods on the basis of an understanding of the nanodynamics of interacting nanomaterials and interfacing nanostructures (Siddhartha, 2014).

Nanofabrication involving clays is advantageous as these materials are available in abundance and are cheap, so farmers would be able to afford them when they are commercialized. From the viewpoint of the environment and biosafety, the inseparable association of clays with the origin and evolution of life makes them most desirable. However, nanofabrication involving clays is a distinct field, because it departs from the conventional field of nanotechnology (eg, nanoelectronics, nanomaterials), and is far more challenging than conventional applications (eg, cell phones, computers, sensors, clothes, and other industrial products). This is because clay is an interface between the physical world and biological world, and soil is the central domain of geosphere, biosphere, atmosphere, and the hydrosphere, so soil scientists have the responsibility to support life and protect environment. It is worth mentioning that the fate and disposal of nanomaterials in farmlands are not comparable with those of their industrial counterparts, especially when clays are involved. However, the soil system obeys the laws of ion exchange, adsorption-desorption, aggregation-dispersion, and solubility-dissolution, and such phenomena must be used to make the system responsive to nanotechnology. The routes of fabrication could rely on charge properties such as: density, origin, and nature of charges; intensity and degree of manifestation of charge in nanoscale; and the nature (geometry) and extent of the interface available for reaction. Fabrication may include extraction, purification, and functionalization involving mild nontoxic materials such as Na_2CO_3 at low concentration (Siddhartha, 2014).

NANOFERTILISERS IN AGRICULTURE

Nanotechnology has provided the feasibility of exploiting nanoscale or nanostructured materials as fertilizer carriers or controlled-release vectors for building of so-called "smart fertilizer" as new facilities to enhance nutrient use efficiency and reduce costs of environmental protection (Cui *et al*., 2006; Chinnamuthu and Boopathi, 2009). Encapsulation of fertilizers within a nanoparticle is one of these new facilities which are done in three ways a) the nutrient can be encapsulated inside nanoporous materials, b) coated with thin polymer film, or c) delivered as particle or emulsions of nanoscales dimensions (Rai *et al*., 2012). In addition, nanofertilizers will combine nanodevices in order to synchronize the release of fertilizer-N and -P with their uptake by crops, so preventing undesirable nutrient losses to soil, water and air via direct internalization by crops, and avoiding the interaction of nutrients with soil, microorganisms, water, and air (De Rosa *et al*., 2010).

Nanoporous zeolites (nano clays and zeolites) a group of naturally occurring minerals with a honeycomb-like layered crystal structure are other strategies for increasing fertilizer use efficiency (Chinnamuthu and Boopathi, 2009). Its network can be filled with nitrogen, potassium, phosphorous, calcium and a complete set of minor and trace nutrients. So acts as a nutrients supply that are slowly released "on demand". Application of soluble N fertilizers is one of the major reasons for groundwater contamination. Nitrogen releasing dynamics of the absorbed form (in zeolites) is much slower than for the ionic form. Millan *et al*. (2008) reported that urea-fertilized zeolite chips, can be used as slow release nitrogen fertilizers. Ammonium-charged zeolites have shown their capacity to raise the solubilization of phosphate minerals and thus improving phosphorus uptake and yield of crop plants. Studies conducted to check solubility and cation-exchange in mixtures of rock phosphate and NH^{+4} and K-saturated clinoptilolite showed that mixtures of zeolite and phosphate rock have the potential to provide slow-release fertilization of plants in synthetic soils by dissolution and ion-exchange reactions (Allen *et al*., 1993).

More recent strategies have focused on technologies to provide nanofertilizer delivery systems which can react to environmental changes. The final goal is production of nanofertilizers that will release their shipment in a controlled manner (slowly or quickly) in reaction to different signals such heat, moisture and etc (Naderi and Danesh-Shahraki, 2013). Furthermore, it is known that under nutrient limitation, crops secrete carbonaceous compounds into rhizosphere to enable biotic mineralization of N and/or P from soil organic matter and of P associated with soil inorganic colloids. Since, these root exudates can be considered as environmental signals and be selected to prepare nanobiosensors that will be incorporated into novel Nanofertilizers (Al-Amin Sadek and Jayasuriya, 2007; Sultan *et al*., 2009). It is considerable point that, what was mentioned is only part of opportunities for using nanotechnology to improve fertilizer formulations and construction of more environmentally friendly fertilizers. In these cases, the emphasis is primarily on improving nutrient use efficiency. Whereas, nanotechnology can also improve the performance of fertilizers in other ways. For instance, due to its photocatalytic characteristic, nano size titanium dioxide has been incorporated into fertilizers as a bactericidal supplement. In addition, nano silica particles that absorbed by roots have been shown that form films at the cell walls, which can improve the plant's resistance to stress and thus increases the crop yield (De Rosa *et al*., 2010).

SMART DELIVERY SYSTEMS

In the future, nanoscale devices with novel properties could be used to make agricultural syatems "smart". For example, devices could be used to identify plant health issues befor these become visible to the farmer. Such devices may be capable of responding to different situations by taking appropriate remedial action. If not, they will alert the farmer to the problem. In this way, smart devices will act as both a preventive and an early warning system. Such devices could be used to deliver chemicals in a controlled and targeted manner (Singh, 2014).

Technologies such as encapsulation and controlled release methods, have revolutionized the use of pesticides and herbicides. Many companies make formulations which contain nanoparticles within the 100-250 nm size range that are able to dissolve in water more effectively than existing ones (thus increasing their activity). Other companies employ suspensions of nanoscale particles (nanoemulsions), which can be either water or oil-based and contain uniform suspensions of pesticidal or herbicidal nanoparticles in the range of 200-400 nm. These can be easily incorporated in various media such as gels, creams, liquids etc., and have multiple applications for preventive measures, treatment or preservation of the harvested product (Singh, 2014).

In other areas, Scientists are working on various technologies to make fertilizer and pesticide delivery systems which can respond to environmental changes. The ultimate aim is to tailor these products in such a way that they will release their cargo in a combined manner (slowly or quickly) in response to different signals eg. magnetic fields, heat, ultrasound, moisture etc (Singh, 2014).

PROBLEMS WITH NANOTECHNOLOGY

Unlike most of the industrial production systems, there exist many gray areas in making farm production systems responsive to desired productivity levels, maintenance of environmental quality, and adherence to societal ethics. With nanotechnology being a new entrant in agriculture, we need to revisit the contemporary theoretical foundations and practices of agriculture to conform to next-generation farming. Similarly, investigations need to be directed to simulation of the properties, behavior, transport, and reactivity of nanomaterials in the ecosystem in a predesigned and holistic manner. Our understanding of these aspects could possibly be improved if hitherto unexplored areas like the theory of chaos, especially in nonlinear dynamic systems, are used to the fullest extent, especially given that equilibrium thermodynamics never works with anything approaching perfection in the natural environment.

Foresight and patience are essential for applying nanotechnology in agriculture because generation of data in most agricultural fields is time-consuming and expensive, and success is uncertain due to involvement of a large number of variables in farm production systems, and because of the complex intrinsic relationship between nanomaterials and nature. It is worthwhile to recognize that a large number of nanomaterials have existed since time immemorial in soils, plants, and the atmosphere (Li *et al*., 2012; Wilson *et al*., 2008; Theng and Yuan, 2008).

CONCLUSION

The opportunity for application of nanotechnology in agriculture is prodigious. Research on the applications of nanotechnology in agriculture is less than a decade old. Nanotechnology promises a breakthrough in improving our presently abysmal nutrient use efficiency through nanoformulation of fertilizers, breaking yield and nutritional quality barriers through bionanotechnology, surveillance and control of pests and diseases, understanding the mechanism of host-parasite interactions at the molecular scale, development of new-generation pesticides and safe carriers, preservation and packaging of food and food additives and use of clay minerals as receptacles for nanoresources involving nutrient ion receptors, precision water management, regenerating soil fertility, reclamation of salt-affected soils, checking acidification of irrigated lands, and stabilization of erosion-prone surfaces, to name a few. Nanotechnology requires a thorough understanding of science, as well as fabrication and material technology, in conjunction with knowledge of the agricultural production system.

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