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Review

Nanotechnology and Agroecosystem

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Nanotechnology is working with the smallest possible particles which raise hopes for improving agricultural productivity through encountering problems unsolved conventionally. Improvement of crops in agriculture is a continuous process. Breeding varieties to suite the growing needs are done through conventional breeding and biotechnical means. Recently scientists have started using nanotechnology to deliver the genes to specific sites at cellular levels and rearrange the atoms in the DNA of the same organism to get expression of desired character, thus skipping the time consuming process of transferring the gene from the foreign organisms. In the management aspects, efforts are made to increase the efficiency of applied fertilizer with the help of nano clays and zeolites and restoration of soil fertility by releasing fixed nutrients. Research on smart seeds programmed to germinate under favourable conditions with nanopolymer coating are encouraging. In the controlled environment agriculture and precision farming input requirement of crops are diagnosed based on needs and delivered the required quantities in right time at right place with the help of nanobiosensor and satellite system. Nanoherbicides are being developed to address the problems in perennial weed management and exhausting weed seed bank. Remediation of environmental contamination of the industrial waste and agricultural chemicals like pesticides and herbicide residues are possible through metal nanoparticles. Details of possibilities and concepts of application of nanotechnology in the crop production and results obtained already in these areas are reviewed in this paper.

Key words: Nanotechnology, biosensor, nanoherbicides, nanopolymer, nanopesticides, nanofertilizer, smart seeds, food-packaging, environment, climate change

Increasing production and productivity of crops through crop improvement, crop management and crop protection from pest and disease have been in vogue from time immemorial. Conventional and improved technologies have their own limitations. Technologies available are unable to break through some of the bottlenecks. Nanotechnology, the science of working with smallest possible particles, raises hopes for the future to overcome the difficulties encountered in agriculture. Hitherto, use of this new science, nanotechnology in agriculture has been mostly theoretical, but it has begun and will continue to have a significant effect in the main areas of breeding new crop varieties, development of new functional materials and smart delivery systems for agrochemicals like herbicides, fertilizers and pesticides, smart systems integration for food processing, packaging and other areas like remediation of herbicide and pesticide residues from plant and soil, effluent water treatment, etc. (Moraru et al., 2003). The potential is increasing day by day with suitable techniques and sensors being identified for precision agriculture, natural resource management and early detection of pathogens and contaminants in food products,

The term 'nanotechnology' encompasses a wider range of activities. 'Nano' is used in the world of science to mean one billionth. A nanometer is a billionth of a metre. A nanometer is only ten atoms across! Generally nanotechnology is used to mean technology at the nanometer level to achieve something useful through the manipulation. The Royal Society defines: "Nanotechnologies are the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometer scale." (RSRAE, 2004). At such scales, the ordinary rules of

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physics and chemistry no longer apply. For instance, materials' characteristics, such as colour, strength, conductivity and reactivity, can differ substantially between nanoscale and macro.

Indian Agriculture

India's agriculture has grown rapidly enough in recent decades to save the country from the severe food crises of the early 1960s to the food surplus of the early 1990s, even the population grew by 424 million between 1963 and 1993. Despite national food surpluses, widespread poverty and hunger remain because growth of agriculture and national economy have not adequately benefitted the poor. Moreover, with strong growth of income and projected to grow 1.5 billion by 2040, the cereal demand in India is projected as 300 to 350 million metric tonnes. Hence, food grain production needs to increase at around 1.5% per annum (Robert et al., 1999).

Increase in production and productivity of crops was successfully accomplished in India due to the introduction of high yielding varieties during early period of green revolution. Without much improved management technologies the crops yielded their potential due to inherent high fertility status of the soil in the initial years. Continuous and intensive cultivation led to degradation of the natural resource base (soil, water, and climate) of agriculture. Nearly 2/3rds of the farm lands are in some measure either degraded or sick. The difficult situation in Indian agriculture is increasingly ascribed to a 'technology fatigue' (Kalpana Sastry et al., 2007). During 1980's focus was shifted from high yield varieties to improved management strategies like soil health, nutrient management, soil moisture conservation, weed management, pest and disease control and value addition of harvested produce.

Table 1. Nanotechnology and areas of application in Agriculture

Technology	Example	Application
Energy storage, production and conversion	• Novel hydrogen storage based on carbon nanotubes • Photovoltaic cells and organic light emitters (Quantum dots) • Composite film coatings for solar cells (Carbon nanotubes)	• Cheaper and clean energy • Low weight and low cost solar cells • Improved rechargeable batteries
Agricultural productivity enhancement	• Nanoporous Zeolites for slow release and efficient delivery of fertilizers, nutrients and drugs • Nanocapsules for pesticide delivery • Nanosensors for soil quality and plant health monitoring	• More efficient and sustainable production that requires fewer inputs
Food processing and storage	• Nanocomposites in plastic film for food packaging • Antimicrobial nano emulsions for decontamination • Antigen detection at nanoscale	• Cheaper, safer food products with longer storage life
Vector and pest detection and control	• Pest and pathogen detection (Nanosensors) • Nanoparticles for pesticides	• More rapid deployment of safer control strategies

Nanotechnology and Agriculture

Despite the efforts made by the management scientists, productivity of crops has not realized its potential. This is attributed to low nutrient and water use efficiency by crops and stiff competition by the weeds and crop pests. Breaking this yield barrier through the new scientific approach, nanotechnology may bestow expected result to increase productivity of crops and meet challenges of food security of the country in the coming years. Hence, Indian Government is looking towards nanotechnology as a means of boosting agricultural productivity. Planning Commission of India recommends nanotechnology research and development as one of six areas of investment (Sreelata, 2008).

Conventionally, remediation for the stress caused by the biotic and abiotic factors on plants starts only after the development of symptoms. By that time the malady may be widespread and entire fields may have to be destroyed. Nanotechnology operates at the same scale as a virus or disease-infecting particle, and thus holds the potential for very early detection and eradication. Smart treatment delivery systems are envisioned for biology and bioactive systems such as drugs, pesticides, nutrients, probiotics, nutraceuticals and implantable cell bioreactors. Experts in agriculture and nanoscience identified some of the important areas in the field of agriculture that have enormous potential for the application of nanotechnology (Table 1.)

Some of the products like nano pesticides have arrived already in the market, while many others are under developing stage and it may take many years before they are commercialized. These applications are largely intended to address some of the limitations and challenges like problem weed management, slow release fertilizers, conditional release of pesticides and herbicides, precise micro-management of soils, the more efficient and targeted use of inputs and new toxin formulations for pest control (Table 2).

Table 2. Nano-agrochemicals and nano-materials under development

Type of product	Product name & manufacturer	Nano content	Purpose
Nano-agrochemicals			
Super" combined fertilizer and pesticide	Pakistan-US Science and Technology Cooperative Program	Nano-clay capsule contains growth stimulants and biocontrol agents	Slow release of active ingredients, Reducing application rates
Herbicide	Tamil Nadu Agricultural University (India) and Technologico de Monterry (Mexico)	Nano-formulated	Designed to attack the seed coat of weeds, destroy soil seed banks and prevent weed germination
Pesticides, including herbicides	Australian Common wealth Scientific and Industrial Research Organization	Nano-encapsulated active ingredients	Very small size of nanocapsules increases their potency and may enable targeted release of active ingredients
Nano-materials			
Nutritional supplement	Nanoceuticals 'mycrohydrin' powder, RBC Life sciences	Molecular cages 1-5 nm diameter made from silica mineral hydride comple	Nano-sized mycrohydrin has increased potency and bioavailability. Exposure to moisture releases H- ions and acts as a powerful antioxidant.
Nutritional drink	Oat Chocolate Nutritional Drink Mix, Toddler Health	300nm particles of iron (SunActive Fe)	Nano-sized iron particles have increased reactivity and bioavailability.

Table 2. Cont.,

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Type of product	Product name & manufacturer	Nano content	Purpose
Food packaging	Adhesive for McDonald's burger containers, Ecosynthetix	50-150nm starch nanospheres	These nanoparticles have 400 times the surface area of natural starch particles. When used as an adhesive they require less water and thus less time and energy to dry.
Food additive	Aquasol preservative, AquaNova	Nanoscale micelle (capsule) of lipophilic or water insoluble substances	Surrounding active ingredients within soluble nanocapsules increases absorption within the body (including individual cell)
Plant growth treatment	Primo Maxx, Syngenta	100nm particle size emulsion	Nano-sized particles increases the potency of active ingredients, potentially reducing the quantity to be applied

Source : http://www.foeeurope.org/activities/nanotechnology/Documents/Nano_food_report.pdf

Crop Improvement

In agriculture, new tools for molecular and cellular biology are needed that are specifically designed for separation, identification and quantification of individual genes and molecules (Warad and Dutta, 2005). Nanotechnology has that potential to deliver the genes to specific sites at cellular levels and rearrange the atoms in the DNA of the same organism to get expression of desired character, thus skipping the time consuming process of transferring the gene from foreign organisms.

Nanotechnology has also shown its ability in modifying the genetic constitution of the crop plants thereby helping in further improvement. Mutations both natural and induced have long since played an important role in crop improvement. Instead of using certain chemical compounds like EMS, MMS and physical mutagens like X-ray, gamma ray, etc. for conventionally induced mutation studies, nanotechnology has showed a new dimension in mutation research. In Thailand, Chiang Mai University's Nuclear Physics Laboratory has come up with a new white-grained rice variety from a traditional purple coloured rice variety called Khao Kam through nanotechnology. Using nanotechnology, the scientists changed the colour of the leaves and stems of Khao Kam from purple to green and the grain became whitish (ETC, 2004). The research involves drilling a nano-sized hole through the wall and membrane of a rice cell in order to insert a nitrogen atom, using a particle beam and the nitrogen atom is shot through the hole to stimulate rearrangement of the rice's DNA. This newly derived organism through the change at the atomic level is designated as 'Atomically Modified Organism (AMO).

Nanoparticle mediated gene delivery

Nonviral gene delivery has gained considerable attention. Although the efficacy of DNA transfection, which is a major concern, is low in nonviral vector-mediated gene transfer compared with viral ones, nonviral vectors are relatively easy to prepare, less immunogenic and oncogenic, and have no potential of virus recombination and no limitation on the size of a transferred gene. The ability to incorporate genetic materials such as plasmid DNA, RNA, and siRNA into functionalized nanoparticles with little toxicity demonstrates a new era in pharmacotherapy for delivering genes selectively to tissues and cells (Sha Jin et al., 2009).

Crop Management

Controlled Environment Agriculture

Precision farming is one of the most important areas for increasing the productivity of crops by applying inputs in preciously required quantity and in required time (USDA, 2002). Tiny sensors and monitoring systems enabled by nano technology will have a large impact on future precision farming methodologies. Precision farming has been a long-felt goal to maximise output (i.e. crop yields) while minimising input (i.e. fertilizers, pesticides, herbicides, etc) through monitoring environmental variables help reduce the agricultural waste and thus keep environmental pollution to a minimum (Doug Rickman, et al.,2003).

One of the major roles for nanotechnology-enabled devices is the 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. Wireless sensors are in use in certain parts of the USA and Australia. For example, one of the Californian vineyards, Pickberry, in Sonoma County has installed wifi systems with the help of Accenture (Gregory J. Millman, 2004). The initial cost of setting up such a system is justified by the fact that it enables the best grapes to be grown that in turn produce finer wines, which command a premium price. The union of biotechnology and nanotechnology in sensors will create equipment of increased sensitivity, allowing an earlier response to environmental changes.

Crop Nutrition Management

Fertilizers play a pivotal role in enhancing the food grain production in India especially after the introduction of high yielding and fertilizer responsive crop varieties during the green revolution era. Despite the resounding success in grain yield, it has been observed that yields of many crops have begun to stagnate as a consequence of imbalanced fertilization and decline in organic matter content of soils. Excessive use of nitrogenous fertilizer affects the groundwater and also causes eutrophication in acquatic ecosystems. A disturbing fact is that the fertilizer use efficiency is 20-50 per cent for nitrogen and 10-25 per cent for phosphorus.

With nano-fertilizers emerging as alternatives to conventional fertilizers, build-up of nutrients in soils and thereby eutrophication and drinking water contamination may be eliminated. In fact, nano-technology has opened up new opportunities to improve nutrient use efficiency and minimize costs of environmental protection. It has helped to divulge to recent findings that plant roots and microorganisms can directly lift nutrient ions from solid phase of minerals.

Slow-release of nano-fertilizers and nano-composites

Slow-release fertilizers are excellent alternatives to soluble fertilizers. Nutrients are released at a slower rate throughout the crop growth; plants are able to take up most of the nutrients without waste by leaching. Slow release of nutrients in the environments could be achieved by using zeolites that are a group of naturally occurring minerals having a honeycomb-like layered crystal structure. Its network of interconnected tunnels and cages can be loaded with nitrogen and potassium, combined with other slowly dissolving ingredients containing phosphorous, calcium and a complete suite of minor and trace nutrients. Zeolite acts as a reservoir for nutrients that are slowly released "on demand."

Fertilizer particles can be coated with nanomembranes that facilitate slow and steady release of nutrients. Coating and cementing of nano and subnano-composites are capable of regulating the release of nutrients from the fertlizer capsule (Liu et al., 2006). A patented nano-composite consists of N, P, K, micronutrients, mannose and amino acids that increases the uptake and utilization of nutrients by grain crops has been reported (Jinghua 2004). Research on the controlled release pattern of nutrients using clay nanoparticle is on the go at Tamil Nadu Agricultural University.

On site diagnosis of nutrient status

Soil solution can be allowed to react with nanoproducts that will give accurate measurement of availability of nutrients in the soils. Nanosensors can be used to determine nutrient, moisture and physiological status of plants which assists in taking up appropriate and timely corrective measures. Nanoparticles are 'mini-laboratories' that have the potential to precisely monitor temporal and seasonal changes in soil-plant system. Nanosensors detect the availability of nutrients and water precisely, which is very much essential to achieve the mission of precision agriculture (Subramanian et al. 2007).

Diagnosis of nutrient disorders in plants

Nanaoparticles are used as 'smart treatment delivery system' for human health. Similarly, implanting nano-particles in the plants could determine the nutrient status in plants and useful for remedial measures to the malady that causes yield reduction. Fertilizer or irrigation requirement of crops can be scouted by nanotechnology. The exciting possibility of combining agricultural science and nanoscale technology into sensors holds the potential of increased sensitivity and therefore a significantly reduced response-time to sense field problems.

Seed management

Seed is nature's nano-gift to man. It is self perpetuating biological entity that is able to survive in harsh environment on its own. Nanotechnology can be used to harness the full potential of seed. Seed production is a tedious process especially in wind pollinated crops. Detecting pollen load that will cause contamination is a sure method to ensure genetic purity. Pollen flight is determined by air temperature, humidity, wind velocity and pollen production of the crop. Use of bionanosensors specific to contaminating pollen can help alert the possible contamination and thus reduces contamination. The same method can also be used to prevent pollen from Genetically Modified Crop from contaminating field crops.

Novel genes are being incorporated into seeds and sold in the market. Tracking of sold seeds could be done with the help of nano-barcodes (Nicewarner Pena et al., 2001) that are encodable, machine - readable, durable and sub-micron sized taggants. Disease spread through seeds and many times stored seeds are killed by pathogens. Nano-coating of seeds using elemental forms of Zn, Mn, Pa, Pt, Au, Ag will not only protect seeds but used in far less quantities than done today. Su et al., (2004) developed a technique known as quantum dots (QDs) as a flourescence marker coupled with immuno-magnetic separation for E coli 0157:H7, which will be useful to separate unviable and infected seeds.

Technologies such as encapsulation and controlled release methods have revolutionised the use of pesticides and herbicides. Seeds can also be imbibed with nano-encapsulations with specific bacterial strain termed as Smart Seed. It will thus reduce seed rate, ensure right field stand and improved crop performance. A Smart Seed can be programmed to germinate when adequate moisture is available that can be dispersed over a mountain range for reforestation (Natarajan and Sivasubramanian, 2007). Coating seeds with nano membrane, which senses the availability of water and allow seeds to imbibe only when time is right for germination, aerial broadcating of seeds embedded with magnetic particle, detecting the moisture content during storage to take appropriate measure to reduce the damage and use of bioanalytical nanosensors to determine ageing of seeds are some possible thrust areas of research.

Nanotechnology and weeds

Multi-species approach with single herbicide in the cropped environment resulted in poor control and herbicide resistance. Continuous exposure of plant community having mild susceptibility to herbicide in one season and different herbicide in other season develops resistance in due course and become uncontrollable through chemicals (Chinnamuthu and Kokiladevi, 2007).

Foliar applied herbicide in perennial weeds such as Cynodan dactylon, Cyperus spp., and Solanum elaeagnifolium fail to kill them completely. The target domains of the present day herbicide in a plant cell are destruction of structure and function of the plant-specific chloroplast, inhibition of lipid biosynthesis, interference with cell-division by disrupting the mitotic sequence or inhibiting the mitotic entry, inhibition of cellulose biosynthesis and deregulation of auxin-induced cell growth (Böger 1989; Wakabayashi and Sato 1992a; Wakabayashi and Sato 1992b; Wakabayashi 1989; Wakabayashi 1993; Wakabayashi and Peter Böger, 2004). Compared to foliar absorption, root absorption is a simpler process. Roots do not have cuticles like leaves; although, mature roots are covered by a suberized layer. This means that there are few barriers to herbicide absorption by plant roots. Since roots are essentially lipophilic, lipophilic herbicides will be readily absorbed.

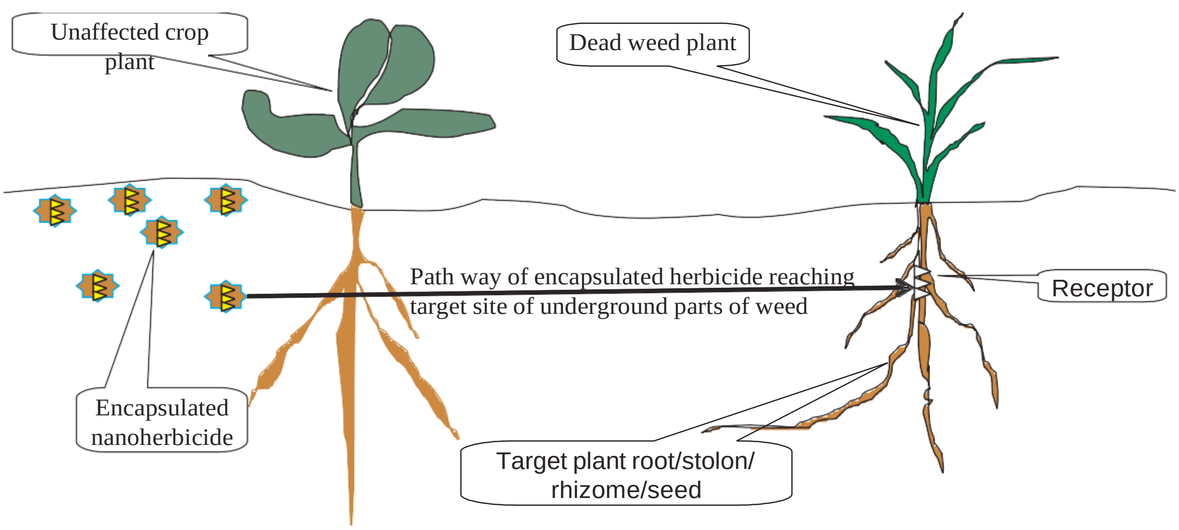
Although molecular mechanisms of action are not yet completely understood even for some commercially available herbicides, about 60% of conventional herbicides interfere with the Photo Electron Transport system of the chloroplast. At present, no commercial herbicides exist that interfere with CO2-fixation and sugar production. Molecular characterization of underground plant parts for a new target domain and developing a receptor based herbicide molecule having specific binding property with nanoherbicide molecules like carbon nanotubes capable of killing the viable and dormant underground propagules of weed seeds (Zimdahl, 1999).

Smart delivery mechanism

Developing a target specific herbicide molecule encapsulated with nanoparticle are aimed for specific receptor in the roots of target weeds, which enter into system and translocated to parts that inhibit glycosis of food reserve in the root system (Fig 1.). This will make the specific weed plant to starve for food and gets killed (Chinnamuthu and Kokiladevei, 2007).

In rainfed areas, application of herbicides with insufficient soil moisture may lead to loss as vapour. Still we are unable to predict the rainfall very preciously; herbicides cannot be applied in advance anticipating rainfall. The controlled

Fig 1. Smart delivery of nanoencapsulated herbicide in the crop-weed environment



Nanoparticle targeting the specific receptors of weed plants

release of encapsulated herbicides is expected to take care of the competing weeds with crops.

Crop Protection

The Integrated Pest Management (IPM) approach, widely adopted in agriculture today, reduces pesticide use on plants and animals by only applying pesticides when needed, based on economic threshold limit. However, continuous monitoring is a time consuming task for the farmer, and requires a significant degree of expertise to recognize and diagnose symptoms of problems from insects, fungal, bacterial or viral pathogens, or nutritional stress.

Plant disease diagnostics

Diseases are one of the major factors in limiting crop productivity. The problem in the disease management lies with the detection of the exact stage of prevention. Most of the times pesticides are applied as a precautionary measure that results in residual toxicity and environmental hazards and on the other hand application of pesticides after the appearance of disease leads to some amount of crop yield losses. Among diseases, viral diseases are the most difficult to control, as one has to stop the spread of the disease by vectors. Nano-based viral diagnostics, including multiplexed diagnostic kit development, have taken momentum in order to detect the exact strain of virus and stage of application. Detection and utilization of biomarkers that accurately indicate disease stages with differential protein production in both healthy and diseased states lead to the identification of the development of several proteins during the infection cycle. These nano-based diagnostic kits not only increase the speed of detection but also increase the power of the detection.

Nanocides: pesticides via encapsulation

A more sophisticated approach to formulating nanoscale pesticides involves encapsulation - packaging the nano-scale active ingredient within a kind of tiny 'envelope' or 'shell'. Both food ingredients and agrochemicals in microencapsulated form have been on the market for several decades. According to industry, reformulation of pesticides in microcapsules has triggered 'revolutionary changes', including the ability to control under what conditions the active ingredient is released. According to the agrochemical industry, re-formulating pesticides in microcapsules can also extend patent protection, increase solubility, reduce the contact of active ingredients with agricultural workers and may have environmental advantages such as reducing run-off rates.

Encapsulating control

Nanotechnology enables companies to manipulate the properties of the outer shell of a capsule in order to control the release of the substance to be delivered. 'Controlled release' strategy is highly prized in medicine since it allows drugs absorbed more slowly, at a specific location in the body or at the say-so of an external trigger. With potential applications across the food chain (in pesticides, vaccines, veterinary medicine and nutritionally-enhanced food), these nano and micro-formulations are being developed and patented by agribusiness and food corporations such as Monsanto, Syngenta and Kraft.

Pesticides containing nano-scale active ingredients are already in the market, and many of the world's leading agrochemical firms are conducting research on the development of new nano-scale formulations of pesticides. For example, BASF of Germany, the world's fourth ranking agrochemical corporation, recognizes nanotech's potential usefulness in the formulation of pesticides. BASF is conducting basic research and has applied for a patent on a pesticide formulation, "Nanoparticles Comprising a Crop Protection Agent," that involves an active ingredient whose ideal particle size is between 10 and 150 nm. The advantage of nano-formulation is that the pesticide dissolves more easily in water; it is more stable and the killing-capacity of the chemical (herbicide, insecticide or fungicide) is optimized. Bayer Crop Science of Germany, has also applied for a patent on agrochemicals in the form of an emulsion in which the active ingredient is made up of nanoscale droplets in the range of 10-400 nm. The company refers to the invention as a "microemulsion concentrate" with advantages such as reduced application rate, "a more rapid and reliable activity" and "extended long-term activity".

Like Bayer Crop Science, Syngenta claims that its Primo MAXX Plant Growth Regulator and Banner MAXX fungicide are extremely small particle size of about 100 nm (or 0.1 micron) prevents spray tank filters from clogging, and the chemicals mix so completely in water that they neither settle in the spray tank not separate from water for up to one year. Additionally the fungicides will be absorbed into the plant's system and cannot be washed off by rain or irrigation.

Post Harvest Food Processing

Food poisoning outbreaks take lives of a large number of people and also cause losses to economy in terms of lost man days and health care expenditure. Nano-materials help to keep products fresh for a longer period of time by using nano-sensors placed in food production and distribution facilities, food packaging or the food itself which can detect all kinds of food pathogens like E.coli, Campylobactor and Salmonella by attaching themselves to the pathogens. A single nano-sensor can have thousands of nano-particles that can detect the presence of any number and kind of bacteria and pathogens rapidly and accurately. Nano-sensors can work by different methods e.g. nano-sensors can be tailor-made to fluoresce into different colours or can be made out of magnetic materials.

In food and beverage industry, attempts have been made to add micronutrients and antioxidants to food substances. But these antioxidants degrade during manufacturing and food storage. Nano cocohleates delivery system protects these substances from degradation. Polyphenols and resveratrol are the substances present in most foods and wine, respectively. They get degraded and oxidized when exposed to air. Nanocochleates solve early oxidation by individually capturing and wrapping them in a phospholipids wrap, and maintaining the internal nutrients secure from water and oxygen. BioDelivery Sciences International have developed nanocochleates, which are 50 nm coiled nanoparticles and can be used to deliver nutrients such as vitamins, lycopene and omega 3 fatty acids more efficiently to cells, without affecting the colour or taste of food. The delivery vehicle is made of soyphosphatidylserine which is 100% safe and provides a protective coat for range of nutrient additives.

Food packaging

Consumers' demand food to be fresh for long time, and the packaging materials should be ease for handling, safe and healthy. A major problem in food science is determining and developing an effective packaging material. Using nanoparticle technology, Bayer has developed an even more airtight plastic packaging that will keep food fresher and longer than plastics, which is "hybrid system" as it is enriched with an enormous number of silicate nanoparticles (Bayer, 2005). Researchers at Leeds University have demonstrated that nanoparticles with antimicrobial properties can be employed for safer food packaging. Nanoparticles such as titanium dioxide, zinc oxide and magnesium oxide, as well as a combination of them, once functionalized can be efficient in killing micro-organisms and are cheaper and safer instead of metal based nanoparticles.

The most problematic element for food packaging engineers is oxygen because it spoils the fat in meat and cheese and turns them pale. Nanoparticles in Durethan®, Bayer's new plastic material, cannot permit air to penetrate like in other conventional plastics. Incorporation of nanoparticles of clay into an ethylene-vinyl alcohol copolymer and into a poly (lactic acid) biopolymer was found to increase barrier properties to oxygen. Polymer-silicate nanocomposites have also been reported to have improved gas barrier properties, mechanical strength, and thermal stability. Nanoclay-nylon coatings and silicon oxide barriers for glass bottles are used to impede gas diffusion.

Biosensors in Agriculture

Nanotechnology plays an important role in the development of biosensors (Haruyama, 2003; Jain, 2003). Sensitivity and other attributes of biosensors can be improved by using nanomaterials. A biosensor is composed of a biological component, such as a cell, enzyme or antibody, linked to a tiny transducer, a device powered by one system which supplies power (usually in another form) to a second system. The biosensors detect changes in cells and molecules that are then used to measure and identify the test substance, even if there is a very low concentration of the tested material.

Development of biosensor will be revolutionized with the advancement in nanotechnology. Nanomaterials are extensively used to design new types of biosensors. In future, nanotechnology-based biosensors will be integrated with biochips with on-board electronics and analytical techniques. This will greatly improve functionality, by providing devices that are small, portable, easy to use, low cost, disposable, and highly versatile diagnostic instruments in every field of agriculture and allied activities.

Nanoparticles for Environmental Remediation

Nanoscience and nanotechnology have the potential to produce major impacts on the environment. Nanoscale particles represent a new generation of environmental remediation technologies that could provide cost-effective solution to some of the most challenging environmental cleanup problems. Nanoscale iron particles have large surface areas and high surface reactivity. Equally important, they provide enormous flexibility for in situ applications. Research has shown that nanoscale iron particles are very effective for the transformation and detoxification of a wide variety of common environmental contaminants, such as chlorinated organic solvents, organochlorine pesticides, and PCBs. Modified iron nanoparticles, such as catalyzed and supported nanoparticles have been synthesized to further enhance the speed and efficiency of remediation.

The environmental chemistry of metallic or zero-valent iron has been extensively documented. Recent research has suggested that as a remediation technique, nanoscale iron particles have several advantages: (1) effective for transformation of a large variety of environmental contaminants, (2) inexpensive, and (3) nontoxic. Recent laboratory research has largely established nanoscale iron particles as effective reductants and catalysts for a wide variety of common environmental contaminants including chlorinated organic compounds and metal ions. Examples are given in Table 3.

Rapid and complete dechlorination of all chlorinated contaminants can be achieved within the water and soil-water slurries. For example, with a nanoscale Pd/Fe particle dose at 6.25 gL-1, all chlorinated compounds were reduced to below detectable limits. Ethane was the major product in all tests. Greater than 99% removal was achieved with nanoscale iron particle in 24 h. Some pesticides that are persistent in aerobic environments are more readily degraded under reducing conditions. One application of this technique uses zerovalent iron (ZVI) as a chemical reductant. Under aerobic conditions, oxygen is the usual electron acceptor, while in anaerobic environment, electron release from the reaction of ZVI with water can be coupled to the reaction of chlorinated and nitroaromatic compounds.

Utilization of "magnetic" bacteria seems useful for metallic ion and heavy metal removal from aqueous solutions (e.g. Ag, Hg, Pb, Cu, Zn, Sb, Mn, Fe, As, Ni, Al, Pt, Pd and Ru). In the presence of magnetic ions such as iron sulphide, heavy metal precipitates onto bacterial cell walls, making the bacteria sufficiently magnetized for removal from suspension by magnetic separation procedure. Research has shown that certain bacteria could produce iron sulfonide, which would act as an adsorbent for several metallic ions. A novel concept was proposed to synthesize

Table 3. Common environmental contaminants that can be transformed by nanoscale iron particles

Chemicals	**Chemicals**
Chlorinated methanes	Trihalomethanes
Carbon tetrachloride (CCl_4)	Bromoform ($CHBr_3$)
Chloroform ($CHCl_3$)	Dibromochloromethane ($CHBr_2Cl$)
Dichloromethane (CH_2Cl_2)	Dichlorobromomethane ($CHBrCl_2$)
Chlorinated benzenes	**Chlorinated ethenes**
Tetrachlorobenzenes ($C_6H_2Cl_4$)	Tetrachloroethene (C_2Cl_4)
Trichlorobenzenes ($C_6H_3Cl_3$)	Trichloroethene (C_2HCl_3)
Dichlorobenzenes ($C_6H_4Cl_2$)	*cis*-Dichloroethene ($C_2H_2Cl_2$)
Chlorobenzene (C_6H_5Cl)	*trans*-Dichloroethene ($C_2H_2Cl_2$)
Pesticides	1,1-Dichloroethene ($C_2H_2Cl_2$)
DDT ($C_{14}H_9Cl_5$)	Vinyl chloride (C_2H_3Cl)
Lindane ($C_6H_6C_{l6}$)	**Other polychlorinated hydrocarbons**
Organic dyes	PCBs
Orange II ($C_{16}H_{11}N_2NaO_4S$)	Dioxins
Chrysoidine ($C_{12}H_{13}C_lN_4$)	Pentachlorophenol (C_6HCl_5O)
Tropaeolin O ($C_{12}H_9N_2NaO_5S$)	Other organic contaminants
Acid Orange	N-nitrosodimethylamine (NDMA) ($C_4H_{10}N_2O$)
Acid Red	TNT ($C_7H_5N_3O_6$)
Heavy metal ions	**Inorganic anions**
Mercury (Hg^{2+})	Dichromate ($Cr_2O_7^{-7}$)
Nickel (Ni^{2+})	Arsenic (AsO_3^{-4})
Silver (Ag^+)	Perchlorate (ClO^-_4)
Cadmium (Cd^{2+})	Nitrate (NO^-_3)

mesoporous magnetic nanocomposite particles. These particles could be used for the removal of harmful agents present in the environment. This new method employs molecular templates to coat nanoparticles of magnetite with mesoporous silica.

Detoxification of herbicide residues

Excessive use of herbicides leave residue in soil and cause damage to the succeeding crops. Continuous use of single herbicide leads to evolution of herbicide resistant weed species and shift in weed flora. Atrazine, an s-triazine-ring herbicide, is used globally for the control of pre- and post-emergence broadleaf and grassy weeds, which has high persistence (half life-125 days) and mobility in some types of soils. Residual problems due to the application of atrazine herbicide pose a threat towards widespread use of herbicide and limit the choice of crops in rotation. Recent finding from Tamil Nadu Agricultural University raises hope to remediate the atrazine residue from soil within a short span of time. Application of silver modified with nanoparticles of magnetite stabilized with Carboxy Methyl Cellulose (CMC) nanoparticles recorded 88% degradation of herbicide atrazine residue under controlled environment (Susha et al., 2009).

Nanotechnology solutions to climate change

Climate Change has emerged as one of the most serious environmental concerns of our times. Warming of the climate system is unequivocal, it could be observed from the increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global mean sea level. Most of the warming that has occurred over the last 50 years is very likely to have been caused by human activities. Besides climate forcing, human activities like burning of fossil fuels, agriculture and land-use changes like deforestation, animal agriculture, ozone depletion due to aerosols and cement manufacture are of major cause, act separately and in conjunction with other factors (Steinfeld et al.2006). To bring climate change to a halt, global greenhouse gas emissions must be reduced significantly.

Seldom single sector or technology can address the entire mitigation challenge. All sectors including buildings, industry, energy production, agriculture, transport, forestry, and waste management could contribute to the overall mitigation efforts, for instance through greater energy efficiency. Many technologies and processes which emit less greenhouse gases are already commercially available or will be in the coming decades (EUROPA, 2009).

One among the new approaches to combat the climate change is the Nanotechnology. Though as of now the nanotechnology is having any direct intervention, its incorporation into larger systems, such as the hydrogen based economy, solar power technology or next generation batteries, potentially could have a profound impact on energy consumption and greenhouse gas emissions (Oakdene Hollins, 2007)

Possible areas identified to intervene through nanotechnology to reduce harmful greenhouse gas emissions are: a) the development of hydrogen powered vehicles; b) enhanced and cheaper photovoltaics or solar power technology; c) new generation of batteries and super capacitors; d) improved insulation of buildings; and e) fuel additives to enhance the energy efficiency of motor vehicles. These technologies are being developed elsewhere in the world contemporarily to reduce the dependence on fossil fuels and consequently begin the process of decoupling carbon dioxide emissions from energy. In addition, these technologies are likely to have a positive impact in reducing the concentrations of NOx and SOx in the atmosphere by reducing the quantity of fossil fuels used in the generation of electricity.

For electricity generation, hydrogen fuel cell is an efficient, non polluting source. Hydrogen Solar Ltd. of United Kingdom has developed Tandem Cell™ technology for the generation of hydrogen fuel using solar energy with zero carbon emissions (Anonymous, 2009).

Besides hydrogen fuel cell, yet another technology which converts solar energy, renewable, unlimited source of emission free, to electricity is photovoltaic technologies. Nanotechnology is widely used in current R&D in photovoltaics. Some of the main areas of research include: nanoparticle silicon systems; use of non-silicon materials such as calcopyrites to develop thin film technology; molecular organic solar cells; organic polymer photovoltaic systems and III-V nitride solar cells (Oakdene Hollins, 2007).

Several different types of photovoltaic panels available in the market are highly expensive and have limited period of life time. Attempts are being made to circumvent this problem through nano technological approach. One such approach attracted considerable attention is the so called Crystalline Silicon on Glass and use of alternate materials such as cadmium telluride.

Next important area which could alleviate the climate change is energy storage. The next generation batteries, more relevant to climate change will be more suitable for use in electric cars and other vehicles, is being attempted using nanotechnology. The Automobile companies, Nissan, Mitsubishi and Sanyo are involved in the development of next generation batteries like lithium ion and nickel metal hydride batteries having more capacity of those already used in hybrid electric vehicles. Nissan has recently developed a new laminated lithium-ion battery for electric vehicles (Autobloggreen, 2007). According to Nissan, it is the same size as a conventional car battery but has double the capacity (140Wh/kg) and 1.5 times the power even after 100,000 kilometers usage over five years. The result is double the driving distance, achieved with no increase in battery load.

Nanonmaterials and substances are currently being developed to improve the fuel efficiency of conventional fossil fuel engines and turbines. Fuel and lubricant additives are near or at market solutions that can deliver small but globally significant carbon savings and emissions reductions through use in conventional engine systems without modification. It is estimated that nanotechnology can deliver 7 % improvement in fuel consumption and pollution emissions across the two applications with greatest improvements in diesel engine fuel consumption and emissions.

Besides generation and storage of energy, saving and effective utilization have tremendous scope for reversing the climate change in future. One such approach is insulation of building located in the extreme weather conditions. Cavity and loft insulation are cheap and effective, however, there are no easy methods for insulating solid walled buildings. Nanotechnology may provide a solution which, if an effective insulation could be found with similar properties to standard cavity insulation. Improving well-being in buildings, in relation to energy conservation, represents a great challenge. In countries like Southern Italy a basic problem is that of keeping buildings cool in the summer months. This problem affects not only newly-erected buildings, but also the large number of existing buildings, some of which are of historical importance. Nano-technology represents an excellent opportunity to harness the salvage of existing buildings to the living requirements of contemporary society. The use of nano-structured materials like paintings, cement, tiles, floorings, etc., in newly-erected buildings will lead to improved performance and a considerable saving of energy (Zdenìk Bittnar et al 2009). Hence, there are possibilities to reduce the green gas emission through nanotechnology solutions to the tune of 18-20 per cent by 2050.

Conclusion

The emerging new science and enabling technology, working with the smallest particle, the nanotechnology raises hope for new innovations in the field biology, especially in agriculture. Many unsolved and bottle necks in the field of life sciences and agriculture could be addressed through this technology. More focused research is required in the area of energy, environment, crop improvement, disease management and efficient resource utilization for increasing the productivity, profit, without hampering the natural ecosystem.

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