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Applications of Nanotechnology in Agriculture: An Overview

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AGRICULTURE provides food for humans, directly and indirectly. Given the increasing world population, it is necessary to use the modern technologies such as nanotechnology in agricultural sciences. Nanotechnology has been defined as relating to materials, systems and processes which operate at a scale of 100 nanometers (nm) or less. Nanotechnology has many applications in all stages of production, processing, storing, packaging and transport of agricultural products. Nanotechnology will revolutionize agriculture and food industry by innovation of new techniques such as: precision farming techniques, enhancing the ability of plants to absorb nutrients, more efficient and targeted use of inputs, disease detection and control diseases, withstand environmental pressures and effective systems for processing, storage and packaging, 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. Nanoherbicides are being developed to address the problems in perennial weed management and exhausting weed seed bank. Efficiency of medicine increases by use of nano particle in animal sciences. Silver and iron nano particles are used in the treatment and disinfection of livestock and poultry. Levels of environment pollution can be evaluated quickly by nano smart dust and gas sensors.

Keywords: Nanotechnology, Agriculture, Food quality, Nanofertilizers, Nanoherbicides, Nanopesticides, Nanopolymers, Smart seeds, Biosensors, Environment, Climate Change.

Growth of the agricultural sector as a context for development objectives is seen as essential in developing countries. Now, after years of green revolution and decline in the agricultural products ratio to world population growth, it is obvious the necessity of employing new technologies in the agriculture industry more than ever. Modern technologies such as bio and nanotechnologies can play an important role in increasing production and improving the quality of food produced by farmers.

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Many believe that modern technologies will secure growing world food needs as well as deliver a huge range of environmental, health and economic advantages (Wheeler, 2005). Food security has always been the biggest concern of the mankind. Nations, communities and governments have been struggling with the issue since long. Recent decades have seen even bigger challenges on this front. The future looks even bleaker with food shortage issue looming large. The challenge is how to feed the growing population by producing more on a stagnant or shrinking landscape; with lesser input costs and with lesser hazards to the eco-system (Anonymous, 2009).

Nanotechnology as a powerful technology allows us to have a look at the atomic and molecular level, and to be able to create nanometer-scale structures. Nanotechnology in agriculture and food production, causing the agricultural land returned to its normal position, greenhouse construction with high performance and productivity, prevent extinction and destruction of plants and animals species, and overall nanotechnology provides the efficiency of the agriculture for higher population. In the agricultural sector, nanotechnology 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 (Mousavi and Rezaei, 2011).

In recent decades, agricultural land and soil pollution with hazardous elements and compounds present in industrial and urban wastewater are the most important factors limiting crop and food production in the world. Nano structured catalysts are able to eliminate the harmful components of agricultural ecosystems safely. This topic is important in point of view of physiological plant diseases; eliminate food poisoning, organic products and finally production of healthier products. This nanotechnology application will help to reduce pollution and to make agriculture more environmentally friendly with use of nano filters for industrial waste water treatment, nano powders for gas pollutants treatment, and nano tubes for storage clean hydrogen fuel (Anonymous, 2009). The relationship between nanotechnology and agricultural sciences can be investigated in the following fields.

What is nanotechnology science?

Nanotechnology is an interdisciplinary field that has been entered in different range of applied sciences such as chemistry, physics, biology, medicine and engineering. Targeted research and development, for understand, manipulate and measure at the materials with atomic, molecular and super molecules dimensions is called nanotechnology. In other words, nanotechnology is the manipulation or self-assembly of individual atoms, molecules, or molecular clusters into structures to create materials and devices with new or vastly different properties. Nanotechnology can work from the top down (which means reducing the size of the smallest structures to the nanoscale, *e.g*. photonics applications in nano electronics and nano engineering) or the bottom up (which involves manipulating individual atoms and molecules into nanostructures and more closely resembles chemistry or biology).

A nanometer is one billionth of a meter. Overall nano refers to a size scale between 1 nanometer (nm) and 100 nm in at least one dimension, and involves developing or modifying materials or devices within that size. In more technical terms, the word "nano" means 10^{-9}, or one billionth of something. For comparison, the wavelength of visible light is between 400 nm and 700 nm. A leukocyte has the size of 10000 nm, a bacteria 1000-10000 nm, virus 75-100 nm, protein 5-50 nm, glucose 1nm, deoxyribonucleic acid (DNA) ~2 nm (width), and an atom ~0.1 nm, (Fig.1). In this scale, physical, biological and chemical characteristics of materials are fundamentally different from each other and often unexpected actions are seen from them. Nanotechnology considers the topics with viruses and other pathogens scale. So it has high potential to identify and eliminate pathogens (Prasanna, 2007 and Predicala, 2009). Recently, nano molecules obtained by nanotechnology; there is possibility manipulation on nano scale level, regulate and catalyzed on chemical reactions by these structures. Nano materials are composed of components with very small size, and these components have impacts on the properties of materials at the macro level. Nano particles can serve as 'magic bullets', containing herbicides, chemicals, or genes, which target particular plant parts to release their content. Nano capsules enable effective penetration of herbicides through cuticles and tissues, allowing slow and constant release of the active substances. This convergence of technology with biology at the nano level is called nano biotechnology (Perea-de-Lugue and Rubiales, 2009).

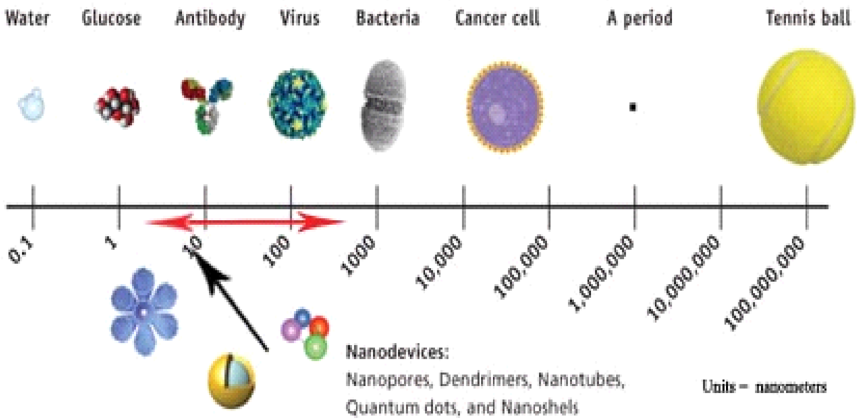

Fig. 1. Nanoscale science and engineering for agriculture and food systems.

Applications of nanotechnology in agriculture

Nanotechnology has the potential to revolutionize the agricultural and food industry 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. An agricultural methodology widely used in the USA, Europe and Japan, which efficiently utilizes modern technology for crop management, is called Controlled Environment Agriculture (CEA). CEA is an advanced and intensive form of hydroponically-based agriculture. Plants are grown within a controlled environment so that horticultural practices can be optimized. The computerized system monitors and regulates localized environments such as fields of crops. CEA technology, as it exists today, provides an excellent platform for the introduction of nanotechnology to agriculture. With many of the monitoring and control systems already in place, nanotechnological devices for CEA that provide “scouting” capabilities could tremendously improve the grower’s ability to determine the best time of harvest for the crop, the vitality of the crop, and food security issues, such as microbial or chemical contamination (Allah Ditta, 2012).

1- Precision farming

Precision farming 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 farming 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. One of the major roles for nanotechnology-enabled devices will be the increased use of autonomous sensors linked into a global positioning system (GPS) for real-time monitoring. These nano sensors 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, For example:

- Nano sensors utilizing carbon nano tubes or nano-cantilevers are small enough to trap and measure individual proteins or even small molecules.
- Nano particles or nano surfaces can be engineered to trigger an electrical or chemical signal in the presence of a contaminant such as bacteria.

• Other nano sensors work by triggering an enzymatic reaction or by using nano engineered branching molecules called dendrites as probes to bind to target chemical sand proteins (Tiju and Morrison, 2006).

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.

2-Applications of nanotechnology in agronomy

As mentioned before, precision agriculture is a new attitude in farm management. With use of nano sensors every small part of a farm needs to fertilizer and chemical pesticides will be determined. Therefore, use of inputs will be optimal and safe products and economic efficiency are increased. Nano sensors help farmers in maintaining farm with precise control and reporting timely needs of plants. Nano sensors and nano-based smart delivery systems could help in the efficient use of agricultural natural resources like water, nutrients and chemicals through precision farming. Through the use of nano materials and global positioning system (GPS) with satellite imaging of fields, farm managers could remotely detect crop pests or evidence of stress such as drought. Once pest or drought is detected, there would be automatic adjustment of pesticide applications or irrigation levels. Nano sensors dispersed in the field can also detect the presence of plant viruses and the level of soil nutrients. Nano fertilizers will be absorbed by plants rapidly and completely. Nano encapsulated slow release fertilizers have also become a trend to save fertilizer consumption and to minimize environmental pollution. 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. Coating and cementing of nano and subnano-composites are capable of regulating the release of nutrients from the fertilizer capsule (Liu *et al.* 2006). A patented nano-composite consists of N, P, K, micronutrients and amino acids that increase the uptake and utilization of nutrients by grain crops has been reported (Jinghua, 2004). Research on the controlled release pattern of 22 nutrients using clay nano particle is now undertaken. Super water adsorbents made by nanotechnology, have an important role in storage and protecting water in arid and semiarid regions. Nanotechnology has many applications in the field of agricultural machinery such as: application in machines structure and agriculture tools to increase their resistance against wear and corrosion and ultraviolet rays; producing strong mechanical components with use of nano coating and use of bio sensors in smart machines for mechanical-chemical weed control; production nano cover for bearings to reduce friction, and use of nanotechnology in production of alternative fuels and reduce environmental pollution. Nanotechnology has also shown its ability in modifying the genetic constitution of the crop plants thereby helping in further improvement of crop plants (Jones, 2006 and DeRosa *et al*., 2010).

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 Sivasubramaniam, 2007). Coating seeds with nano membrane, which senses the availability of water and allows seeds to imbibe only when time is right for germination, aerial broadcasting of seeds embedded with magnetic particle, detecting the moisture content during storage to take appropriate measure to reduce the damage and use of bio analytical nano sensors to determine ageing of seeds are some possible thrust areas of research. Siddiqui and Al-Whaibi (2013) reported that application of nanosilicon dioxide ($nSiO_2$: size 12 nm) significantly enhanced the characteristics of tomato seed germination.

3-Applications of nanotechnology in pests and plant diseases management

Today use of chemicals such as pesticides, fungicides and herbicides is the fastest and cheapest way to control pests and diseases. Uncontrolled use of pesticides has caused many problems such as: adverse effects on human health, adverse effects on pollinating insects and domestic animals, and entering this material into the soil and water and its direct and indirect effect on ecosystems. Intelligent use of chemicals on the nano scale can be a suitable solution for this problem. These materials are used into the part of plant that was attacked by disease or pest. Also, these carriers in nano scale has self-regulation, this means that the medication on the required amount only be delivered into plant tissue. Using nano particles and nano capsules of pesticides is more effective and environmentally friendly; and production of nano crystals to increase the efficiency of pesticides for application with lower dose. Nano particles for delivery of active ingredients or drug molecules will be at its helm in near future for therapy of all pathological sufferings of plants. There are myriad of nano materials including polymeric nano particles, iron oxide nano particles and gold nano particles which can be easily synthesized and exploited as pesticide or drug delivery piggybacks (Sharon *et al.* 2010). Rouhani *et al.* (2012) studied the effect of Ag and Ag-Zn nano particles as insecticides with different concentrations on *APhis nerii*. The result showed that Ag nano particles can be used as a valuable tool in pest management programs of *A. nerii*. Additionally, the study showed that imidacloprid at 1 $\mu L\ mL^{-1}$ and nano particles at 700 mg ml^{-1} had the highest insect mortality effect. Bhagat *et al.* (2013) prepared a nanogel from a pheromone, methyl eugenol (ME) using a low-molecular mass gelator. It has a significant potential for crop protection, long lasting residual activity, excellent efficacy, favorable safety profiles and well-suited for pest management in a variety of crops. Rao and Paria (2013) used sulfur nano particles (SNPs) as a green pesticide on *Fusarium solani* and *Venturia inaequalis* phytopathogens. It has been found that small sized particles of SNP

(~35 nm) are very effective in preventing the fungal growth and can be useful for the protection of important crops such as tomato, potato, apple, grape etc., from different diseases, mainly for ‘‘organic’’ farming.

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 release of encapsulated herbicides is expected to take care of the competing weeds with crops, (Fig. 2), (Chinnamuthu and Murugesa Boopathi, 2009).

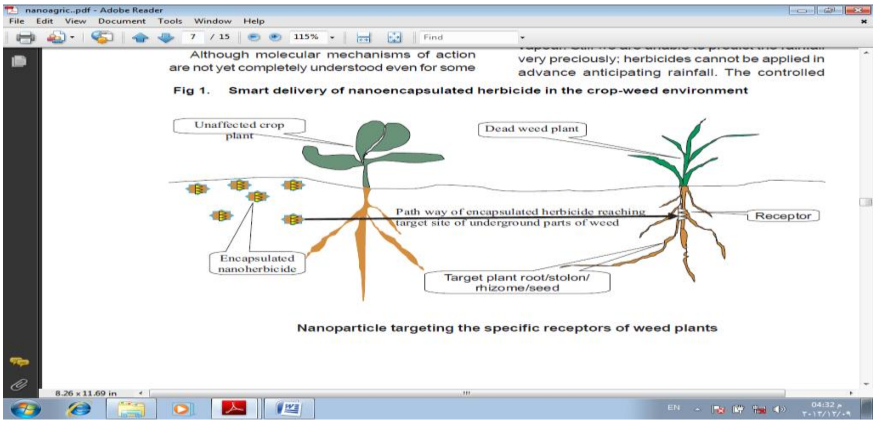

Fig. 2. Smart delivery of nanoencapsulated herbicide in the crop-weed environment.

Diseases are one of the major factors limiting crop productivity. The problem with the disease management lies with the detection of the exact stage of prevention. Most of the times pesticides are applied as a precautionary manner leading to the residual toxicity and environmental hazards and on the other hand application of pesticides after the appearance of disease leads to some amount of crop losses. Among the different diseases, the viral diseases are the most difficult to control, as one has to stop the spread of the disease by the vectors. But, once it starts showing its symptoms, pesticide application would not be of much use. Therefore, detection of exact stage such as stage of viral DNA replication or the production of initial viral protein is the key to the success of control of diseases particularly viral diseases. 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 of some therapeutic to stop the disease. Detection and utilization of biomarkers that accurately indicate disease stages are also a new area of research. Measuring differential protein production in both healthy and diseased states leads 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 (Prasanna, 2007). In the future, nano scale devices with novel properties could be used to make agricultural systems “smart”. For example, devices could be used to identify plant health issues before 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 in the same way as nano medicine has implications for drug delivery in humans. Nano medicine developments are now beginning to allow us to treat different diseases such as cancer in animals with high precision, and targeted delivery (to specific tissues and organs) has become highly successful (Joseph and Morrison, 2006).

4-Applications of nanotechnology in food industry

Oxygen is a problematic factor in food packaging, because it can cause food spoilage and discoloration. One of the applications of nanotechnology in the food industry is developing new plastic for food packaging industry. The nano particles are used in the production of these plastics. Nano particles have been found to zigzag in the new plastic, and prevent the penetration of oxygen as a barrier. In other words, the oxygen for entry into package should take longer route, and hence with the long route for oxygen molecules, food can be spoiled later. Polymer-silicate nano composites 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. Recently, nano-coatings are produced for fruit that cover the fruits completely, and prevent fruit weight loss and shrinkage. (Predicala, 2009). Developing smart packaging to optimize product shelf-life has been the goal of many companies. Such packaging systems would be able to repair small holes/tears, respond to environmental conditions (*e.g*. temperature and moisture changes), and alert the customer if the food is contaminated. Nanotechnology can provide solutions for these, for example modifying the permeation behavior of foils, increasing barrier properties (mechanical, thermal, chemical, and microbial), improving mechanical and heat-resistance properties, developing active antimicrobic and antifungal surfaces, and sensing as well as signaling microbiological and biochemical changes (Moraru *et al.* 2003 and Joseph & Morrison, 2006).

Duncan (2011) reviewed that silver nano particles could be used as potent antimicrobial agents, and nano sensors and nano material-based assays for the detection of food relevant analytes (gasses, small organic molecules and food-borne pathogens). In addition, with coating the enzymes by nanotechnology, we can keep them away of environment and prevent of working them. Thus, the nutrients corruption will be postponed and their longevity increases. Ethylene absorbent is the most important material that is produced by nanotechnology. Absorbent ethylene nano materials, absorb ethylene gas that is produced by fruits (fruit decay increases by ethylene gas) and increase persistence of fruit for long periods. Nano barcodes and nano processing could also be used to monitor the quality of agricultural products. 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 that then 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. When the substance binds with the biological component, the transducer produces a signal proportional to the quantity of the substance. So if there is a large concentration of bacteria in a particular food, the biosensor will produce a strong signal indicating that the food is unsafe to eat. With this technology, mass amounts of food can be readily checked for their safety of consumption (Johnson, 2005).

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 cochleae delivery system protects these substances from degradation. Bio Delivery Sciences International have developed nano cochleae, which are 50 nm coiled nano particles 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 (Chinnamuthu and Murugesa Boopathi, 2009).

5-Applications of nanotechnology in animal science

Nanotechnology will have a potential and ability on future approaches in veterinary and treatment of domesticated animals. Nanotechnology has the ability to provide appropriate solutions for providing food items, veterinary care and prescription medicines and vaccines for domesticated animals. Use of nano capsules for cap and protection of some particular enzymes and proteins would be effective in the livestock and poultry food rations in order to increase yield and effectiveness in the specific context. Taking certain medications such as antibiotics, vaccines, and probiotics, would be more effective in treating infections, nutritional and metabolic disorders, when used in the nano level. Medicine use is in the nano level has multilateral properties to remove biological barriers to increase efficiency of medicine. Appropriate timing for the release of drug, self-regulatory capabilities and capacity planned are the main advantagous uses of nanotechnology in the drug treatment. Silver nano particles have been considered as a strong antiseptic (antibacterial and antimicrobial), and it's widely used for disinfection in the livestock and poultry places. In the cancer treatment, nano particles are connected to the membrane receptors cancer cells, and cancer cells are destroyed with increasing their temperature to 55 °C by infrared waves generated by the nano particles. Also, iron nano particles destroy cancer cells by creating magnetic radiation. Breeding suitable time and cross management in livestock, requires cost and long time in dairy cattle farms. Use of nano-tubes inside the skin of the livestock shows peak real-time of estrus and estrogen hormone, and the exact and actual time insemination (Scott, 2005, Patil *et al*., 2009 and Chakravarthi & Balaji, 2010).

Nano-particles for environmental remediation

Nanoscience and nanotechnology have the potential to produce major impacts on the environment. Nano scale particles represent a new generation of environmental remediation technologies that could provide cost-effective solution to some of the most challenging environmental cleanup problems. Nano scale iron particles have large surface areas and high surface reactivity. Equally important, they provide enormous flexibility for in situ applications. The environmental chemistry of metallic or zero-valent iron has been extensively documented. Recent research has suggested that as a remediation technique, nano scale iron particles have several advantages: (1) effective for transformation of a large variety of environmental contaminants, (2) inexpensive, and (3) nontoxic. Al-Zawi *et al.* (2013) reported that nanotechnology offers a number of emerging techniques much more effective and less costly that could work to immobilize contaminants. They used nano particles; nano scale zero valent iron “nZVI”, nZVI-bentonite, nano-alginite, nano-carbon, bentonite and dendrimers; to eliminate Cd and Pb from polluted soil. The prepared nano particles proved to have very small size (less than 70 nm), high surface area and cation exchange capacity ranged from 155-257 m^2g^1, and 30.3-60.7 $Cmol_ckg^{-1}$, respectively. Also, the prepared nano particles proved high adsorption capacity for Pb and Cd, and high retention for adsorbed metal. The maximum adsorption capacity of nano particles ranged from 3954-25974 and 1598-93458 $mgkg^{-1}$ for Pb and Cd, respectively. That is beside; only small quantities (9.3-20% and 0.4-23%) were released from the previously adsorbed ones.

Recent laboratory research has largely established nano scale iron particles as effective reductants and catalysts for a wide variety of common environmental contaminants including chlorinated organic compounds and metal ions. Rapid and complete de-chlorination of all chlorinated contaminants can be achieved within the water and soil-water slurries. For example, with a nano scale 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 nano scale iron particle in 24 hr. Some pesticides that are persistent in aerobic environments are more readily degraded under reducing conditions. One application of this technique uses zero-valent iron (ZVI) as a chemical reductant. Under aerobic conditions, oxygen is the usual electron acceptor, while in anaerobic environment; electron releases from the reaction of ZVI with water can be coupled to the reaction of chlorinated and nitro-aromatic 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 mesoporous magnetic nano composite particles. These particles could be used for the removal of harmful agents present in the environment. This new method employs molecular templates to coat nano particles of magnetite with mesoporous silica. Also, nano smart dust and gas sensors are used in determining the amount of pollutants and dust in the air. It is possible to evaluate the presence of pollutants in the environment by the sensors (that are made by nano technology) in few minutes (Scott and Chen, 2003).

Nano-fibers: When hydrophobic organic pollutants enter the soil through water, they are easily absorbed by the water insoluble solids. Porous nano-polymers are very similar to the pollutants molecules, and are considered the most suitable means for separating organic pollutants of soil and water. Similar nano fiber-based fabrics are being used as a detection technology platform to capture and isolate pathogens. The nano fibers in this fabric are embedded with antibodies against specific pathogens. The fabric can be wiped across a surface and tested to determine whether the pathogens are present, perhaps indicating their presence by a change in colour (Hager, 2011).

Nano-filtration: Due to the big demand for freshwater in the world, developing new methods is essential for producing freshwater. The use of nano particles and nano-filtration provides possibility of refining and improving water with speed and accuracy. Also, nano-filter has a widespread application in eliminating microbial contaminants of water. In the new method for water desalination, hot saltwater passes on thin sheets of carbon nano tube membranes, that have small holes (nano-holes). Only the steam passes through these holes and liquid of water, salts and other minerals remain in the membrane. Cold water containers are located in the other side of membrane, that steam is converted to liquid again with passing through it. The most important features of carbon nano tubes can include: smaller and denser holes; allowing high flow rate passing each hole (Thorsen and Flogstad, 2006). In the processing of dairy products nano-filters are also used. Nano-filters provide selective passing particles. Also, nano-filtration is used to detect metabolites quality control in food industry and pathogenic factors, and is a major change in food packaging and storage (Yacubowicz and Yacubowicz, 2007). Bunani *et al.* (2013) studied the application of nano-filtration for reuse of municipal wastewater and quality analysis of product water. Oatley-Radcliffe *et al.* (2013) studied the practice of nano-filtration modelling strategies for seawater desalination and further insights on dielectric exclusion.

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 28 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. 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 (Oakdene Hollins, 2007). 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 (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: nano particle 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 next generation batteries like lithium ion and nickel metal hydride batteries having more capacity than those already used in hybrid electric vehicles (Autobloggreen, 2007).

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 wellbeing 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. Nanotechnology 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 percent by 2050.

Now, the most important environmental issue is to reduce green house gases in order to prevent the climate changes, where carbon dioxide (CO_2) is the major contributor. In this regard, CO_2 capture and utilization using solid adsorbents, in large scales, attain greater attention among the scientific community. Tamilarasan and Ramaprabhu (2012) developed polyaniline/ magnetite nano capsules (PANI/MNCs) nano composite for CO_2 capture at high pressures. PANI/MNCs nano composite shows fast sorption kinetics (~42 mmol/g within 90 min at 28 ◦C) along with a high sorption capacity (47.5 mmol/g with 12 bar pressure at 28 ◦C) as a consequence of physical and chemical interaction with CO_2 molecules.

Perceived risks and benefits of nanotechnology

Siegrist *et al.* (2008) reported that to avoid some of the problems GM technology was faced with, it will be important to take public views of nanotechnology foods into account at an early stage of product development. It is the goal of this study to identify food applications that are more likely, and food applications that are less likely, to be accepted by the public. An additional goal is to examine general factors that may be important for public acceptance of nanotechnology foods (Table 1).

The risks could be practically zero or they could be significant, depending on the properties of a particular product and exposure levels. For the most part, no one knows. Few risk assessments have been done that allow one to predict what happens when these very small materials, some designed to be biologically active, enter the human body or are dispersed in the environment. A recent analysis of nanotechnology-related environmental, health, and safety research, done by the Project on Emerging Nanotechnologies, could find no research on the impact of nano-materials on the gastrointestinal tract, though this will be of primary concern for food applications (Kuzma and VerHage, 2006).

TABLE 1 Percived risks and benefits (mean and S.D.)

Applications	Risk		Benefit	
	M	S.D.	*M*	S.D.
Individually modifiable foods	4.00	1.11	2.13	1.19
Health-promoting feed and forage	3.57	1.27	2.75	1.22
Nutritional supplement capsules	3.50	1.25	2.49	1.23
Bacteria-fighting poultry feed	3.47	1.22	2.79	1.25
Cancer-preventing supplement	3.41	1.25	2.97	1.35
Bread with higher nutritional value	3.35	1.35	2.65	1.33
Toxin remover for soil	3.34	1.20	2.89	1.28
Antibacterial milk bottle for babies	3.26	1.24	2.57	1.27
Bacteria detection spray	3.01	1.23	2.84	1.32
Decay-inhibiting film	2.74	1.23	3.15	1.28
Antibacterial food container	2.67	1.23	3.03	1.28
Oxygen-absorbing film	2.64	1.20	3.00	1.18
Health-promoting green tea	2.59	1.35	2.66	1.35
Oxygen-blocking plastic bottle	2.57	1.27	2.90	1.30
Salmonella detector	2.56	1.25	3.27	1.31
Non-stick coating	2.54	1.27	3.19	1.25
Stronger packaging film	2.50	1.24	3.26	1.27
UV-protection packaging	2.34	1.27	3.14	1.20
Barcodes for guaranteed food security	2.31	1.23	3.33	1.32

Note: The question was ‘‘How beneficial (risky) do you consider each of the following applications to be for Swiss society as a whole?’’ The endpoints of the 5- point scales were labelled ‘‘very low’’ (1) and ‘‘very high’’ (5), (Siegrist *et al.,* 2008).

It is important to recognize, however, that as new particles and applications are developed, and as more information becomes available on fate and behavior, routes of uptake and entry into the atmosphere, these predictions may change. Moreover, the nano materials once entered in the environment have the potential to accumulate in the environmental organisms. In accordance with the exposure routes resulting from production, processing and use, the fate of the starting products of nano scale substances and their transformation products must be followed (life-cycle analyses, exposure scenarios) and measured in the target compartments. Several steps must be followed: identification of the nano particles that are persistent and accumulate in the environment through suitable measurement methods for the identification in water, soil and sediment; analysis of the behavior of the nano materials after use, during disposal, land filling, incineration or reutilization; testing of ecotoxicity during the entire life. A crucial factor for the determination of a risk of exposure to nano materials is the stability of these nano particles; in particular it should therefore be examined how stable and long-lived these forms are, whether and under which conditions undergo modifications, upon entry into the environment (Bradley *et al.*, 2011, Silvestre *et al.*, 2011 and Cushen *et al.,* 2012).

Future applications:

- 2011-2015 – nanobiomaterials, microprocessors, new catalysts, portable energy cells, solar cells, tissue/organ regeneration, smart implants.

- 2016 and beyond – molecular circuitry, quantum computing, new materials, fast chemical analyses.

References

Allah Ditta (2012) How helpful is nanotechnology in agriculture. Advances in natural sciences: Nanosci.andNanotechnol.3: 033002 (10pp) Online at stacks.iop.org/ANSN/ 3/033002.

Al-Zawi, A.M., Hela, M.I. and Khater, H.A. (2013) Application of nanotechnology in remediation of heavy metals polluted soil: I- Preparation and characterization of nanoparticles. *The First International Conference of National Research Center "Food and Agriculture: New Approaches" 2-4 December, Cairo*, Egypt.

Anonymous (2009) Nanotechnology and nano science applications: revolution in India and beyond. Strategic Applications Integrating Nano Science, www.sainsce.com.

Autobloggreen (2007) Mitsubishi-forms-jv-with-gsyuasa-to-build-lithium-ionbatteries. http://www.autobloggreen.com/2007/05/08/

Bhagat, Deepa, Suman K. Samanta and Santanu Bhattacharya (2013) Efficient management of fruit pests by pheromone nanogels. *Sci. Rep*., **3**, 1294-1302.

Bradley, E.L., Castle L. and Chaudhry, Q. (2011) Applications of nanomaterials in food packaging with a consideration of opportunities for developing countries. *Trends in Food Science & Technology*, **22**, 604-610.

Bunani, S.; Yörükoğlu; E. G. Sert; Yüksel; Ü. Yüksel, M. and Kabay, N. (2013) Application of nanofiltration for reuse of municipal wastewater and quality analysis of product water. *Desalination*, **315**, 33–36.

Chakravarthi, P.V. and Balaji, N.S. (2010) Applications of nanotechnology in veterinary medicine. *Veterinary World*, **3** (10), 477-480.

Chinnamuthu, C.R. and Murugesa Boopathi, P. (2009) Nanotechnology and Agroecosystem. *Madras Agric. J*., **96** (1-6), 17-31.

Cushen, M., Kerry, J., Morris, M., Cruz-Romero, M. and Cummins. E. (2012) Nanotechnologies in the food industry – Recent developments, risks and regulation. *Trends in Food Science & Technology*, **24**, 30-46.

DeRosa, M.C., Monreal, C., Schnitzer, M., Walsh, R. and Sultan, Y. (2010) Nanotechnology in fertilizers. *Nature Nanotechnology*, **5**, 91.

Duncan, T.V. (2011) Applications of nanotechnology in food packaging and food safety: Barrier materials, antimicrobials and sensors. *Journal of Colloid and Interface Science*, **363**, 1-24.

Europa. (2009) Climate Change. http://ec.europa.eu/environment/climat/home_en.htm**.**

Hager, H. (2011) Nanotechnology in agriculture. http://www.topcropmanager.com.

Jinghua, G. (2004) Synchrotron radiation, soft X-ray spectroscopy and nano-materials. *J. Nanotechnol*., **1**, 193-225.

Johnson, A. (2005) *Agriculture and Nanotechnology*. University of Wisconsin-Madison.

Jones, P. (2006) A nanotech revolution in agriculture and the food industry. *Information Systems for Biotechnology*. http://www.isb.vt.edu/articles/jun0605.htm.

Joseph, T. and Morrison. M. (2006) *Nanotechnology in Agriculture and Food. A Nanoforum Report*, Institute of Nanotechnology May 2006, www.nanoforum.org.

Kuzma, J. and VerHage, P. (2006) Nanotechnology in agriculture and food production. Project on emerging nanotechnologies.

Liu, X., Feng, Z., Zhang, S., Zhang, J., Xiao, Q. and Wang. Y. (2006) Preparation and testing of cementing nano-subnano composites of slower controlled release of fertilizers. *Scientia Agricultura Sinica,* **39**, 1598-1604.

Moraru, C.I., Panchapakesan, C.P., Huang, Q., Takhistov, P., Liu, S. and Kokini, J.L. (2003) Nanotechnology: a new frontier in food science. *Food Technology*, **57** (12), 24-29.

Mousavi, S.R. and Rezaei. M. (2011) Nanotechnology in agriculture and food production. *J. Appl. Environ. Biol. Sci*., **1**(10), 414-419. *Nanotechnol*., **1**, 193-225**.**

Natarajan, N. and Sivasubramaniam, K. (2007) Nanotechnology application in seed management. *In Application of Nanotechnology in Agriculture*, C.R. Chinnamuthu, B. Chandrasekaran, and C. Ramasamy (Ed.), Tamil Nadu Agricultural University, Coimbatore, India.

Oakdene Hollins. (2007) Environmentally Beneficial Nanotechnologies,48. http://www.defra.gov.uk/environment/nanotech/policy/pdf/envbeneficialreport. Pdf

Oatley-Radcliffe, D.L., Williams, S.R., Barrow, M.S. and Williams. P.M. (2013) Critical appraisal of current nanofiltration modelling strategies for seawater desalination and further insights on dielectric exclusion. *Desalination*, Article in press.

Patil, S.S., Kore1, K.B. and Kumar, P. (2009) Nanotechnology and its applications in veterinary and animal science. *Veterinary World,* **2**(12), 475-477.

Perea-de-Lugue, A. and Rubiales. D. (2009) Nanotechnology for parasitic plant control. *Pest Management Science Journal*, **65**, 540-545.

Prasanna, B.M. (2007) *Nanotechnology in agriculture*. ICAR National Fellow, Division of Genetics, I.A.R.I., New Delhi–110012.

Predicala, B. (2009) *Nanotechnology: potential for agriculture*. Prairie Swine Centre Inc., University of Saskatchewan, Saskatoon, SK, 123-134.

Rao, K. Jagajjanani and Santanu Paria. (2013) Use of sulfur nanoparticles as a green pesticide on *Fusarium solani* and *Venturia inaequalis* phytopathogens. *RSC Adv*., **3**, 10471–10478.

Rouhani, Mohammad, Samih, M. A. and Salma Kalantari (2012) Insecticide effect of silver and zinc nanoparticles against *Aphis nerii* boyer de fonscolombe (hemiptera: aphididae). *Chilean Journal of Agricultural Research*, **72**, 590-594.

Scott, N. and Chen, H. (2003) Nanoscale science and engineering for agriculture and food systems. A report submitted to cooperative state research, education and extension service, USDA, *National Planning Workshop, Washington*.

Scott, N.R. (2005) Nanotechnology and animal health. Revue scientifique et technique. *International Office of Epizootics*, **24**, 425-432.

Sharon, M., Choudhary, A.K. and Kumar. R. (2010) Nanotechnology in agricultural diseases and food safety. *Journal of Phytology*, **2**(4), 83-92.

Siddiqui, M.H. and Al-Whaibi, M.H. (2013) Role of nano-SiO_2 in germination of tomato (*Lycopersicum esculentum* seeds Mill.). *Saudi J. Biol. Sci*., Article in press.

Siegrist, M., Orlow, P. and Keller, C. (2008) The effect of graphical and numerical presentation of hypothetical prenatal diagnosis results on risk perception. *Medical Decision Making*, **28**, 567–574.

Silvestre, Clara, Donatella Duraccio and Sossio Cimmino. (2011) Food packaging based on polymer nanomaterials. *Progress in Polymer Science*, **36**, 1766–1782.

Steinfeld, H.P., Gerber, T., Wassenaar, V., Castel, M. and de Haan Rosales, C. (2006) Livestock's long shadow.http://www.virtualcentre.org/en/library/key_pub/ longshad/ A0701E00.htm.

Tamilarasan, P. and Sundara Ramaprabhu (2012) Polyaniline–magnetite nanocapsules based nanocomposite for carbon dioxide adsorption. *International Journal of Greenhouse Gas Control*, **10**, 486–493.

Thorsen, T. and Flogstad, H. (2006) Nanofiltration in drinking water treatment. Literature Review, *TECHNEAU*.

Tiju, J. and Morrison, M. (2006) Nanotechnology in agriculture and food. *A Nanoforumreport*, available from, www.nanoforum.org.

Wheeler, S. (2005) Factors influencing agricultural professionals' attitudes toward organic agriculture and biotechnology. Center for Regulation and Market Analysis, University of South Australia.

Yacubowicz, H. and Yacubowicz, J. (2007) Nanofiltration-properties and uses. *Koch Membrane Systems*.

Zdenìk Bittnar, Peter J. M. Bartos, Jiøí Nìmeèek, Vít Šmilauer and Jan Zeman(2009) Nanostructured materials in new and existing buildings: To improved performance and saving of energy. *In Nanotechnology in Construction* 3 Proc.NICOM3. Prague.

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تطبيقات تقنية النانو فى الزراعة،نظرة عامة

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الزراعة توفرالغذاء للإنسان بصورة مباشرة وغير مباشرة و نظرا لزيادة عدد سكان العالم، فمن الضروري استخدام التقنيات الحديثة مثل تكنولوجيا النانو في العلوم الزراعية. وقد تم تعريف تقنية النانو بأنها تتعلق بالمواد والنظم والعمليات التي تعمل على مقياس من 100 نانومتر (nm) أو أقل. تكنولوجيا النانو لديها العديد من التطبيقات في جميع مراحل الإنتاج والتصنيع والتخزين والتعبئة والنقل للمنتجات الزراعية. وسوف تحدث ثورة تكنولوجيا النانو فى الزراعة والصناعات الغذائية عن طريق إبتكار تقنيات جديدة مثل: تقنيات الزراعة الدقيقة وتعزيز قدرة النباتات على امتصاص العناصر الغذائية واستخدامها بكفاءة عالية واستهداف المدخلات والكشف عن المرض والسيطرة على الأمراض ومقاومة الضغوط البيئية ولديها أنظمة فعالة للتجهيز والتخزين والتعبئة والتغليف. وزيادة كفاءة الأسمدة المضافة بمساعدة الطين النانو والزيولايت، واستعادة خصوبة التربة عن طريق إنطلاق المواد الغذائية المثبتة. البحوث على البذور الذكية المبرمجة لكى تنبت في ظروف مواتية مع النانو بوليمر المغلفة مشجعة. ويجري حاليا تطويرمبيدات أعشاب النانو لمعالجة المشاكل في إدارة الحشائش المعمرة. أما كفاءة الدواء فإنها تزداد من خلال استخدام النانو في علوم الحيوان. وتستخدم جسيمات الفضة والحديد النانو في علاج وتطهير المواشي والدواجن. ويمكن تقييم بسرعة مستويات تلوث البيئة من خلال اجهزة استشعار الغبار والغاز النانو الذكية.