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Nanotechnology and its application in agriculture biotechnology

Veer Singh
Dept. of Zoology
Banaras Hindu University, Varanasi
Email: vs1996@gmail.com

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Abstract

Nanomaterials have emerging applications in several areas like agriculture, biomedical engineering, pharmaceutical engineering, and optical physics. The importance of the nanomaterials in various industries is due to its unique chemical, physical as well as biological properties. According to ISO and ASTM guidelines, the size of nanoparticles varies from 1 to 100 nm. The structure of nanoparticles exists in various dimensions, such as zero-dimension, one dimension, two dimensions, and three dimension. These nanomaterials are also classified into multiple categories, such as inorganic and organic-based nanoparticles. Nanoparticles have unique enhanced properties due to its high reactivity, small particle size, large surface area. Nanoparticles can be synthesized using several chemicals, physical as well as biological methods. Nanotechnology plays a vital role in the agriculture field. It has an application in crop improvement, crop protection, water purification, remediation of toxic materials, food processing, and packing. The chapter focused on the classification, properties, synthesis methods, characterization methods, and application of nanotechnology in agriculture.

Keywords: Nanomaterials; synthesis methods; classification of nanomaterials; characterization; agriculture.

1.0 Introduction

Nanotechnology has an important application in the field medicine, biofuel production, wastewater treatment, drug delivery, agriculture optical physics [Pramanik et al., 2020]. Norio Taniguchi first used the word nanotechnology in 1974 [Taniguchi, 1974]. According to USEPA, the size of nanoparticles varies from 1-100 nm [USEPA, 2020]. The small size and large surface area of nanoparticles provide some unique features to the nanoparticles like high reactivit [Hasan, 2015]. Some critical applications of nanotechnology are shown in Figure 1.

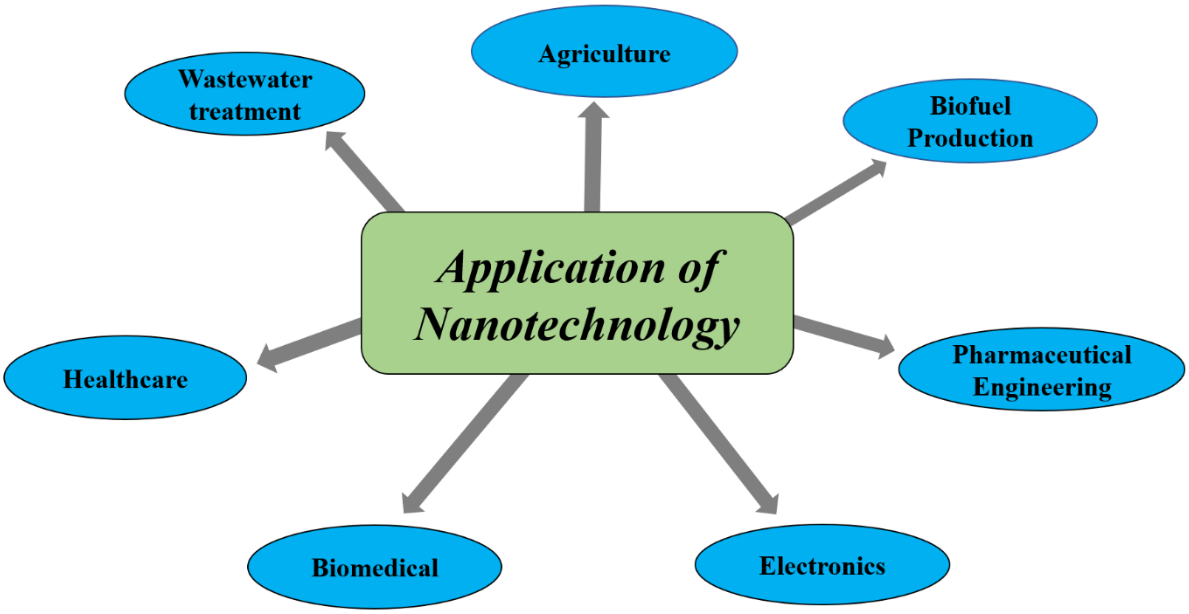

Figure 1. The Figure showed the application of nanotechnology in various fields.

Various organizations, US Environmental Protection Agency (USEPA), US Food and Drug Administration (USFDA) and International Organization for Standardization (IOS) have been given their own opinion about nanomaterials. According to the US Environmental Protection Agency (USEPA), nanomaterials have various unique properties than abundant compounds [USEPA, 2020]. US Food and Drug Administration (USFDA) also explained about nanomaterials. According to USFDA, the nanomaterials must have at least one dimension, and size ranges from 1- 100 nm [USFDA, 2011]. International Organization for Standardization (IOS) also has the same opinion about nanomaterials, according to IOS, nanomaterials have a dimension between 1 to 100 nm [Boverhof et al., 2015]. The nanomaterials can be classified into several classes. The classification of nanomaterials is generally based on the materials involved in the synthesis and dimension of the nanomaterials. The inorganic nanomaterials derive from non-carbon metals like silver, iron, gold, magnesium, copper, and tungsten-based compounds. The carbon-based nanomaterials originate from organic compounds, and some examples of carbon nanomaterials are carbon nanotubes, nanowire, carbon nanosheets, and carbon nanodots [Mody et al., 2010]. The dimension of nanomaterials is an essential factor which plays an important role. Nanomaterials are classified as zero, one, two, and three-dimension nanomaterials [Singh et al., 2020].

Nanomaterials are widely used in the field of electronics, optical science, cancer therapy, wastewater treatment, crop improvement, food processing, and packing and biofuel production. The application of nanomaterials depends on their unique properties like chemical, biological, and larger surface area to volume ratio, which provides the possibilities for improvement of the functionality of nanomaterials [Khan et al., 2019]. Nowadays, nanotechnology is an emerging field of science and technology that can improve the livelihood of people. As a technology, nanotechnology has applications in various sectors such as water purification, energy production and management, health care sector, agricultural biotechnology, and some biodiversity-related issues [Singh et al., 2020]. According to the survey of the United Nations (UN), the yield of agriculture sector improvement through nanotechnology is an essential goal for developing countries. Water treatment, energy conservation, and medicine are also the most crucial sector and showed the emerging application of nanotechnology in these sectors [Pramanik et al., 2016]. Nanotechnology has a practical and beneficiary application in the agriculture field. Nanotechnology plays a significant role in the enhancement of productivity of crops. Hence, nanotechnology can offer a second green revolution in the agriculture sector of India [Chen et al., 2011]. This chapter aims to review the introductuction of nanotechnology, nanoparticles synthetic methods, properties of nanomaterials, characterization techniques and application of nanotechnology in agriculture.

2.0 Classification of nanomaterials

Classification of nanomaterials is a fundamental process in nanotechnology. Nanomaterials are generally classified on the basis of the composition of nanoparticles and the structure of the nanoparticles in the term of dimension.

2.1 Classification of nanomaterials bases on composition

The nanomaterials can be synthesized using carbon sources, inorganic materials or synthesized from a combination of more than one type of material. Different types of nanomaterials based on materials used for synthesis have discussed below:

Carbon-based nanomaterials made up of organic materials contain carbon atoms and exist in various morphologies. These types of nanomaterials can be like a tube, sphere, fiber or sheet. Several methods can be used for synthesis, such as chemical vapor deposition, arc discharge method, and laser ablation method [Kumar et al., 2016]. Fullerenes (C60) is a spherical carbon molecule and arranged in sp^2 hybridization. Fullerene molecule contains 28-1500 carbon atoms arranged in a spherical structure. The diameter of spherical is 8.2 nm for a single layer and width up to 36 nm for a multi-layered molecule. The arrangement of carbon atoms in a hexagonal pattern and makes 2D planar surfaces. The thickness of the two-dimension sheet is about 1-2 nm. Carbon Nano Tubes (CNT) also contain graphene molecules. The carbon atoms in the CNTs arranged in honeycomb lattice-like structure and formed hollow cylinders like the structure. CNT diameter is about 100 nm, and length varies from a few µm to a few mm. Carbon black is an amorphous nanomaterials material, and carbon atoms are arranged in spherical shape structure of carbon black, and diameters of spherical vary from 20 to 70 nm. The carbon black particle-particle interaction is so high, so they bound with each other and form aggregates around 500 nm [Kumar et al., 2016].

Inorganic-based nanomaterials are generally made up of metals and metal oxides. These nanomaterials can be synthesized from metals like Ag, Au, and Fe, the metal oxides are TiO2, ZnO, and MnO2 [Jeevanandam et al., 2018].

Nanocomposites contain more two types of nanoparticles. These nanomaterials are combined with nanoparticles with other nanoparticles or bulk materials or more complex materials like metal frameworks. The nanocomposites can be synthesized from inorganic or organic or composite of both types of materials. These materials have different morphologies depends on the synthesis and required properties for desired applications [Li et al., 2012; Zhang et al., 2011; Badrossamay et al., 2010; Gokarna et al., 2014].

2.2 Classification of nanomaterials based on the dimension

Nanoparticles can be classified based on their dimensions. Nanomaterials exist in the zero, one, two, and three dimensions. The nanoparticles must be having at least one dimension of 1-100 nm. The nanomaterials exist in single, aggregated or fused forms with several shapes like tubular, spherical as well as irregular shapes. The most common types of nanomaterials are nanofibers, nanotubes, quantum dots, as well as the nanosheets [Jeevanandam et al., 2018].

Zero dimensions nanoparticles are the most common type of nanomaterials. This type of particle has all dimensions within Nanoscales (no dimensions of nanoparticles are larger than 100 nm). These nanoparticles are point-like particles. The most common example of these particles is quantum dots (uniform particle arrays), hollow spheres, and nano lenses. One-dimension nanoparticles have all dimensions within nanoscale except one dimension. The examples are one-dimension nanoparticles are nanotube, nanorods, and nanofibers [Jeevanandam et al., 2018]. Two-dimension nanoparticles have at least two sizes larger than nanoscale and others within the nanoscale. The well-known examples of two-dimension nanoparticles are nanofilms, nanolayers, and nanocoating [Mondal S, 2020]. Three-dimensional nanoparticles have at least three dimensions larger than nanoscales. But all components of three-dimension nanomaterials have a size range from 1-100 nm. These materials are generally nonporous and have many applications. The well-known examples of these types of nanomaterials are nanocomposites and bundles of nanofibers [Jeevanandam et al., 2018].

3.0 Properties of nanomaterials

Nanoparticles are small in size and have large surface area comparison to macromolecules or bulk materials. Nanoparticles have some unique properties which make it more applicable compared to bulk materials. The physical and chemical properties of nanomaterials have been discussed in this section.

3.1 Physical properties

The physical properties of nanomaterials are described in terms of optical, mechanical, hydrophilicity, hydrophobicity, suspension, settling, thermal, magnetic, and electrical properties. These properties are responsible for the stability, selectivity, and specific activity of nanomaterials. The optical properties of nanoparticles are considered as color, light penetration, reflection, and UV absorption properties [Langlois et al., 2019]. The mechanical properties of nanoparticles play an important role in its application in various fields. The mechanical properties are including elasticity, tensile strengths, hardness, and flexibility [Naghdi et al., 2018]. The magnetic and electric properties of nanomaterials can be defined in the term of conductivity, semi-conductivity, and resistivity. On the basis of magnetic and electrical properties, nanomaterials can be used in modern electronics [Khan et al., 2019].

3.2 Chemical properties

The chemical properties of nanomaterials include toxicity, Corrosive and anti-corrosive, oxidation, reduction, anti-fungal, anti-bacterial, and disinfection. The chemical property of nanomaterials plays an important role in the application of nanomaterials in the chemical as well as biomedical engineering. These properties of nanomaterials depend on the materials used for nanomaterial synthesis [Burdusel et al., 2018]. The chemical property of nanomaterials is highly affected by the size of materials. The small nanomaterials have a large number of atoms on their surface compared with bulk materials. Hence, nanomaterial shows more molecules and platforms for the chemical reaction. Thereby, nanomaterials show more reactivity than bulk materials [Ge et al., 2014].

A large number of atoms present on the surface of nanomaterials play an important role in the dynamic behavior nanomaterials. When nanoparticles present on the surface of bulk material as a coating, it enhances some properties of bulk material such as electrical transport and more surface area for chemical reaction [Iqbal et al., 2017].

(2) A large number of atoms on the surface of nanomaterials have higher average energy than more extended structures. For example, nanomaterials have more catalytic activity than bulk materials. The nanomaterials show more chemical activity per atom of the exposed surface.

The catalytic activity decreases in the bulk materials compared with the nanomaterials. The more chemical activity is due to the large number of atoms exposed on the surface.

(3) The impurities may be attracted to surfaces of nanomaterials and the interactions between nanoparticles, and those small dimension impurities can depend on the structure of nanomaterials and type chemical bonding between those impurities and nanoparticles.

4.0 Synthesis of nanomaterials

Bottom-up and top-down are widely methods used for the synthesis of nanomaterials. The large size bulk materials can be converting into nanosized particles by using top-down approaches. The bottom-up method is based on the aggregation of small particles. The small size particles come together and form nanoscale aggregates.

4.1.0 Bottom-up method

This method is widely used for the synthesis of nanomaterials. This method is based on the nanocrystal formation from atomic range particles. These are several strategies like sol-gel, spinning, and chemical vapor deposition generally used in the bottom-up method.

4.1.1 Sol-gel

Sol-gel is the colloidal solution of solid particles, and these solid particles present in the liquid form. This method is based on the simple and cost-effective operation. Hence, this method mostly preferred for the synthesis of nanomaterials. The sol-gel method is a wet process in which chemical reagents used as a precursor molecule for nanoparticle synthesis. The metal oxide and chlorides are widely used in the sol-gel mode [Ramesh, 2013]. These metal oxides, as well as chlorides, are dispersed in liquid medium by heating, followed by stirring or shaking or sonication. The resultant consists of a solid as well as the liquid phase. The nanoparticles are separated by various processes such as centrifugation, filtration, and sedimentation [Mann et al., 1997].

4.1.2 Spinning

This nanoparticle synthesis approach is depending on the spinning, and the spinning can be done by spinning disc reactor (SDR). The SDR has various features such as rotatory disc and several physical parameters like temperature, humidity, and pressure. The inner oxygen-free environment of the SDR camber can be created by nitrogen gas and some other inert gases. Oxygen may be initiating various chemical reactions during nanoparticle formation and decrease the efficiency of nanoparticle synthesis. Thereby, the removal of oxygen from the SDR reaction chamber is much necessary [Tai et al., 2007]. The atomic size nanoparticles come together and fused and form nanosized crystal after precipitation. The precipitated materials collect and need to wash several times. After washing, the obtained materials dry in the hot air oven [Mohammadi et al., 2014]. The properties and characteristics of these nanomaterials depend on the various parameters such as rotation speed, temperature, precursor /liquid ratio, the surface area of the disc, etc.

4.1.3 Chemical Vapour Deposition (CVD)

This technique is based on the deposition of gaseous molecules on the solid substrate. The deposition process is performed at the optimum temperature of the reaction compartment. The CVD reaction is initiated at high temperature and followed by the interaction of gaseous molecules and heated substrate [Bhaviripudi et al., 2007]. The chemical vapour deposition method is considered an advantageous method due to the formation of highly pure and uniform nanoparticles. The synthesis of nanoparticles from this method is highly dependent on the temperature. The chemical vapour deposition method also has some disadvantages such as the formation of toxic gases (by-products) and the requirement of costly equipment for the synthesis of nanoparticles [Adachi et al., 2004].

4.1.4 Pyrolysis

Pyrolysis is a critical process for the synthesis of nanoparticles at the industrial level. The pyrolysis method is based on the burring of raw materials in the absence of air at high temperatures. The precursor or raw materials used in this process exist in liquid or gaseous form and pass into the furnace through a small hole present in the furnace [Kammler et al., 2001]. This process is cost-effective and easy to handle compared to other methods. This method has some other advantages, such as it is a continuous process, produces the best quality of nanoparticles with high yield [Amato et al., 2013].

4.1.5 Biosynthesis

Biosynthesis is an eco-friendly, pure, and based on cost-effective nanoparticles. Biosynthesized nanomaterials are biodegradable, biocompatible, and non-toxic [Kuppusamy et al., 2014]. Several biological precursors such as plant extract, fungal biomass, bacterial biomass, and agriculture waste have been used for the synthesis of nanoparticles. Nanomaterials synthesized from this method have some unique and enhanced properties comparison with nanomaterials synthesized from other methods. Due to these unique properties, biosynthesized nanomaterials have been used in medicine, biomedical engineering, as well as pharmaceutical engineering [Hasan et al., 2015].

4.2.0 Top-down method

It is a size reduction method of nanoparticle synthesis. The top-down approach is based on the size decrement of bulk or large materials to nanoscale materials. Ball milling, thermal decomposition, and laser ablation are the most widely used methods for nanomaterials synthesis.

4.2.1 Mechanical ball milling

Out of other top-down methods, the mechanical ball milling method is more appropriate and beneficial for the synthesis of various types of nanoparticles. The bulk materials are milled in the presence of air as well as the inert environment. Some important factors, such as cold-welding, plastic deformation, and particle fraction, influence the production process as well as the quality of synthesized nanomaterials. Plastic deformation is an important factor responsible for maintaining the shape of nanoparticle, and particle fracture are related to the size of nanomaterials during synthesis. It reduces the size of materials. The cold-welding also correlated with the size of nanomaterials. It can minimize the particle size during the synthesis of nanomaterials [Yadav et al., 2012].

4.2.2 Nanolithography

Nanolithography is an important method for the synthesis of nanomaterials from bulk materials. The nanoparticles synthesized from these methods vary from 1 – 100 nm in size. Several nanolithography processes such as electron-beam, optical process, nanoimprint, and high energy proton beams have been involved in the synthesis of particles. Generally, lithography produces nanoparticle of desired shape and size from light-sensitive bulk materials. The synthesis of a single size nanoparticles is the main advantage of this method. There are few disadvantages of this method, such as the requirement of expensive equipment and complex synthesis process [Pimpin et al., 2012; Hulteen et al., 1999; Duan et al., 2003, Ding et al., 2005].

4.2.3 Laser ablation

Laser ablation is the method for nanoparticle synthesis from several precursor solvents. The solution of desired metal or materials mixed in the liquid water and exposed with the laser beam. Laser bean initiates the synthetic reaction and produces nanoparticles that have a size range from 1-100 nm. Laser ablation delivers a substitute for chemical reduction methods for nanoparticle synthesis. Chemical reduction methods have some disadvantages like generate a large number of toxic by-products during nanoparticles synthesis. Therefore, the Laser ablation method is more appropriate for nanoparticle synthesis due to an eco-friendly and cost-effective process. Another advantage of the laser ablation method, it does not generate toxic materials as a by-product. This method is independent of the organic solvent, reducing agent or stabilizing agent for nanoparticle synthesis. Nanoparticles produced from this method are more stable compared to chemical reduction methods [Amendola et al., 2009; Zhang et al., 2017].

4.2.4 Sputtering

Sputtering is based on the deposition of nanomaterials on the solid surface. The deposition of nanomaterials occurs between ejecting materials and ions [Ealias et al., 2017]. The deposition of nanoparticles on the surface is usually in the form of a thin layer. The thickness of the layer depends on the various parameters such as temperature, duration of annealing time, and used materials for synthesis, etc. These parameters also determine the size as well as the shape of nanoparticles [Lugscheider et al., 1998].

4.2.5 Thermal decomposition

The thermal decomposition method is highly dependent on temperature. This method is also considered as endothermic. The nanoparticles synthesis process occurs through deposition and breakage of bonds within compounds of the bulk material. The temperature at which bulk metal compound becomes decomposes known as decomposition temperature. The decomposition of the materials also affected by various parameters like the pressure of the reaction chamber and reaction time [Salavati-niasari et al., 2008].

5.0 Characterization of nanomaterials

Nanotechnology has several applications in the field of agriculture, biomedical engineering as well as biofuel production. The characteristic of nanomaterials plays an important role in the selection of nanomaterials for the desired application.

The size of nanomaterials exists between 1-100 nm, and it can measure by using several techniques such as transmission electron microscope (TEM), zeta sizer, or optical particle counter equipment. The size of nanomaterials is an essential factor and describes the properties of materials. Small size nanoparticle has more surface area and provides more space for reactant as well as exposes more surface functional groups involved in physiochemical reaction [Baer et al., 2013].

The surface area of nanoparticles can be measure by using BET in solid phage. In the liquid phase, the surface area can be measured by using NMR equipment and chemical titration method. The surface area of the nanoparticle in the gaseous period can be measured with the help of a differential mobility analyzer and scanning mobility particle sizer [Szekeres et al., 2002].

Nanocomposites made up of more than one type of metallic or non-metallic material. Determination of the composition of nanocomposites is much important before the use of nanocomposites in the desired field. The composition of nanomaterials can be estimated in the solid phase by using various techniques such as X-ray photoelectron spectroscopy (XPS), electron dispersive X-ray analysis (EDX), and chemical digestion method. The component of the nanomaterials in the liquid phase can be analyzed by mass spectrometry and ion chromatography. In the gaseous phase, the nanomaterial composition can be determined by spectrometric or wet chemical methods [Asmi et al., 2010; McMurry et al., 2009]. The surface morphology of the nanoparticles can be determined by scanning electron microscope (SEM) and transmission electron microscope (TEM) [Hodoroaba et al., 2014]. Nanoparticles also have some charge on their surface, and these charges can be estimated by point zero charge (pHzpc), zeta potential, and differential mobility analyzer in the solid, liquid, and gaseous phase, respectively [Marsalek, 2014; Kumal et al., 2015; Schleh et al., 2012].

6.0 Application of nanotechnology in agriculture

Agriculture fields have been received a number of benefits from various innovation approaches like tissue culture, hybrid varieties, fertilizers, herbicides, and pesticides. These conventional technologies can fulfill global needs, which depend on the agriculture sector. However, the world's human population is increasing to time, and modern traditional agriculture approaches may be unable to complete the food demands of the global population. Thereby, the agricultural sector is strongly in need of more advance and smart technology for growth in the agriculture field [Mukhopadhyay, 2014]. The nanomaterials increase the efficiency of fertilizers and overall enhance the yield of agriculture products. They reduce the use of hazardous chemicals like chemical fertilizers, pesticides, and herbicides. Nanotechnology is also applicable to the detection of food items, food packaging, processing, and smart delivery system [Moraru, 2003; Chau et al., 2007]. Nanomaterials can be improved agricultural productivity through genetic modification in the crops/plants [Kuzma, 2007; Scott, 2007]. Nanomaterials can act nanofilters or nanocatalyst and able to degrade the pollutants present in the soil and wastewater [Gehrke et al., 2015]. Thereby, nanomaterials enhance the health of the soil, and it also converts no-airable land to arable land. Nanotechnology has a large number of applications including some above mentioned. The few selective application of nanotechnology is given below in detail.

6.1 Crop improvement

Nanotechnology has an important role in crop improvement. Nanomaterials can increase the yield of crops by inducing plant growth and germination. Nanotechnology can also cause mutation in the plant cell, which responsible for breed improvement. Nanoparticles can penetrate the cell wall and membrane of the plant cell and induce targeted mutation without harming other essential parts of the plant [Anonymous, 2004].

The nanotechnology showed promising results at the improvement at the seed level. It is a very safe comparatively application of nanotechnology at other stages. It is responsible for increasing the germination of seeds and suppressing the growth of weeds. Khodakovskaya et al. 2009 and Prasad et al. 2012 reported that nanoparticles showed promising results in an enhanced yield of different crops. It has been reported that TiO_2 and SiO_2 nanoparticles jointly improve the germination of seeds [Lu et al., 2002]. Zhang et al. 2005 reported that TiO2 nanoparticles increased seed germination and enhanced crop improvement in *Spinacia oleracea* (spinach). TiO2 nanoparticles also increase the nitrogen metabolism and photosynthetic efficiency in plants and improve the yield of crops [Zhang et al. 2005; Hong et al., 2005]. Uncoated alumina nanoparticle can prevent the growth of few plants such as *Zea mays* (corn), *Daucus carita* (carrot), *Brassica oleracea* (cabbage), etc and enhance the yield of the crops [Yang and Watts, 2005].

6.2 Nonofertilizers

Fertilizers are essential to maintain soil fertility as well as the better yield of crops. But conventional fertilizing methods (spraying and broadcasting) have many drawbacks, and these methods cause the loss of fertilizer after spraying and broadcasting. Leaching, runoff water, evaporation, microbial and photolytic degradation are the major routes of loss of fertilizers in the fields. Thereby the loss of fertilizers causes a very little amount of fertilizers to reach the targeted site or desired crop. It has been reported that about 40-90% of fertilizers lost in the environment, and this caused the repetitive use of fertilizers in the fields. The excess use of fertilizers in the land responsible for environmental pollution and the reduction of microflora in the soil [Tilman et al., 2002]. Hence, the optimum use of chemical fertilizer and minimum loss of these fertilizers is very necessary. This issue can solve by using nanotechnology. The nanomaterials used in the fertilizers known as nano fertilizer, and these nano fertilizers can supply nutrient to the targeted site of the crop and shows better performance than convention fertilizing methods [Liu and Lal, 2015]. Nonofertilizers deliver the nutrient to the specific location and enhance nutrition efficiency, as well as nano fertilizers also minimize the loss of fertilizers [Rai et al., 2012]. Generally, three strategies used for the synthesis of nutrients loaded nanomaterials or nano fertilizers; nutrients are (a) coated with a thin film-like polymer, (b) encapsulated in the pores of nanomaterials, and (c) delivered in the form of nanoparticles. The fertilizers strongly bind to the nanomaterials due to high surface tension [Brady and Weil 1999]. Nanopartilizers have some specific properties such as high solubility, stability, enhanced target activity, timely released, eco-friendly, cost-effective, and cause does not reduce soil fertility [Torney et al., 2007; Green and Beestman, 2007].

6.3 Remediation of toxic pollutants

The remediation of toxic pollutants from the contaminated sites is much needed for environmental health as well as living health. The soil contamination in the airable land is caused due to the use of pesticides, herbicides, and excess consumption of chemical fertilizers. These contaminations inhibit the growth of microflora and nitrogen fixation in the soil. Therefore, soil contaminations reduce the fertility of the land. These toxic pollutants also cause pollution in groundwater and surface water. These pollutants travel with runoff to surface water bodies like rivers, ponds, and lakes. These poisonous pollutants reduce the quality of surface water and make useless for drinking as well as cause various types of harmful effects in the aquatic animals. The contamination in the groundwater is caused due to the reaching of toxic pollutants through leaching of contaminated surface water. Hence, the removal of these toxic pollutants from soil and wastewater is considered an urgent requirement. The application of nanotechnology in the remediation of contaminants is cost-effective and more rapid.

The nanomaterials can be used in the treatment of wastewater and contaminated soil. The nanomaterials are also applicable in the removal of pollutants from the air [Crane and Scott, 2012]. The nanomaterials are small in size and provide more surface area for various types of reaction like reduction and oxidation. The toxic pollutants become transform or degraded when they come to contact with nanomaterials. Some well-known examples of nanomaterials, such as carbon nanotube, zeolites, metal oxides, and aquaporins, have emerging applications in the remediation of pollutants. Carbon nanotube and zeolites are applicable for removal of heavy metals, bacteria as well as organic pollutants. Nanomaterials derived from metal oxides can be applied for removal of arsenic, reduction of toxic hexavalent chromium to less toxic trivalent chromium, and remediation of other pollutants contaminated water and soil [Gehrke et al., 2015].

6.4 Crop protection

The global food demand for the growing world population depends on agriculture. The increasing demand for agriculture products is responsible for the excessive use of chemical pesticides for crop protection purposes. Nowadays, a large number of pesticide use in the agriculture field but very less amount of pesticides reach target sites due to leaching, spray drift, photodegradation, and off-site deposition of the pesticides. Therefore, it causes application costs and also responsible for environmental pollution [Castro et al., 2013]. Nanotechnology, one of the lastest techniques, plays an essential role in crop protection due to specific physical and chemical properties of nanomaterials. The small size nanomaterials strongly bind to the pathogen cell wall and responsible for the degradation of cell wall due to more energy transfer and finally causing its death. Nanomaterials have two important aspects;

(a) use as a pesticide, and (b) zero toxic effect or reduce toxicity [Mousavi and Rezaei, 2011]. Nanomaterials use as controlled release of encapsulated pesticides against pathogens. Nanomaterials can be used nanosensor detection of diseases in plants [Ghormade et al. 2011]. Nanomaterials are more reactive compared to the higher scale materials. Hence very less amount of nano pesticides can be spread up to more areas and provide much protection from pests. Small size nanomaterials also reduce the cost of application. Nanopesticides entirely absorbed by the host plants and persist for in the plant for a long duration. The nanosensors can detect the soilborne disease in the plant through microbial oxygen demand in the soil.

7.0 Conclusion

Nanotechnology plays an important role in various fields, such as agriculture, medical, biofuel, and optical physics. The nanomaterials have some specific physical, chemical, and biological properties due to are small, large surface area and high reactivity. Nanomaterials classified in various categories like zero, one, two, and three-dimension nanomaterials. The nanomaterials can be synthesized through bottom-up and top-down methods. The size, shape, and other properties like reactivity and stability are highly dependent on the nanomaterial's synthetic methods and materials used for synthetic purposes. The characterization of materials is an essential step in nanotechnology. We can understand about physiochemical and biological properties synthesized nanomaterials through characterization methods. It is also helpful in the selection of nanomaterials for the desired application. Nanotechnology has emerging applications in agriculture. It has many applications in the form of nano fertilizers, nano pesticides, crop improvement agents, nanosensors, and effective remediating agents. Nanotechnology is a cost-effective and eco-friendly approach for crop improvement. Based on previous studies, we can conclude that nanotechnology is safe and more effective techniques which can enhance the yield of agricultural production. It can be beneficial to the farmers due to minimum investment and maximum earn in a given period.

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