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Nanotechnology in agriculture: Prospect, opportunities and challenges

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Abstract

Ensuring food security in emerging nations is extremely difficult due to the low agricultural sector output, depletion of natural resources, significant post-farming losses, lack of value addition, and rapid population expansion. Researchers are working to implement novel breeding technologies to improve the supply and close the gap between food supply and demand. Uses of conventional farming technologies are not so much productive and effective as they are time consuming and labor intensive. This necessitates the use of nanotechnology that has the potency to massively influence the agriculture industry by reducing the negative effects of conventional farming techniques on the surroundings and wellness of humanity, boosting farming capacity, sustainability, and food safety, (as enforced by the anticipated rise of global demography) and fostering communal and economic parity. Nanotechnological meddling in farming has promising futures for enhancing nutrient use efficiency via the use of nanoformulations of fertilizers. Further, it knocks out the farming output hurdles through the blending of biotechnology with nanoscience and targeted and effective vigilance against external pressures. Moreover, it assists scientists in comprehending the molecular-level mechanisms of host-parasite interactions, thereby facilitating the development of new pesticides and carriers that improve efficacy and reduce toxicity. Additionally, nanosensors can be employed to monitor soil quality for agricultural practices. Furthermore, this approach can serve as a milestone in addressing the present challenges faced in the agriculture sector. However, more research is necessary to address the safety and health issues posed by the technology. In this article, we have discussed the various role and prospects of nanotechnology in agriculture.

Keywords agriculture, nanoformulation, nanoparticles, nanosensors, nanotechnology

Introduction

The issue of ensuring food security for a world population that is continually expanding is the biggest global concern facing humanity. According to predictions, as the world population increases to 9 billion people by 2050, the demand for food is anticipated to increase from 59 to 98% [1]. To make agriculture more economically sound, environmentally sustainable, and efficient, there has been a growing emphasis on the use of modern technologies and practices [2]. Farmers all over the world will concentrate on utilizing modern advancements and technologies to improve crop yield through intense and extensive agriculture. Newer technologies that will boost productivity and decrease food waste are crucial for the country to sustain livable living standards and ensuring food security [3]. The ongoing efforts of utilizing novel technologies can be further boosted by the use of nano-modified stimulants created by the use of nanotechnology [4]. Nanotechnology is one of the quickly developing technologies that have the potential to support sustainable agricultural growth. The term "Nanotechnology" was first introduced by Norio Taniguchi in 1974 [5]. It pertains to the exploration and comprehension of atoms or structures ranging in size from 1 to 100 nanometers, where each atom possesses distinctive characteristics. The ability to control an atom or piece of matter at this nanoscale can help us comprehend how physical, chemical, and biological processes work. Also, the development of superior materials or structures unquestionably has a favorable effect. At the nanoscale, the change in property is due to changes in the atoms and gains magnetic strength. One can assume that nanomaterials with smaller sizes have greater surface area and are more active [6]. Nanotechnology is attempting to enter the realm of perception in this way. Tellurium, antimony-bismuth, and sulfur atoms all contribute to the polymer's development of its magnetic feature. Furthermore, research has revealed that molecules exhibit magnetic properties when they come into contact with dopant and europium atoms. Consequently, the altered properties of nanomaterials are linked to greater reactivity in many fields, including biological processes [7]. The emerging uses of nanotechnology in farming systems will stay dependent on the material's capacity for problem-solving and are not expected to slavishly stick to the top limit of 100 nm. Further, this approach has to address the unique challenges of farming systems, which are often characterized by low input use efficiency, high resource demands, and complex interactions between flora, fauna, and the corresponding micro-environment, which may necessitate nanoparticles but nevertheless efficaciously accomplish duties in farming production systems [8].

Nanoparticles and their function

The lengthiest and leanest axes of a nanoparticle are not significantly different in length, which elucidated nanoparticles as nano-entity having total exterior dimensionality in the nanoscale (10^{-9}). Terms like "nanoplates" or "nanofibers" are considered to be superior over "NPs" if the size in terms of length and breadth diverged strikingly (typically higher than three times) [9]. Nanoparticles can exist in various dimensional forms like zero-dimensional (0D), one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) structures, relying on their size, shape, and composition [10]. Zero-dimensional (0D) nanoparticles, also comprehended as quantum dots or nanodots, have a set dimension and form, with all three dimensions contracted to a single focal point. One-dimensional nanoparticles, namely carbon nanotubes, have a constant length and diameter, with their height lessened to a nanoscale. Two-dimensional nanoparticles, such as graphene, have a fixed length and width, but are excessively narrow and have a high surface area-to-volume ratio. Three-dimensional nanoparticles, such as gold nanoparticles, have a fixed length, width, and height. It's important to consider that nanoparticles can also have complex, multi-dimensional shapes that combine features of all structures, such as nanorods, nanospheres, and nanocubes [11]. In accordance with the specific material, fabrication technique, and utilization, nanoparticles can have a vast range of shapes, sizes, and structural features. It can be asymmetrical or spherical/round, cylindrical/tubular, cone-shaped/conoid, cavernous core, spiral/helical, flat/even, etc. The surface may have surface differences and be uniform or asymmetrical. Nanoparticles are either crystalline or amorphous based on the compactness of single or multiple crystal solids [12]. The various nanoparticles used in agriculture were shown in Table 1.

Classification of Nanoparticles (NPs)

Based on their composition, NPs are typically classified into three grades: organic, carbon-based, and inorganic [11].

Table 1. List showing commonly used nanoparticles in agriculture [13]

Types of Nanoparticle	Uses in Agriculture
Polymeric Nanoparticles	Release of agrochemicals, excellent compatibility by having minimal effect on non-targeted molecules
Silver and Gold Nanoparticles	Having antimicrobial properties and used in Nanobiotechnology for crop improvement
Nano alumino-silicates	Used as efficient pesticides for crop protection
Titanium–oxide Nanoparticles	Used as a disinfectant for water bodies
Carbon Nanoparticles	Act as a source of improved crop growth by enhancing seed germination
Liquid Nanoparticles	Used in form of Nanofertilizers for enhanced crop growth

Organic nanoparticles

This category includes NPs formed of any organic substance, including polymers, lipids, and proteins [14]. Dendrimers, liposomes, micelles, and protein complexes like ferritin are some of the most acclaimed instances of the corresponding class. The majorities of these NPs are biocompatible, harmless, easily degradable, and occasionally even have a cavernous core like liposomes do. Organic NPs are susceptible to electromagnetic and thermal emissions, including heat and light. The possible field of use of organic NPs is resolved by the number of diversified factors, including configuration, surface shape, firmness, bearing magnitude, etc. The biomedical industry now uses organic NPs primarily for targeted medication delivery and cancer therapy [15].

Polymeric nanoparticles

They are typically spherical, nanocapsular nanoparticles with an organic basis. The earlier are matrix particles with a solid overall mass, and other compounds are adsorbed at the spherical surface's outer edge. NPs of this class have a wide application in agriculture due to their simple functionalization property [16].

Carbon nanoparticles

This group of NPs is built up entirely of carbon atoms [11]. Depending on their dimensions and structure, carbon nanoparticles can be divided into various forms, including fullerenes, carbon nanotubes, graphene, and carbon quantum dots [17]. Carbon compounds known as fullerenes have a uniform closed-cage configuration. NPs made of carbon are being employed in many diverse uses, because of their distinctive electroconductivity, high tensile strength, affinity towards electrons, ocular, thermic, and sorption properties [16].

Inorganic nanoparticles

Micron-sized particles known as inorganic nanoparticles are formed of inorganic substances including metals, metal oxides, semiconductors, or ceramics. They have distinctive chemical and physical properties that differentiate them from their bulk counterparts.

Metal based nanoparticles

These are extremely small metallic particles, usually fewer than 100 nanometers in diameter. Silver, gold, platinum, and iron are metal nanoparticles that are most frequently employed [18]. These nanoparticles exhibit special physical, chemical, and biological characteristics, such as high surface area-to-volume ratios, and susceptibility to external variables. This makes them valuable in a variety of applications, including sensing, imaging, medication administration, and catalysis.

Metal oxide-based nanoparticles

These are tiny particles composed of metal and oxygen atoms, ranging in size from 1 to 100 nanometres (nm). These nanoparticles have distinctive physicochemical properties such as their improved reactivity and effectiveness. It includes oxides of various metals viz. Iron oxide, Cerium oxide, Aluminum oxide, Silicon dioxide, and Titanium oxide. Comparing these nanoparticles to their metal counterparts reveals that they have extraordinary qualities [19].

Semiconductor based nanoparticles

Semiconductor nanoparticles have characteristics of both metals and non-metals and are made up of tiny (<10 nm) semiconductor materials. In contrast to bulk semiconductor materials, these NPs have distinctive broad bandgaps and exhibit a dramatic change in their characteristics with bandgap tuning [15]. The optical properties of this kind of nanoparticle can be fine-tuned to emit specific colors of light. Therefore, these NPs are crucial components in photocatalysis, ocular and electronic devices [20].

Synthesis of nanoparticles

The various techniques [21] used to create the nanoparticles are elaborated in Figure 1.

Top –down syntheses

This strategy takes a destructive approach. Bigger molecules are first broken down into smaller pieces and subsequently transformed into nanoparticles [22]. A straightforward top-down approach was used to create colloidal carbon granules with controlled size. The method of fabrication was centered on the ongoing chemical adsorption of polyoxometalates on the surface of the carbon interfacial. It reduced the size of the carbon black aggregates into globules with a large capacity for dispersion and a limited size variation [23].

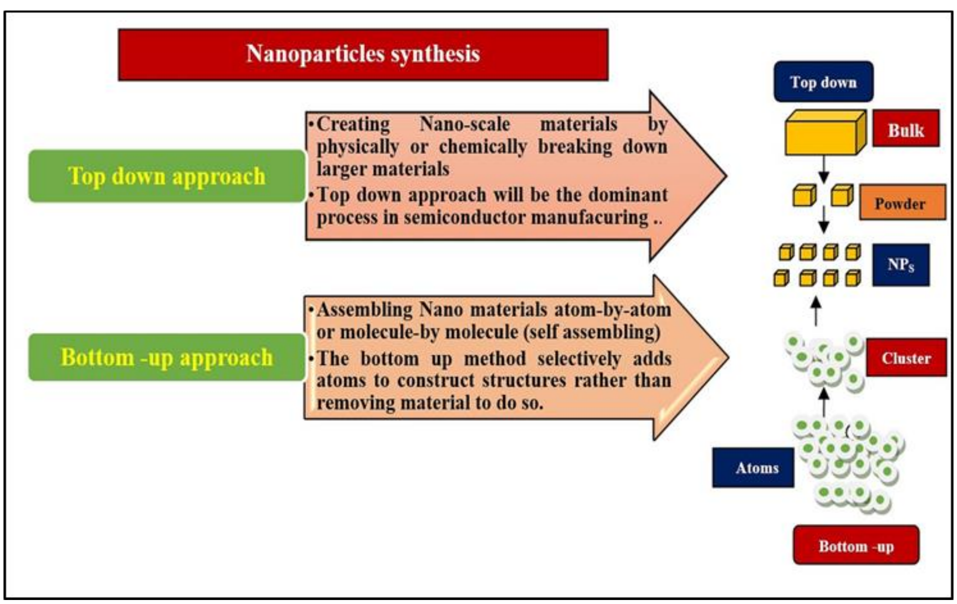

Figure 1. Approaches of synthesis of Nanoparticles (Modified and redrawn from Ion et al., [27])

Bottom -up syntheses

Bottom-up synthesis of nanoparticles involves building up the nanoparticle atom by atom or molecule by molecule, usually via a constructive approach. This method is used in reverse since nanoparticles are made of very simple chemicals; therefore, it is also a building-up method. Bottom-up synthesis can be accomplished using a variety of methods viz. co-precipitation, hydrothermal synthesis, pyrolysis, and sol-gel synthesis. The preferred approach is determined by the required nanoparticle characteristics and the particular application. Most of the nanoparticles are synthesized from sol-gel method due to its simplicity [24]. Pyrolysis is the most widely used method in industrial organizations for the mass manufacturing of nanoparticles [25]. A green and environmentally acceptable method for creating nontoxic, recyclable nanoparticles is biosynthesis [26]. As opposed to employing conventional chemicals for bioreduction and capping, biosynthesis produces nanoparticles using bacteria, plant extracts, fungi, and other microorganisms together with the precursors.

Nanomaterials and agriculture

For the sustainable growth of agriculture, nanotechnology can play a significant role in productivity through nutrient management [8]. It is impractical to provide a comprehensive evaluation of the health and environmental concerns associated with nanomaterials due to their wide range of properties and uses [28]. This technology is effective at managing the resources of agricultural fields, delivering medications to plants, and maintaining the fertility of the soil. Due to their effectiveness and speed in the environmental impact analysis of pollutants in soils and water, nanosensors are now frequently used in agriculture [29]. The major tools for sensing the heavy metals in the microscopic spectrum will be a variety of sensors that utilize nano-detection technology.

Nanofertilizers

The use of nano-fertilizers in contemporary farming systems is crucial because they have the right formulations and delivery systems to guarantee effective uptake and utilization by plants [30]. Nano-fertilizers are nutrient carriers of nano-dimensions having large surface areas, a strong capacity to contain a large number of nutrient ions, and the ability to release them gradually and steadily in accordance with crop requirements. By investigating NPs based on various metals and metal oxides for use in agriculture, these nanoscale fertilizers explore nutrient use efficacy as well as environmental sustainability [31], while reducing nutrient losses owing to leaching and avoiding chemical modifications. Depending on the technique of treatment and the characteristics of the particles, plants may consume NFs through their roots or foliage. NFs help plants better withstand biotic and abiotic pressures. It lowers production costs and lowers the impact on the environment. The NFs' numerous advantages provide fresh perspectives on encouraging sustainable farming and reducing climate change [32].

Nanopesticides

Nowadays, pest infestation is creating havoc for farmers and posing a serious threat to the farming system, so in future research should be centered on using nanomaterials in pesticide formulation to protect plants with greater efficacy [33]. Nanopesticides, the most current agricultural use of nanotechnology, are regarded as the key to sustainable agriculture through integrated pest management (IPM; pests, weeds, and pathogens control). Any formulation that contains components in the nm size range and/or promises novel capabilities related to these small size ranges is considered a nano-pesticide. Plant protection compounds known as "nano-pesticides" have either their active ingredient or their carrier molecule produced using nanotechnology. Next-generation intelligent nanopesticides (such as metal-based nanomaterials and nanocarrier-encapsulated nanopesticides) have controlled, targeted, and steady discharge of active ingredients in IPM based on crop demands and other biotic/abiotic stimuli, as opposed to conventional pesticides [34].

By improving water solubility, bioavailability, and protecting agrochemicals from environmental degradation, nanopesticides formulations potentially revolutionize the management of diseases, weeds, and insects in agriculture [13].

Formulations of Nano-pesticides

As per their targeted use, nanopesticides are created in ways that improve their solubility, delay the release of their active ingredients, stop deterioration, etc. Prominent nano-formulations include:

Nano-emulsions

The chemical's active ingredient is disseminated in water as nanosized droplets in this formulation, while surfactant molecules are kept limited at the pesticide-water interface.

Nano-suspension

The process of creating nano-suspensions, also known as nano-dispersions, involves spreading the pesticide as solid nanoparticles in aqueous environments.

Polymer based nanoparticles

The gradual and targeted release of active chemicals to the target region is a primary use of polymer-based pesticide nanocarriers.

Nano-encapsulation

It involves the incorporation of hydrophobic or hydrophilic active components within a polymer coating or membrane.

Nanospheres

These vesicular nanostructures are homogenous, meaning that the bioactive component is evenly distributed through the polymer matrix.

Nanogels

They also go by the name of hydrogel nanoparticles. They are created by cross-linking hydrophilic groups on polymeric nanoparticles.

Nano-fibers

Electro spinning and thermally induced phase separation are used to create nano-fibers.

Nanopesticides have advantages as reducing early active ingredient loss, improving plant foliar adherence, increasing IPM effectiveness, and reducing adverse effects on nontarget species (e.g., soil microfauna). If properly applied, nanopesticides could increase crop output, food security, and nutritive quality.

Nanosensors

Environmental contamination and a substantial loss of soil and water quality are the results of mechanized farming and inappropriate agricultural methods. To address the difficulties and limitations of modern agriculture, several technological advancements have been made: One is the nanosensor [35]. Nanosensors, which are chosen transducers, with a featured measurement of the nanometer scale, have become crucial tools for non-destructive, minimally invasive, and authentic analysis surveillance of biological systems like plant signal transduction pathways and metabolism [36]. The unusual electrochemical, optical, Raman, catalytic, and super-paramagnetic features of these sensors account for their exceptional sensitivity [37]. For instance, optical nanosensors based on Förster resonance energy transfer (FRET) have been used to analyze protein interactions, cellular elements, and biophysical properties, while electrochemical nanosensors have been employed to monitor oxidation and reduction potential in plants.

Nanobiosensor

Nano-biosensors significantly contribute to the modernizing of agriculture with the creation of diagnostic instruments and methods. The term "nanobiosensor" refers to a customized version of the term "biosensor," which is often used to refer to a small analytical instrument or unit that includes a biologically sensitive element connected to a physio-chemical transducer. Nanobiosensor contains immobilized bioreceptor probes specific to particular analyte molecules and is typically constructed at the nanoscale to collect, interpret, and analyze data at the microscopic level. Three pieces make up a standard nanobiosensor: a probe made of physiologically sensitive materials, a transducer, and a detector. The biologically attuned component (probes) includes receptors, enzymes, antibodies, nucleic acids, lectins, tissue, microorganisms, organelles, etc. These components respond to signals from the sample matrix of interest and communicate them to the transducer. The transducer serves as an interface, converting the energy from the reaction at the bioreceptor/sensitive biological element into a detectable electronic signal. The microprocessor amplifies and analyses the impulses from the transducer after being captured by the detector element. The information is subsequently transmitted to user-friendly output and showcased [38]. When it comes to addressing numerous food, agricultural, and environmental challenges, these sensors are precise, productive, and reasonably priced. Nanobiosensors act as a screening tool for disease and soil quality analysis, encourage sustainable development, effectively detect pollutants and other molecules, and monitor DNA and protein [39].

Application of nanotechnology in agriculture

The poor world has long relied heavily on agriculture. To fight the global concerns of population growth, climate variability, and limited food sources, technological advancements in agriculture are essential. A concept called "sustainable farming acceleration" aims to increase agricultural output using the identical current acreage without having a negative influence on the environment [40]. Nowadays, nanotechnology seems to be a wiser approach to sustainable agriculture. It is an approach that encompasses the capability to view and oversee every individual atom of any structure's matter and to transform any structure at the microscopic resolution. Nanotechnology will be capable of addressing many ingrained issues in agriculture as a result of this special characteristic [41]. Among the many uses of nanotechnology in agriculture includes improving crop growth by using Nanofertilizers, using nanozeolites and hydrogels for soil enhancement, protecting plants from insects and diseases using nanopesticides, crop improvement by using nanobiotechnology, delivering intelligent monitoring by utilizing wireless communication devices and nanosensors as shown in Figure 2.

Nanotechnology for crop growth

Green revolution plays an important role in improving grain yield using HYVS and fertilizers. Notwithstanding the overwhelming success in grain output, a plateau in grain yield has been observed due to poor soil health conditions. In addition to harming aquatic habitats, excessive nitrogen fertilizer use also has an impact on groundwater. Only by using Nanofertilizers, an innovative substitute to conventional fertilizers, is it feasible to completely eradicate eutrophication and drinking water contamination with a potential accumulation of soil nutrients [43]. The use of nanofertilizer increases nutrient use efficiency through the slow and controlled release of nutrients, resulting in accelerated plant growth. These fertilizers have a higher rate of diffusion along with solubility as compared to traditional fertilizers. The small size of nanofertilizers helps the plant for rapid uptake of nutrients through nano-sized pores as well as via molecular transport channels and root exudates [44].

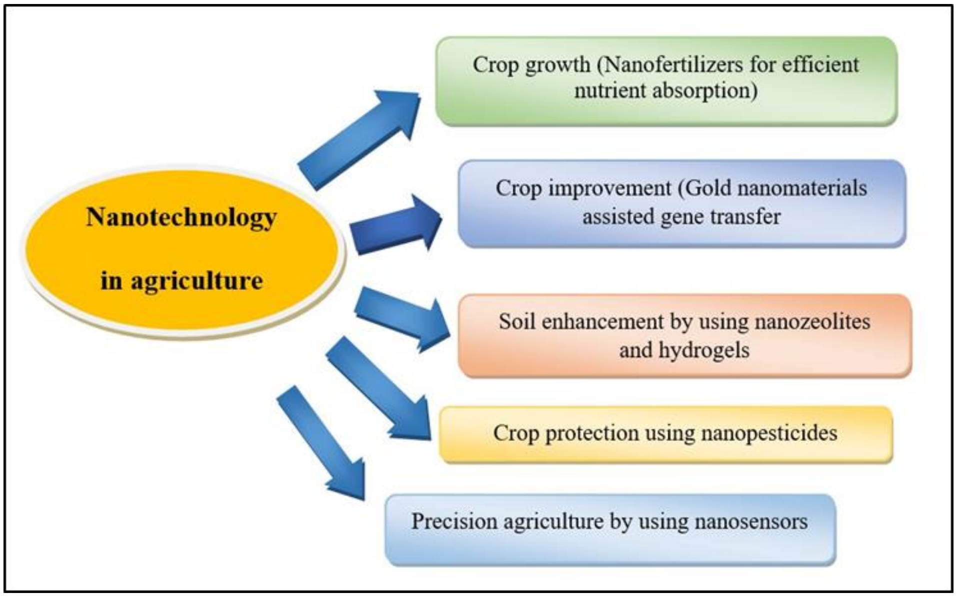

Figure 2. Application of nanotechnology in agriculture [42]

Nanotechnology in plant protection

Over 90% of the pesticides used are either squandered in the surroundings or fail to penetrate the intended areas required for pest management [45]. This necessitates the use of nano-sized based products for the sustainable development of agriculture for efficient integrated pest management (IPM). Using nanotechnology's advantageous properties, herbicides, fungicides, bactericides, and insecticides against weeds and phytopathogenic are improved. Improved bioavailability, tailored distribution, sustained release, resistance to deterioration, and increased efficacies are some benefits of nanosized platforms. It should be emphasized that in order to provide improved plant defense against pest incursion and eventual crop loss, the active components of preparation must be present at the selected sites in the minimal appropriate dose [42]. A nanotechnology strategy called "nano-encapsulation" can be utilized to increase the pesticidal value while shielding the active ingredient from harmful external factors and fostering persistence. Nanoencapsulation involves sealing tiny amounts of the active substances inside a shell or casing with a small membrane. Insecticides, fungicides, and nematicides can be nanoencapsulated to create formulations that effectively manage pest infestation while limiting the build-up of leftovers in the soil [46]. This technology offers the controlled and timely release of the active constituent of formulation in the root zone with an increase the efficacy of the applied formulation. This will also save the total amount of applied pesticides which the cost of production. Many mental oxide-based nanoparticles are known to provide disease resistance against pathogens viz., Zno against Alternaria, Fusarium, Mucor, and Rhizopus species [47].

Nanotechnology in crop improvement

In addition to farming purposes, the fusion of nanotechnology with genetic engineering offers novel molecular carrier tools that can be used to alter genes and even create new creatures [48]. The conventional method of gene delivery method faces innumerable challenges viz., such as restricted host specificity, constrained introduced genetic structure size, transit across the biological membranes, and also nuclear migration issue [49]. These challenges can be overcome by using nanoparticles in efficient gene delivery system to the targeted host system. By increasing the effectiveness and precision of the intended target host, nanomaterials could reduce the extent of off-target alterations. This method involves binding of nanoparticles (Gold Magnetite, carbon materials, ca phosphate, etc.) with genetic material to deliver the gene in the targeted host system. Here, delivery of gene becomes a précised and efficient approach by reducing the particle size from the micro to the nanoscale dimensions, cell wall obstruction can be avoided, and cell injury can be reduced. Here, a gene of interest can be directly delivered to chloroplast and mitochondria [50]. Silicon dioxide (SiO2) nanostructures have been developed for use in genetic engineering to safely transport DNA snippets and motifs to the intended species [51].

Nanotechnology for soil enhancement

Due to the excessive use of chemicals compound on crops, the quality of soil is deteriorating day by day. Accumulation of heavy metals posing detrimental effects on the availability of beneficial nutrients to the plants as well as soil microbe population and soil reactions (PH, CEC). These challenges accelerate the use of nanotechnology to face these challenges to improve the quality of the soil. The use of nanomaterials improves soil fertility and encourages the balanced use of nutrients by adhesion of nanoparticles on clay lattice which precludes the retention of nutrient ions, and consequently, the nutrients become come into the solution and become available to plants [52]. Moreover, nanoparticles stop the precipitation of the nutritional ions that are freely mobile. This procedure increases crops' ability to utilize fertilizer more effectively while reducing nitrogen loss. The use of nanomaterials boosts the pH and structure of the soil. Along with lowering soil erosion, it also limits the dispersion, bioavailability, and cytotoxicity of heavy metals. In addition to lowering the soil's shear capacity, nanoparticles in the soil also minimize coherence and friction coefficient. Less soil particle adhesion makes it easier and more energy-efficient to smash boulders. Zeolites, a class of minerals that exist naturally with a layered structure resembling a honeycomb and an alternative to traditional fertilizers, can be used to slowly discharge nutrients into the ecosystem. In addition to other gradually dispersing substances providing phosphorous, calcium, and a full range of trace and minor nutrients, it is possible to incorporate nitrogen and potassium into its web of interconnecting galleries and cages. Nutrients are held in zeolite and distributed gradually "on desire." It's also important to carefully consider the Nano-composites that are being considered to give all the micronutrients in the proper amounts through "Smart" delivery methods [42].

Nanotechnology for precision agriculture

Precision farming is commonly acknowledged to be a farm management system that relies on technological advances and information that identifies, analyses, and manages fluctuation within fields by performing all crop production techniques in the proper locations, at the proper times, and in the proper ways for maximum profitability, environmental stewardship, and safeguards of the farmland. A systems-based methodology to farming called "precision agriculture" aims to maximize the efficiency of agricultural resources. The application of nanomaterials in precision farming lowers costs and labor requirements, boosts productivity, and promotes ecologically friendly expansion. The innovation of nanosensors to gauge and track agricultural production and soil properties, nutrient depletion, oxidative stress, epidemics, and the admittance of agro-chemicals into the surrounding would be helpful in the improvement of soil and plant health [51]. Nanosensors are employed to track the timings of crop harvesting, predict the health status of crops and also determine the chemical and microbial contamination of crops. Plants equipped with various nanosensors help in scheduling irrigation and crop inputs based on crop demand. A mobile sensor helps to predict the various stresses and accordingly management can be scheduled [53]. However, given the substantial literature on this subject, the persuasive implementations of nanosensors, particularly in field research, are unexpectedly lacking, opening up a novel avenue for coming future investigation.

Challenges of nanotechnology in agriculture

Considering a major breakthrough in exploring probable applications for nanotechnology in farming, there are still a lot of hurdles regarding the implication of nanoscience that must be handled in the nearest time before this technology acts as a revolution in the field of agriculture. Production of nanomaterials in sufficient volume with standard size of Nanoscale along with acceptable standards is quite costly and technical and requires a machined infrastructure equipped with technical hands. Concerns regarding the accumulation of fabricated nanoparticles and their potential infiltration into the food supply chain are raised by the accelerated development of nanotechnology [54]. The use of nanotechnology imposes threats to ecological stability by using toxic nanoparticles and acts as a risky element for human health. The execution and promotion of nanomaterials options in farming are being hindered by concerns about the acute toxicity on the health of individuals and the environment during the manufacturing, trucking, and managing of nanomaterials as well as by the inconsistent worldwide surveillance and regulation policies [55]. Therefore, there is a need to explore the area of research in nanotechnology with efficient regulation of policies for sustainable development of agriculture in the future.

Conclusion

Ensuring food security for a huge population in the era of climate change is one of the biggest obstacles for agriculture scientists. The field of nanotechnology paved the way for the sustainable development of agriculture by using various nanomaterials. The use of nanofertilizers, enhances the nutrient use efficiency by slow and controlled release of nutrients into the soil and thereby crop growth can be increased. Nanosensors provide the real-time status of cultivated crops and therefore farmers can schedule their farming activities in the field in advance. Efficient utilization of resources through the invention of nanotechnology lowers the cost of production. The integration of nanotechnology with genetic engineering provides an efficient system of gene delivery into the host cell. With lowered farming hazards, the promise of nanomaterials inspires a sustainable green revolution. Furthermore, there remain a lot of unknowns regarding the toxicants, acceptable threshold, and absorption capacity of various nanomaterials. In the future, more research is necessitated vitally to comprehend the behavior and outcome of changed farm produce as well as their interactions with biological macromolecules found in living systems and surroundings.

Conflict of interests

The authors declare that they have no conflict of interest.

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