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The Significance Of Nanomaterials In Enhancing Soil Microbial Communitya Short Review

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Abstract

A severe threat to agricultural output and sustainability are global problems including soil erosion, contaminants, and agricultural productivity loss brought on by urbanization and agricultural expansion. Many technological advancements are being used to improve the quality of contaminated soils or purify contaminants in the soil, but they haven't been able to restore or improve the condition of the soil to the desired levels because they are expensive, impractical, or, to a lesser extent, require a lot of labour. Recent developments in nanotechnology promise to raise crop yields and soil quality indices while maintaining environmental sustainability. It has been discovered that the existence of nanomaterials (NMs) within soils may influence or enhance the efficiency of rhizosphere microbes or farming crucial microbes, allowing the access of nutrients to crops and improving the functioning of root systems as well as crop growth in general, creating up an opportunity for the enhancement of soil health. It could be useful to assess nanotechnology in order to learn more about the actual utilization of NMs for enhancing soil health.

Keywords: Agricultural expansion, productivity, soil health, nanotechnology, microbial community.

Introduction:

Unfavourable agroclimatic circumstances have the potential to worsen in the future, which will surely lead to an increase in the number of pressures that will negatively affect the effectiveness of agriculture and soil quality. With a number of actions that can help in order to reduce changing conditions, the soil is a vital component of a natural system that sustains plants and animals. Long-term food security depends on fertile soils (Rajput et al., 2022). However, due to climate change and ineffective farming practices, food security continues to be a major problem in many developing nations. Increasing soil productivity, enhancing reproductive health, improving crop adaptability and tolerance, and making optimal use of agrochemicals are only a few of the significant challenges the agriculture sector currently faces. As a result, there has been a surge in the use of nanotechnology in agriculture over the past few years. Because it has been demonstrated that nanomaterials (NMs) have a direct impact on soil organism productivity, if the application procedure is optimized, they may promote plant development by enhancing the physical and chemical features of the soil. By promoting soil enzymes, the application of nanotechnology enhanced nutrient transport and soil fertility (Zaho et al., 2021). The relationship between NMs and bacterial colonies in the rhizosphere can improve soil health and crop development. The usage of NMs-based goods with industrial coatings, such as nano-fertilizers, which benefited the community of soil bacteria, is one cause of NMs' predominance in the rhizospheric region (Chaudhary et al., 2021). Other factors include changes in the rhizospheric microbiome and plant growth, yield, and yield quality. However, a review found that adding NMs to the soil ecosystem has an impact on the rhizosphere's activity and soil structure (Rajput et al. 2018, Khanna et al. 2021).

Global issues like soil deterioration and contaminants brought on by urbanization and agricultural expansion put productivity and sustainability in agriculture in danger. In order to increase soil health, technology has failed due to expense, labour demands, and practical limitations. Opportunities to improve crop yields, soil health, and ecological balance are presented by the development of nanotechnology. By examining them, we can discuss more about how nanoparticles are used to enhance soil health.

Nanoparticles: Based on recent studies, nanoparticles are made of the element carbon, metal, alloys of metals, or biological material and vary in size from one to one hundred nanometers. The nanoparticles have specific physical, chemical, as well as biological properties. Carbon nanotubes, small fibers, and electrochemically active fullerenes are a few recently developed and utilized incredibly sensitive biological sensors.

By enabling soil analysis, biochemical sensing, and nutrient delivery with greater mechanical strength, nano sensors improve water management, appropriate applications, and fertilizer delivery in agriculture. The impacts on non-target plant tissues and low levels of the chemical in the environment can be considerably reduced with the use of target-specific nanomaterials. Because they have a larger surface area and different quantum characteristics at this scale than their bulk counterparts, nanomaterials exhibit distinct optical, magnetic, electrical, chemical, and other aspects.

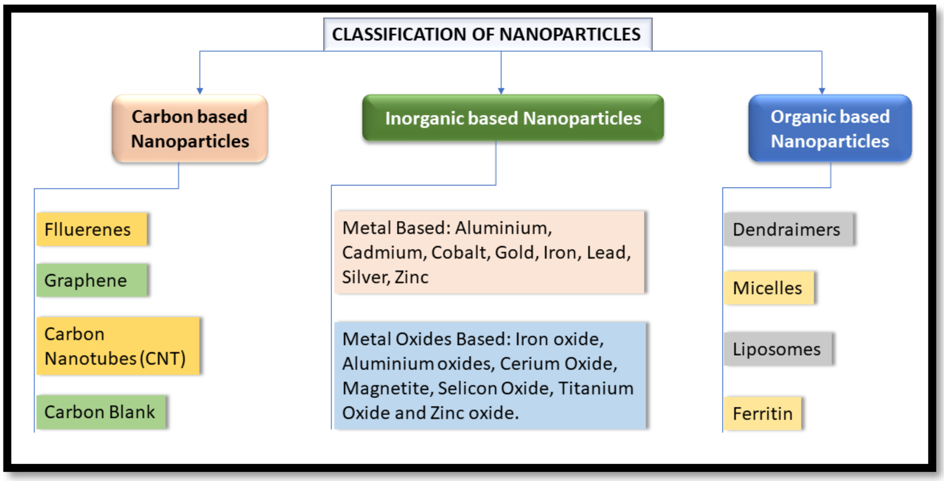

Fig 1: Classification of Nanoparticles

Production of Nanomaterials: Diverse nanomaterials can be produced by specific synthetic processes, such as those used to make coverings, dispersions, or combinations. It is claimed that ideal production and reaction conditions are necessary to produce such size-dependent particle properties. However, particle size, chemical makeup, crystallinity, and form are affected by temperature, pH level, chemical makeup concentration, and surface modification techniques. In both fundamental research and a variety of real-world applications, these methodologies make use of nanoparticles to investigate the unique properties of nanomaterials. The "top-down" and "bottom-up" methods are the two basic techniques for producing nanoparticles and nanomaterials. The "top-down" method mechanically crushes the raw material using a milling process. In the "bottom-up" design, structures are produced through chemical processes (Figure 2). Therefore, when selecting a particular approach, consideration is given to the quantity of chemical makeup and the necessary characteristics of the nanoparticles (Khan et al., 2019).

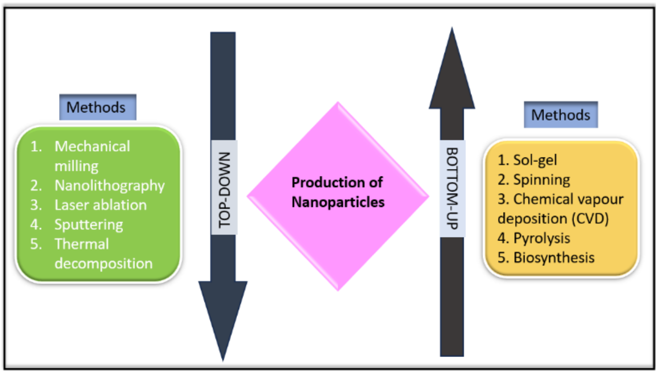

Fig 2: Procedure of Nanomaterial Production

Nanoparticles in Restoration of Soils: The nutrient cycle, carbon conversions, soil composition maintenance, and organic-carbon mediated domains such as the fluid, solid, and volatile phases of soil have all been found to significantly affect soil quality and functionality health. Since interactions between organisms and soil creatures are thought to be the main factor affecting soil health, NMs app places that might boost these effects may lead to gains in fertilization, soil health, and productivity.

It is possible to restore degraded soil by the use of a variety of cultivation methods and soil-health-enhancing additives, which helps to build a more climate-resilient farming system by enhancing the metabolic functions of soil microbes and animals. Major effects are caused by the soil characteristics on which crops are cultivated. In this situation, soil stress factors that can hinder plant performance include salt, dryness, acidity, inadequate nutrient availability, inadequate root region temperature, and soil biota functioning (Rajput *et al.*, 2021).

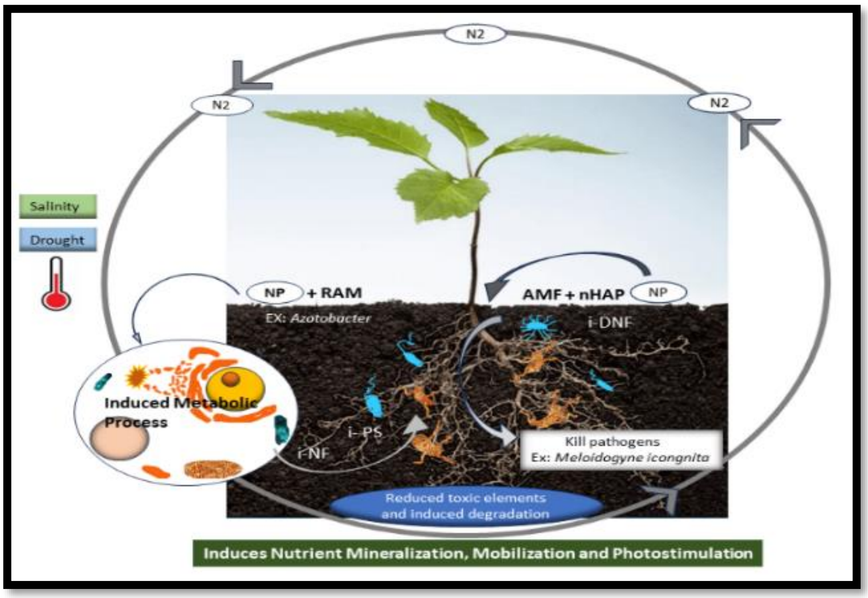

Fig 3: By bolstering root-associated microbial activities, improving nutrient cycling, and promoting plant development under unfavorable environmental conditions by i-NF, i-DNF, and NP processes, nanotechnology improves phytostimulation.

Nanotechnology-based Soil Microbes Management towards Improving Soil Quality: The phrase "plant microbes" describes the total bacterial community that is found in the aerial portions of plants, including the surfaces of the leaves (phyllosphere), the outermost layer of the roots (rhizoplane), the portion of the rhizosphere, and the interior of the plant's mechanism, i.e., the endosphere. In order to alter the bio-physicochemical characteristics of soil, it is preferable to combine rhizospheric bacteria, biological material in

the soil, plant excretion from roots, and NMs. This is because the NM surface can promote nutrient mobilization and degradation through several kinds of interconnected mechanisms.
These studies provided evidence that NMs may be used as efficient methods for reducing soil pH and improving the movement of nutrients and soil quality. NMs can boost Phyto-stimulation by affecting food delivery, carbohydrate, fatty acid, and amino acid synthesis, raising the generation of phytohormones, and changing the regulation of genes, antioxidant activities, and other processes. With the aid of siderophores, some elements including Cu, Zn, and Mn, along with mineral stages are capable of being sedimented and degraded more quickly. Due to the high proportion of NMs and the mobilization of the siderophore during the metabolism of the Fe-doped, the toxicity of the Fe was significantly reduced.

Nano-materials as Nano-fertilizers: Nanomaterials offer thermal stability, constrained dispersion, and adjustable porosity for effective fertilizers in agriculture. These unique methods boost use efficiency, reduce nitrogen loss, and minimize environmental impact as compared to conventional chemical fertilizers. Nano fertilizers are collected from various vegetative or reproductive sections of the plant utilizing a range of chemical, physical, mechanical, or biological procedures in order to boost soil reproducibility, efficiency, and the quality of agricultural output. NFs, or nanoparticles, serve as carriers for conventional fertilizers and give essential nutrients to improve agricultural plants. They improve absorption, nutrient intake, and efficiency while reducing eutrophication-related issues including nitrogen losses. These nanoparticles are more reactive and may permeate soil and plants more effectively due to their smaller size and higher surface area-to-volume ratio. Degradation of soil health is caused by a number of causes, including the careless application of agricultural inputs like fertilizer and other agricultural toxins, the decreasing supply of water supplies, and the uneven distribution of meteorological conditions that lead to low input utilization efficiency.

Table 1: The Nanomaterials used as Nano - fertilizers

Nanomaterials	**Functions**
Carbon nanotubes	**Germination of seed**
Nano -nutrients	**Plant/ animal/human nutrition**
Nano pesticides	**Plant protection**
Nanoscale carriers	**Efficient delivery of fertilizer and pesticides**
Nanosensor	**Detection of nutrients and contaminants**

Nanotechnology in Promoting Plant Development by Decreasing Soil Toxicity: - By cultivating bicolor, Se-based NMs, the high-temperature stress is lessened. The bacteria *Brevibacterium frigoritolerans, Bacillus thuringiensis, and Bacillus velezensis* are just a few of those that have been found to reduce NaCl stress by supplying essential nutrients through root secretion. Combining Si-Zn NMs with microorganisms that promote plant development might lessen the detrimental impact of salt on plant development. Different variety of instances of both abiotic and biotic challenges that can have an influence on plant performance and directly on cultivation include salinity, compaction, pH value, improper root region temperature, access to nutrients, soil types, and the efficiency of the soil biota (Rajput et al.,2021).

Salinity Stress: The likelihood of successful and outstanding agriculture is going down due to the rising salinity of soils around the world. A nutritional imbalance, reactive oxygen species (ROS), and toxicity to cells are all results of stress, which is brought on by salt excess. Plant transmembrane malfunction and cellular metabolic inefficiency are influenced by these environmental factors. These findings suggest that agricultural methods need to be enhanced in order to satisfy the demands of more people (Chauhan et al., 2022). The plant will accumulate organic chemicals including glycine betaine, proteins, glucose, quaternary ammonium compounds, as well as polymers during the process of osmoregulation, decreasing its osmotic capacity even more. When combined with bacteria such as *Brevibacterium frigoritolerans, Bacillus thuringiensis, and Bacillus belenenses,* NMs significantly increased growth metrics such as leaf-relative water content, chlorophyll content, leaf-photosynthesis rate, stomatal conductance, and tuber production. Plant growth, biological reactions, irrigation rate, intrinsic elements, and leaf abscisic acid concentrations all rose as a result.

Drought Stress: -

A significant environmental element that slows plant development and reduces plant production is drought stress (Kumari et al., 2018). By reducing oxidative stress, increasing photosynthetic enzymatic activity, and other factors, nano fertilizers effectively outperformed control plants (2000 mg kg1).

Availability of Nutrients: -

Effective pesticide methods for getting into plant cells, delivered by spraying, irrigation systems, or furrow water supply, leading to the loss of nutrients or excess nutrients, are necessary for both accurate agriculture as well as sustainable crop yields. It has been demonstrated that using NFs enhances the bioavailability and nutrient uptake by crop plants (Khan et al., 2017). According to studies, the capacity of zeolite-based nano fertilizers to gradually deliver nutrition to agricultural crops increases the crop's availability of nutrients during the growing season and reduces the elimination of nutrients due to breakdown, leaching, the removal of n(nitrogen), and soil fixation. For the growth and nutritional availability of O. sativa, a study looked at the soil characteristics of sandy soil, silt loam, along with silty clay loam. TiO2-based nanoparticles (NMs) increased plant matter, diameter, and photosynthetic pigment levels; Ca, Fe, and P served as significant nutrients.

Nanomaterials	Amount	Function
CuO NM	500mg/kg	Stimulate root exudation under hydroponic feeding conditions, and increase soil pH in acidic soil.
TiO_2 and Fe_3O_4 NM	50-200mg/kg	By bringing the pH of salinity or alkaline soil down and mobilizing nutrients, you can encourage plant root exudation.
Fe_2O_3 NM		Increase microbial siderophore production.
TiO_2 NM		Detect the change in the microbial population.
Se NM		Interact with the OH groups of exopolysaccharides to create fresh C-O-Se bonds, and improve antioxidants' properties against superoxide anion radical and ABTS radical cations.
ZnO NM	100mg/kg	Boost up photosynthetic enzymatic machinery to mitigate the impact of salt stress.
SiO_2NM		Lessen the stress brought on by water storage.

Conclusion

Agrochemicals including fertilizers, insecticides, fungicides, and herbicides pose serious threats to the sustainability and health of the soil. These concerns, such as residues on food products and heavy metal contamination in water, can be decreased with proper input management and control. By affecting rhizosphere bacteria and enhancing nutrient supply to plants and organisms, nanomaterials (NMs) can enhance soil health. NMs can improve agricultural production and soil health by displaying root structures and crop growth. Modern agriculture's quality and yields can be improved by the use of high-tech agricultural systems that employ environmentally friendly, designed smart nanotools**.**

Possible Outcomes

This review highlights the importance of food security and health in addressing global soil health degradation. The inclusion of microbes (microorganisms) can help clean up contaminated soils by integrating nanotechnology (NMs) through their metabolic processes. This approach has the potential to increase soil health and agricultural output, paving the way for novel nanotechnologies with biological and agricultural applications.

Future Prospect

- In the future, nanotechnology could also enable objects to harvest energy from their environment.
- Nanotechnologies help to improve soil quality and food production.
- If we use nanotechnology in the future, we can decrease the use of chemical pesticides.
- It can yield a new generation of nanomembranes for the separation of soil contaminants by removing and reducing soil contaminants.

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