



Role of Nanotechnology in Soil and Plant Nutrition

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ABSTRACT

Nanotechnology is an emerging concept in present day agriculture for improving nutrient management efficiency. Conventional fertilizers have played a major role in increasing crop production, but processes like leaching, volatilization can result in considerable losses and environmental problems. Thus, nanotechnology serves an alternative approach that can improve availability of nutrients and plant uptake. In recent studies, nanomaterials are used for monitoring soil conditions and detecting nutrient deficiencies but their performance depends more on the soil properties, type of crop and method of application. Concerns regarding their long-term environmental fate, cost and field-scale performance still need research. Thus, nanotechnology should be considered as an alternative component of integrated nutrient management rather than an option for replacing the usage of conventional fertilizers.

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1. INTRODUCTION

Balancing growing demand for food and ensuring soil fertility still remains as a challenge in agriculture. Conventional fertilizers helps in improving crop productivity but considerable nutrient losses can occur through leaching and surface runoff (Mehta *et al.*, 2024; Ramalakshmi *et al.*, 2025). Nanotechnology helps in improving nutrient-use efficiency by nanomaterials which has specific property of high surface-area-to-volume ratio. This property helps in interaction with soil, nutrients, microorganisms and plant tissues. Development of nanofertilizers will increase availability of nutrients (Channab *et al.*, 2024). It also include nanosensors for detecting deficiency of nutrients. In order to determine

the long-term effectiveness and environmental safety, further studies are needed (Couto *et al.*, 2025).

2. NANOTECHNOLOGY AND SOIL NUTRIENT MANAGEMENT

Plants obtain most of the nutrients from soil but the availability of nutrients in soil is affected by various factors like soil pH, SOM, moisture content and microbial activity. Through targeted nutrient delivery systems, nanotechnology will help to overcome these limitations. Nano-fertilizers are fertilizers in which nutrients are supplied in nanoscale form. Controlled nutrient supply to the rhizosphere can improve nutrient usage and reduce losses compared to application of conventional fertilizer (Mehta *et al.*, 2024;

Pragnya *et al.*, 2026a). Based on the composition of nanoparticles, they may interact with soil, organic matter and microorganisms.

3. ROLE OF NANOTECHNOLOGY IN PLANT NUTRITION AND NUTRIENT UPTAKE

One of the most important applications of nanotechnology is improving the discharge of nutrients to plants whereas conventional fertilizers release nutrients into the soil, then the plants absorb them through their roots. Nano-enabled formulations provide a more controlled release of nutrients near the rhizosphere which contain containing N, P, K and micronutrients such as zinc and iron have been found for enhancing nutrient status of plant. This approach can be advantageous in terms of nutrient-use and decreasing the amount of nutrient being unused in the soil. (Channab *et al.*, 2024; Pragnya *et al.*, 2026). Nanomaterials are able to reach plants by different pathways such as root or foliar application. Recent studies also revealed that movement of nanomaterials through apoplastic and symplastic pathways (Couto *et al.*, 2025). Particle size, surface properties, chemical composition and plant species can affect absorption and movement within the plant. This serves as an option for micronutrient uptake though they are required in small quantities their deficiency can affect crop growth and plant nutritional status (Dai *et al.*, 2024).

4. LIMITATIONS AND ENVIRONMENTAL CONCERNS

Lack of adequate long-term field information will be a major limitation. Nanoparticle behaviour can be influenced by type of soil, temperature, moisture content, organic matter and microbial communities. These nano-based fertilizer has to be tested prior with respect to crop response and also its effect on soil ecosystem because soil microorganisms are essential for nutrient cycling, organic matter decomposition and overall soil health. The after effects of nanomaterials is also a concern because they can undergo transformations in soil and plants, which may change their mobility, bioavailability and toxicity. Wei *et al.* (2024) in his study mentioned regarding transformation of nanoparticle and their effects on plants. Higher cost, ease of availability, farmer awareness are other challenges. Recent research therefore reveals that there is need for standardized testing, regulatory frameworks and long-term field evaluation before adoption at large scale (Couto *et al.*, 2025).

5. FUTURE SCOPE

1. In future the scope of nanotechnology in soil and plant nutrition adheres to developing crop-specific, soil-specific nutrient delivery systems.
2. Development of biodegradable and biologically synthesized nanomaterials.
3. Focus has to be more on long-term field experiments rather than on laboratory studies.
4. As part of integrated nutrient management, there is chance for combining nanofertilizers with biofertilizers and organic amendments.

6. CONCLUSION

Nanotechnology offers a new approach in managing fertility of soil and plant nutrition by enhancing the way nutrients are discharged, used and absorbed. Nano fertilizers, nano-enabled micronutrients and nano sensors have the potential in improving nutrient-use and reducing unnecessary nutrient losses. At the same time, their performance is strongly influenced by soil conditions, crop species and formulation and application rate. The technology is promising, but it is at developing stage and its long-term environmental and economic implications require proper assessment. Currently, nanotechnology should be considered as an additional technology rather than replacing conventional fertilizers completely.

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