

# Harnessing Nanotechnology and Artificial Intelligence for Precision Agriculture in Smart Cities

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**Abstract** This short review article, titled "Harnessing Nanotechnology and Artificial Intelligence for Precision Agriculture in Smart Cities," delves into the fusion of nanotechnology, artificial intelligence (AI), and precision farming to drive sustainable agriculture in alignment with the United Nations' 2030 Sustainable Development Goals. It spotlights the transformative potential of nanotechnology, encompassing both natural and man-made nanoparticles, to enhance crop growth and mitigate environmental impacts. Nano-fertilizers and nano-pesticides are unveiled as promising strategies for optimizing nutrient availability while minimizing harm to ecosystems. The integration of AI into precision farming, supported by cutting-edge nanoinformatics, emerges as a linchpin for the establishment of safe and sustainable agricultural practices, enabling smart and resilient agriculture. However, as this integrated approach accelerates progress and provides vital insights for addressing contemporary agricultural challenges, it also underscores the paramount importance of scrutinizing nanotechnology's effects on soil microbial communities and plant health. The phytotoxicity of nanoparticles, contingent upon size, concentration, and plant species, necessitates further examination. In conclusion, this comprehensive article calls for interdisciplinary collaboration to fully exploit the potential of nanotechnology and AI in transforming agriculture, all the while ensuring the preservation of environmental and human health and advancing the global sustainability agenda for agriculture in smart cities by 2030.

**Keywords:** Nanotechnology, smart cities, AI, and Precision farming, biological properties

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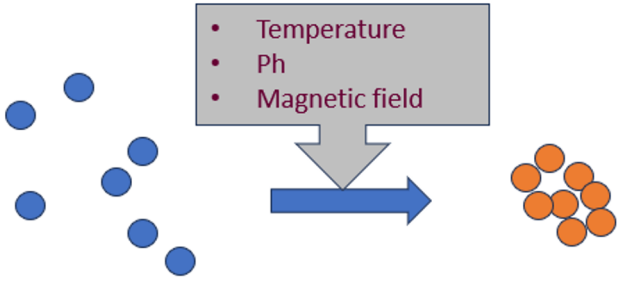
## 1.Introduction

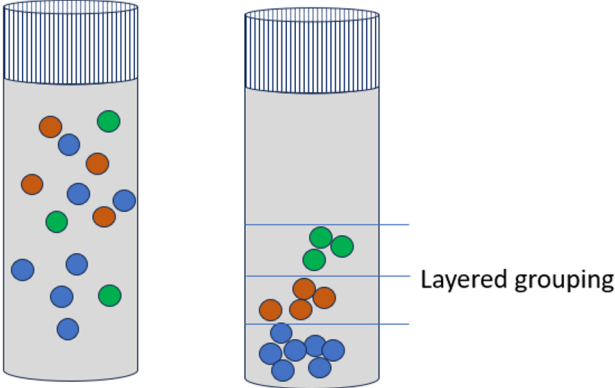
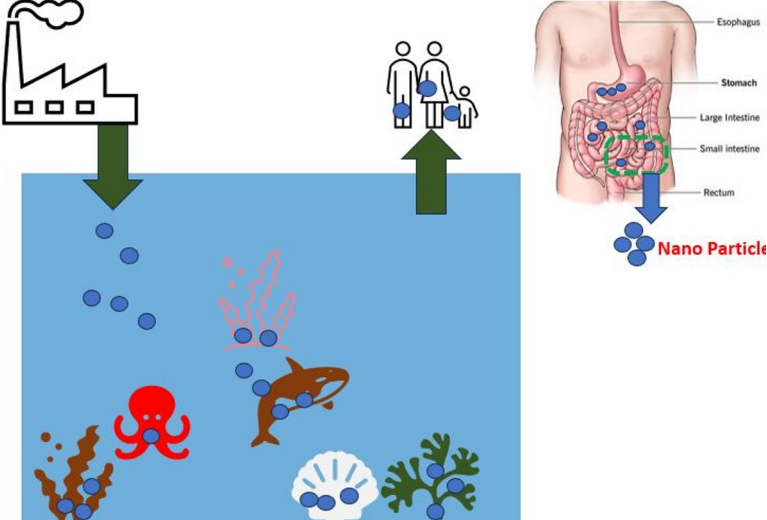
Researchers and agricultural specialists have dedicated extensive efforts to advancing crop enhancement, aligning their focus with the United Nations' Sustainable Development Goals for 2030 [1]. They place significant emphasis on improving both the quality and quantity of crops. With advancements in various technologies, including nanotechnology, artificial intelligence (AI), and the rapid progress in technologies related to the concept of smart cities, there is a growing potential to address existing barriers and promote sustainable and resilient agriculture in alignment with the UN's 2030 agenda. One important aspect of UN SDG's is ensuring food security through goal number one, goals eight, nine, ten, eleven and twelve. These goals can be empowered through the integration of nanotechnologies, AI, and agriculture [2]. Here in this short review s article, we study the various advances in Nanotechnologies, AI, and Precision farming. We present the challenges and opportunities that the researcher community might find useful to carry out future research.

## 2.Developments in Nano Technology

When one says nanotechnology, it usually implies that one is looking at the dimensions of 1-100 nano meter ( $10^{-9}$ m). It is at this scale that the properties of these materials differ from their larger scale counter parts in terms of – chemical, thermal, physical and biological properties. The study of these particles with the help of high-precision scientific equipment has led to the development of nano devices, nano electronics etc [3]. For the sake of discussions lets broadly classify the nano particles into two categories- (a) Natural Nanoparticles (NNP) – these exist in nature and (b) Man-Made Nano particles (MNP) that are made by humans in a lab. The interconnected process through which the nano particles impact the environment around them is listed in table 1. It has been found through extensive research that nanoparticles, their origins notwithstanding have the same effect on the environment around them and interact with same processes[4].

Table 1. Processes - Nano particles

Processes	Natura l Nano Particl es	Man Made Nano Particl es
 <p style="text-align: center;">Aggregation of NPs</p>	✓	✓

<p>Sedimentation</p>  <p>Sedimentation of NPs</p>	✓	✓
<p>Bioaccumulation</p> 	✓	✓
	✓	✓

<p><b>Biomagnification</b></p> <p>The diagram illustrates the process of biomagnification. It starts with a factory emitting particles into the environment. These particles enter the ocean and are taken up by various organisms like an octopus, a shark, and a clam. A human figure is shown consuming these organisms. An anatomical diagram of the human digestive system (Esophagus, Stomach, Large Intestine, Small Intestine, Rectum) shows the initial concentration of particles, labeled as <b>Bioaccumulation</b>. A large arrow labeled <b>TIME</b> points to a second anatomical diagram showing a much higher concentration of particles, labeled as <b>Bio Magnification</b>.</p>		
<p><b>Dissolution</b></p> <p style="text-align: center;"><b>Dissolution of Nano Particles</b></p> <p>The diagram details the factors influencing the dissolution of nano particles. It is organized into three main sections:</p> <ul style="list-style-type: none"> <li><b>External Factors:</b> Includes Exposure Media and Storage Conditions.</li> <li><b>Surface Chemistry Effects:</b> Includes Exposed Plane, Surface Chemistry, and Crystallinity.</li> <li><b>Size and Surface Area Effects:</b> Includes Aggregation, Shape, Surface Area, Composition, and Size.</li> </ul>	✓	✓

Chemical and Physical Alterations	✓	✓
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### Development of Nanotechnology specific to agricultural applications

Humanity has developed new technologies to farm over the past century, we no longer follow the practices that our ancestors used to follow. The advancement of nanotechnology has brought its effects on agricultural practices. These are classified in table 2.

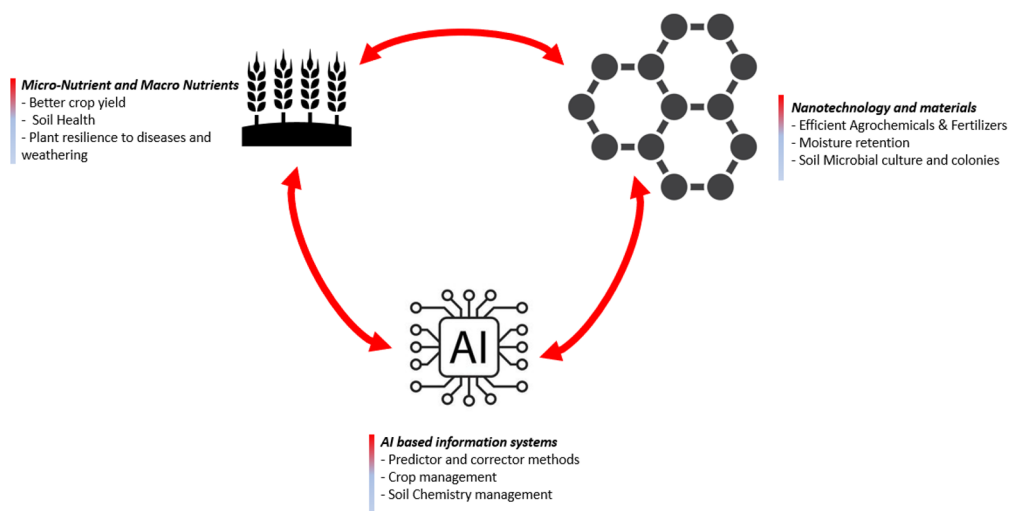
Technology	Significant advances
Nano fertilizers	- Use of nano fertilizers was suggested here for addressing the scenario of poorly bioavailable nutrients in the soil - Zinc and phosphorous [6].
	- Use of growth promoters such as TiO <sub>2</sub> was suggested in [7].
	- Likewise, the carbon nanotubes were studied and it was found that there is a noticeable rise of approximately 17% in ryegrass ( <i>Lolium perenne</i> ) root length when exposed to 2000 mg/L of MWCNT (ryegrass), in comparison to the untreated controls [8].
	- The impact of citrate-coated water-soluble carbon nanotubes (ws-CNTs) on chickpea ( <i>Cicer arietinum</i> ) was investigated after a 10-day exposure to a concentration of 6.0 mg/mL. Internalization of the CNTs was visualized through electron microscopy. The authors postulated that, once present within the vascular tissue, ws-CNTs formed an 'aligned network,' leading to increased water uptake efficiency and directly contributing to the observed enhancement in plant growth [9].
	Examined the impact of pristine multi-walled carbon nanotubes (MWCNTs) with a diameter of approximately 30 nm and oxidized-MWCNTs (o-MWCNTs) with a diameter of around 20 nm on mustard ( <i>B. juncea</i> ) at concentrations ranging from 2.3 to 46.0 µg/L. Found that both o-MWCNTs and pristine MWCNTs enhanced germination, root growth, and shoot growth. Specifically, o-MWCNTs, at the lowest concentrations, resulted in higher germination rates (99% in 22 days) compared to pristine MWCNTs (94% in 26 days), although germination rates decreased at higher MWCNT exposure levels. In the first 5 to 10 days of exposure to the lowest concentrations, both root and shoot lengths increased by 2.5x and 1.6x, respectively, compared to untreated controls [10].
	By one research group it was found that exposure to 50 µg/mL of single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) led to a 75% and 110% increase in the total fresh biomass of tomato seeds, respectively, in comparison to activated carbon and graphene [11].
	Wang et al in the year 2012 evaluated the impact of oxidized multi-walled carbon nanotubes (o-MWCNTs) with lengths ranging from 50 to 630 nm on wheat plant development and physiology. Concentrations of 10 to 160 µg/mL were used, and the results

	<p>showed that after 7 days of exposure, there was faster root growth and increased vegetative biomass. However, there were no significant differences in seed germination and stem length compared to the control group. The study also examined cellular-level changes, revealing that o-MWCNTs could penetrate the cell wall and enter the cytoplasm of the plant's roots. In particular, the cell length in the root zone increased by 1.4-fold when exposed to 80 µg/mL of o-MWCNTs, and there was a concentration-dependent increase in dehydrogenase activity. These findings indicate that o-MWCNTs can significantly enhance cell elongation in the root system and increase dehydrogenase activity, leading to faster root growth and higher biomass production. [12].</p>
Nano Pesticides	<p>The study investigated the larvicidal properties of water-dispersible nanopermethrin. Nanopermethrin, with a mean particle size of 151±27 nm and an amorphous structure, was created using a solvent evaporation method from an oil-in-water microemulsion. Larvicidal tests on <i>Culex quinquefasciatus</i> demonstrated that nanopermethrin had a significantly lower LC50 (0.117 mg/L) compared to bulk permethrin (0.715 mg/L), suggesting its potential as a potent and selective larvicide for <i>Cx. quinquefasciatus</i>. [13-15].</p> <p>Anjali et al nanoemulsion was developed using neem oil and the non-ionic surfactant Tween 20. The nanoemulsion had a mean droplet size ranging from 31.03 to 251.43 nm, with the smallest droplet size (31.03 nm) achieved at a 1:3 ratio of oil to surfactant. The resulting nanoemulsion was stable. As the concentration of Tween 20 increased, the droplet size decreased and the viscosity of the nanoemulsion increased. The larvicidal effect of this nanoemulsion was tested against <i>Culex quinquefasciatus</i>, and the lethal concentration (LC50) was determined for different oil-to-surfactant ratios. The study found that the nanoemulsion with a droplet size of 31.03 nm exhibited effective larvicidal properties, with an LC50 of 11.75 mg/L. This nanoemulsion could be a promising choice as a potent and selective larvicide for controlling <i>Cx. quinquefasciatus</i>, and it represents the first report of a neem oil nanoemulsion of this specific droplet size [16].</p> <p>Nanosilica, with sizes ranging from 5 to 15 nm, is versatile, used in pharmacy as a booster and enterosorbent. It can interact with cells, causing membrane changes, and has applications in dental composites. The high surface area and surface charge of nanoparticles make them suitable for catalysis. Additionally, nanosilica is explored as a novel nanobiopesticide, effective against various agricultural insect pests and ectoparasites. This research showcases the potential of nanosilica in various fields, from medicine to agriculture [17].</p>
Nano Technology for soil nutrition	<p>Researchers aerosolized engineered nanoparticles and applied them to watermelon plants. Smaller nanoparticles (under 100 nm) showed enhanced penetration and transport within the plants, reaching roots and shoots more effectively. Aerosolized magnesium oxide (MgO) nanoparticles exhibited no leaf damage, while larger iron oxide (Fe<sub>2</sub>O<sub>3</sub>) particles (94 nm) led to leaf damage due to stomatal blockage. Crystal characteristics of the nanoparticles were identified,</p>

	<p>and the study outlined a potential transport pathway through stomata and the phloem system. These findings highlight the importance of nanoparticle size in plant foliar uptake and its impact on plant health [18].</p>
	<p>Aerosol-based foliar delivery of 30-80 nm gold nanoparticles to watermelon plants demonstrated that nanoparticles can be taken up through direct penetration and transported through stomata. Evidence of nanoparticle translocation from leaves to roots suggested they travel via the phloem mechanism. Uptake, accumulation, and transport were influenced by nanoparticle shape, application method, and plant tissue characteristics. This research showcases the potential of nanotechnology to improve nutrient delivery in agriculture, enhancing sustainability, yields, and environmental outcomes while reducing ecosystem and health risks associated with traditional agrochemicals [19].</p>
	<p>The article discusses titanium (Ti) and titanium dioxide nanoparticles (TiO<sub>2</sub>NPs) in plants. It outlines that Ti absorption through plant roots is not well-documented, and it may interact with iron uptake mechanisms. Foliar application of Ti allows absorption through leaves. TiO<sub>2</sub>NPs applied to seeds can enhance germination, but negative effects may occur due to penetration. Ti is primarily retained in plant roots, while translocation from leaves occurs via the phloem. The presence of Ti-binding proteins is hypothesized. Under limited iron supply, Ti application may improve iron uptake, enhancing plant growth. Ti also exhibits antimicrobial properties, potentially suppressing crop diseases via photocatalysis. Further research is required to elucidate these interactions comprehensively. [20].</p>

### 3.Integration of AI into Precision Farming

Suggestions on the utilization of electronics, and information technologies in farming is not a new concept and has been proposed nearly 4 decades ago [21]. In fact, several such IoT based smart agriculture systems are available in commercial forms- vertical farms, hydroponics/aquaponics [22-24]. One article that suggests the usage of AI and nanotechnology, highlights the growing importance of science and regulation in ensuring the safety of nanotechnology as it continues to advance and be applied in various industries and products. It points out a gap between the assessment of risks to human and environmental health from nanomaterials, which is partly due to differences in exposure pathways. With the emergence of agricultural nanotechnologies, there is a pressing need to address these complex issues through a transdisciplinary approach, incorporating the One Health concept. This approach aims to support the sustainable development of nanotechnologies by considering their impact on human health, the environment, and agriculture simultaneously [25].



*Figure 1. integration of AI and Nano technology for smart and precision farming*

The combination of AI and nanotechnology in precision agriculture has the potential to speed up progress and provide valuable insights for overcoming current challenges. Nanoinformatics will play a crucial role in investigating the characteristics of nanomaterials used in fertilizers and pesticides. This aims to minimize their impact on soil health, reduce harm to plants, and ensure there are minimal nanomaterial residues in edible plant parts. Furthermore, it will help in understanding and predicting how plants and ecosystems respond to nanomaterials under varying climate and soil conditions across multiple growing seasons. This integrated approach ensures safe and sustainable agricultural practices, drawing from advancements in cheminformatics for drug design [26].

#### 4.Challenges&Opportunities

In this section we discuss the challenges and opportunities that stand in our way for the integration of Nanotechnology with AI for realization of smart agriculture.

Effects on the Microbial community of the soil	<p>Soil quality greatly depends on biological indicators, as soil organisms directly impact processes like organic matter decomposition and nutrient cycling. Engineered nanoparticles (ENPs), used in various industries and entering soils, pose a challenge. These ENPs include metals, fullerenes, metal oxides, complex compounds, quantum dots, and organic polymers. While studies have assessed ENPs' antimicrobial effects on human pathogens and beneficial microbes in controlled settings, little is known about their impact on soil microbial communities in natural conditions. Initial findings suggest that small metal and metal oxide ENPs can harm these communities, although soil organic matter and its components might counteract their toxicity. Understanding these interactions in field conditions is essential [27].</p> <p>There is limited knowledge about the impact of engineered nanoparticles (ENPs) on soil microbes. ENPs might affect soil microorganisms directly through toxicity, alter the availability of toxins or nutrients, interact with natural organic compounds, or interact with toxic organic compounds, potentially amplifying or alleviating their effects [28].</p>
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	<p>Engineered nanoparticles pose several potential risks due to their ability to cause various adverse effects. Firstly, they can disrupt the integrity of cellular membranes, which is essential for the proper functioning of cells. Secondly, these nanoparticles have the potential to destabilize and oxidize proteins, which could impact critical cellular processes. Additionally, they may cause damage to nucleic acids, affecting genetic material within cells. Furthermore, the generation of reactive oxygen species by nanoparticles can lead to cell damage and oxidative stress. Moreover, these nanoparticles can interfere with energy transduction processes, which are essential for the cell's energy production. Lastly, they have the potential to release toxic components, further emphasizing the importance of understanding and managing the risks associated with their use across various applications [29].</p>
Effects on Plants & Crops	<p>The findings regarding the phytotoxicity of various nanoparticles (NPs), particularly Zinc Oxide (ZnO), Silver (Ag), Copper (Cu), and Titanium Dioxide (TiO<sub>2</sub>), present a complex interplay between these NPs and plant growth. ZnO NPs exhibit dual effects on plant growth, showing inhibition in germination and root growth in some cases, but also enhancing growth when providing essential Zn<sup>2+</sup> ions. Ag NPs are commonly used in various applications, but they can induce adverse effects on plants, affecting root and shoot growth and leading to genotoxicity. Cu NPs have been shown to inhibit leaf growth and transpiration while affecting the physiological processes of plants. On the other hand, TiO<sub>2</sub> NPs display a more favorable impact, enhancing photosynthetic activity, improving plant growth, and mitigating stress. The genotoxicity of NPs is closely related to ROS production in plant cells, which can lead to DNA damage, chromosome aberrations, and cell membrane disruption. However, the effects vary depending on the size, concentration, and plant species, making the phytotoxicity of NPs a complex and context-dependent phenomenon. Overall, NPs can have both positive and negative impacts on plant health, highlighting the need for careful consideration when using them in agriculture and environmental applications [30].</p> <p>This review explores the potential threats posed by the toxicity of nanoparticles (NPs) to plants and microbial diversity. It discusses the impact of metal-based NPs on the environment, highlighting that exposure to NPs can reduce soil microbial biomass and enzymatic activity, affecting microbial communities. Furthermore, NPs can cause various abnormalities in plants. The increased use of NPs raises concerns about their effects on beneficial microbial communities, crop yield, soil properties, and human health. This study underscores the need to evaluate the implications of NPs on agriculture, soil ecosystems, and overall environmental health [31].</p> <p>This article provides an overview of the potential environmental impact of increased nanomaterial production, particularly in medical and nanobiotechnological applications. It focuses on the phytotoxicity and regulation of plant growth associated with various nanomaterials. Emphasis is placed on how nanomaterials are transported and localized within plants and their interaction with plant responses. The article also highlights the risks of nanomaterial contamination in the food chain through plants. It discusses the toxic effects of carbon-based and</p>

metal-based nanomaterials on processes like seed germination, root growth, biomass accumulation, and organ development. Additionally, the potential for nanomaterials to regulate plant growth at the molecular level is explored [32].
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## 5. Conclusions

In conclusion, this short review article underscores the promising opportunities for future research in the fields of nanotechnology, artificial intelligence (AI), and precision farming to enhance crop production and advance sustainable agriculture, in alignment with the United Nations' 2030 Sustainable Development Goals. The following conclusions can be drawn from the discussions:

1. **Developments in Nano Technology:** Research in the realm of nanotechnology offers potential breakthroughs in agriculture, including the development of nano fertilizers and nano pesticides. These innovations can optimize nutrient availability, promote plant growth, and mitigate the environmental impact of traditional agrochemicals. The findings presented here emphasize the need for further exploration in this field to refine the application of nanomaterials for sustainable agriculture.
2. **Integration of AI into Precision Farming:** The integration of AI with nanotechnology presents a powerful tool for precision agriculture. The research community can delve into nanoinformatics to comprehend the characteristics of nanomaterials used in agriculture better. Understanding how these materials interact with plants and ecosystems across various conditions and seasons is crucial. This integrated approach can drive safe and sustainable agricultural practices and minimize the risks associated with conventional agrochemicals.
3. **Challenges and Risks:** Research in this area should focus on investigating the challenges and risks associated with the introduction of nanotechnology in agriculture. Soil quality and microbial communities are particularly sensitive to the presence of engineered nanoparticles. Further inquiry is required to assess their impact on these crucial components of agricultural ecosystems. Additionally, research should continue to explore the phytotoxicity of different nanoparticles, taking into account their complex interactions with plant growth.

In summary, the opportunities for future research hold the potential to revolutionize agricultural practices and contribute to global efforts to achieve food security and sustainable agriculture by 2030. This multidisciplinary approach, combining nanotechnology, AI, and precision farming, can pave the way for innovative solutions to the challenges faced by the agricultural sector. It is imperative that researchers, policymakers, and stakeholders collaborate to further explore these opportunities and address the complexities of integrating nanotechnological advancements into agriculture while safeguarding environmental and human health.

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