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NANOTECHNOLOGY AND AGRICULTURAL NANOFERTILIZERS (REVIEW ARTICLE)

Waleed F. Abobatta
Horticulture Research Institute, Agriculture Research center, Giza, Egypt

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Correspondence Email:
wabobatta@arc.sci.eg

ABSTRACT

Due to the adverse effects of continuous climate change on agricultural production and the increased food demand globally, there is an urgent need to use new strategies to improve agricultural production in a sustainable manner and maximize the efficiency of available natural resources. Nanotechnology represents a key tool for the advancement of agriculture with biotechnology, which could be a new management practice that increases the efficiency of agricultural resources and reduces the excessive use of agrochemicals, which pose a serious threat to the environmental system, while also producing healthy and safe food, reducing production costs, and preserving the environment. Nanotechnology includes several tools, including nanomaterials such as nano fertilizers and nano pesticides, in addition to nano-packaging materials, nano-devices such as sensors, nano-robots, and nano-barcode devices. There are three main methods used in the manufacture of nanomaterials, including chemical, physical, and biological routes, the chemical route is the most widespread so far. Nanotechnology is one of the important tools that have a profound impact on agricultural practices to enhance growth and increase crop yield. Nanoparticles, due to their unique properties, provide many benefits, whether in improving the growth and productivity of different crops, reducing the quantities of fertilizers used, reducing the negative effects of climate change on production, or diagnosing diseases in their early stages. Nano fertilizers could be applied as a foliar or soil application, so they are considered one of the most important applications in agriculture due to their numerous benefits.

College of Agriculture and Forestry, University of Mosul.

INTRODUCTION

Agricultural sector provides food products and raw resources for all human activities. In the last decades, agriculture has been subjected to numerous challenges concerning climate change, degradation of cultivated soil, continuous use of agrochemicals, excessive consumption of natural resources, endangerment of various plant and animal species, air pollution, etc. Therefore, looking for new techniques to combat various challenges is urgently required to sustain agricultural production and provide enough food for humanity (Tsoraeva, *et al*., 2020). Moreover, with continuous population increase worldwide, there is more demand for food and other daily requirements, which required duplicate agricultural production to provide

adequate nutritional requirements for humanity from the same available natural resources.

Nanotechnology is the latest scientific revolution that works at the molecular level and changes the physical and chemical properties of materials. Nanotechnology uses modern equipment capable of processing bulk materials and converting them into nanoscales.

The use of frontier techniques such as nanotechnology and precision farming are successful strategies to confront the effects of severe climate changes and growing demand for food globally, in order to increase the productivity of various crops and reduce post-harvest loss rates, which contributes to providing more food security worldwide (Agrimonti, *et al*., 2021).

The use of nanotechnology in the agricultural sector represents a key tool for sustainable agriculture and assists farmers with new practice management systems such as precision agriculture systems, which aim to increase productivity and reduce expenses (Abobatta, 2020). The devices have been used in the manufacture of sensors to assess crop health with high spatial and temporal resolution (Giraldo, *et al*., 2019). For instance, using nanoscale sensors to detect the actual plant requirements of different nutrients, identify pathogens, address the problems facing farmers firsthand, and enhance the efficiency of natural resources, particularly fresh water and cultivated soil.

Nano-robots one of efficient application of nano technology, which play an important role in detecting and diagnosing disease symptoms in plants through scanning, as well as being efficient in diagnosing veterinary disease, and identifying symptoms of insect infestations earlier, which assists in controlling infection with minimum loss (Jha, *et al*., 2015).

The potential applications of nanomaterials are increasing in various fields, such as agriculture, particularly in biotechnology and precision agriculture, due to their unique properties that provide beneficial effects for plants and improve their growth and productivity (Zhao, *et al*., 2020).

Moreover, there are many applications of nanotechnology in agriculture are used on a large scale, such as bioimaging tools, nano-remote sensing, photocatalysis, and nanocarriers for agrochemicals (Neme, *et al*., 2021). Furthermore, nanotechnology is used in the agriculture sector in the synthesis of nanofertilizers, nanopesticides, nanoscale plant growth regulators, the manufacture of nanosensors (Dasgupta, *et al*., 2017), nano barcodes (Kumar, *et al*., 2017), and biotechnology (Singh and Gurjar, 2022).

Nano fertilizers have numerous advantages, as demonstrated in (Table 1), which include increased yield, improved fruit quality, decreased production costs due to fewer applications, reduced consumption of bulk synthetic chemicals, and limited leaching of bulk fertilizers all contributing to increased nutritional efficiency. Additionally, coating seeds with nano micronutrients like Zn and Cu has boosted the survival rate and accelerated seed germination (Prerna, *et al*., 2021; Seleiman *et al*., 2020).

Moreover, many agrochemicals such as microelements and some pesticides could be covered or coating with thin layers of nanoparticles to enhancing their efficiency and facilitate their entry into the plant tissues, in order to reduce the used quantities of bulk agrochemicals (Abobatta, 2018a).

Various substances could be loaded on the nanoparticles, such as pesticides, to form a stable compound that extends the shelf life, facilitates penetration, and improves the efficiency of these materials (Nuruzzaman, *et al*., 2016).

The mechanism of nanomaterials in plant cells, their effects, and the main targeted site are still in their infancy and ununderstood completely.

This review generally exploring the various applications of nanotechnology in agriculture and focuses on future prospects for the use of nano fertilizers.

Synthesis of Nanoparticles

There are three main methods to synthesize nanoparticles :

- Physical route.
- Chemical route.
- Biological or green route .

Chemical synthesis of nanoparticles is considered the most popular, synthesis is according to the chemical characteristics of components and carriers, there are different methods are used (Pourzahedi & Eckelman, 2015). Chemical synthesis of nanoparticles is carried out using several techniques, depending on the chemical characteristics of the components and carriers, as follow:

- The emulsifying solvent first evaporates.
- Evaporation and dual emulsion.
- Adding salt
- Emulsions – Diffusion.
- Sedimentation or solvent displacement.

Grading of Nanoparticles

There is different grading of nanomaterials as follow:

1. Based on synthesis methods (Up to down method & Bottom to up).
2. According to dimension, it is classified as one-dimension nanoparticles, two-dimension nanoparticles, and three-dimension nanoparticles.
3. Synthesis methods of Nanoparticles are by chemical, physical, or biological techniques.
4. Regarding the nanoparticles shapes, Nanotubes increase the ability of materials to penetrate plant cells.

Nanoparticle size is one of the effective factors in the absorption of Nano substances, therefore, preferable using a small size is preferable, and Nanoparticle size ranging from five to 60 nanometers is the acceptable size, while 20 nm range is the proper size for applying to plant cells (Thwala, *et al*., 2021).

Nano technology and agriculture

There are numerous applications for nanoparticles in agriculture that include nano fertilizers, nano pesticides, nano-plant stimulators, preserving cut flowers, anti-

stress, increasing the shelf life of horticultural commodities, particularly leafy and fragile crops, nan coating, nan packaging, and nanosensor in precision agriculture (Abobatta, 2019).

The main components of nanotechnology include nano tools, nano devices, and engineered nanomaterials (Abobatta, 2018a).

Nano-tools and devices are different types of sensors and nano-robots that are used in various operations, such as precision farming tools (Rohrer, 2012). Engineered nanomaterials are materials based on nano-carbon particles, metal nanoparticles, metal oxide nanoparticles, and non-metallic nanoparticles that have unique properties such as a very high surface area (Lowry, *et al*., 2019).

Potentials of nanoparticles in agricultural sector

The unique properties of nanomaterials, such as their high surface area and higher penetration ability, in addition to their potential applications, have attracted more attention in various fields, such as the agricultural sector. Therefore, nanotechnology has an increasing interest in various applications in agricultural systems. Whereas transportation of nanoparticles is a possible pathway for plants to achieve more beneficial effects (Chen, 2018).

Nanoparticles have great potential in the agricultural sector (Figure 1). For instance, nanofertilizers regulate the release of nutrients according to the plant's needs, improving the vegetative growth of plants and fruit quality.

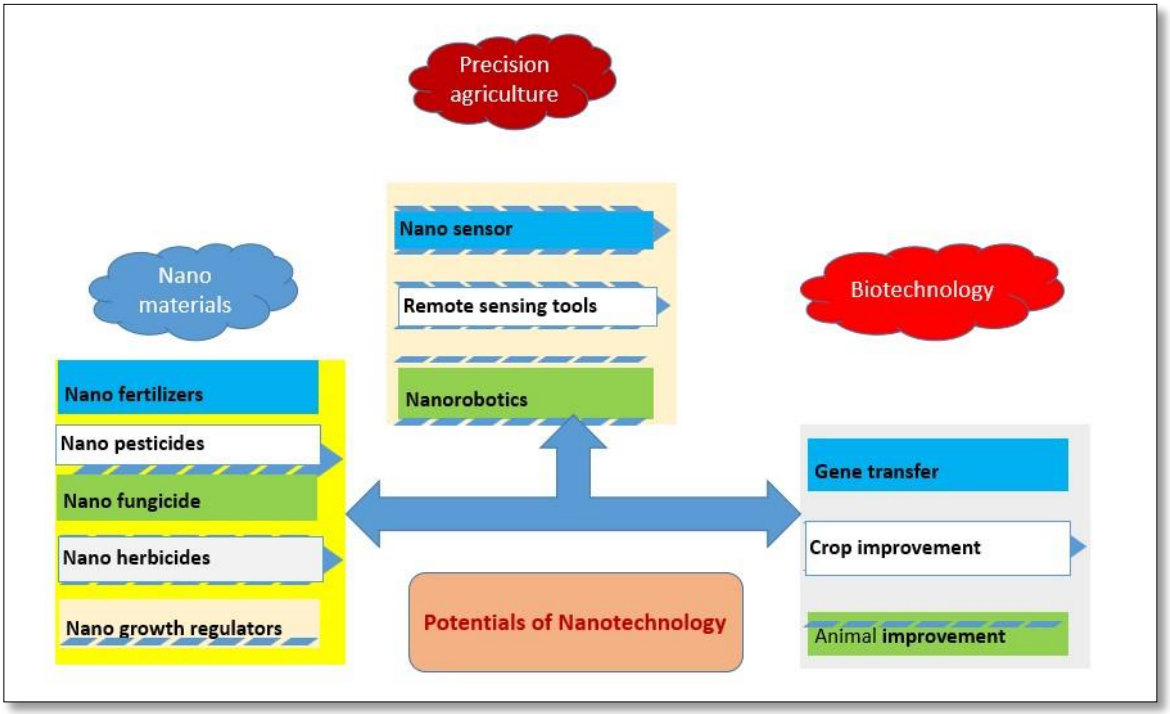

Figure (1) Potential of nanotechnology in agriculture.

Nano devices and biotechnology also have an effective role in the diagnosis of plant pathogens and in enhancing crop productivity. Furthermore, there are positive impacts of using nan-tools during food processing to reduce spoilage, packaging, dairy, and the shelf life of agricultural products (Pandey, 2018).

Moreover, nano fertilizers are used in small quantities compared to bulk fertilizers, which reduces environmental pollution. Nanoparticles that are sprayed on plants interact through various pathways, such as through the stoma into the leaf and cuticle (Kara and Sabir, 2010) .

Efficiency of nano-fertilizers could be due to their providing more space for various metabolic reactions in the plant that increase the rate of photosynthesis, produce more dry matter, and increase crop yield, they also have a slower release in uniform quantities compared to the use of conventional fertilizers (Abobatta, 2018b). Thus, nano-fertilizers have reduced environmental damage and avoided a nutrients loss to soil or groundwater through direct delivery to a specific site in the plant tissue, as well as having high efficiency as pesticides and controlling pathogens, especially soil-borne pathogens.

Moreover, nanoparticles play important roles in precision agriculture, prolonging the shelf life of perishable agricultural products, and as packaging materials for horticultural commodities.

Uses of nanotechnology in agriculture

Nanoparticles contribute to overcoming the problems faced by different agricultural management practices by promoting targeted delivery of agrochemicals and increasing the efficiency and management of plant nutrition on the farm scale. The tiny size of the nanoparticles helps in the formation of agrochemicals that encourage the spread of sustainable agricultural practices, particularly in fertilization and irrigation (Gilbertson, *et al*., 2020).

There are numerous uses of nanotechnology in the agricultural sector, including nano-devices, nanomaterials, and nanorobotics. While the common uses of nano applications in agriculture (Figure 1) include, nano fertilizers, nano pesticides, nano sensors, nano edible coating materials, and packaging materials.

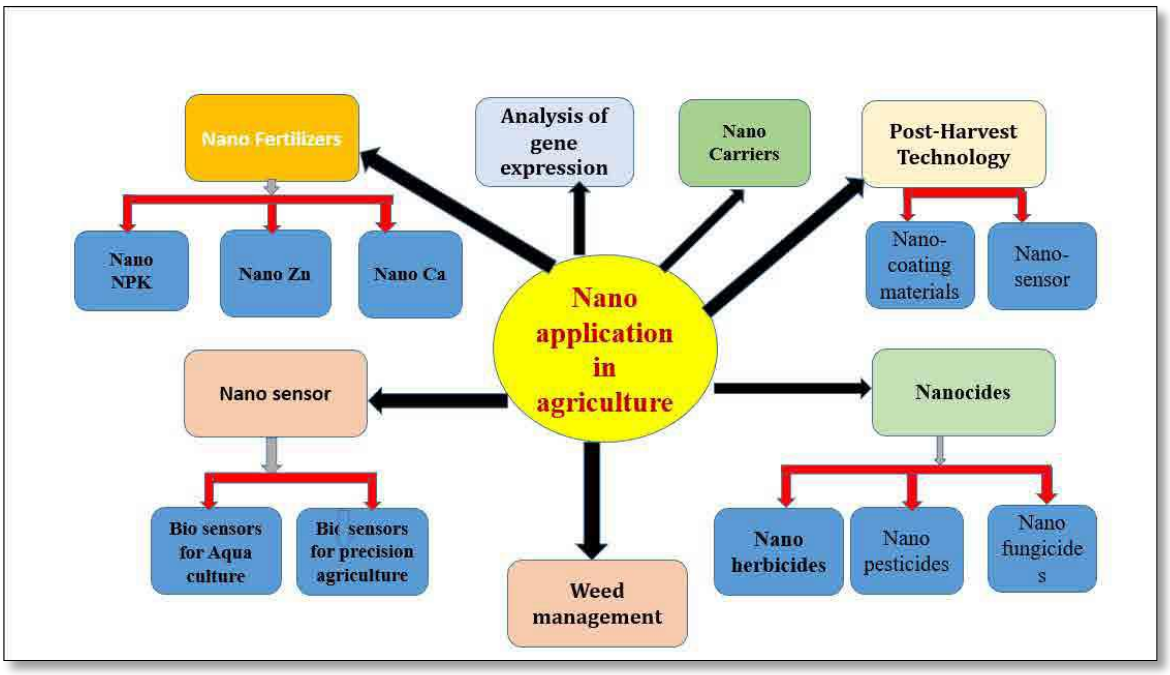

Figure (2). Schematic for main nano applications in agriculture (Abobatta, 2021)

Absorption of nanoparticles in plant

There are different elements that affect the absorption and translocation of nanoparticles that are applied to plants through the various pores in plant tissue, which include the properties of nanoparticles, the size of nanoparticles, environmental situations, plant species, and phenological growth stages. Furthermore, adding other substances to nanoparticles, such as nutrients, pesticides, and plant hormones, increases the uptake of agrochemicals.

Generally, the nanoparticles are applied to plants in two ways: foliar application on aerial parts and soil application. While plants absorb nanoparticles through natural pores on plant surfaces of both aerial parts and the root system (Tarafdar, 2015).

Spray Mechanisms

Foliar application of nano-based nutrients increases crop growth and yield, thereby improving the efficiency of photosynthesis by reducing the adverse effect of abiotic stress on the process, as well as acting as a light trap, which increases the efficiency of chlorophyll in absorbing light, reduces reactive oxygen species, and stimulates the electron transport system (Adisa, *et al*., 2019). Furthermore, due to the unique properties of nano-nutrients that improve their adhesion to leaves, which increases the efficiency of nutrient uptake by cuticle and mesophyll cells. That is why foliar spraying of nanoparticles such as nano-Zn, Cu, B, Fe, Zno, Si, and Tio2 increased crop yield through an effective targeted delivery system of agrochemicals (Nandini & Geetha, 2021).

The use of precision agriculture tools such as fine nozzle droplets (aerosol spray) is one of the techniques required to spray nanomaterials in the agricultural field. To increase their efficiency, these tools are more effective and increase penetration through plant cells than traditional spraying equipment (Abobatta, 2020).

Preferable, using low size nanoparticles ranged from 30-60 nanometer, moreover, during application using light concentration of in spray solution.

It is well documented that Nanomaterials must be used in a size less than 100 nanometers. Moreover, when used for agricultural purposes, preferable to use small nanoparticles ranging in size from 30-60 nm to obtain the highest efficiency. Moreover, it is preferable to use low concentrations of nanomaterials in the solution to increase the penetration, absorption, and translocation of nanomaterials through plant tissues (Tarafdar, *et al*., 2021).

Nanoparticles, when sprayed on the vegetative growth of plants, could enter through several entrances on the plant surface, due to their small size and unique characteristics (Figure 3), so there are several paths used to enter the cells and translocate inside the plant, whether through the xylem or phloem system, including the following:

- Stomata
- Cuticle & Epidermis
- Bark & other surfaces

- Hydathodes
- Other entry pores

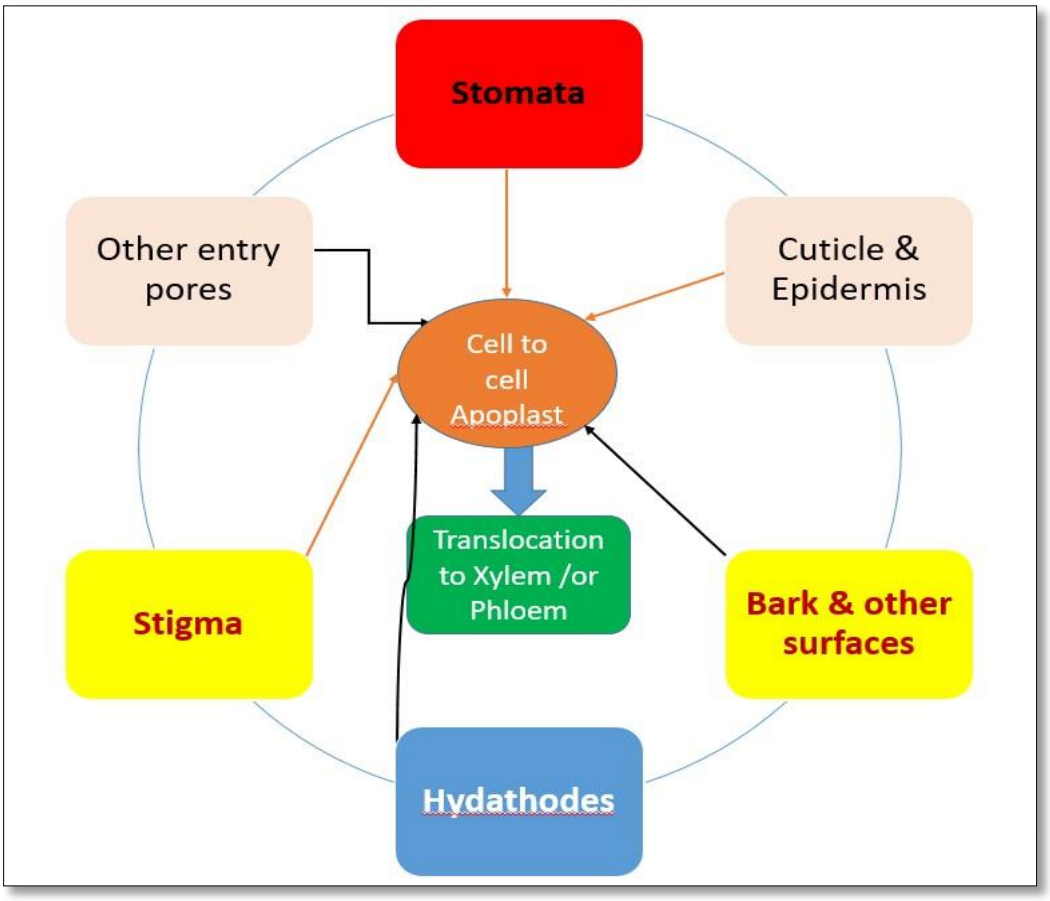

Figure (3) Expected pathway of nanoparticles and translocation through aerial parts (Modified from Tarafdar 2015)

Soil application of nanoparticles

Plants are absorbed nanoparticles that applied as soil application through various entrances in the root system include:

- Root tips
- Rhizodermis/cortex
- Lateral root junctions
- Wounding

Why Nanofertilizers ?

Nanofertilizers enhancing photosynthesis and the formation of more NADPH consequently increase the production of carbohydrates and other molecules, which improve plant growth and productivity (Elfeky, *et al*., 2013) on basil plants (*Ocimum basilicum*); Siva & Benita (2016) on Ginger (*Zingiber officinale Rosc*.).

Nanofertilizers are used in tiny quantities compared with bulk materials due to high surface area. For instance, plants required huge amounts of bulk fertilizers as soil application could range from 1-100 kg/ha from Iron. Furthermore, in calcareous soil plants suffer from Fe deficiency due to antagonisms between calcium and Iron,

under these conditions, farmers had to use foliar applications with more chemicals to supply plant requirements. Nano magnetite particles improve the chlorophyll content of basil leaves particularly when used as a foliar application (Elfeky, *et al*., 2013).

Table 1: Effect of Nano fertilizers on the growth and productivity of various crops

Nano particles	Crop	Action	Reference
Nano Calcite Fertilizer	Rice (*Oryza sativa*)	Improving growth, yield, seed quality, and insect resistivity.	Kumara, *et al*., (2019)
Silica nanoparticles	Maize (*Zea mays*)	Improve the sustainable farming of maize crop as an alternative source of silica fertilizer	Suriyaprabha, *et al*., (2021)
Nano-Zn chelate	Grapevines (*Vitis vinifera*)	improving growth, yield, and berry quality	Sabir, *et al*., (2014)
Iron nano chelated	Wheat (*Triticum sative*)	Improving plant growth and yield	Ghafari & Razmjoo, (2013)
khazra iron nano	Rapeseed (*Brassica spp.*,)	Positive effects on yield, and total dry biomass	Mahdi, *et al*., (2019).
Nano-iron Chelate	Mung Bean (*Vigna radiate L.*)	increased shoot length	Karimi, *et al*., (2014)
Silver nanoparticles (SNPs), iron nanoparticles (FeNPs), zinc nanoparticles (ZnNPs)	*Philodendron (Philodendron bipinnatifidum*	Improve the anatomical characters of leaves and stem and increase total chlorophyll and carotenoid content	El-Shawa, *et al*., (2022).
Fe2O3 nanoparticles	Soybean (Glycine max (L.) Merr.)	Enhanced photosynthetic parameters	Alidoust & Isoda, (2013).
Silver nano-particles	Wheat (*Triticum aestivum L.*)	Improvement leaf area and increase grain yield	Jhanzab, *et al*., (2015).
Nano Nitrogen	Sage (*Salvia officinalis*)	Increase vegetative growth and volatile oil	Rehab, *et al*., (2018)

NPK nano-fertilizers	Rice (Oryza sativa L.)	Increase yield	Valojai, *et al*., (2021)

Disadvantage of nanomaterials

The toxicity of Nanoparticles and nano-based composites is being investigated for both environmental and plant applications (Hassanisaadi, *et al*., 2022). Furthermore, the behavior of nanometal oxides such as magnetite, nano silver, and Nano copper still needs more investigation to determine the side effects on living organisms (Iavicoli, *et al*., 2017).

CONCLUSIONS

The potential applications of nanotechnology are increasing in agriculture, particularly in biotechnology and precision agriculture, nano materials provide beneficial effects for plants and improve their growth and productivity. There are numerous potentials for nanotechnology in agriculture, such as nanofertilizers, nanopesticides, nano-plant growth regulators, nano-sensors, nano barcodes, nano robot, and biotechnology. Nano fertilizers have high penetration rates, so they are used in smaller quantities compared to conventional fertilizers. Nano fertilizers reach specific sites in plant tissues, which increases efficiency. Nano fertilizers act as light traps, thus increasing the rate of photosynthesis and forming dry matter, thereby enhancing plant growth and production. Moreover, nano fertilizers protect the environment from the excessive use of traditional fertilizers.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

تقنية النانو والاسمدة النانوية الزراعية

وليد فؤاد ابوبطة
معهد بحوث البساتين / مركز البحوث الزراعية / الجيزة / مصر

الخلاصة

نظرا للآثار الضارة للتغيرات المناخية على الانتاج الزراعى, وزيادة الطلب على الغذاء عالميا, هناك حاجة ملحة لاستخدام استراتيجيات جديدة لتحسين الانتاج الزراعى بطريقة مستدامة, وزيادة كفاءة استخدام الموارد الطبيعية المتاحة. تعد التقنية النانوية والتقنية الحيوية أداة متميزة لتحسين الانتاج الزراعى، و ستصبح احد طرق ادارة العمليات الزراعية التي تزيد فعالية الموارد الطبيعية, وتقلل الاستخدام المفرط للكيماويات الزراعية والتي تسبب مشاكل بيئية خطيرة, مما يساهم في الحفاظ على البيئة, وانتاج اغذية صحية , وتقليل تكاليف الانتاج. تشمل التقنية النانوية ادوات مختلفة تستخدم في القطاع الزراعى ومنها الاسمدة النانوية, والمبيدات النانوية,

بالإضافة لمواد التعبئة والتغليف النانوية, والاجهزة الدقيقة مثل المستشعرات الحساسة والروبوتات, واجهزة الباركود النانوية. ويتم تصنيع المواد النانوية بثلاثة طرق اساسية, تشمل الطرق الكيماوية والطبيعية, والحيوية, بينما تعتبر الطرق الكيماوية هي الاكثر شيوعا حتى الان. التقنية النانوية من الادوات المهمة التى لها تأثير إيجابي على العملية الزراعية من خلال تحسين نمو النباتات وزيادة انتاجيتها. نظرا للخصائص الفريدة للجزيئات النانوية فأنها توفر العديد من المميزات في نمو و انتاجية المحاصيل المختلفة, تقليل كميات الاسمدة المستخدمة, الحد من الاثار السلبية للتغيرات المناخية على الانتاج, كما تعمل على تشخيص الامراض النباتية في مراحل مبكرة من الاصابة. ويمكن استخدام الاسمدة النانوية بصور مختلفة سوآءا رشا او الإضافة للتربة, وتعتبر الاسمدة النانوية احد اهم تطبيقات التقنية النانوية في المجال الزراعى.

الكلمات المفتاحية: التقنية النانوية، الزراعة، الانتاج، الاسمدة النانوية، الاجهزة النانوية.

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