Review on the Use of Nanotechnology in Fertilizers

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Abstract: These The field of nanotechnology has seen tremendous growth over the past and the present decade, and it has improved and impact a measurable effect on all the sectors in the society, such as medical (Drug delivery, biomarker mapping, molecular imaging, detection, gene delivery, diagnosis, and diagnosis monitoring), food (production, food processing, food safety, food packaging, and Nutrition), engineering (optical engineering, nanodevices, bioengineering, tissue engineering), polymer sector (textile, plastic, and polymer), electronic, etc. Nevertheless, in the agricultural sector, the agricultural diagnostic, the remediation of soil, and water, pollution monitoring, sustainable agriculture, nano pesticides, precision farming section, and fertilizer were improved, but nanotechnology in the applications of the agricultural sector is still relatively under development, especially in the fertilizer. Nanotechnology is the best and potential solution for problems caused by conventional fertilizer in the agricultural system. This paper aims to highlight the use of nanotechnology in the fertilizer system and also provide information onnano - fertilizers that are used for plant growth and nutrition. Under three themes in nanotechnology implementation for fertilizers such as Nanoscale Fertilizer Inputs, Nanoscale Fertilizer Additives, and Nanoscale Coatings/Host Materials for Fertilizers, especially explore the potential directions of usages Nanoscale fertilizer inputs. This paper will also discuss the advantages and disadvantages of Nanotechnology in fertilizer systems for agriculture.

Index Terms: agriculture, nanofertilizer, nanoparticles, nanotechnology.

1 INTRODUCTION

Global food security is under serious condition across the world, because of the limited availability of natural sources such as lack of land, quality seeds, and water sources. The estimated world population is 7.8 billion people, in 2050 will increase to approximately nine billion. Therefore, the global agricultural system is facing numerous unexpected challenges with including rapid climatic changes.

Agriculture is always an important sector for developing countries. The main purpose of using fertilizer in agriculture give full-fledged macro and micronutrients, which usually lack in soil. The fertilizers play a vital role in increasing agricultural production, where 35 – 40 % of crop productivity depends upon fertilizer. The excessive use of chemical fertilizers negatively damages the chemical systems of soil and limited the available place or area for crop production. Therefore, the farmers focus on the development of fertilizers system for plants. Nanotechnology is the smarter way to overcome all these drawbacks from the agriculture system. Nanotechnology is a range of technologies related to the development of matter at a length scale of 1-100 nm. Particles which are less than 100 nm are seen as atoms or molecules and at the end corresponding bulk material, which can lead to dramatic modifications in the physicochemical properties of the material. The importance of nanoparticles may be due to, a greater density in reactive surface areas on the particles. therefore, with the use of nanoparticles and nanopowders, researchers can produce controlled or delayed release fertilizer [1]. The consolidation of nanotechnology in fertilizer products may improve release profiles and increase uptake efficiency, leading to significant economic and environmental benefits.

Scientists have identified that the nano-size particles of fertilizer will improve crop production while maintaining the chemical ecology of soil. Nano- fertilizer involves the employment of nanoparticles in agriculture to provide the beneficial effect of plant growth or crop production [2]. The biosynthesis nano fertilizer was innovated by Indian agro- scientist. The Novel nano-fertilizers will bring down the use of chemical fertilizers by 80 – 100 times. This article provides spacious information on the state of nanotechnology in agricultural products, specifically fertilizers. Examining the publications of Nanoscale Fertilize inputs, which is one of the most important themes in nanotechnology implementation for fertilizers. This paper will also discuss the effect of nanoscale fertilizer on crop production, growth, and nutrition, also the pros and cons of nanofertilizer.

2 NANO – FERTILIZERS

Fertilizers are chemical compounds applied to plant to promote growth and yield. The artificially synthesized inorganic fertilizers are used for a plant with appropriate concentration, and the fertilizer usually supplies Nitrogen, Phosphorus, and potassium (N, P, and K) as the three main nutrients for various crops and growing conditions, (Fig. 1) shows some important application of nanotechnology in the agriculture sector. The leaf growth and forms proteins and chlorophyll promoted by Nitrogen, the contribution of the root, flower, and fruit development promoted by Phosphorus, and the contribution of stem and root growth and protein synthesis done by Potassium [3].

Nano-fertilizer is a substance that can hold a great number of nutrients, slow and steady release purposes. It facilitates the uptake of nutrients matching the crop necessity level without any toxicity of customized fertilizer inputs [4]. Nanoscale refers to a billionth of a meter (1–100 nm or 0.1–99.0 nm). At this stage, the materials' physical, chemical, and biological properties vary with the large scale particles. The use of nanotechnology in agriculture and crop production mainly includes nanotechnology-enabled delivery of agriculture chemicals, especially fertilizers [5]. Some naturally occurring nanoparticles have been previously implemented for agricultural use, such as zeolite minerals. However, engineered nanomaterials are synthesized with the required chemical and physical properties to meet various applications. Based on the outcomes of research publications, the Nano - fertilizers are being studied as a way to increase nutrient efficiency and improve plant nutrition, compared with traditional fertilizers. There are three main classes of Nano - fertilizer is proposed: (1) Nanoscale fertilizer (nanoparticles which contain nutrients), (2) Nanoscale additives (traditional fertilizers with nanoscale additives), and (3) Nanoscale coating (traditional fertilizers coated or loaded with nanoparticles) [6].

Nanoscale fertilizer: In this section, the fertilizer inputs as particles or an emulsion with the nanoscale range, because the enhancement of size reduction of inputs will lead to improving the uptake and better overall release efficiency with potential amount nutrition that the plant required and with less toxicity. Fertilizer nano-objects, including particles prepared from urea, ammonium salts, peat, and other traditional fertilizers, fall under this category.

Nanoscale additives: In this category, a nanomaterial is not facilitating directly as the nutrient itself but it replaces such a small amount of macroscale inputs as an additive to improve the properties of the macroscale inputs. The nanomaterial may act or provide some role in the plant growth, such as fertilizer, micronutrient, or it may be an addendum substance that can provide a binder or water retention material. Nanoscale additives to fertilizer are mostly used to provide resistance to pest or anti-microbial activity for plants.

Nanoscale coating: In this section, where the macroscale fertilizer is encapsulated by the nanoscale coating or a film. The film may have nanoscale pores or spaces, which can facilitate the slow release of nutrients solubility. These applications are in infancy in agriculture but are already adopted for medical and engineering applications. Another wonderful use of nanotechnology in the encapsulation of beneficial microorganisms, which can efficiently improve the plant root growth and health purposes. In this application the various bacteria or fungi were included, where it can enhance the availability of Phosphorus, Nitrogen, and potassium in the plant root zone. Clays finding applications in fertilizer products include those such as kaolinites, smectites, halloysites, and palygorskites.

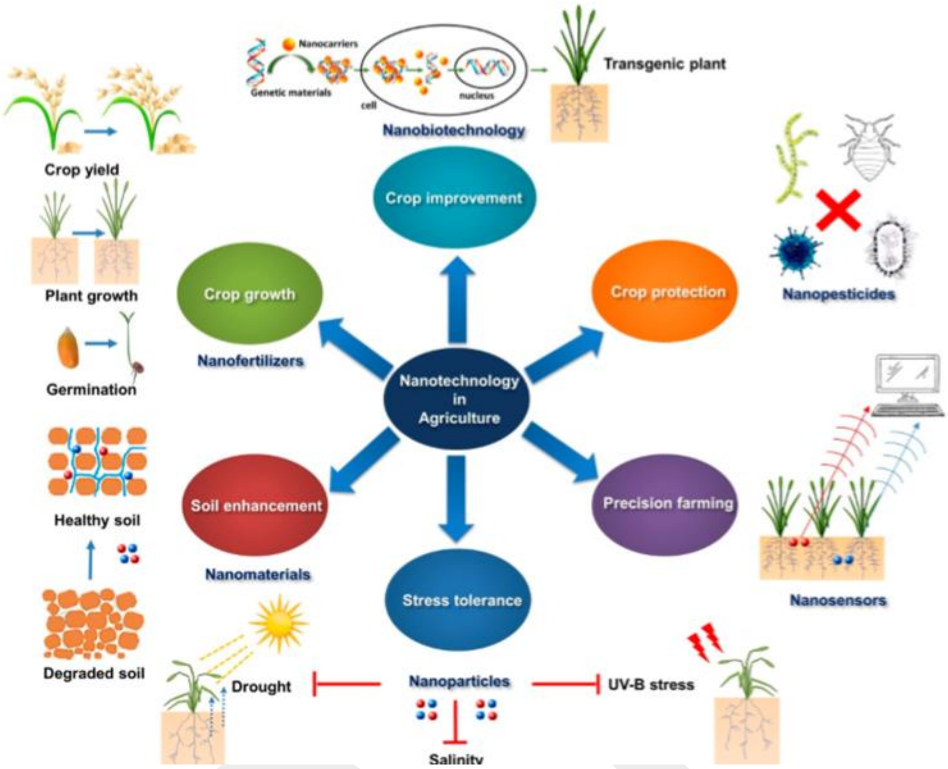

Fig. 1. Application of nanotechnology in agriculture[7]

There are some other potential ways to design nano – fertilizer for crop production,

1. Slow-release fertilizer: the nanocapsule slowly releases nutrients over a specified period.
2. Quick-release fertilizer: the nanoparticle shell breaks upon contact with a surface (such as striking a leaf).
3. Specific release fertilizer: the shell breaks open when it encounters a specific chemical or enzyme.
4. Moisture release fertilizer: the nanoparticle degrades and releases nutrients in the presence of water.
5. Heat release fertilizer: the nanoparticle releases nutrients when the temperature exceeds a set point.
6. pH release fertilizer: the nanoparticle only degrades in specified acid or alkaline conditions.
7. Ultrasound release: the nanoparticle is ruptured by an external ultrasound frequency.
8. Magnetic release: a magnetic nanoparticle ruptures when exposed to a magnetic field.

In recent years, slow-release fertilizers have become one of the important innovative technologies to save fertilizer consumption and minimize environmental pollution. A surface modified with urea (water-soluble plant nitrogen nutrient source), and a fertilizer composition was prepared by encapsulation of urea-modified HA nanoparticles into micro/nanoporous cavities of the young stem of *Gliricidiasepium* under pressure[8]. These cavities are made up of cellular polymers such as cellulose, hemicellulose, and lignin. The bio nanocomposite was then dried and its pellets were prepared. Upon soil application of the pellets, it was stipulated that this nano - fertilizer formulation will absorb the moisture, leading to a slow release of nitrogen into the soil due to diffusion and microbial degradation, of the biopolymeric matrix.
Furthermore, a soluble micron-sized coating or encapsulation is required to facilitate the nano fertilizer's slow or controlled release. The slow-release has been done for widely used micron-sized N, P, K fertilizers

using various formulations such as polysulfone spheres [9], polysulfone/polyacrylonitrile/cellulose acetate spheres, polymeric granules, and zeolite. Slow-release of metal micronutrients has also been achieved using the respective metal-polyphosphate composites. Some of the naturally synthesized nano – fertilizer is also used as slow-release applications, such as zeolite and biochar based, which is also preferred as environmentally friendly.

Ammonium salts, phosphates, and nitrates also preferred to use a slow or control release of fertilizer. Further, zinc–aluminium layered double-hydroxide nanocomposites have been used for the controlled release of chemical compounds that regulate plant growth [10].

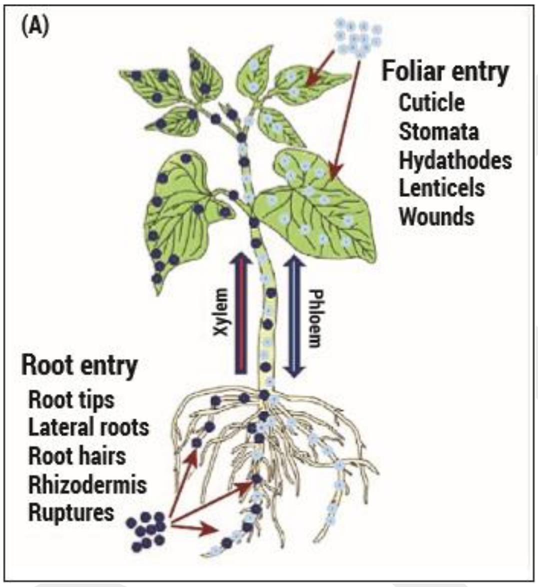

Fig. 2.The potential points where the nanoparticles can enter into the plant

In the fertilizer applying system, there are three ways; (1) fertilizer applied through the soil (for uptake by plant roots), (2) fertilizer applied through foliar spray (for uptake through leaves) [11], and (3) fertilizer applied in both ways together [12], Fig. 2 shows the potential entry points of nanoparticles into the plant. According to that, the delivery of nanofertilizer can synchronize their release with their crops uptake, thus preventing undesirable loss of nutrients to soil [13].

3 NANOSCALE FERTILIZER INPUTS

Nitrogen-based nanoparticles as a fertilizer

Nitrogen is well known as the most important nutrient available for plant growth. The 50–70% of the nitrogen applied using conventional fertilizers, but it absorbs by soil due to leaching and lowers nitrogen utilization efficiency (NUE) of plants. The Attempts taken to increase the NUE in conventional fertilizer formulations have not been much effective. Nanotechnology-based nitrogen fertilizers will be more effective than even polymer-coated conventional slow-release N fertilizers [14]. In research, the release of nitrogen by urea hydrolysis has controlled through the insertion of urease enzymes into nanoporous silica [15]. The nitrogen sometimes makes lost in the environment. It is not utilizable by crops, which causes large economic and resource losses and is instrumental to very serious environmental pollution. If the problem should reduce, some properties should be noted in the fertilizer, such as applying an adequate amount of fertilizer, deep placement of fertilizer, use of granular Urea, improving crop response knowledge, and using slow-release nanofertilizer. The nitrogen is getting from the Urea because it is a rich source of nitrogen. The farmers focus on to slow release of nitrogen to the plant. According to that the Urea-Hydroxyapatite

Nanohybrids fertilizer, where the Urea interacts with the HA NPs by amine and carbonyl groups. This provides a slow release of nitrogen, an important nutrient for plants, Fig. 3 shows the nitrogen release of Urea and functionalized Urea. They suggest that these slow-release properties to a better rice crop yield at a 50 % lower concentration of urea [16], [17], [18], [19], [20]. Further studies were carried out by Pabodha et al. to see the possibility of using this Urea coated nanohydroxyapatite composite as a seed coating by applying Urea-hydroxyapatite-polymer nanohybrids as seed coatings for enhanced germination of seasonal crops and succeeded [21].

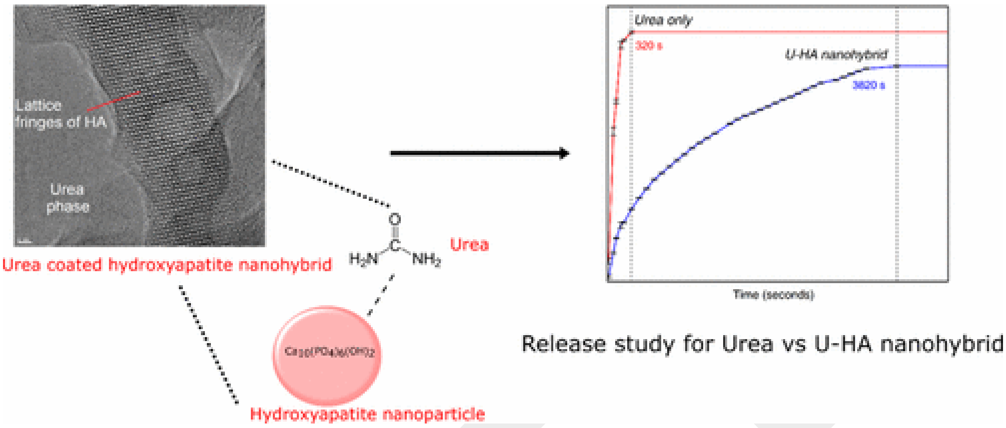

Fig. 3. The release kinetics of nitrogen in Urea - HA nanohybrid [16]

There is another novel material called urea-silica nanohybrids, which provide slow release plant nutrient for effective and precise delivery of nitrogen and silica to the plant. The higher nitrogen loading also developed in this material once compared with other nitrogen releasing fertilizers [22], [23]. The nitrogen nano – fertilizer, which is synthesized using zeolite improves the uptake and concentration of nitrogen is better than that of conventional fertilizer, Fig. 3 shows the release of nitrogen to plant. A higher amount of nitrogen is absorbed by the Ipomoea Aquatica (Kalmi) plant for their growth when the fertilizer in the nanoscale range. The nano fertilizer application in soil showed better pH, moisture, CEC, and available nitrogen under nano fertilizer treatment than the conventional fertilizer [24].

The evaluation of K Nano fertilizer and N bio-fertilizer on the yield of red bean (pheseolus Vulgaris L.) shows the positive effect on yield and yield components of the red bean by increasing leaf area index, the number of grain per pod a 1000 grain weight of treated plants. Based on the results, the combined application of N bio-fertilizer and Khazraa K chelate Nano-fertilizer (KKCNF) showing a better yield of red bean rather than a single application of them. Therefore, can replace chemical fertilizers with these fertilizers, because it provides more efficient economic and environmental and has better crop performance [25]. The Urea–hydroxyapatite nanohybrid is a slow-release nanofertilizer for the yield of Camellia sinensis (L.) Kuntze (tea), where it significantly increased soil P, leaf N, and P concentration in Low country tea plants. this kind of fertilizer is a potential alternative to reduce the high usage of urea and the amount of fertilizer required in cultivations [26].

Another recent research was reported on efficient slow-release fertilizer, which shows five times lesser solubility of urea when compare with the solubility of pure urea, using nano calcium carbonate. Urea coated nano calcium carbonate (Urea-CC) nanocomposite was obtained by rapid carbonation (in-situ) method. A platelike nanoparticles were resulted and they stacked together to form pine cone-like structures. Nitrogen release behavior of this novel nanohybrids exhibited controlled release properties over pure urea [27].

4 PHOSPHORUS NANOFERTILIZERS

The second major nutrient for the plant is phosphorus (P). There are some fertilizers such as TSP (triple superphosphate, ($NH_3H_2PO_4$), DAP (diammonium phosphate, MAP (mono ammonium phosphate, ($(NH_3)_2HPO_4$), or Ca ($(H_2PO_4)_2$) are commercially available water-soluble phosphate salts. There is a huge problem in human, while the P entre into the water. Therefore, remediation technology has been proposed to reduce P fertilizer application and prevent the applied P from entering into water bodies [28]. Therefore, the nanotechnology surface functionalization of P will change the chemical properties and which will be brought down the mobility in the soil and bioavailability of the algae. The synthesis of phosphorus-based nanofertilizer as a conventional fertilizer for agricultural purposes, would enhance agronomic production, use efficiency of P, and improve the surface-water quality [29]. The usage of nano-sized hydroxyapatite increases the height of soybean plant by 30 % than the regular P fertilizer ($Ca(H_2PO_4)_2$) treatment. The P is an essential nutrient for the healthy growth of soybean and other lentils, where it is a vital and controlling component for the plant. Fig. 4 shows the Scanning electron microscope images of synthesized HA nanoparticles (A), and urea surface-modified HA nanoparticles (B).

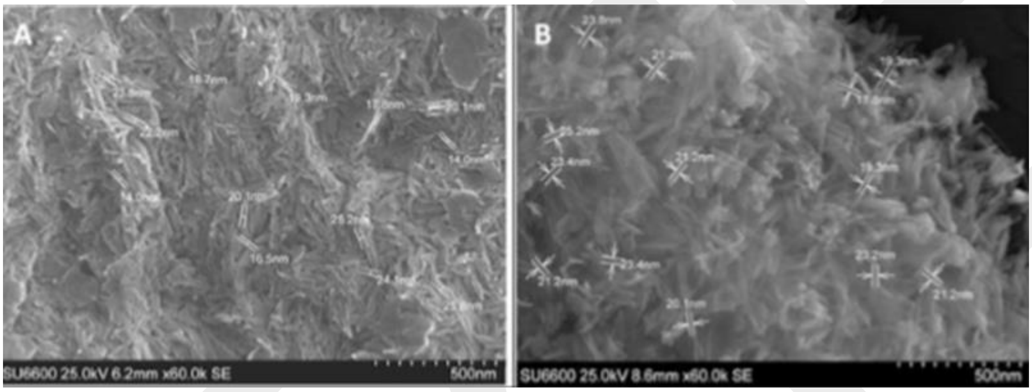

Fig. 4. SEM images of synthesized HA nanoparticles (A), and urea surface-modified HA nanoparticles (B) [30]

In another parallel study, Samavini et al. have focused on developing an efficient P nutrient system that could overcome the inherent problems arising from current P fertilizers. Attempts have made to synthesize citric acid surface-modified hydroxyapatite nanoparticles using wet chemical precipitation. Its effectiveness as a P source has investigated using water release studies and bioavailability studies using Zea mays as the model crop. It has concluded that the availability of P increased in the presence of organic acids compared with pure hydroxyapatite nanoparticles and rock phosphate [31], [32].

The NPK nanofertilizer has prepared by incorporating nitrogen (N), phosphorous (P), and potassium (K) into chitosan nanoparticles, enhanced uptake of nutrients, photosynthesis, and growth of coffee plants. Application of the nanofertilizer improved 67.50% potassium 17.04% nitrogen, and 16.31% phosphorous content in the leaves of the treated area once compared to the control. Total chlorophyll content increased up to 30.68% and 71.7% of photosynthesis net rate as well as enhanced leaf number, plant height, and leaf area of the coffee seedlings. This is the evidence to nanofertilizer to enhance use efficiency of fertilizers for coffee. The Chitosan nanoparticles are prepared by ionic gelation with TPP, which can provide a potential controlled slow-release carrier to produce NPK nanofertilizer. These evaluations prove that NPK nanofertilizer can be a novel fertilizer for developing green and sustainable agriculture in the near future [33].

Nano silica as a fertilizer for plant

Silicon material is also referring between essential and nonessential substances for the plant because it is not participating in the survival of most plants, but in the cause of different environmental stress conditions, the plants can adapt and get benefits in the presence of silica. Therefore, it is worth to study the way Si nanoparticles behave in the agricultural system.

The role of silicon dioxide nanofertilizer in the cucumber (*Cucumissativus L.*) plant shows increasing plant height, number of leaves, number of fruits (fruit weight) and also the foliar spray of SiO_2 improve growth parameter of cucumber once compare with untreated [34]. Nano silica particles absorbed by roots will enhance the plant's resistance to stress and improve yields because the absorbed silica forms films around the cell walls of the plant.

The researchers have been reported that improves seed germination, increases plant fresh weight, dry weight, and chlorophyll content with proline accumulation in tomato and squash plants under NaCl stress with the application of nano-SiO_2 [35]. Besides, the foliar application of nano-Si at 2.5 mM concentration significantly improves Cd stress tolerance in rice plants by regulating Cd (Cadmium) concentration, as well as it showed that nano-Si is also effective against Pb, Cu, and Zn with Cd. Nano-Si fertilizers may have an advantage over traditional fertilizers in reducing heavy metal accumulation by the plant [36]. Nanomaterials like nano-SiO_2 or nano-ZnO application increases the accumulation of free proline and amino acids, nutrients and water uptake, and activity of antioxidant enzymes including superoxide dismutase, catalase, peroxidase, nitrate reductase, and glutathione reductase, which ultimately improve plant tolerance to extreme climate events [37].

Titanium Nanoparticles as a Fertilizer

Photocatalytic materials are attracting attention as important resources for agricultural purposes. For recent requirement the use of biocompatible titanium dioxide-based photocatalytic nanomaterials (TiO_2–PN) as models to the harvest, post-harvest problems, and unravel agricultural growth. The TiO_2–PN has been used as an antimicrobial, growth-regulating, and fertilizer-like agent. TiO_2 NPs are shown to stimulate photosynthesis for plants [38].

The treatment with TiO_2 nanoparticles promoted the plant growth of maize, but the bulk treatment of TiO_2 will affect and also negligible for the plant. Titanium nanoparticles increased light absorption and photo energy transmission. In another experiment, they prove that the compound of SiO_2 and TiO_2 nanoparticles increased the activity of nitrate reductase in soybeans and when making use with water and fertilizer more efficient to intensified plant absorption capacity [39].

Zinc oxide nanoparticles as a fertilizer

The ZnO (Inorganic sources of Zn) is the most commonly used Zn fertilizer that is applied to the crops in Zn-deficient regions [40]. The application of ZnO nanoparticles into fertilizers as a source of Zn might be a promising approach that can proceed novel solubility option of ZnO NPs to improve the efficiency of Zn fertilizers.

Further, the application of ZnO NPs as a source of Zn in Zn fertilizers may improve the efficiency of the fertilizer and Zn availability to plants by enhancing the rate and extent of Zn dissolution. The Zn NPs may be applied as a foliar spray for the plant to improve the functions. This treatment may potentially enhance uptake and the penetration of zinc oxide nanoparticles in the plant leaves, Fig. 5 shows the TEM image of ZnO powder (a) and ZnO nanoparticle (b). The foliar spray has evaluated that plants sprayed with 20 mg mL1 ZnO NPs solution showed improved growth and biomass production over control plants [41]. The use of ZnO nanoparticles has been found that produce healthy seeds and reduce the flowering period in onion by twoweeks [42].

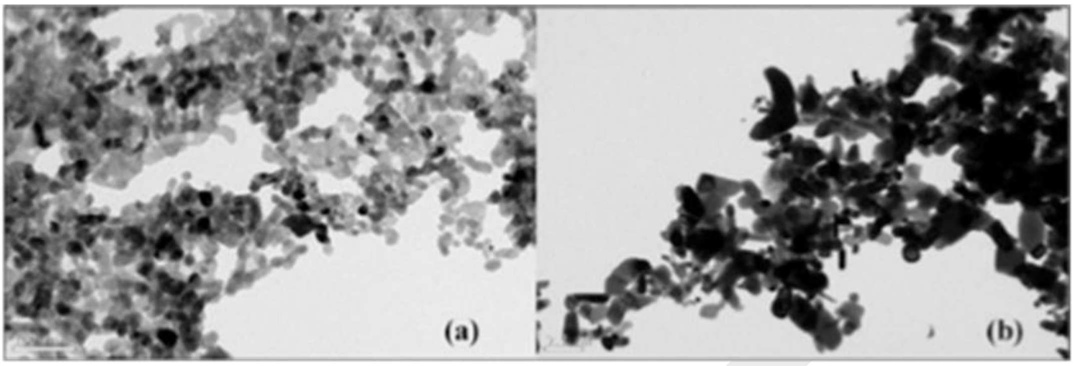

Fig. 5. The TEM image of ZnO powder (a) and ZnO nanoparticle (b)[30]

The Sweet basil (*Ocimumbasilicum L.*) is an annual herbal plant of the *Lamiaceae* (or *Labiatae*) family. Popularly the oils from this plant are used for dental, fragrances, food flavouring, traditional rituals, medicines, and oral products. The basil oils are mostly present in the leaves and the flowering tops extracted by the steam distillation process. Therefore, the growth of the plant is most important.

They identified that the promoting growth and yield of sweet basil plant with ZnO nanofertilizer and He Ne laser irradiation, where the ZnO NPs foliar spray only or combined with pre-sowing He Ne laser irradiation had a significant enhancement on the total chlorophyll, total carbohydrate, essential oil content, iron content, and plant growth characteristics (branches and leaves, number of plants) and consequently, will improve the total yield of the sweet basil plant. The results of this work show strong evidence for the high efficiency of this new nanofertilizer on plant growth enhancement. This work confirmed that ZnO nanofertilizers using is eco-friendly, safe, and produce healthier and more resistant to disease plants at appropriate concentrations but must avoid the high ZnO NPs concentrations [43].

Furthermore, plant diseases are the main problem in crop production, especially “Meloidogyne incognita” is the root-knot nematode (RKN), which is one of the most adverse phytopathogens all over the world [44], that cause severe damage to vegetable crops in tropical and subtropical areas. Therefore, the use of nano-Zn oxide for fertilization of tomato will enhance plant growth and protect M. (Root-knot nematode, M) incognita infection. At the same time, it proved enhancement of plant growth parameters and to keep a stronger and healthier plant, when using the Nano-ZnO with the addition of Nano-Fe oxide. Moreover, it is effective to reduce the cost of fertilizer for crop production and also minimize pollution hazard [45].

Other than the above applications, the ZnO nanoparticles provide change to improve the growth of rice. The application of Zinc oxide nanoparticles significantly improved the growth, yield, and yield-attributing characters in rice cv. PR-121 grown in Zn-deficient soil. The microbial counts and the dehydrogenase enzyme activity were also improved by foliar application of Zinc oxide nanoparticles. This study confirmed the potential of foliar application of zinc micronutrient nanofertilizer for remediation of the Zn-deficiency symptoms in rice cv. PR-121. Further, it also showed enhanced growth, yield, and grain Zn contents of rice plant besides improvement of the chemical and microbial characteristics of Zn-deficient soil [46].

Copper oxide nanoparticles as a fertilizer

Copper oxide nanoparticles show a positive effect on germination but are phytotoxic at seeding growth. However, some studies have been evaluating the potential of copper nanoparticles in crop growth.

Visualizing enormous beneficial aspects of metal nanoparticles shows the possible role copper nanoparticles can play in enhancing growth and increasing the yield of plants.

The CuO NPs can enhance the yield of wheat in a concentration-dependent manner [47]. Besides, in a recent study, the CuO NP carrying carbon nano - fibers (CNFs) are shown to penetrate the gram seeds and effectively translocate within the plant. The CuO-CNFs enhance plant growth by increasing its water uptake capacity and chlorophyll and protein contents [48]. The CuO nanoparticles have the ability to penetrate plant cells and translocate inside roots and shoots has also been used for the delivery of biomolecules such as DNA and protein, Fig. 6 shows the penetration of CuO NPs in the cell wall [49], corroborating the potential of nano-sized species to serve as a nutrient carrier in plants.

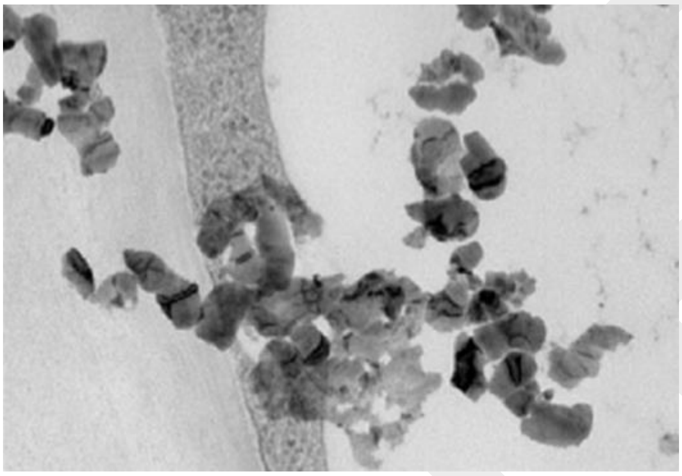

Fig. 6. A corn root is surrounded by copper oxide nanoparticle that is penetrating through the cell wall.

Carbon nanotubes as a fertilizer

Multi-walled carbon nanotubes (MWCNTs) shown to penetrate thick seed coats and induce changes in gene expressions of mustard, tobacco, and tomato, enhancing plant growth [50]. Further, Carbon nanotubes have recently used to penetrate tomato seeds and provide higher moisture uptake and seed growth. Fig. 7 shows the variation of the growth of weight variation by using carbon nanofertilizer. It concludes that new nutrient delivery systems that exploit the nanoscale porous domains on plant surfaces can be developed. Another study proved that a polymeric formulation of PVA–starch was synthesized as a substrate for the slow release of the Cu–Zn micronutrient carrying carbon nanofibers (CNFs). A formulation of PVA–starch film as a practical substrate to the Cu and Zn micronutrients carrying CNF. The prepared PBMC nanofertilizer enhanced the growth of chickpea plant, Fig. 8 shows the growth of plant leaf and shoot with and without PBMC, and facilitated by the slow release of Cu and Zn NPs from the CNFs dispersed in the PVA–starch blend wherein starch increased the biodegradability of PVA [51].

Fig. 7. The weight variation by using nanocarbon fertilizer.

Other than those results, the carbon nanotubes (CNTs) presence in the soil will induce changes in metabolic function, increase in biomass, and yield of plants. The CNTs provide the seed germination and growth in radish (*RaphanusSativus*), rapeseed (*Brassica Napus*), rye, lettuce, maize, and cucumber and multi-walled carbon nanotubes can facilitate the seed germination of *Brassica Juncea L*. and *Phaseolus Mungo L.*

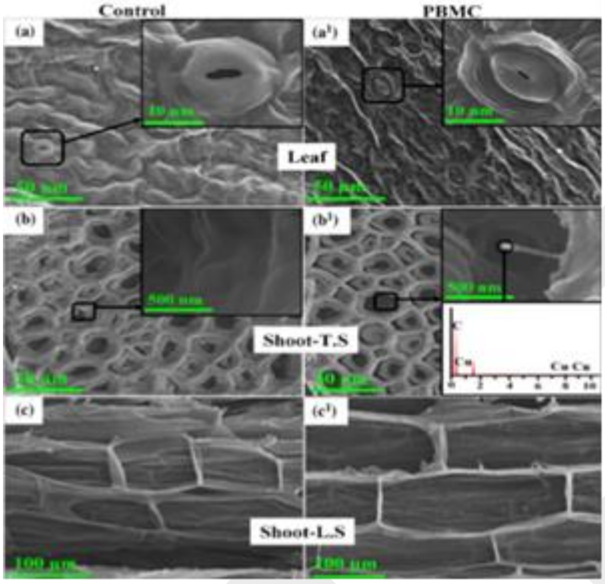

Fig. 8. The SEM images of the plant (leaf and shoot) were grown with and without PBMC.

The single-walled carbon nanotubes (SWCNTs) bring a positive effect on root growth of lettuce, cucumber, tomato, carrot (*DaucusCarota*), and onion (*Allium Cepa*), and tomato. Once compare the SWCNTs and MWCNTs, the MWCNTs show a higher rate of germination in hybrid Bt cotton (*GossypiumHirsutum*), Indian mustard (*Brassica Juncea*), urad bean (*Vigna Mungo*), and rice (*Oryza Sativa*). According to about application, the CNTs are beneficial in agriculture, especially in plant fertilization systems [52]. The insertion of single-walled carbon nanotubes (SWNTs) increases the electron transfer rate of light-adapted chloroplasts by 49% under in vivo conditions by augmenting photo absorption [53].

6 Conclusion

Nanotechnology is one of the most tremendous tools in modern agriculture products that provide nutrition, protect plants, monitor plant growth, and detect diseases. The article explores useful information about Nanoscale fertilizers currently used to crop production and how they affect a positive way to improve production than the conventional fertilizer. The use of nanotechnology in fertilizer provides such wonderful benefits, such as a three times increase in Nutrient Use Efficiency (NUE), 80 – 100 times less requirement for chemical fertilizers. 10 times more stress-tolerant by the crops, 30 % more nutrient mobilization by the plants, 17 – 54 % improvement in the crop yield, controlling eutrophication and pollution of the environment with water resources, and provide ultrahigh absorption rate of fertilizer. If nano fertilizer has more advantages, there are some disadvantages. There are some risks and problems towards the health and environment when the applicable level goes up, some shows the toxic effects when entered into the human body. Therefore, once use the limited level safely can overcome this problem. Scientists are still seeking new nanotechnology applications in agriculture and the food industry to overcome the challenges that are faced by the world. The agriculture sector will indeed see tremendous change for the better in the coming years with sustainable crop production.

References

[1] N. Kottegoda, C. Sandaruwan, G. Priyadarshana, A. Siriwardhana, U. Rathnayake, D. Berugoda Arachchige, A. Kumarasinge, D. Dahanayake, V. Karunaratne, and G. Amaratunga, "Urea-hydroxyapatite nanohybrids for slow release

of nitrogen. ACS Nano 11: 1214–1221," ed, 2017.

[2] S. Morla, C. R. Rao, and R. Chakrapani, "Factors affecting seed germination and seedling growth of tomato plants cultured in vitro conditions," *Journal of Chemical, Biological and Physical Sciences (JCBPS),* vol. 1, p. 328, 2011.

[3] K. Mandal, K. Hati, and A. Misra, "Biomass yield and energy analysis of soybean production in relation to fertilizer-NPK and organic manure," *Biomass and bioenergy,* vol. 33, pp. 1670-1679, 2009.

[4] V. Ghormade, M. V. Deshpande, and K. M. Paknikar, "Perspectives for nano-biotechnology enabled protection and nutrition of plants," *Biotechnology advances,* vol. 29, pp. 792-803, 2011.

[5] G. Manimegalai, S. S. Kumar, and C. Sharma, "Pesticide mineralization in water using silver nanoparticles," *International Journal of Chemical Sciences,* vol. 9, pp. 1463-1471, 2011.

[6] E. Mastronardi, P. Tsae, X. Zhang, C. Monreal, and M. C. DeRosa, "Strategic role of nanotechnology in fertilizers: potential and limitations," in *Nanotechnologies in food and agriculture*, ed: Springer, 2015, pp. 25-67.

[7] Y. Shang, M. Hasan, G. J. Ahammed, M. Li, H. Yin, and J. Zhou, "Applications of nanotechnology in plant growth and crop protection: a review," *Molecules,* vol. 24, p. 2558, 2019.

[8] N. Kottegoda, I. Munaweera, N. Madusanka, and V. Karunaratne, "A green slow-release fertilizer composition based on urea-modified hydroxyapatite nanoparticles encapsulated wood," *Current science,* pp. 73-78, 2011.

[9] M. Tomaszewska and A. Jarosiewicz, "Use of polysulfone in controlled-release NPK fertilizer formulations," *Journal of agricultural and food chemistry,* vol. 50, pp. 4634-4639, 2002.

[10] M. Z. bin Hussein, Z. Zainal, A. H. Yahaya, and D. W. V. Foo, "Controlled release of a plant growth regulator, α-naphthaleneacetate from the lamella of Zn–Al-layered double hydroxide nanocomposite," *Journal of controlled release,* vol. 82, pp. 417-427, 2002.

[11] A. O'Neill, B. S. Gupta, and D. H. Phillips, "Distribution of arsenic and risk assessment of activities on a golf course fertilised with arsenic-containing Ascophyllum nodosum seaweed," *Science of The Total Environment,* vol. 482, pp. 252-259, 2014.

[12] X.-L. Yan, T.-F. Dai, and L.-M. Jia, "Evaluation of the cumulative effect of drip irrigation and fertigation on productivity in a poplar plantation," *Annals of forest science,* vol. 75, p. 5, 2018.

[13] M. C. DeRosa, C. Monreal, M. Schnitzer, R. Walsh, and Y. Sultan, "Nanotechnology in fertilizers," *Nature nanotechnology,* vol. 5, pp. 91-91, 2010.

[14] K.-Z. Hossain, C. M. Monreal, and A. Sayari, "Adsorption of urease on PE-MCM-41 and its catalytic effect on hydrolysis of urea," *Colloids and Surfaces B: Biointerfaces,* vol. 62, pp. 42-50, 2008.

[15] K.-Z. HOSSAIN, A. SAYARI, and C. M. MONREAL, "UREASE IMMOBILIZATION ON PORE-EXPANDED MESOPOROUS SILICA AND ITS CATALYTIC EFFECT ON HYDROLYSIS OF UREA," in *Nanoporous Materials*, ed: World Scientific, 2008, pp. 697-708.

[16] N. Kottegoda, C. Sandaruwan, G. Priyadarshana, A. Siriwardhana, U. A. Rathnayake, D. M. Berugoda Arachchige, A. R. Kumarasinghe, D. Dahanayake, V. Karunaratne, and G. A. Amaratunga, "Urea-hydroxyapatite nanohybrids for slow release of nitrogen," *ACS nano,* vol. 11, pp. 1214-1221, 2017.

[17] N. Kottegoda, D. Siriwardhana, W. Priyadarshana, C. Sandaruwan, D. Madushanka, U. Rathnayake, S. Gunasekara, D. Dahanayake, A. DeAlwis, and A. Kumarasinghe, "Compositions and methods for sustained release of agricultural macronutrients," ed: Google Patents, 2014.

[18] N. Kottegoda, G. Priyadharshana, C. Sandaruwan, D. Dahanayake, S. Gunasekara, A. G. Amaratunga, and V. Karunaratne, "Composition and method for sustained release of agricultural macronutrients," ed: Google Patents, 2014.

[19] N. Kottegoda, N. Madusanka, and C. Sandaruwan, "Two new plant nutrient nanocomposites based on urea coated hydroxyapatite: Efficacy and plant uptake," *Indian J Agr Sci,* vol. 86, pp. 494-9, 2016.

[20] N. Kottegoda, C. Sandaruwan, G. Priyadarshana, G. P. Gunaratne, S. Abeysinghe, S. Hettiarachchi, V. Karunaratne, and A. Gehan, "Hydroxyapatite–urea nano-hybrid as efficient plant nutrient systems," 2017.

[21] D. Pabodha, D. Rathnaweera, G. Priyadarshana, C. Sandaruwan, H. Kumara, K. Purasinhala, S. Chathurika, S. Daraniyagala, V. Karunaratne, and N. Kottegoda, "Urea-hydroxyapatite-polymer nanohybrids as seed coatings for enhanced germination of seasonal crops," in *ABSTRACTS OF PAPERS OF THE AMERICAN CHEMICAL SOCIETY*, 2018.

[22] M. de Silva, D. P. Siriwardena, C. Sandaruwan, G. Priyadarshana, V. Karunaratne, and N. Kottegoda, "Urea-silica nanohybrids with potential applications for slow and precise release of nitrogen," *Materials Letters,* p. 127839, 2020.

[23] T. Siriwardena, G. Priyadarshana, C. Sadaruwan, M. De Silva, and N. Kottegoda, "Urea Modified Silica Nanoparticles Next Generation Slow Release Plant Nutrients," 2017.

[24] A. A. Rajonee, F. Nigar, S. Ahmed, and S. I. Huq, "Synthesis of nitrogen nano fertilizer and its efficacy," *Canadian Journal of Pure and Applied Sciences,* vol. 10, pp. 3913-3919, 2016.

[25] A. Farnia and A. Ghorbani, "Effect of K nano-fertilizer and N bio-fertilizer on yield and yield components of red bean (Phaseolus vulgaris L.)," *Biosci, Int J,* vol. 6655, pp. 296-303, 2014.

[26] S. Raguraj, W. Wijayathunga, G. Gunaratne, R. Amali, G. Priyadarshana, C. Sandaruwan, V. Karunaratne, L. Hettiarachchi, and N. Kottegoda, "Urea–hydroxyapatite nanohybrid as an efficient nutrient source in Camellia sinensis (L.) Kuntze (tea)," *Journal of Plant Nutrition,* pp. 1-12, 2020.

[27] D. N. Rathnaweera, D. Pabodha, C. Sandaruwan, G. Priyadarshana, S. Deraniyagala, and N. Kottegoda, "Urea modified calcium carbonate nanohybrids as a next generation fertilizer," 2019.

[28] L. E. De-Bashan and Y. Bashan, "Recent advances in removing phosphorus from wastewater and its future use as fertilizer (1997–2003)," *Water research,* vol. 38, pp. 4222-4246, 2004.

[29] R. Liu and R. Lal, "Synthetic apatite nanoparticles as a phosphorus fertilizer for soybean (Glycine max)," *Scientific reports,* vol. 4, p. 5686, 2014.

[30] M. R. Khan and T. F. Rizvi, "Application of nanofertilizer and nanopesticides for improvements in crop production and protection," in *Nanoscience and Plant–Soil Systems*, ed: Springer, 2017, pp. 405-427.

[31] R. Samavini, C. Sandaruwan, M. De Silva, G. Priyadarshana, N. Kottegoda, and V. Karunaratne, "Effect of citric acid surface modification on solubility of hydroxyapatite nanoparticles," *Journal of agricultural and food chemistry,* vol. 66, pp. 3330-3337, 2018.

[32] R. Samavini, C. Sandaruwan, M. de Silva, G. Priyadarshana, N. Kottegoda, and V. Karunaratne, "Hydroxyapatite-citric acid nanohybrids for optimum release of phosphorus in fertilizer applications," in *ABSTRACTS OF PAPERS OF THE AMERICAN CHEMICAL SOCIETY*, 2018.

[33] N. M. C. Ha, T. H. Nguyen, S.-L. Wang, and A. D. Nguyen, "Preparation of NPK nanofertilizer based on chitosan nanoparticles and its effect on biophysical characteristics and growth of coffee in green house," *Research on Chemical Intermediates,* vol. 45, pp. 51-63, 2019.

[34] A. Yassen, E. Abdallah, M. Gaballah, and S. Zaghloul, "Role of silicon dioxide nano fertilizer in mitigating salt stress on growth, yield and chemical composition of cucumber (Cucumis sativus L.)," *Int. J. Agric. Res,* vol. 22, pp. 130-135, 2017.

[35] M. Haghighi, Z. Afifipour, and M. Mozafarian, "The effect of N-Si on tomato seed germination under salinity levels," *J Biol Environ Sci,* vol. 6, pp. 87-90, 2012.

[36] S. Wang, F. Wang, S. Gao, and X. Wang, "Heavy metal accumulation in different rice cultivars as influenced by foliar application of nano-silicon," *Water, Air, & Soil Pollution,* vol. 227, p. 228, 2016.

[37] T. A. Shalaby, Y. Bayoumi, N. Abdalla, H. Taha, T. Alshaal, S. Shehata, M. Amer, É. Domokos-Szabolcsy, and H. El-Ramady, "Nanoparticles, soils, plants and sustainable agriculture," in *Nanoscience in Food and Agriculture 1*, ed: Springer, 2016, pp. 283-312.

[38] B. Sekhon, "Nanotechnology, science and applications," *Dovepress,* vol. 7, pp. 31-53, 2014.

[39] C. Lu, C. Zhang, J. Wen, and G. Wu, "Effects of nano material on germination and growth of soybean," *Soybean Sci,* vol. 21, pp. 168-171, 2002.

[40] D. Martens and D. Westermann, "Fertilizer applications for correcting micronutrient deficiencies," *Micronutrients in agriculture,* vol. 4, pp. 549-592, 1991.

[41] J. Panwar, "Positive effect of zinc oxide nanoparticles on tomato plants: A step towards developing nano-fertilizers," in *International conference on environmental research and technology (ICERT),* 2012.

[42] S. Laware and S. Raskar, "Influence of zinc oxide nanoparticles on growth, flowering and seed productivity in onion," *International Journal of Current Microbiology Science,* vol. 3, pp. 874-881, 2014.

[43] M. A El-Kereti, S. A El-feky, M. S Khater, Y. A Osman, and E.-s. A El-sherbini, "ZnO nanofertilizer and He Ne laser irradiation for promoting growth and yield of sweet basil plant," *Recent Patents on Food, Nutrition & Agriculture,* vol. 5, pp. 169-181, 2013.

[44] D. L. Trudgill and V. C. Blok, "Apomictic, polyphagous root-knot nematodes: exceptionally successful and damaging biotrophic root pathogens," *Annual review of phytopathology,* vol. 39, pp. 53-77, 2001.

[45] A. G. El-Sherif, S. B. Gad, A. A. Megahed, and M. I. Sergany, "Induction of tomato plants resistance to Meloidogyne incognita infection by mineral and nano-fertilizer," *Journal of Entomology and Nematology,* vol. 11, pp. 21-26, 2019.

[46] R. Bala, A. Kalia, and S. S. Dhaliwal, "Evaluation of efficacy of ZnO nanoparticles as remedial zinc nanofertilizer for rice," *Journal of Soil Science and Plant Nutrition,* vol. 19, pp. 379-389, 2019.

[47] A. Hafeez, A. Razzaq, T. Mahmood, and H. M. Jhanzab, "Potential of copper nanoparticles to increase growth and yield of wheat," *J Nanosci Adv Technol,* vol. 1, pp. 6-11, 2015.

[48] M. Ashfaq, N. Verma, and S. Khan, "Carbon nanofibers as a micronutrient carrier in plants: efficient translocation and controlled release of Cu nanoparticles," *Environmental Science: Nano,* vol. 4, pp. 138-148, 2017.

[49] F. Torney, B. G. Trewyn, V. S.-Y. Lin, and K. Wang, "Mesoporous silica nanoparticles deliver DNA and chemicals into plants," *Nature nanotechnology,* vol. 2, pp. 295-300, 2007.

[50] M. V. Khodakovskaya, K. De Silva, A. S. Biris, E. Dervishi, and H. Villagarcia, "Carbon nanotubes induce growth enhancement of tobacco cells," *ACS nano,* vol. 6, pp. 2128-2135, 2012.

[51] R. Kumar, M. Ashfaq, and N. Verma, "Synthesis of novel PVA–starch formulation-supported Cu–Zn nanoparticle carrying carbon nanofibers as a nanofertilizer: controlled release of micronutrients," *Journal of materials science,* vol. 53, pp. 7150-7164, 2018.

[52] N. Kizilbash, J. Alruwaili, A. Hai, H. M. Khachfe, and J. Ambreen, "Water soluble carbon nanotubes increase agricultural yields," *J Biochem Biotech 2020; 3 (1): ${pages}. 2 J Biochem Biotech 2020 Volume 3 Issue,* vol. 1, p. 3.

[53] J. P. Giraldo, M. P. Landry, S. M. Faltermeier, T. P. McNicholas, N. M. Iverson, A. A. Boghossian, N. F. Reuel, A. J. Hilmer, F. Sen, and J. A. Brew, "Plant nanobionics approach to augment photosynthesis and biochemical sensing," *Nature materials,* vol. 13, pp. 400-408, 2014.