Nanofertilizer for Precision and Sustainable Agriculture

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Abstract: Nanotechnology has shown promising aims to contribute to sustainable agriculture. This article explores recent advances in nanotechnology applications in sustainable agriculture, including crop production and defense, focusing on nanofertilizers. Slow-release fertilizers are believed to have the potential to address most of the conventional fertilization challenges. Nanofertilizers appear as a promising alternative to agricultural chemical fertilizers. Nanofertilizers can play a critical role by reducing the release of nutrients and increasing nutrient use quality. The introduction of nanofertilizers in agriculture is specifically intended to minimize mineral losses in fertilization and increase yields during mineral management and promote the growth of agriculture.

Index Terms: agriculture, nanofertilizer, nanotechnology, slow-release.

1 INTRODUCTION

Despite the limited supply of natural resources such as fertile land, high-quality seeds, and water, global agricultural systems face numerous unforeseen challenges. Fertilizers play a virtual role in increasing agricultural production. However, the improper use of chemical fertilizers irreversibly destroys the soil's chemical ecosystem and limits the area available for crop production. By developing an enhanced crop production system that ensures sustainability, modern nano-engineering techniques are being used to solve an agricultural crisis.

In conventional farming, excess fertilizer is added directly to the soil or sprayed on the leaves, exceeding the plant's nutritional requirements. This is because, due to leaching of chemicals, evaporation, drift, hydrolysis, run-off and photolytic or microbial degradation, a very low percentage of fertilizer enters its target location. Nanotechnology, which uses nanomaterial of less than 100 nm scale, may give an unparalleled opportunity to develop concentrated sources of plant nutrients with higher absorption rates, the efficiency of utilization and minimal losses, potential to boost crop productivity and to control nutrient distribution to plants and targeted sites effectively, and can increase crop yield by increasing the availability of fertilizer nutrients in soil and plant nutrient uptake.

To reduce the negative environmental impact of conventional agricultural practices, nanofertilizers have been introduced to increase the rate of seed germination, seeding growth, and photosynthetic activity. In compliance with the crops' nutritional requirements, nanofertilizers are now used in particular quantities, ensuring minimal differential losses.

2 NANOFERTILIZER USE FOR SUSTAINABLE AGRICULTURE

There are three types of nanofertilizers. Those are (i) nanoscale fertilizers; made with nanoparticles containing nutrients, (ii) nanoscale additive-fertilizers; with nanoscale additives, (iii) nanoscale coating-fertilizers; coated with nanoparticles. The most common procedure of producing nanofertilizers with nanomaterial is the nutrient encapsulation. The preliminary nanomaterial is produced by using both physical (top-down), and chemical (bottom-up) approaches. In recent times, the targeted nutrients are either encapsulated inside nonporous materials, coated with thin polymer film particles, or coated with nanoscale emulsions. Based on the action, nanofertilizers can be classified in to:

1. Control or slow-release fertilizers.

2. Control loss fertilizers.
3. Magnetic fertilizers or Nanocomposite fertilizers.
4. Quick release.
5. Specific release.
6. Moisture release.
7. PH release fertilizers, etc.

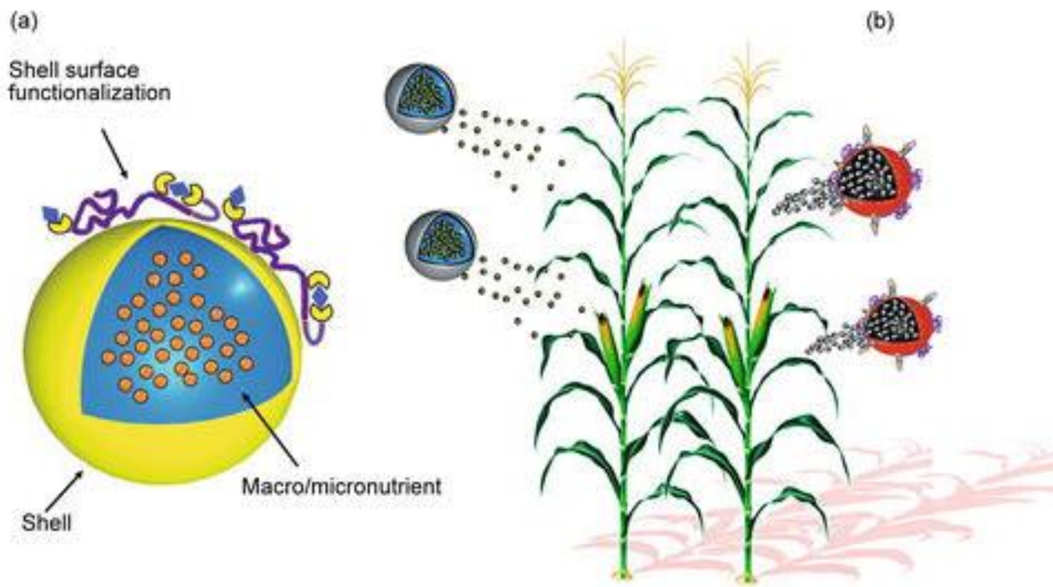

Fig. 01. Schematic diagram of (a) a cross-section of nanocapsule containing macro/micronutrients, (b) release of nutrients [1]

Several research works have reported that a decrease in nanomaterial size promotes an increase in the particle surface mass ratio, allowing the absorption of abundant nutrient ions that are subsequently slowly and steadily desorbed over an extended period. Therefore, nanotechnology approaches have increased interest to produce successful nitrogen, phosphorous, and potassium fertilizers. In practice, most conventional fertilizer systems have not met plant nutrient requirements due mainly to the poor nitrogen utilization efficiency (NUE) of plants [2]. Several attempts have reported developing efficient fertilizer systems, especially for the supply of nitrogen, which is the key nutrient required for plant development. Being an excellent candidate for nitrogen fertilizer, Urea is a must for effective and targeted delivery for crops [3].

Nanofertilizers based on zeolites is capable of slowly releasing nutrients to crops that increase nutrient availability to crops over a growth period that prevents the loss of nutrients from de-nitrification, volatilization, and soil flushing, especially NO3-N and NH3-n fixation due to nanoparticles show a very high surface: volume ratio [4].

Besides, nanoparticles' high surface area makes it possible to bind a large number of urea molecules. Nanohybrid urea-modified hydroxyapatite allows a 6:1 ratio of Urea to hydroxyapatite by weight to be synthesized as fertilizer by in situ coatings of hydroxyapatite with Urea at the nanoscale [5]. In addition to the stabilization due to the high surface area imparted, supplementary stabilization leading to high urea loading was provided by flash drying of the suspension to obtain a solid nanohybrid for the nanoparticles' volume ratio. This 40 % of nitrogen-weight nanohybrid provided a platform for its gradual release. Its potential application to sustain yield and decrease the amount of Urea used in agriculture is demonstrated.

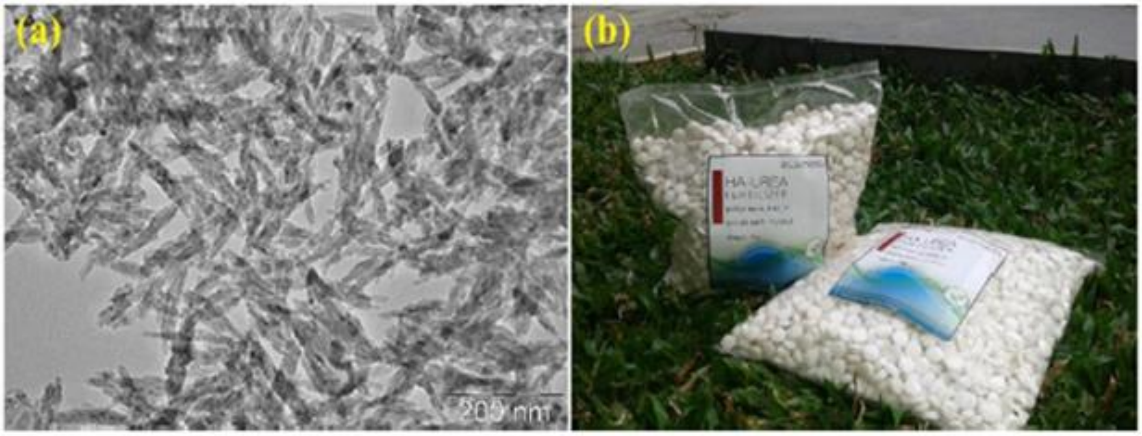

Fig. 02. HA–urea nanohybrids (a) transmission electron microscopy (TEM) images at 200 nm scale; (b) pilot-scale pelletized product developed at Sri Lanka Institute of Nanotechnology [6]

Based on the results of the release analysis and plant uptake studies, it was concluded that the nanohybrids produced have opened up new pathways for the production of an effective Phosphorous (P) nutrient system with increased solubility and plant availability. In particular, several attempts have been made to develop efficient fertilizer systems to supply Nitrogen, which is the main nutrient required for plant development. By integrating it into a matrix of urea-carrying hydroxyapatite nanoparticles, the high solubility of urea molecules has been decreased, and that can be released in a programmed manner [7-10]. The Uva area was evident for increased tea (*Camellia Sinensis*) yield obtained by slow-release urea – hydroxyapatite nanohybrid nanofertilizer and a positive impact was pronounced in adverse climatic conditions [11]. Due to their excellent biocompatibility, while serving as a rich phosphorus source, hydroxyapatite nanoparticles have been picked.

Silica nanoparticles play a dual function by serving as a carrier matrix for urea and providing silicon, a micro-plant nutrient essential for plant growth. Relevantly, the gradual and sustained release activity of nanohybrids prevents premature loss of urea. As a result, the current research focuses on a novel energy-efficient synthesis of urea-silica nanohybrids with high nitrogen loading. A modified in-situ sol-gel route was employed to synthesize urea-silica nanohybrids with a high urea loading of 36% (w/w) and a loading efficiency of ~83%. The developed urea-silica nanohybrids could be utilized as a potential candidate for slow-release nitrogen fertilizers due to their slow and sustained release behaviour exhibited by nanohybrids in water for more than ten days [12, 13].

Chitosan-NPK (Nitrogen, Prosperous, and Potassium) nanoparticles were easily applied to leaf surfaces and entered the stomata through gas uptake, avoiding direct contact with soil systems transporting via phloem tissue. When the wheat plants were treated with nano-chitosan-NPK fertilizer, a substantial increment in harvest, crop, and mobilization indexes were observed. Accelerating plant growth and productivity by using nanofertilizers will open up new agricultural practice perspectives by shortening the life-cycle of nano fertilizer wheat plants to 23.5 % of normal fertilized wheat plants [14].

Nitrogen release actions of novel nanohybrids exhibited controlled release properties over pure urea, demonstrating that urea modified calcium carbonate (urea-CC) nanocomposites have been introduced [3]. Urea modified CC formulations of 0.5:1, 1:1 and 2:1 urea-CC composites display comparatively controlled release activity over traditional nitrogen fertilizer systems, leading to a further novel controlled release of fertilizer while responding to reduce the tonnage of daily fertilizer use and urea-CC nanohybrid was synthesized using an in-situ rapid carbonation process that reduces nitrogen solubility by at least five times compared to pure urea. Calcium carbonate has been introduced due to its biocompatibility and non-toxicity, making the nanohybrid more flexible, cost-effective, and efficient as a nitrogen fertilizer. Cubic plate-like nanoparticles, which together formed pine corn as a structure giving a platform for urea's controlled release properties for the crops [3].

In both economic and environmental terms, there are major problems associated with the production and supply of fertilizers and prices due to non-renewability of the phosphorus mineral and emission of greenhouse gases when producing the nitrogen fertilizer. Researchers study the use of synthetic hydroxyapatite nanoparticles (HANP) for controlled release of phosphorous in soybean, the use of HANP as a phosphorous fertilizer in wheat and incorporated into biodegradable, soluble host matrixes. Urea coated HANP for slow release of Nitrogen in rice for controlled release of P in agriculture. Developing an effective P nutrient system that could solve inherent problems resulting from current P fertilizers by synthesizing citric acid surface adjusted hydroxyapatite nanoparticles using wet chemical precipitation [15,16]. The pot experiments' results, the optimum growth parameters, efficient and gradual release were obtained with the in situ modified composite samples compared to the conventional P fertilizers.

Various investigations have shown that the impact of nano-grade fertilizer on seed and seed vigor was significantly influenced by seed germination and seed growth due to its easy penetration into the seed. Nano ZnO reported higher percentage germination and root growth of peanut seeds than bulk zinc sulfate and similarly positive germination efficacy of nanoscale SiO_2 and TiO_2 was reported in soybean bean. Recorded higher seed germination, shoot length, root length under nanofertilizer treatment over or without nanofertilizer treated seeds and increased availability of nutrients to growing plants that increase chlorophyll formation, photosynthesis, dry matter production and result in improved overall plant growth [4].

Agricultural nanofertilizers aim to minimize mineral fertilizer losses and increase mineral production and foster growth in agriculture. Several studies have carried out the effects of micronutrient oxide nanoparticles of zinc, iron, and manganese, as well as the combination of these oxides as a foliar application on the development, yield, and quality of squash plants using a green microwave-assisted hydrothermal process, analytical grade salts of ferric, manganese, and zinc nitrate were used as precursors for the preparation of nano oxide fertilizers. The resulting nano oxides have an average particle size and small surface areas of about 20-60 nm. The results have shown that the spraying of manganese oxide nanoparticles on plants has yielded the best vegetative growth characteristics, including the characteristics of the fruits, yield, and photosynthetic pigment content. Compared with untreated plants, the use of the prepared nano oxides as a foliar application increased growth and yield [17].

3 CONCLUSION

The use of nanofertilizers in agriculture should be of more significant concern to society. In agriculture, the use of nanotechnology requires the controlled release of certain substances, especially pesticides and fertilizers. According to this article, nanotechnology will play an essential role in sustainable agriculture by adding nano pesticides and nanofertilizers to crops. Nanofertilizers are advantageous over conventional fertilizers as they increase soil fertility by target drug delivery, control or slow-release fertilizers in a programmed manner, enhance poor nitrogen utilization quality, root growth, improve harvest by boost crop productivity, improve plant nutrients with higher absorption rates reducing mineral losses, improving the rate of seed germination having a coating of nanoparticle are some of the significant advantages that have achieved from nanotechnology in sustainable crop production than conventional agriculture so far.

REFERENCES

[1] L. Marchiol, "Nanotechnology in agriculture: new opportunities and perspectives," *New Visions Plant Sci*, vol. 9, p. 121, 2018.

[2] 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.

[3] 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.

[4] M. D. Singh, "Nano-fertilizers is a new way to increase nutrients use efficiency in crop production," *International Journal of Agriculture Sciences, ISSN*, pp. 0975-3710, 2017.

[5] 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.

[6] 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.

[7] 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.

[8] 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.

[9] 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.

[10] 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.

[11] 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.

[12] 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.

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

[14] H. M. A. Aziz, M. N. Hasaneen, and A. M. Omer, "Nano chitosan-NPK fertilizer enhances the growth and productivity of wheat plants grown in sandy soil," *Spanish Journal of Agricultural Research*, vol. 14, p. 17, 2016.

[15] 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.

[16] 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.

[17] A. Shebl, A. Hassan, D. M. Salama, A. El-Aziz, and M. S. Abd Elwahed, "Green synthesis of nanofertilizers and their application as a foliar for Cucurbita pepo L," *Journal of Nanomaterials*, vol. 2019, 2019.