Nanotechnology for sustainable food production

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Abstract: With the global population's increment, feeding the world is a daunting challenge due to the running out of food and leads to food insecurity of the world. Low habitable lands for agriculture, the low nutritional value of food and soil, diffusion of fertilizer from the grounds, and excess application of fertilizers indirectly lead to the world's food insecurity. Agriculture as a major economical driving force of most countries, it is essential to find a way out of these food insecurity issues. With the use of limited natural resources, lands, and water that can envisage a sustainable world through agriculture by increasing productivity through the effective use of modern technology. Nanotechnology is the modern platform for agriculture and every industry, which affects a better way to increase the productivity of agriculture by developing efficient nutrient and pest control systems, together with improved crop varieties and fertilizers without harm to the ecosystem. Conventional fertilizer systems used in practice have not met the plant nutrient requirements because of the low Nitrogen Use Efficiency (NUE) of plants. Therefore, the review enlightens the modern nanotechnological innovations on fertilizers which consist of nitrogen as main plant nutrients include micro and macronutrients, that act as nanohybrids, nanocomposite and surface modified nanocarriers; also the contribution of the innovations compared to conventional systems.

Index Terms: food security, macronutrients, nanofertilizer, nanohybrids, urea.

1 INTRODUCTION

Feeding over seven billion of increasing population on earth is a burning problem of the present and near future due to the demand for food, which is considered a symbol of sustainable development. Even though Food security is a desperate problem; the world suffers to ensure better access to health qualities and nutrient content of food in a sustainable way. United Nations' Committee on World Food Security, defined food security as, that all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for active and healthy life (IFPRI.org). Estimated records of Food Security and Nutrition in the World 2019 declare the rising hunger of the world started from 2015, radiated through 821 million people all over the world in 2018 by implying rescue of the food security is a vital requirement for the sake of future to diminish hunger, micronutrient deficiency, undernourishment.

According to the United Nations, among every nine people to one suffers from hunger that depicts food insecurity and a way of putting world health at significant risk. Therefore, to ensure food security along with nutritional values and to stop suffering from hunger, need to be discussed to improve sustainable agriculture with long term aspects [1]. Out of the habitable lands in the world half of it use for agricultural and food production purposes. Nevertheless, the rapid increase of oil price of the past decade; which lead to let down the food production including the harvest due to high fertilizer costs.

2 AGROCHEMICALS AND FERTILIZERS

According to the studies and researches; increase the efficient usability or supply of agrochemicals or fertilizers, developing novel crop varieties with enhanced nutritional values, pest controllability, and high yield of crops like rice and wheat which easily affordable for the increasing population have explored as novel pathways to extend the food security called as "green revolution" [2],[3],[4]. The attraction for the new technological solutions; specially nanotechnology-based developments, to ensure food security; starts from fertilizers that readily supply to the crops for better yield [4],[5].

Fertilizers or agrochemicals for the plants mainly consist of nitrogen (N), potassium (K), and phosphorus (P) known as plant primary macronutrients to earn high genetic yield. Also, calcium (Ca), magnesium (Mg), and sulfur (S)are known as secondary macronutrients that accommodate plant growth [1],[6],[7]. As well as macronutrients, boron (B), chlorine (Cl), manganese (Mn), iron (Fe), Zinc (Zn), copper (Cu), molybdenum (Mo), and selenium (Se) are the micronutrients required in small amounts for plant growth [6],[7]. However, it is crucial to consider; the capability of maximum plant uptake of these nutrients from the supplied fertilizer and the ways of losing the nutrients that are costly in the market[8]. Nitrogen is the primary nutrient required for plant growth contain mostly in conventional fertilizers; which are not meeting the actual required amount by the plants in a common practice called low nitrogen use efficiency [4],[9],[10]. Therefore, the research interests focused on cost-effective and efficient plant uptake fertilizers with a technologically better approach or a system to meet the nutrient requirement for increased crop yield. Soil fulfil the nutrient requirement of plants by absorbing through roots; nevertheless, the absorbance does not satisfy the actual requirement due to the low availability[4].

The external supply of conventional fertilizers covers the gap; but results in high wastage due to the leaching, volatilization of fertilizers from regional tropical soil, premature decomposition, and urease enzyme release fertilizers as gaseous ammonia or nitrogen oxide which leads to low harvest and food insecurity of the world [1]. So, it is evident as a timely requisite to fulfil the principal requirement of plant nutrients to the exact target and quantity; balanced fertilization, efficient programmed releasing fertilizers using improved techniques [5].

3 NANOTECHNOLOGY FOR SPECIFIED FERTILIZER SYSTEMS

Developing a fertilizer with a slow-releasing system for a straightforward approach to the plant is the recent research focused area to reduce the mentioned wastage of conventional fertilizers and to increase the nitrogen use efficiency due to gradual nutrient supply; with advantages such as balance nutrient uptake, rather than regular application supply timely, less wasting, less labour cost and cost-effectiveness, easy handling and storing properties, retaining properties for a given time and easy collaboration with other nutrients using various ways, etc. [11]. Nanotechnology is the innovative pathway that the world counts on solutions that provide for most of the world's leading problems; the sustainable use of fertilizers and novel techniques like the slow release of nitrogen fertilizers reduce the issues due to their higher surface area to volume ratio and the nanoscale size. So, control release fertilizers, chemically coated control release fertilizers, and bio inhibitors are used as solutions for the challenging nutrient problem of plants and the insecurity.

Kottegoda et al. reported a study about the slow-release of nitrogen by developing a urea-hydroxyapatite nanohybrid. Urea is a conventional fertilizer that exhibits excellent fertilizer properties; consists of 46% nitrogen by weight. Study based on hydroxyapatite nanoparticles; which is a biocompatible material used in various industries with reactive functional groups due to high surface chemistry. With the help of properties of hydroxyapatite nanoparticles surface, modified with urea as the rich nitrogen source. Experimentally the nanoparticles incorporated with urea in a 6:1 ratio (urea: hydroxyapatite). Due to high surface area to volume ratio, nanoscale size, and good biocompatibility of hydroxyapatite nanoparticles, a phosphorus source binds urea molecule into its matrix; resulting in a slower release of urea into the soil by reducing decomposition, leaching, and by other ways [2]. This reported study scientifically concludes that the surface-modified nanohybrid release urea as nitrogen slower than pure urea and in a water medium can exist for one week [2]. In addition to reducing the decomposition of urea, it is timely important to introduce cost-effective fertilizer systems that fulfil both requirements at once. Composite known as a mixture of fibres and matrix in common

practice; but when it became a nanocomposite, it has more compatibility with chemicals, a nanoscale size, shape, high surface to volume ratio; can easily be used for different application like controlled-release fertilizers.

As a cost-effective, commercially available material; calcium carbonate nanoparticles are coated with urea to increase the nitrogen use efficiency, reduce the releasing rate of nitrogen considered in research studies by synthesizing a nanohybrid. Ratnaweera et al.reported a controlled release, targeted delivery urea fertilizer incorporated with calcium carbonate nanoparticles synthesized by the bottom-up process which provide lower wastage of urea and five-time lower solubility rather than pure urea in their research [4]. The research study described that urea-modified calcium carbonate nanoparticles synthesize using one-step in-situ rapid carbonation method. For the experiment, five different ratios (0.5:1, 1:1, 2:1, 4:1, and 6:1) of urea-CaCO3 nanohybrids were prepared respectively (Fig. 1) [4].

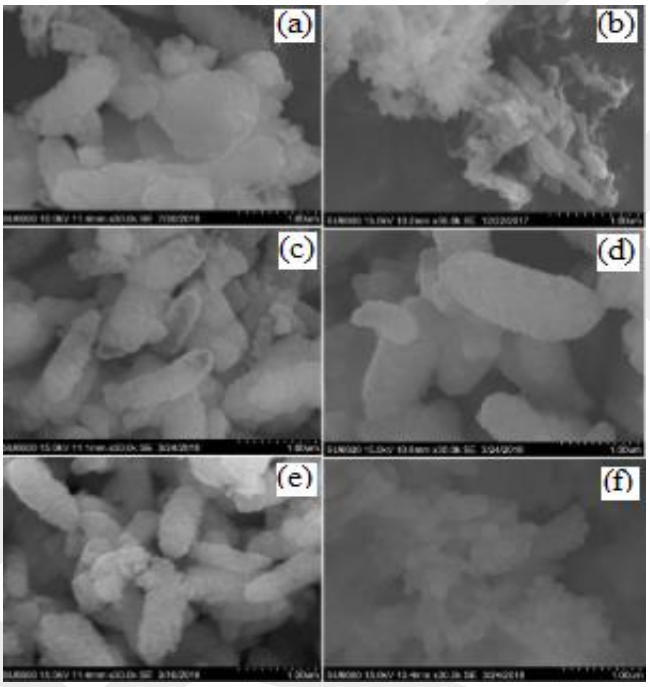

Fig.1. SEM images of synthesized (a) pure $CaCO_3$, (b) 0.5-1 urea-$CaCO_3$ composite, (c) 1-1 urea-$CaCO_3$ composite, (d) 2-1 urea-$CaCO_3$ composite, (e) 4-1 urea- $CaCO_3$ composite, (f) 6-1 urea-$CaCO_3$ composite [4]

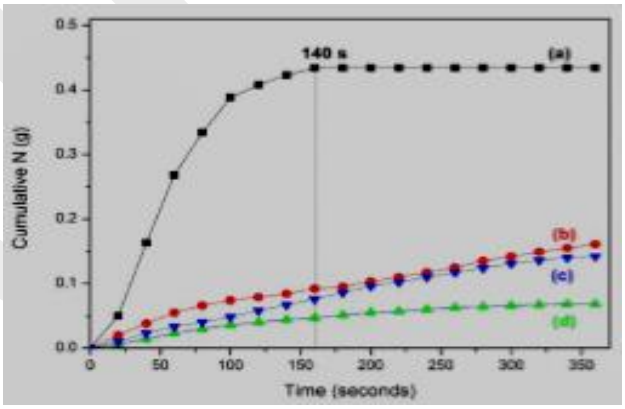

Fig. 2. Comparison of release behavior of (a) urea, (b) 0.5:1 urea-$CaCO_3$ composite, (c) 2:1 urea-$CaCO_3$ composite, and (d) 1:1 urea-$CaCO_3$ composite in water [4]

In the rapid release test explained in the study, the synthesized composites of 0.5:1, 1:1, and 2:1 urea-CaCO3were given a slow, controlled release behaviour compared to pure urea. Other than the 6:1, 4:1 ratio,0.5:1, 1:1, and 2:1 exhibit the ability to retard nitrogen solubility five times than urea (Fig. 2).

Further to surface modification, the encapsulation of surface-modified nanoparticles was reported in Kottegoda et al. in another research study [1]. The research method explains urea-hydroxyapatite nanoparticle contained wood chips soaked in potassium chloride (KCl) solution to achieve the encapsulation of potassium that also use as a plant nutrient. Also, the study explains urea-hydroxyapatite nanoparticles encapsulate with MMT clay nanocomposite. Both fertilizer systems showed better and balanced nutrient uptake by the plant. Wood chip encapsulated system interpret slow and controlled release of nutrients that increased plant uptake due to its porous cavity structure of wood surface; work as a fertilizer releasing reservoir in a programmed manner. Also, wood as a biocompatible material; when it is added to the soil, subjects to slow diffusion of fertilizers together leach out due to microbial degradation. Moreover, urea-hydroxyapatite with MMT, which resulting electrostatic interaction interrupts the higher solubility of urea.

The food insecurity of the world and the world demand for food and beverage products like tea, coffee, cocoa, etc. are affected by the low quality; especially the flavour, aroma changes, and yield issues due to the direct impact of fertilizers. A country like Sri Lanka provides unique flavoured tea to the global market as the number one highly affected by fertilizer and nutrients uptake of plants. Like high yield crops, tea production depends on the number of application and fertilizer usage; that leads to research studies developing new fertilizer formulation with better properties [5]. Raguraj et al. reported that HA–urea nanohybrids' effect on tea yields of Sri Lankan large-scale fields in different climatic zones. In the study, slow-release fertilizers were applied at different frequencies and the soil, and plant nutrient status, yield, and quality of tea were reported (Fig. 3).

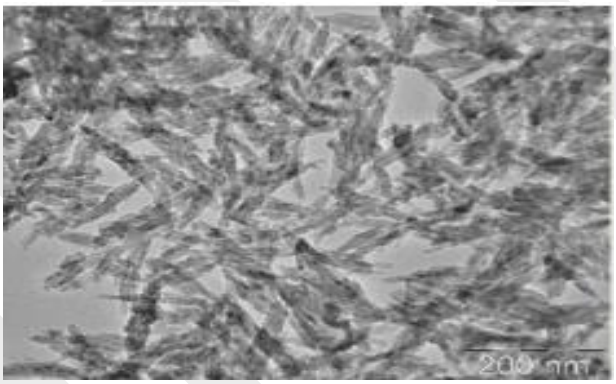

Fig. 3. HA–urea nanohybrids transmission electron microscopy (TEM) image at 200nm scale [5]

In the study Urea-coated hydroxyapatite nanohybrids used as the base for the experiment, for three tea plantation areas in Sri Lanka, resulting in the enhancement of nitrogen use efficiency, up to 10–17% increment in the yield, and reduces environmental impacts using the new fertilizer formulation up to 50% reduction of urea applied as the N source. Also, as a result, the quality parameters such as brightness, total polyphenols, and total amino acids of tea leave increased by urea–HA nanohybrids. So, the study concluded that HA–nanohybrid urea fertilizer is a potential alternative to minimizing the amount of fertilizer needed and reducing the number of applications and reducing the excessive usage of urea fertilizer in tea cultivations [5].

For the efficient delivery of plant nutrients using nanohybrids as a carrier related to agriculture, Madhavi et al. reported the development of urea embellished silica nanoparticles with a urea loading of 35.6% (w/w). Silicon

is a micronutrient that needs plant growth, and in the research study, silica acts as a carrier matrix for urea; the nitrogen resource of the plant [12]. The process was carried out as a greener synthetic procedure that the surface of silica nanoparticles modified with urea; which interacted with the surface hydroxyl groups of silica nanoparticles through carbonyl and amine groups by forming H-bonds without causing any substantial adjustment to the structure of nanoparticles. So, the nanohybrid exhibited the slow release of urea for more than ten days and reduced urea's premature loss [12],[13].

Sulphur is a secondary macronutrient that is an essential effect on plant growth and the crops' nutritional values. Sulphur available as nitrogen in the soil in both organic and inorganic forms; the deficiency becomes a common nutritional problem due to continuous use of wide yielding crop varieties, Sulphur-free fertilizers, intensive multiple cropping systems and high sulphur requiring crops along with the restricted or no use of organic manures have accrued in depletion of the soil sulphur reservoir. After a period of intensive cultivation due to crop removal, organic matter losses, leaching and erosion losses and use of non-sulphur containing fertilizers in areas found out as sufficient in sulphur start to show sulphur deficiency[14].

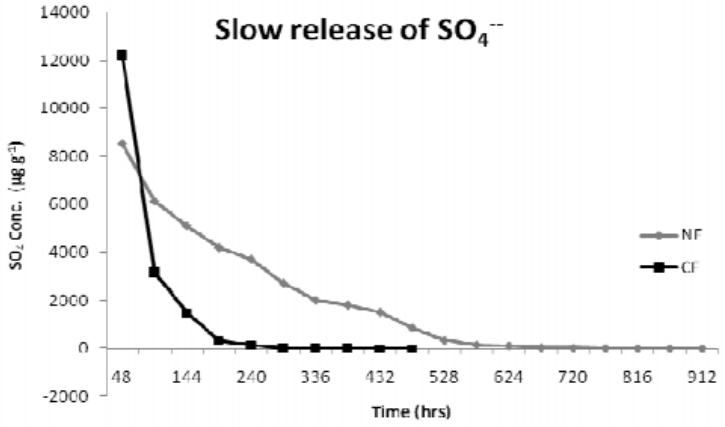

Fig. 4. Slow-release of SO_4^{2-} from pure $(NH_4)_2 SO_4$ and SO_4^{2-} loaded SMNZ [10]

Thirunavukkarasu, M., and Subramanian, k. reported sulphate loaded surfactant-modified nano-zeolite (SMNZ) as slow sulphur releasing fertilizer by comparing with pure fertilizer (NH4)2SO4 which were subjected to sulphate release using the percolation reactors. The results (Fig. 4) indicated the slow release of sulphate from sulphate-loaded surface-modified nano-zeolite. This slow release of sulphur may be attributed to the surface-modified nano-zeolite-based sulphur fertilizer are slowly soluble because of the massive number of pores, cages, and channels present in the zeolite structure which hold the SO42-; thereby steady release SO4 2- reported.

Phosphorus is an essential nutrient for its function as an energy transfer and storage in plants and a nutrient both as a part of several essential plant structure compounds and as catalysts in converting numerous key biochemical reactions in plants[15]. The research study of Sharmila Rahale reported about the surface modification of PO4-using various nano clays and Zeolite and its release pattern in a percolation reactor [16]. Nano- formulations with surface modified phosphate reported the release for an extended period of 40- 50 days, and the conventional fertilizer let out nutrients only up to 10- 12 days. Therefore, the research study concludes that surface-modified Zeolite could be a potential strategy to promote Phosphorus use efficiency, which hardly exceeds 18- 20 % in the conventional system [15],[16].

4 CONCLUSION

Based on the review about nanotechnology for sustainable food production; successfully explain the potential of nanotechnology-based innovations to solve the significant problems that need to be addressed in food and agriculture industries. Scientists, involved in research studies base on nanotechnology to ensure food security; due to the growing demand for food in the world. For an increased crop yield, suitable fertilizer systems need to be applied, and slow-release or controlled-release nano fertilizer systems explain promising results. Due to challenging fertilizer base problems, a considerable amount of waste results. Therefore, the review describes the innovations that provide cost-effectively, controlled, and timely targeted delivery systems that will save the world's future food security with a rising population.

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