Nanofertilizer Use for Modern Agriculture

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Abstract: Performing all the farming practices, sustainably is the key to achieve agricultural sustainability. It is necessary for conservation and enhancement of the natural resources such as soil, water, plant and animal diversity, vegetation cover, renewable energy sources, climate, and ecosystem services, which are considered the fundamentals for healthy, long-term functioning of agriculture. However, it is a necessity to guarantee the food security of the rising population. Development and implementation of novel nutrient management practices and fertilization technologies will open up the way to uplift the crop yields and close the gap between actual and attainable yield to ensure food security. Therefore, this article's main idea is to review the worthiness of using nanofertilizers to attain sustainability of agriculture.

Index Terms: agriculture, fertilizers, nanofertilizers, sustainable

1 INTRODUCTION

Sustainability is a process of transition in which investment direction, technology orientation, resources management, institutional growth and functioning, and the advancement of human and community well-being aim to meet current needs and aspirations without undermining future generations' ability to meet their own needs and aspirations [1]. As far as agriculture's sustainability is concerned, it can be defined as the ability of a system to sustain the movement towards socially agreed objectives, namely: (a) meeting human needs for food and fiber; (b) improving the quality of the environment and natural resources; (c) ensuring the economic viability of farms and agricultural enterprises; and (d) improving the quality of life of farmers, farm workers, and society [1].

The main reason for addressing this agricultural sustainability is the incapability of fulfilling the growing demand for food with the forecasted increment of the human population which is predicted to reach 9.6 billion by 2050 [2],[3] with the need to provide about 50%–70% more food than now being produced [1],[4]. Apart from that, improved income, dietary changes, economic development, and nutritional deficiencies in the human population drive an ever-increasing food demand [2]. Although, the decrement of global food security (due to agricultural crop diseases and pests), climatic change events (droughts and low nutrient use efficiency), groundwater contamination, soil erosion, depletion of fossil resources, finite arable land availability, loss of long term productivity, low farm incomes and risks to human health and wildlife habitats which associated with the consequences of the conventional agricultural approaches also claim the agricultural development to be sustainable [5],[6]. But the failure to satisfy the growing demand for food without reliance on the extensive use of chemical fertilizers is the main difficulty to approach agricultural sustainability [6]. Although the available agrochemicals effectively enhance crop productivity and inhibit pests and diseases [7], those have more possibilities to generate unfavourable long-term outcomes. Technological innovations and nanotechnology are regarded as the potential auspicious options to transform conventional agriculture into modern agriculture that aligns with sustainability.

2 IMPORTANCE OF FERTILIZERS FOR CROP GROWTH

Plant nutrients are vital components of sustainable agriculture [8]. It is one of the most important factors for controlling productivity and quality of agriculture [9] as well as a balanced supply of essential nutrients leads to increased crop growth [10]. A shortage of one nutrient can inhibit or stunt plant growth. So,

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fertilizers need to be applied at the level required for optimal crop growth based on crop requirements and agroclimatic conditions [11]. Agricultural food production relies on the external supply of major nutrients such as N, P, and K to the plants for their proper growth as the soil itself does not have enough nutrient quantities [12],[13]. Accordingly, Nitrogen promotes leaf growth and forms proteins and chlorophyll. Phosphorus leads to root, flower, and fruit growth [7], and it has a significant positive interaction with N absorption and plant growth. Thus it is a commonly held that increased growth requires more of both N and P, the inference being that mutually synergistic effects result in growth stimulation and enhanced uptake of both elements[10]. Potassium contributes to the growth of stems and roots and protein synthesis [7].
Other than macronutrients, plants require micronutrients for their growth. Micro-nutrients such as Cu, Mn, and Zn are critical for enzyme activation and the synthesis of biomolecules involved in plant defence [2]. Therefore, with the help of scientists and agronomists and the help of farmers working towards that end, improving nutrient efficiency is an appropriate goal for all those involved in agriculture and the fertilizer industry. For the sake of efficiency, however, effectiveness can not be sacrificed [14].

3 LIMITATIONS OF EXTENDED USAGE OF FERTILIZERS IN CONVENTIONAL AGRICULTURE

Capital-intensive, large-scale, highly mechanized agriculture with a monoculture of crops and extensive use of artificial fertilizers, herbicides and pesticides with intensive animal husbandry has been known as conventional agriculture [15]. According to the definition mentioned above, traditional agriculture uses very high amounts of fertilizers to acquire the required productivity. But this high usage of fertilizers does not guarantee the improved crop yield [16]. Although agricultural production is adequate by this method to meet the current food demand, there are abundant indications that their products' foundations are at risk [17]. The large imbalance between the supply and removal of plant nutrients reflects a cost for the community and the farmer and has a substantially detrimental effect on the environment[18]. For instance, it has been reported that key macronutrient elements, including N, P, and K, applied to the soil are lost by 40–70 %, 80–90 %, and 50–90%, respectively, causing a considerable loss of resources [4]. Based on the relation between animal production and actual consumption of animal products, it was estimated that only 50% of the nitrogen, 57% of the phosphorus, and 64% of the potassium are found in the animal body's consumed parts. The rest is waste[18]. The above data illustrate that there is limited nutrient use efficiency due to conventional fertilizers' high nutrient release rates. Also, the nutrients lost from soils through fixation, leaching, or gas emissions can reduce fertilizer efficiency [8].

The inorganic fertilizers are artificially synthesized and are formulated in appropriate concentrations and the combinations that usually supply three main nutrients: nitrogen, phosphorus, and potassium (N, P, and K) for various crops and growing conditions [7]. However, due to several complexes, edaphic processes cause these elements to become immobilized within the soil, obstructing its timely and adequate availability for their uptake by the plants [19]. Several scientists have reported that plants utilize only 30 percent of applied fertilizers and the rest are susceptible to leaching, mineralization, and bioconversions [10]. This will give rise to serious environmental constraints such as groundwater pollution and water eutrophication. Eutrophication is most often the result of an elevated supply of nutrients, particularly nitrogen and phosphorus, to surface waters that result in enhanced production of primary producers, particularly phytoplankton and aquatic plants [20]. As a result of this lowering the quality of drinking water, development of bad odor, generating or/and supporting for oxygen deficiency in the bottom of water bodies, the proliferation of unwanted species, production of toxic NH_3, algal blooms, changes in the spatial distribution of marine organisms, increase and depletion of fish stocks, change in reproduction conditions for fish and marine fauna can happen [21]. Other than this, nitrogen in nitrogenous fertilizers reaches the water resources, especially to the groundwater by draining, leaching, or flowing by emerging a problem of

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groundwater pollution through 'nitrate' which is known as the dissolved form of nitrogen [9],[22].

Non-organic fertilizers mainly contain phosphate, nitrate, ammonium, and potassium salts [9]. The usage of these inexpensive fertilizers and high-yielding varieties of crops offer the possibility to grow a crop on the same field year after year a practice called monocropping without depleting nitrogen reserves in the soil or causing serious pest problems. So, farmers began to concentrate their efforts on monoculture. Unfortunately, these practices set the stage for extensive soil erosion [3] due to the soil salinity, and this repeated use of fertilizers leads to a decrease in soil fertility, thereby making the path for future crop losses [4]. Moreover, the fertilizer industry is considered a source of natural radionuclides (such as 238U, 232Th, and 210Po) and heavy metals like Hg, Cd, Pb, and Cu, Ni, and Cu [9]. So, the application of fertilizers more than the land requirement also can be a cause to generate toxic nature and heavy metal accumulation in soil and plant systems [23].

In addition to these problems, low nutrient bioavailability due to nutrient transformations, terminate the enzyme activation involved plant defense, need of fertilizers as bulk quantities, deterioration of product quality due to uneven application of fertilizers and cost increment and reduce profit margins for growers due to over-application of fertilizers are some other disadvantages in alliance with inorganic fertilizers. Apart from using chemical fertilizers, there is an increased emphasis on the integrated nutrient management systems (INMS), which use biofertilizers and organic fertilizers and chemical fertilizers. But the disadvantages of this system, including the less knowledge of farmers on this practice, manifest the requirement of another fertilizing method beneficial than INMS.

Yet, conventional agriculture's long-term profitability seems questionable with these environmental and health costs [5]. Thus the requirement to focus on new technology for fertilization was realized with the desire of making an efficient, environmentally friendly fertilizing method along with long-term profitability.

4 IMPORTANCE OF NANOFERTILIZERS FOR SUSTAINABLE AGRICULTURE

Nanofertilizers are synthesized or modified types of conventional fertilizers, bulk material fertilizers or extracted by various chemical, physical, mechanical or biological methods from various vegetative or reproductive parts of the plant, using nanotechnology to increase soil fertility, productivity and agricultural production quality [14]. There are three classes of nanofertilizers namely [24];

1) nanoscale fertilizer (nanoparticles that contain nutrients),
2) nanoscale additives (traditional fertilizers with nanoscale additives) and
3) nanoscale coating (traditional fertilizers coated or loaded with nanoparticles).

The main important property of nanofertilizers that facilitate higher nutrient use efficiency is their higher surface area due to the very less size of particles ranging from 1-100 nm in size [14]. The low surface area of nanofertilizers provides more sites to facilitate high reactivity needed for the different metabolic processes in the plant system. Also, possessing a very small particle size less than the pore size of roots and leaves allow the ease of more nutrient penetration into the plant from the applied surface such as soil or leaves [14].

Although the high solubility of nanofertilizers in solvents such as water which usually differ from the same material found in bulk form is another importance of the use of nanofertilizers over conventional fertilizers [16], according to the literature, citric acid surface-modified nanofertilizer which is synthesized using a wet chemical precipitation process can identify the increased solubility and plant availability of citric acid-modified hydroxyapatite nanoparticles a phosphorus nanofertilizer than its natural form of rock phosphate. Also, it eliminates the less nutrient availability property of a commercial form of phosphorous fertilizers due to having very high water solubility [12].

Nanomaterials usually have potential contributions to the slow release of fertilizers. Furthermore,

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nanomaterials' nano-coatings or surface coatings on fertilizer particles hold the material more strongly from the plant due to higher surface tension than conventional surfaces [25]. In nanofertilizers, nutrients can be encapsulated by nanomaterials, coated with a thin protective film, or delivered as emulsions or nanoparticles [25]. This type of nanofertilizers can release nutrients in response to environmental fluctuations such as soil acidity, moisture, and temperature to enhance plant growth more effectively than traditional fertilizers [25]. Other than these benefits, the controlled release mechanism also improves product quality by balancing the nutrient supply to plants. Also, it indirectly enables plants to combat various biotic and abiotic stresses. The urea functionalized hydroxyapatite nanoparticles can get as the perfect example for nanofertilizer which use the slow-release mechanism. The use of urea in nano form as a nitrogen fertilizer can eliminate the disadvantage of the premature decomposition of urea in soil due to water, volatilization, and urease enzyme, leading to the development of ammonia before the plant can effectively absorb it [26-31]. Other than that, it was reported a pronounced positive effect of HA–urea nanohybrids during unfavourable climatic conditions [32].

Despite that, the novel urea-silica nanohybrid fertilizer was also developed to exhibit a slow and sustained release behaviour of urea for more than ten days by the surface modification of silica nanoparticles with urea via a greener synthetic procedure [33]. This behaviour was aligned with the Korsmeyer–Peppas model implying that the release rate of urea is controlled by the diffusion rate of urea via the silica nanoparticle matrix in which urea has been bound while claiming the suitability of urea-silica nanohybrids as a slow-release plant nutrient formulation for the effective and precise delivery of nitrogen and silica to plants. Here, silica nanoparticles play a dual role by acting as the carrier matrix for urea and supplying silicon, a micro plant nutrient necessary for plant growth [34]. Except that, urea modified calcium carbonate nanohybrids also can identify as a novel scalable, cost-effective, and efficient nitrogen fertilizer, which retards the solubility of nitrogen at a minimum of five times compared to pure urea [35]. The application method in the field depends on the kind of crop concerned [14]. Several possible fertilizer application methods are also possible for nanofertilizers, including soil and foliar application as well as the soaking method.

Except for these advantages, because of their small size and physicochemical characteristics such as shape, surface chemistry, electrical charge, and agglomeration, nanofertilizers can be synthesized depending on the requirements and needs of each crop, using several kinds of material such as titanium dioxide, zeolite, copper, silica, alumina, carbon, zinc, and nitrogen [3].

Due to these all advantages of nanofertilizers available at present over conventional fertilizers and having high potential to achieve the goals of sustainable agriculture, active research programs need to evaluate for the future explorations of nanotechnology-enabled fertilization. Also, extensive studies are required to understand the mechanism of nanomaterials toxicity and their impacts on the natural environment [36]. Continued scientific input is required to fill in our knowledge gaps and to judiciously apply the precautionary principle. The appropriate goal of these efforts needs to be helpful and protect environmental and human health while ensuring the nanotechnology industry's long-term sustainability [37].

5 CONCLUSION

The usage of nanofertilizers is gaining attention as a successful way of fulfilling growing food demand with the growing world population as those fertilizers minimize some of the main problems associate with conventional fertilizers like less bioavailability to plants, toxicity caused by the excess release of fertilizers, and low nutrient use efficiency. This is due primarily to some nanotechnological techniques used in non-fertilizers such as controlled release mechanism, controlled loss mechanism, magnetized fertilization mechanism, nutrient encapsulation, surface functionalization, and use of nano-coatings or nano-composites.

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