Nanofertilizers and their roles in sustainable agriculture

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ABSTRACT: Because of the limitation in arable lands and water resources, the development of agriculture sector is only possible by increasing of resources use efficiency with the minimum damage to production bed through effective use of modern technologies. Among these, nanotechnology has the potential to revolutionize the agricultural systems, biomedicine, environmental engineering, safety and security, water resources, energy conversion, and numerous other areas. Nanostructured formulation through mechanisms such as targeted delivery or slow/controlled release mechanisms and conditional release, could release their active ingredients in responding to environmental triggers and biological demands more precisely. Studies show that the use of nanofertilizers causes an increase in nutrients use efficiency, reduces soil toxicity, minimizes the potential negative effects associated with over dosage and reduces the frequency of the application. Hence, nanotechnology has a high potential for achieving sustainable agriculture, especially in developing countries.

Key words: Nanotechnology, Nanoporous Zeolites, Nutrients Use Efficiency, Smart Fertilizer

INTRODUCTION

With the global uprising in population and rapid urbanization, agronomists are left with the critical duty of feeding more people from agricultural fields which are decreasing correspondingly. Investigations show that, the world population is expected to be 9.1 billion people by 2050. If food consumption in developed countries is coordinated by the other parts of the world and all of these people are to be fed adequately, total food consumption will have to rise by 50–70% (Keeney, 1997; Jaggard et al., 2010). Consider that, the amount of arable lands changed very slightly and may even have reduced in some parts of the world due to urbanization (Kaarstad, 1997). In addition, satellite images reveal that the earth is quickly running out of fertile land and that food production will soon be incapable to keep up with the growing world population (Baruah and Dutta, 2009).

Fertilizers have an axial role in enhancing the food production in developing countries especially after the introduction of high yielding and fertilizer responsive crop varieties. In spite of this, it is known that yields of many crops have begun to depression as a result of imbalanced fertilization and decrease in soil organic matter. Moreover, excessive applications of nitrogen and phosphorus fertilizers affect the groundwater and also lead to eutrophication in aquatic ecosystems. Such cases along with the fact that the fertilizer use efficiency is about 20-50 percent for nitrogen and 10-25 percent for phosphorus fertilizers implies that food production will have to be much more efficient than ever before (Shaviv, 2000; Chinnamuthu and Boopathi, 2009).

According to this and limited availability of land and water resources, development of agriculture can be achieved exclusively through increasing productivity by effective use of modern technologies. Among these, nanotechnology has the potential to revolutionize the agricultural systems, biomedicine, environmental engineering, safety and security, water resources, energy conversion, and numerous other areas (Baruah and Dutta, 2009).

The objective of this study is giving a brief overview on nanotechnology and its role in sustainability of agriculture. Such studies will provide the theoretical backgrounds that are needed for applied agricultural research in this field.

Importance and role of nanofertilizers in improvement of nutrients use efficiency

According to Royal Society, "Nanotechnologies are the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometer scale"(Chinnamuthu and Boopathi, 2009). Nowadays, nanotechnology is progressively moved away from the experimental into the practical areas (Baruah and Dutta, 2009). For example, the development of slow/controlled release fertilizers,
conditional release of pesticides and herbicides, on the basis of nanotechnology has become critically important for promoting the development of environment friendly and sustainable agriculture. Indeed, nanotechnology has provided the feasibility of exploiting nanoscale or nanostructured materials as fertilizer carriers or controlled-release vectors for building of so-called “smart fertilizer” as new facilities to enhance nutrient use efficiency and reduce costs of environmental protection (Cui et al., 2006; Chinnamuthu and Boopathi, 2009).

Encapsulation of fertilizers within a nanoparticle is one of these new facilities which are done in three ways a) the nutrient can be encapsulated inside nanoporous materials, b) coated with thin polymer film, or c) delivered as particle or emulsions of nanoscales dimensions (Rai et al., 2012). In addition, nanofertilizers will combine nanodevices in order to synchronize the release of fertilizer-N and -P with their uptake by crops, so preventing undesirable nutrient losses to soil, water and air via direct internalization by crops, and avoiding the interaction of nutrients with soil, microorganisms, water, and air (DeRosa et al., 2010).

**Nanoporous zeolites**

Nano clays and zeolites that are a group of naturally occurring minerals with a honeycomb-like layered crystal structure are other strategies for increasing fertilizer use efficiency (Chinnamuthu and Boopathi, 2009). Its network can be filled with nitrogen, potassium, phosphorous, calcium and a complete set of minor and trace nutrients. So acts as a nutrients supply that are slowly released "on demand". However, Leggo (2000) stated that the main application of zeolites in agriculture is in nitrogen capture, storage and slow release. Application of soluble N fertilizers is one of the major reasons for groundwater contamination. Nitrogen releasing dynamics of the absorbed form (in zeolites) is much slower than for the ionic form.

Millan et al. (2008) reported that urea- fertilized zeolite chips, can be used as slowrelease nitrogen fertilizers. Ammonium-charged zeolites have shown their capacity to raise the solubilization of phosphate minerals and thus goes to improved phosphorus uptake and yield of crop plants. Studies conducted to check solubility and cation-exchange in mixtures of rock phosphate and NH$_4^+$ and K-saturated clinoptilolite showed that mixtures of zeolite and phosphate rock have the potential to provide slow-release fertilization of plants in synthetic soils by dissolution and ion-exchange reactions (Allen et al., 1993).

Li (2003) demonstrated the possibility of using surfactant-modified zeolite using hexa decyl trimethyl ammonium as fertilizer carrier to control nitrate release, and deduced that surfactant-modified zeolite is a suitable sorbent for nitrate, since slow release of nitrate is achievable. These dual properties propose that surfactant-modified zeolite has the potential to be used as fertilizer carrier to control the release of nitrate and other anions.

**Slow/controlled release nanofertilizers**

Coating and binding of nano and subnano-composites are able to regulate the release of nutrients from the fertilizer capsule (Liu et al., 2006). In this regard, Jinghua (2004) showed that application of a nano-composite consists of N, P, K, micronutrients, mannose and amino acids enhance the uptake and use of nutrients by grain crops. Moreover, nanotechnology could supply tools and mechanisms to synchronize the nitrogen release from fertilizers with crop requirements. This will be accomplished only when they can be directly internalized by the plants. Zinc–aluminium layered double-hydroxide nanocomposites have been employed for the controlled release of chemical compounds which act as plant growth regulators. Studies has shown that fertilizer incorporation into cochleate nanotubes (rolled-up lipid bilayer sheets), had improved crop yield (DeRosa et al., 2010).

More recent strategies have focused on technologies to provide nanofertilizer delivery systems which can react to environmental changes. The final goal is production of nanofertilizers that will release their shipment in a controlled manner (slowly or quickly) in reaction to different signals such heat, moisture and etc. Furthermore, it is known that under nutrient limitation, crops secrete carbonaceous compounds into rhizosphere to enable biotic mineralization of N and/or P from soil organic matter and of P associated with soil inorganic colloids. Since, these root exudates can be considered as environmental signals and be selected to prepare nanobiosensors that will be incorporated into novel Nanofertilizers (Ali-Amin Sadek and Jayasuriya, 2007; Sultan et al., 2009). In addition to Cases where mentioned, some of advantages related to transformed formulation of conventional fertilizers using Nanotechnology are presented in table 1.
Table 1. Some of advantages related to transformed formulation of conventional fertilizers using Nanotechnology (Cui et al., 2006).

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<tr>
<th>Desirable Properties</th>
<th>Examples of Nanofertilizers-Enabled Technologies</th>
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<tr>
<td>Controlled release formulation</td>
<td>So-called smart fertilizers might become reality through transformed formulation of conventional products using nanotechnology. The nanostructured formulation might permit fertilizer intelligently control the release speed of nutrients to match the uptake pattern of crop.</td>
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<tr>
<td>Solubility and dispersion of mineral micronutrients</td>
<td>Nanosized formulation of mineral micronutrients may improve solubility and dispersion of insoluble nutrients in soil, reduce soil absorption and fixation and increase the bio-availability.</td>
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<tr>
<td>Nutrient uptake efficiency</td>
<td>Nanostructured formulation might increase fertilizer efficiency and uptake ratio of the soil nutrients in crop production, and save fertilizer resource.</td>
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<td>Controlled release modes</td>
<td>Both release rate and release pattern of nutrients for water-soluble fertilizers might be precisely controlled through encapsulation in envelope forms of semi-permeable membranes coated by resin-polymer, waxes and sulphur.</td>
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<tr>
<td>Effective duration of nutrient release</td>
<td>Nanostructured formulation can extend effective duration of nutrient supply of fertilizers into soil.</td>
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<tr>
<td>Loss rate of fertilizer nutrients</td>
<td>Nanostructured formulation can reduce loss rate of fertilizer nutrients into soil by leaching and/or leaking.</td>
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It is considerable point that, what was mentioned is only part of opportunities for using nanotechnology to improve fertilizer formulations and construction of more environmentally friendly fertilizers. In these cases, the emphasis is primarily on improving nutrient use efficiency. Whereas, nanotechnology can also improve the performance of fertilizers in other ways. For instance, due to its photocatalytic characteristic, nanosize titanium dioxide has been incorporated into fertilizers as a bactericidal supplement. In addition, nanosilica particles that absorbed by roots have been shown that form films at the cell walls, which can improve the plant’s resistance to stress and thus increases the crop yield (DeRosa et al., 2010).

CONCLUSIONS

Since fertilizers, particularly synthetic fertilizers, have a major potential to pollute soil, water and air; in recent years, many efforts were done to minimize these problems by agricultural practices and the design of the new improved fertilizers. The appearances of nanotechnology open up potential novel applications in different fields of agriculture and biotechnology. Nanostructured formulation through mechanisms such as targeted delivery or slow/controlled release mechanisms, conditional release, could release their active ingredients in responding to environmental triggers and biological demands more precisely. There is the possibility of using these mechanisms to design and construction of nanofertilizers. The use of these nanofertilizers causes an increase in their efficiency, reduces soil toxicity, minimizes the potential negative effects associated with over dosage and reduces the frequency of the application. Nanofertilizers mainly delays the release of the nutrients and extends the fertilizer effect period. Obviously, there is an opportunity for nanotechnology to have a significant influence on energy, the economy and the environment, by improving fertilizers. Hence, nanotechnology has a high potential for achieving sustainable agriculture, especially in developing countries.

REFERENCES


