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Nano-fertilizers : A Novel Approach for Sustainable Crop Production under Changing Climate

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Introduction

Outburst of world population in past decade has forced the agricultural sector to extend crop productivity to satisfy the needs of billions of people particularly in developing countries. Since green revolution, chemical fertilizers are deemed as an indispensable input of modern crop production systems, however these are associated with environmental and ecological consequences. This has necessitated the search for environmental friendly fertilizers significantly those with high nutrient use potency as nutrient fertilization plays a vital role in maintaining soil fertility and boosting crop productivity and quality. In recent years, nanotechnology has extended its relevance in plant science and agriculture. Advancement in nanotechnology has improved ways for large-scale production of nanoparticles of physiologically vital metals, which are now used to improve fertilizer formulations for enhanced uptake in plant cells by minimizing nutrient loss. This article briefly sheds light on the potential role of nanotechnology in developing nano-fertilizers, its formulation, functioning, advantages and limitations and some field evidences showing its significant role in sustaining crop production.

Potential role of Nano-technology in developing Nano-fertilizers

Nanotechnology is a novel scientific approach that involves the use of materials and equipments capable of manipulating physical moreover chemical properties of a substance at molecular levels. Nanotechnology utilizes nano-materials of less than 100 nm size which offer an unprecedented opportunity to develop concentrated sources of plant nutrients having

high absorption rate, utilization efficacy and minimum losses. Like all other fields, the solid impact of nano-materials is being felt in agriculture sector.

Modern intensive farming systems utilize organic and mineral manures in order to supply essential plant nutrients, but this approach has resulted in serious deterioration of ecosystems and environment. Loss of nitrogen as nitrous oxide and nitrates leaching has resulted in eutrophication and manifesting the impacts of global warming and climate change. Phosphate fertilizers have even lesser nutrient use efficacy (NUE) that has been reported to be below 20%. A nano-fertilizer is any product that is made with nanoparticles or utilizes nanotechnology to enhance nutrient use efficiency owing to higher nutrients uptake caused by smaller surface area of nano-materials which increases nutrient-surface interaction. Along with boosting crop yield on sustainable basis, nano-fertilizers hold potential to minimize environmental pollution caused by fertilizers. Slow release fertilizers coated with nanoparticles significantly reduced nitrate leaching and de-nitrification. Moreover, controlled releasing fertilizers coated with nano-materials for reducing surface area may provide excellent source of supplying plant nutrients in future.

Formulation of Nano-fertilizers

Nano-sized particles have been prepared from urea, ammonia, peat and other synthetic fertilizers as well as plant wastes. A formulation process which involves urea deposition on calcium cyanamide resulted in nano-sized N fertilizer. In another formulation, grinded urea was mixed with different bio-fertilizers to prepare an effective nano-fertilizer to supply nutrients slowly and gradually for a longer period of time. In similar fashion, ammonium humate, peat and other synthetic materials were mixed to prepare nano-sized fertilizers. Mechanical cum biochemical approach is employed to prepare such nano-fertizers where materials are grinded to nano-sized particles through mechanical means and then biochemical techniques are put in action to prepare effective nano-scale formulations. Nano-emulsions are also being prepared by adding nano-sized colloids to emulsions. In short, fertilizers encapsulation with nanoparticles offers wide perspective for developing plant nutrient sources with greater absorption and nutrient use efficiency. The encapsulation of nutrients with nano-materials can be performed in three distinct ways;

1. Plant nutrients can be encapsulated within the nano-materials of varying nature and chemical composition.
2. Nutrient particles may be coated with a thin layer of nano-materials such as polymer film.
3. Nutrients may also be delivered in the form of emulsions and particles having dimension in the range of nanoparticles.

Functioning of Nano-fertilizers

Nano-fertilizers combine with the nano-devices in order to synchronize the release of fertilizer N and P with their uptake by crops, preventing undesirable nutrient losses to the soil, water and air via direct internalization by crop and avoiding the interaction of nutrients with soil, microorganisms, water and air. Nanostructured formulation might increase fertilizer efficiency and uptake ratio of the soil nutrients in crop production, and save fertilizer resource. Controlled release modes have properties of 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. Effective duration of nutrient release has desirable property of Nanostructured formulation, it can extend effective duration of nutrient supply of fertilizers into soil. Nanostructured formulation can reduce loss rate of fertilizer nutrients into soil by leaching and/or leaking.

Advantages of Nano-fertilizers over conventional fertilizers

Mineral nutrients applied to crops in the form of nano-fertilizers offer numerous benefits for making the crop production more sustainable and eco-friendly. Some salient advantages are-

1. Nano-fertilizers feed the crop plants gradually in a controlled manner in contradiction to rapid and spontaneous release of nutrients from chemical fertilizers.
2. Nano-fertilizers are more efficient in terms of nutrient absorption and utilization owing to considerably lesser losses in the form of leaching and volatilization.
3. Nanoparticles record significantly higher uptake owing to free passage from nano-sized pores and by molecular transporters as well as root exudates. Nanoparticles also utilize various ion channels which lead to higher nutrient uptake by crop plants.

Within the plant, nanoparticles may pass through plasmodesmata that results in effective delivery on nutrient to sink sites.

4. Due to considerably small losses, these can be applied in smaller amounts in comparison to synthetic fertilizers which are being applied in greater quantities keeping in view their major chunk that gets lost owing to leaching and emission.
5. Nano-fertilizers offer the biggest benefit in terms of small losses which lead to lower risk of environmental pollution.
6. Comparatively higher solubility and diffusion impart superiority to nanofertilizers over conventional synthetic fertilizers.
7. Smart nano-fertilizers such as polymer coated fertilizers avoid premature contact with soil and water owing to thin coating encapsulation of nanoparticles such as leading to negligible loss of nutrients. On the other hand, these become available as soon as plants are in position to internalize the released nutrients.

Limitations of Nano-fertilizers

Despite of having numerous benefits pertaining to sustainable crop production,nano-fertilizers also have some limitations regarding research gap, absence of rigorous monitoring and lack of legislation which are currently hampering the rapid development and adoption of nanoparticles as a source of plant nutrients. A few limitations and drawbacks associated with use of nano-fertiliazers for sustainable crop production is enlisted below.

1. Nano fertilizers related legislation and associated risk management continue to remain the prime limitation in advocating and promoting nano-fertilizers for sustainable crop production.
2. Production and availability of nano-fertilizers in required quantities is another limiting factor and wide scale adoption of nano-fertilizers as a source of plant nutrients has remained the foremost limitation.
3. The higher cost of nano-fertilizers is a hurdle in the way of promulgating them for crop production under varying pedo-climatic conditions across the globe.
4. Another major limitation pertaining to nano-fertilizers is the lack of recognized formulation and standardization which may lead to contrasting effects of the same nano-materials under various pedoc-limatic conditions.

5. There are many products being claimed to be nano but in fact are submicron and micron in size. This dilemma is feared to remain persistent until and unless uniform size of nanoparticles (1–100 nm) gets implemented.

Field evidences of impact of Nano-fertilizers on sustainable crop production

In a field investigation ,it was proved that nano nitrogen fertilizers have ability to boost the productivity of rice. Nano nitrogen fertilizers can be used in place of mineral urea and it can reduce environmental pollution caused by leaching, de-nitrification and volatilization of chemical fertilizers. Similarly, exogenously applied nutrients as nano-materials increased the vegetative growth of cereals including barley, while in contrast, nano-fertilizers applied in conjunction with reduced doses of mineral fertilizers were found to be instrumental in boosting yield attributes and grain yield of cereals. Nano-fertilizer of zinc applied as ZnO was found to be instrumental in boosting peanut yield due to robust plant growth, increased chlorophyll content of leaves and significantly better root growth.

In agreement to these findings, it was also reported that nano-fertilizers of zinc improved the seed production of vegetables. Similarly, nano carbon incorporated fertilizers effectively reduced the days to germination and promoted root development of rice seedling. It was inferred that nano-composites have the potential to promote vital processes such as germination, radicle and plumule growth and development . Another aspect of nano-fertilizers was explored regarding crop cycle as nanoparticles which were loaded with NPK, reduced the crop cycle of wheat up to 40 days, while grain yield was also increased in comparison to mineral fertilizers applied at recommended rates. Slow release fertilizer coated with nanoparticles boosted the productivity of wheat-maize cropping system. In addition to soil applied nano-fertilizers, foliar application of chitosan was reported to be instrumental in boosting tomato yield by 20%, while it remained non-significant as far as carrot yield was concerned. However, growth promoting effect of foliar applied chitosan was also recorded for horticultural crops such as cucumber, beet-root etc. The significantly higher selenium uptake by many crops including green tea was observed when it was applied as nano-sized particles. There are various other impacts that can be imparted by nano-materials in different crops and some of these have been described in the table below.

Nano-fertilizers	Crops	Imparted characteristics
Nanoparticles of ZnO	Chickpea	Increased germination, better root development, higher indole acetic acid synthesis.
Nano silicon dioxide	Maize	Drought resistance, increment in lateral root roots number along with and shoot length.
Nano silicon dioxide	Maize	Increased leaf chlorophyll.
Nano silicon dioxide	Tomato	Taller plants and increased tuber diameter.
Colloidal silica + NPK fertilizers	Tomato	Increased resistance to pathogens.
Nano-TiO_2	Spinach	Improved vigor indices and 28% increased chlorophyll.
Polyethylene + indium oxide	Vegetables	Increased sunlight absorption
Polypropylene + indium–tin oxide	Vegetables	Increased sunlight utilization
Gold nanoparticles + sulfur	Grape	Antioxidants and other human health benefits.
Kaolin + SiO_2	Vegetables	Improved water retention.
Bentonite + N-fixing bacteria inoculation	Legumes	Improved soil fertility and resistance to insect-pest
Nanocarbon + rare earth metals + N fertilizers	Cereals	Improved nitrogen use efficiency
Stevia extract + nanoparticles of Se + organo-Ca + rare-earth elements + chitosan	Vegetables	Enhanced root networking and root diameter
Nano-iron slag powder	Maize	Reduced incidence of insect-pest
Nano-iron + organic manures	Cotton	Controlled release of nutrients acts as an effective insecticide and improves soil fertility status.

Impact of nano-fertilizers on different crops under varying pedo-climatic conditions

Conclusion

Nano-fertilizers applied alone or in conjunction with organic materials have the potential to reduce environmental pollution owing to significant less losses and higher absorption rate. In addition, nano-materials were recorded to improve germination rate, plant height, root development and number of roots, leaf chlorophyll and fruits antioxidant contents. Moreover, controlled and slow released fertilizers having coating of nanoparticles, boost nutrient use efficiency and absorption of photosynthetically active radiation along with considerably

lower wastage of nutrients. The future of nano-fertilizers for sustainable crop production and time period needed for their general adaptation as a source of plant nutrients depend on varied factors such as effective legislation, production of novel nano-fertilizers products as per requirement and associated risk management. There is a dire need for standardization of nano-materials formulations and subsequently conducting rigorous field and greenhouse studies for performance evaluation. For sustainable crop production, smart nano-fertilizers having the potential to release nutrients as per plants requirement in temporal and spatial dimensions must be formulated. Lastly, researchers and regulators need to shoulder the responsibility by providing further insights in order to take full advantage of the nano-fertilizers for sustainable crop production under changing climate with the risk of causing environmental pollution.