

Smart Fertilizers

—A boon for Indian agriculture

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In recent years, there has been a concern regarding the quantity of mineral fertilizers used in agriculture that adversely affect the environment. Attention has been drawn to the fact that when nutrients are applied to crops, they are not all taken up by the plants immediately. There is also concern that some farmers might be applying inappropriate quantities of fertilizer. The main fertilizers having adverse effects on the environment are nitrate, phosphate and organic matter such as animal manure. In the coming future, there will be increasing pressure on global food systems and Indian agriculture will have the challenge to feed growing population without impacting environment quality. Application of smart fertilizers or rather smart input management is the key to supply sufficient food. Smart fertilization strategy has a great potential to achieve greater crop production and decrease the negative impact on the environment.

Keywords: Biochar, Crop residue, Nutrient Use Efficiency, Smart Fertilization

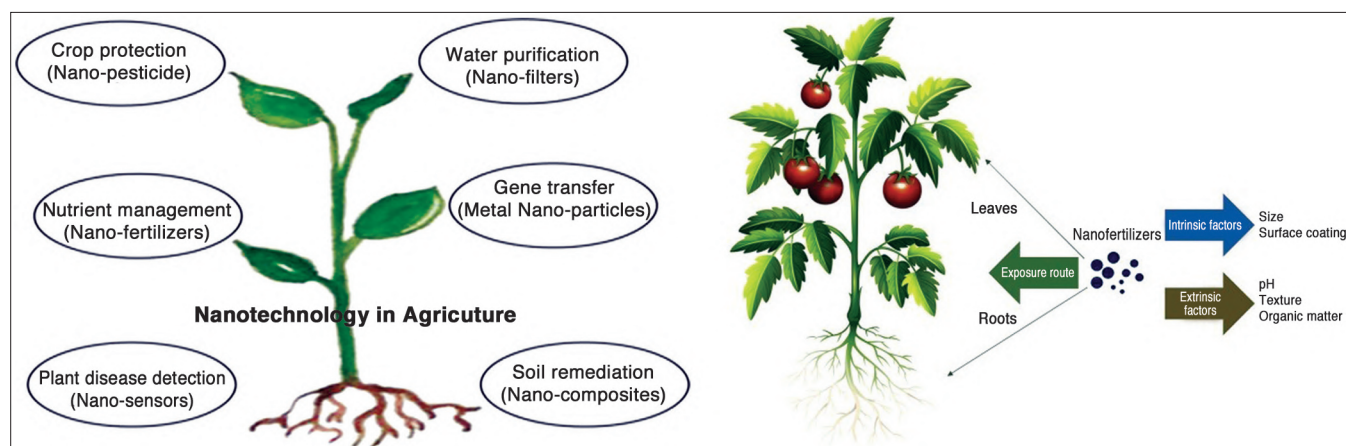
IMBALANCED nutrient fertilizer application leads to multinutritional deficiency and increases different problems in soil. Nitrogen and phosphorus are essential nutrients for development of plant growth and subsequently high fertilization rates lead to N and P losses with negative impact on atmospheric greenhouse gases concentration and water quality. There is an urgent need to improve Nutrient Use Efficiency (NUE) in Agriculture and manage biochemical cycles in a sustainable way.

The NUE of urea, the major nitrogen fertilizer, currently only averages 30-40% due to its sensitivity to volatilization, denitrification and leaching. The use of slow- and controlled-release fertilizers remains limited. China is by far the largest producer and consumer of smart fertilizers, amounting to one-third of global smart fertilizer (CRF) production. On-field experiments in China have shown 10-40% increase in rice yields with controlled-release fertilizers compared to those with

urea. Even when less nitrogen was used, controlled-release fertilizers increased rice yield by 15%. Smart fertilizer use requires 20-30% less nitrogen fertilizer, reducing CO₂ emissions for production. Smart fertilizers have lower N₂O emissions during the growing season than common nitrogen fertilizers. Common nitrogen fertilizers lose 1-5% of application as N₂O, a greenhouse gas 300 times stronger than CO₂. Over the last 150 years, atmospheric N₂O levels have risen 18%, largely due to nitrogen fertilizer use throughout the world. Smart fertilizers have lower N₂O emissions during the growing season than common nitrogen fertilizers. While the cost effectiveness of applying encapsulated controlled release fertilizers in high-value crops is proven, there is also scope for their application to low-value crops.

Total production costs can be reduced by 30% to 50% using smart fertilizers. The controlled supply of nutrients by a single application of a CRF is expected to increase NUE,

save labor and/or application costs and improve crop quality and yield. Smart fertilizers are especially beneficial where nutrient loss from conventional fertilizers are high, such as on lightly textured soils with excess rainfall or irrigation. In order to enhance nutrient use efficiency, new types of smart fertilizers with an emphasis on controlled-release and carrier or delivery systems are need. The development of smart fertilizers could also be based on the use of microorganism or bio-fertilizers and nonmaterial (nanofertilizers) thereby reducing nutrient losses. Increased nutrient use efficiency reduced dose of phosphate by half to one fourth and increased yields by 10% thereby farmer income can be raised upto 15-20% . The use of smart fertilizers or rather smart input management should be directed to the economic benefits of Indian farmers for better adaptability. We can then only achieve sustainable agriculture which can feed our next generations to ensure food security and environmental health. In the following article some of new



Nanotechnology in Agriculture. (Source: <https://www.sciencedirect.com/science/article/abs/pii/S0168945219309021>).

fertilizer material are discussed which have potential in this context.

Synthetic polymers

Synthetic polymers are widely used in agriculture especially for fertilizer development. A broad range of synthetic materials such as petroleum based polymers like polysulfone, polyacrylonitrile, polyvinyl chloride (PVC), polyurethane (PU) and polystyrene are the materials used currently for coating water soluble fertilizers. These polymers are not only safe for environment but also biodegradable and improve water-holding capacity, which in turn enhances nutrient uptake and crop yield. Biodegradable polymers have also been used in bio-formulation acting as microbial carrier for example sodium alginates are widely used for bio formulations (bacterial fertilizers). This bio-formulation is not only environmental friendly but also low cost polymer. Recently, properties of these polymers need to be mixed with synthetic polymers to increase the efficacy of these materials. Triple polymer fertilizer application enhanced the soil water holding capacity thereby enhancing the fertility and productivity. Surface coating on fertilizers with nano materials increased the surface tension resulting in controlled release. Biodegradable polymers protect the microbial inoculants from stress thereby increase the shelf life. It is found that different properties of coating materials can influence the availability of macronutrients (N, P and K) which are present in the core of the coated fertilizers. Different

experiments conducted abroad showed that the use of triple polymer fertilizers to encapsulate, enhanced the mechanical properties of different fertilizers like urea. They also suggested that polyethylene in first layer, acrylic acid-co-acryl amide used as super absorbent in second layer and butyl methacrylate in the third layer give good performance in controlled release of urea. Several studies have reported the utilization of these degradable polymers for a wide range of nutrients.

Nanofertilizers and their types

Nanofertilizers, also called smart fertilizers not only increase nutrient use efficiency but also reduce adverse effects on the environment compared to the use of conventional mineral fertilizers. Nanofertilizers involve the

materials at nanoscale level ranging from 1 to 100 nm. There are three main types of nanofertilizers: nanoscale fertilizer (synthesized nanoparticles), nanoscale additives (bulk products with nanoscale additives) and nanoscale coating or host materials (product coated with nanopolymers or loaded with nanoparticles) (Table 1). Slow release nanofertilizers are suitable alternatives to soluble fertilizers. Some nutrients are released at a slower rate during crop growth resulting in reducing their losses. Slow release of nutrients in the environment could be achieved by using Zeolites, also called natural clays, used as a reservoir for nutrients released at slower rate. The nanocomposites, on the other hand, are hybrid materials consisting of a

Table 1. Nutrients and their absorbents

Nutrient	Absorbent	Size (nm)
Nitrogen (N)	Zeolite	7-10
		20-30
		87
		200
	Montmorillonite	35-45
Phosphorus (P)	Carbon nanotubes, hydrogels organic	40-80
	Zeolites complexes	
	Zeolite	25-30
Potassium (K)	Montmorillonite, Bentominete and apatite	35-40
	Zeolite	25-30
	Montmorillonite,	35-40
NPK	Nanocoating of sulphur layer chitosan	78-100
Nanocomposites	Kaolinite	30-80
Sulphur (S)	Zeolite	25-30
Zinc (Zn),Iron (Fe) and	Zeolite	25-30
Boron (B)	Montmorillonite	35-40
	Nano Zn and Nano ZnO	35-20
PGPR microorganism	Gold nanoparticles	-
and bimolecular as enzymes	Nanoclays (Allophane)	100

Source: Nanotechnologies in Food and Agriculture. Springer, Switzerland, pp. 69–80.

continuous phase or matrix and a dispersed (nanofiller) phase. The dispersion of a small amount (<10%) of nonmaterial in the polymer matrix can lead to marked improvement in both physical and mechanical properties. Recent research is focused to introduce different nanocomposites to supply essential nutrients through smart delivery system. For the first time in India, IFFCO launched nano-tech based fertilizers like nanonitrogen, nanozinc and nanocopper for on-field trials. Listing out other benefits, IFFCO said these nanoproducts help in reduction in the requirement of conventional chemical fertilizer by 50%, raise crop production by 15-30%, improve soil health and cut emission of greenhouse gases. As coating and cementing materials, the nanofertilizers and sub-nanocomposites can also be used to regulate the release of nutrients from the fertilizer capsule. Thus, the future improvement must focus on nanofertilizer which allow nutrient release from nanofertilizers triggered by environmental conditions. In this perspective, nanodevices or additives such as nanotubes, aptamers, double hydroxides, nanocomposites, urease enzymes, nanosize titanium dioxide, and nanosilica particle can be associated to nanofertilizers to synchronize the fertilizer release with plant demand.

Biostimulants, Biofertilizers and plant growth promoting Rhizobacteria (PGPR)

Biostimulants are natural or synthetic substances that can be applied to seeds, plants, and soil.

These substances cause changes in vital and structural processes in order to influence plant growth through improved tolerance to abiotic stresses and increase seed, grain yield and quality. In addition, biostimulants reduce the need for fertilizers. In small concentrations, these substances are efficient, enhancing nutrition efficiency, abiotic stress tolerance, and crop quality traits, regardless of its nutrients content. These substances when applied exogenously have similar actions to the groups of known plant hormones, viz. auxins, gibberellins and cytokinins. In general, biostimulants are produced as a junction of natural or synthetic substances composed of hormones or precursors of plant hormones. When applied correctly in the crops, they act directly on the physiological processes providing potential benefits for growth and development, respond to water and salinity stress, and elements such as toxic aluminum. These products, which differ from traditional nitrogen, phosphorus and potassium fertilizers, may contain in their formula a variety of organic compounds, such as humic acids, seaweed extracts, vitamins, amino acids, ascorbic acid and other chemicals. Major groups of biostimulants are humic substances, protein hydrolysate and amino acid stimulants, seaweed extract and PGPR.

Biofertilizers on the other hand have an indirect effect on the availability of nutrients without itself supplying nutrients. They are live microbial formulations which help in availability and uptake of nutrients.

Diazotrophic bacteria are capable of converting atmospheric dinitrogen (N_2) into NH_3 , which can be used by plants. A number of free living soil bacteria are considered to be PGPR because of their competitive advantage in carbon rich and nitrogen poor situations. PGPR associated with root helps in production and regulation of phytohormones, slow release of nutrients (e.g. P and N Fixation) fixed nutrients chelating micronutrients (siderophores among other) produce of antibiotics (phytopathogens) and are anti-pathogenic. Encapsulation microorganism in carrier material (bioformulation) is designated to protect them during storage and from adverse condition, viz. pH and temperature. Agri-Life SOM Phytopharma (India) Limited produces Agri Boom (foliar spray), Aminoacid-Gr, Kohinoor as biostimulants and Fe-sol B, Agri-Life Nitrofix as biofertilizers. Materials suitable for immobilization and preservation of bacteria include alginate gels, synthetic gels (Sol-Gel) polyacrlamide agar and agarose, polyurethane vermiculite and polysaccharides.

Harvested residues as smart fertilizer

Low cost materials like straw are abundantly available resources in current agricultural systems which contain lignin, hemicelluloses and cellulose that impart mechanical strength properties. Wheat straw contains surface carboxyl, hydroxyl, ether, amino and phosphate which increase its reactivity and physiochemical properties, useful in



Crop residue as a fertilizer (Source: <https://extension.umn.edu/corn-harvest/crop-residue-management>)



Biochar (Source: <https://www.slideshare.net/saibhaskar/biochar-and-soil-environment>)

the preparation of absorbent materials for the treatment of waste water and slow release fertilizers. However, straw is susceptible to rapid decomposition in soil. A combination of clay or biochar along with wheat straw can act as release fertilizers. Cellulose obtained from residues has been also used in bioformulation as carrier for bacterial inoculants with broad spectrum antifungal activity and suppression of fungal pathogens. The menace of burning crop residues can be reverted back by using these residues for smart fertilizer. Potential use of wheat straw for the development of slow release N and boron fertilizers with water retention properties has been well known. Lignocelluloses and compost are subject to rapid decomposition once incorporated into soil. In order to further improve their properties as slow release fertilizers, they could be combined with clay minerals or biochar to reduce their decomposition.

Use of biochar for smart fertilizer

Harvesting residues such as wheat straw may also be used as feedstock for energy producing pyrolysis systems which generate biochar or pyrogenic carbon (biochar). Biochar has been widely used as soil

ameliorant and also used to increase C sequestration. Biochar is obtained through pyrolysis of agricultural or other lignocelluloses biomass at temperature ranging from 350°C to 700°C. Biochar was found to increase the C sequestration potential of soil through its high stability. Biochar produced from corncob, banana stalk and pomelo peel displayed an excellent retention ability in holding NH_4^+ associated to the presence of carboxyl and keto groups when the material was prepared at 200°C, suggesting that material could be used as slow-release carrier for N. Recent studies have also investigated the use of biochar and charcoal as carriers in combined formulations with beneficial microorganism. Biochar was a useful carrier for different bacterial populations. The use of biochar as carrier for smart fertilizers could be highly beneficial, as it combines nutritional benefits for plants with improvement of many other soil functions due to the addition of biochar itself. In particular, biochar addition to soil has positive effects on water holding capacity as well as C sequestration.

SUMMARY

In Indian agriculture, there is a lot

of technological development taking place. Despite availability of smart fertilizers, their use in agriculture is very limited i.e. less than 1% of the total worldwide fertilizer consumption. Several advantages could be observed in smart fertilizer compared to conventional fertilizer. Smart fertilizers based on slow or controlled-release and carrier delivery system have been shown to improve crop yields, soil productivity and lower nutrient loss compared to conventional fertilizers. Seven materials like clays, monoclays, polymers and harvesting residues are suitable for the development of smart fertilizers by acting as carrier matrices for nutrients and bacterial inoculants. Smart fertilizers would reduce losses of nutrients, prolong fertilizer cycles and enhance effective nutrient uptake by crops. These can substantially decrease the risk of environment pollution. Taking into account these economic aspects and the extremely important environmental aspect, the use of smart fertilizers in Indian agriculture would benefit farmers. Smart fertilizer could be boon for Indian agriculture.

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*Plant trees,
Conserve water,
Protect environment.*

