# Nano Fertilizers - IFFCO Experience

**Yogendra Kumar**
Indian Farmers Fertiliser Cooperative Limited
IFFCO Sadan, C-1, District Centre
Saket, New Delhi, India

Email : yogendrakumar@iffco.in

**Enhancing nutrient use efficiency (NUE) with minimal threat to environmental quality has become critical for our agriculture food production systems (FPS) to sustain the burgeoning population. Nanotechnology with nanoscale inputs for production of nano agri-inputs (NAIPs) has emerged as an innovative solution for addressing issue of low or declining use efficiency of nutrients with minimum environment footprints. Indian Farmers Fertiliser Cooperative Limited (IFFCO) - the farmers' own fertilizer cooperative has been in the forefront for promotion of agro-technologies and novel agri-inputs to mitigate problems faced by the farmers. It has indigenously innovated at its Nano Biotechnology Research Centre (NBRC) at Kalol, Gujarat and succeeded in R& D and manufacturing of proprietary nano-fertilizers *viz.* nano nitrogen, nano zinc, and nano copper. These nano-fertilizers utilise the dynamics of shape, size, surface area and bio-assimilation. These were evaluated on the basis of multi-locational multi-crop trials in varying seasons, both by the research institutes and also on the progressive farmers' fields across 11,000 locations on 94 crops across India. Independently, nano nitrogen, nano zinc, and nano copper have also been tested for bio-efficacy- biosafety- toxicity and environment suitability. IFFCO nano-fertilizers meet all the current national and international guidelines related to nanotechnology or nanoscale agri-inputs. They are in sync with OECD testing guidelines (TGs) and "Guidelines for Testing of NAIPs and Food Products " released by the Department of Biotechnology, Government of India. Harvested produce of crops applied with IFFCO nano nitrogen, nano zinc, and nano copper have been found fit for consumption with no adverse effect. Journey of IFFCO nano-fertilizers from conception to PILOT to PLANT stage has been covered in this paper.**

## Introduction

Ensuring food security for the nation with lesser environmental footprint has led to continuous search for novel and affordable solutions by the scientific community. Globally, sustainable and balanced food production systems are currently needed in view of climate change and erratic weather phenomenon for agrarian economies like India. Nitrogenous fertilizers remain the key input, critical for augmenting sustainable high crop production. Its role in utilisation of the full yield potential of crops is sufficiently documented. Efficiency of currently used nitrogenous fertilizer is quite low. Current use efficiency of fertilizers is low being 40–50% for N and 2-5 % for micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and boron (B). It offers a vast scope to improve the low nutrient use efficiency (NUE).

Excessive use of fertilizer increases economic cost of product and also dents the farmer's income. In retrospect, excessive use of fertilizers and their losses from root zone are the cause of soil, water and air pollution. To address this issue, nutrient supply needs to be synchronised with crop demand which has a potential of reduction in nutrient losses with improvement in NUE. For this several measures have been adopted world over but R& D of fertilizers have not been adequate enough to economically address this issue effectively.

Lately, nanotechnology has emerged as an effective alternative solution for addressing crop nutritional

deficiencies through enhanced bioavailability of nutrients and limited losses to the environment. Nanoscale materials can enhance the fertilizer use efficiency while foliar application can meet the crop nutrient requirement effectively as per its need. Thus, fertilizing the crop rather than soil saves the farming systems from the inherent challenges posed by low or declining nutrient use efficiencies.

**Scenario of Fertilizer Consumption; Declining Nutrient Use Efficiency and Increasing Multi-nutrient Deficiencies**

In India, there is a little scope of bringing in more area under cultivation; therefore, growth in food grain production has to come largely through productivity enhancement. Food grain productivity has registered a phenomenal increase from 522 kg $ha^{-1}$ in 1950-51 to 2,235 kg $ha^{-1}$ in 2017-18 but the decline in factor productivity of fertilizers in respect of food grain production indicates nutrient depletion in soil pool and reduction in NUE.

This has resulted into decrease in crop response to application of plant nutrients from 15 kg food grain $kg^{-1}$ NPK during 5th plan (1974-79) to < 6 kg food grain $kg^{-1}$ NPK in 11th plan period (2007-12) (Prasad, (2013), which has further reduced to 2.7 kg food grain/$kg^{-1}$ NPK in irrigated cropping systems **(Figure 1)**. Alternatively, fertilizer use efficiency (FUE), which is dependent on several factors including nutrient uptake efficiency and soil health, determines our agricultural and environmental stability. Innovative fertilizers can fulfil the 4R principles effectively to address issue of declining FUE.

Fertilizer consumption in India is imbalanced, skewed in favour of urea-N. Resultantly, the NPK consumption ratio has widened from 4:3.2:1 in 2009-10 to 7.0:2.8:1 in 2019-20. Nitrogen application has spiked post-NBS-2010 after a brief correction **(Figure 2)**. Nitrogen application has to be balanced in higher application regions and increased in the lower application regions.

Among secondary and micronutrients, widespread deficiencies of sulphur (S), Zn and B have been recorded in India **(Figure 3)**. At the state level, this disparity is more alarming. Analysis of district-wise, village level data of soil samples (46,180) for secondary and micronutrients by Tamil Nadu Agricultural University (TNAU), Coimbatore has shown the Zn deficiency to be 42.0% followed by B at 19.9% and Cu at 16.7%. This suggests that the state-specific micronutrient deficiencies have to be ameliorated for better crop productivity and farmers profitability. Biofortification of micronutrients in crops will address human and animal micronutrient deficiencies too. Only enhanced NUE of major and micronutrients with better soil health and agronomic management practices can meet the challenges, being currently faced by the farmers and policy makers.

**Injudicious Application of Urea – Matter of Growing Concern**

Imbalanced and injudicious application of urea is a matter of grave concern. Farmers have been called upon to reduce urea consumption by at least 25% for better environmental quality and their own

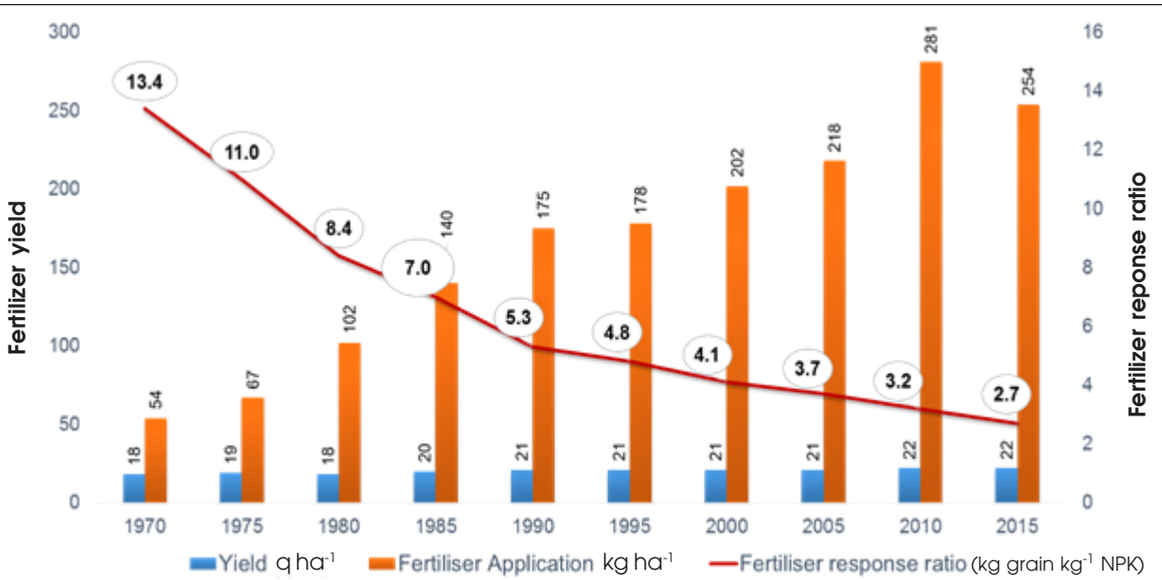


**Figure 1. Increasing food grain production *vis-a-vis* decreasing fertilizer response ratio**

**(Source: Chaudhari et al., 2015)**

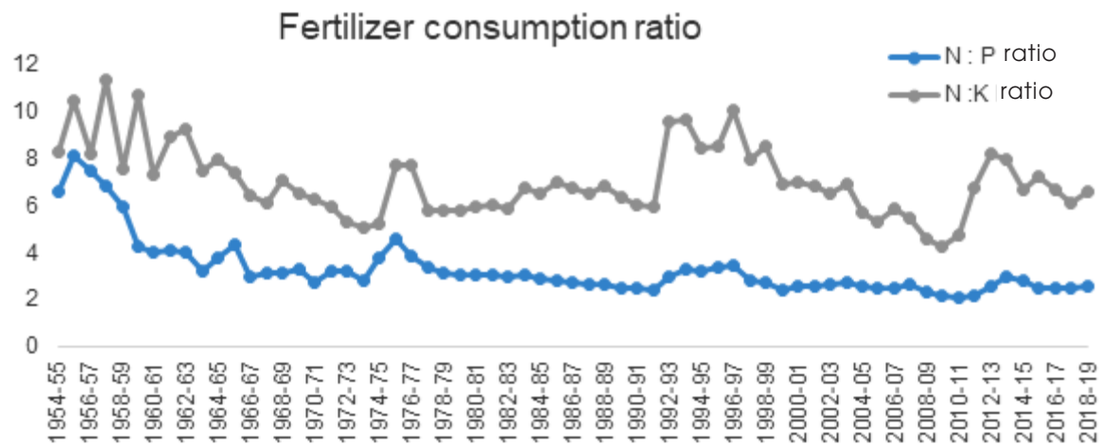


**Figure 2. Temporal variation in fertilizer consumption (Source: FAI, 2019)**

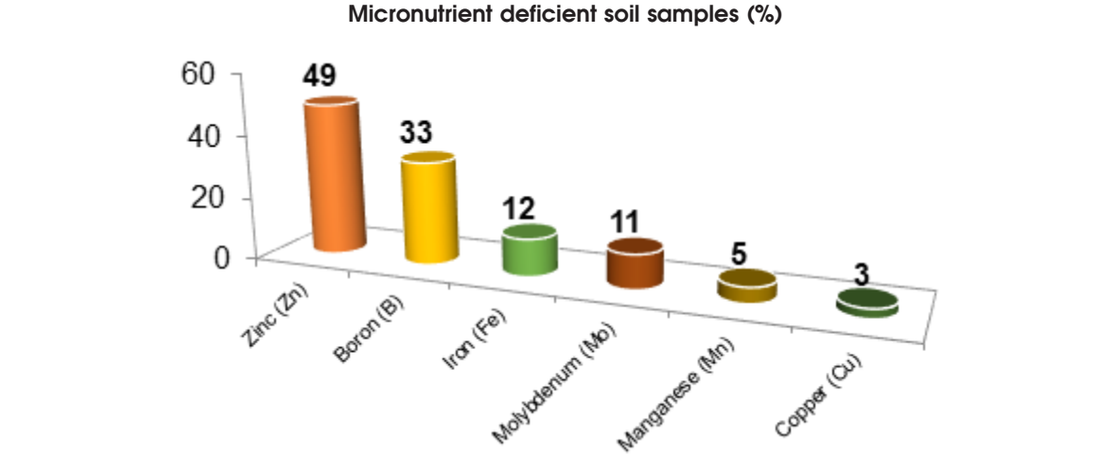


**Figure 3. Increasing incidences of micronutrient deficiencies**

profitability. This issue needs to be relooked in the light of sustainability of whole agriculture production systems and biogeochemical cycles. Urea accounts for >82% of the nitrogenous fertilizers applied to majority of the crops in India. Around 33 million tonnes (Mt) urea is applied to various crops every year. Its consumption is projected to reach 37 Mt during 2020-21 **(Table 1)**. There has been a commensurate increase in production, import and consumption of urea over consecutive years. Import of urea has

**Table 1. Production, import and consumption of urea during last 5 years**

| Year | Production (Mt) | Import (Mt) | Urea consumption (Mt) | | |
|---|---|---|---|---|---|
| | | | *Kharif* | *Rabi* | Total |
| 2016-17 | 24.20 | 4.97 | 14.36 | 15.26 | **29.62** |
| 2017-18 | 24.02 | 6.01 | 14.83 | 15.06 | **29.89** |
| 2018-19 | 23.90 | 7.56 | 15.45 | 16.57 | **32.02** |
| 2019-20 | 24.46 | 9.12 | 15.37 | 18.33 | **33.70** |
| 2020-21* | 15.15 | 6.61 | 17.78 | 2.43 | **20.21** |

*Figures for *kharif* 2020 and *rabi* 2020-21 (as on 10/11/2020)

| Table 2. Subsidy paid by Government of India for urea during last 3 years (Rs. Crore) | | | |
|---|---|---|---|
| Year | Indigenous urea | Imported Urea | Total |
| 2016-17 | 40,000 | 11,257 | 51,257 |
| 2017-18 | 36,974 | 9,980 | 46,954 |
| 2018-19 | 32,190 | 17,155 | 49,345 |
| Note: 1 crore = 10 million | | | |

increased over the years, reaching a figure of 9.12 Mt during 2019-20 and is expected to be about 6.61 Mt upto 10th November, 2020 in the current year (**Table 1)**. Subsidy burden on account of urea import constitutes 26% of the overall urea subsidy paid in a year by Government of India (**Table 2**). Arresting increasing urea consumption through its judicious application, R&D efforts, introduction of innovative products and contemporary policy measures is hence required.

**Innovative Fertilizers - Key to Sustainability**

Novel and innovative fertilizers apart from enhanced nutrient uptake efficiency offer benefits in terms of reduction in environment footprints. Fertilizer industry has pioneered and introduced enhanced efficiency fertilizers (EEF) which cater to a niche market only. For highly subsidised Indian fertilizer market, an innovative high tech fertilizer which is economically affordable too can be a real solution. Nanotechnology can be leveraged to develop agricultural intensification solutions, which can increase food production per unit of inputs and resources. Nanofertilizers based on nanotechnology because of their size advantage and controlled manufacturing process through chemical, physical and biological means have emerged as a viable option to fulfil this gap in conventional and innovative fertilizer market.

**Nano-fertilizers**

Nano-fertilizers by definition are, "Synthesized or modified form of traditional fertilizers, fertilizer bulk materials or extracts of different botanical, microbial or animal origin manufactured by chemical, physical, mechanical or biological methods with the help of nanotechnology but not limited to it". These nanoparticles can also be made from bulk conventional fertilizers.

At nano scale, physical and chemical properties of nano-fertilizers are dynamic and different from their counterpart. Due to higher surface area to volume size ratio and nano size, they have high availability and absorption. Particle size of nano-fertilizers is less than 1-100 nm in at least one dimension which facilitates better uptake from soil or leaves, resulting in production of more photosynthates and biomass required for healthy crops.

Nano-fertilizers have benefits in terms of application and small requirement, slow release mechanism, reduction in transportation and application cost, and cause comparatively low salt accumulation in soil *vis-à-vis* conventional fertilizers. These effectively meet crop nutrient requirement with increased bioavailability of nutrients. Foliar applied nano-fertilizers increase NUE and nutritional quality of crops through bio-fortification.

***IFFCO Ventures into R&D and Manufacturing of Nano-fertilizers***

IFFCO explored the innovative approaches through nanotechnology to increase NUE for increasing crop yields; reduce bulk fertilizer's consumption and increase farmer's profitability at reduced environmental cost. To achieve these objectives, Nano Biotechnology Research Centre at Kalol, Gandhinagar, Gujarat was established by IFFCO on 3rd November, 2019 (**Figure 4**).

NBRC has indigenously developed proprietary patented three products - nano nitrogen, nano zinc and nano copper **(Figure 5)**. These nanoscale nutrients have desired particle shape, particle size, particle purity, composition, concentration, stability, polydispersity index (PDI value), pH and crystal phase. They are bioavailable and within the scientific limits of application (10 to 80 ppm) as per their desired content in plants thus, fulfilling plant nutritional requirement as a fertilizer.

*1. Nano Nitrogen*

Nano nitrogen based on principles of nanotechnology provides novel alternative to wean the farmers away from urea. Nanoscale advantages of nitrogen particles have to be leveraged for addressing effectively the nitrogen requirement of crops (**Figure 6).** Precision and targeted application of nitrogen through foliar application of nano nitrogen reduces urea losses; increases nutrient uptake efficiency; and addresses environmental issues of soil, air and water pollution. It results in better crop harvest with lesser nitrogen application per unit area thus, leading to better farm economics.

Spraying of nano nitrogen at the rate of 2-4 mL per litre of water at critical crop growth stages triggers crop response, fulfils its nutritional requirement and also improves nutrient availability in the rhizosphere. When sprayed on leaves, nano N fertilizer easily gets absorbed and also enters through stomata due to its nano size (<100 nm) **(Figure 7).** It is distributed to other plant parts through phloem translocation and


**Figure 4. Nano Biotechnology Research Centre**


**Figure 5. Nano fertilizers (L-R): nano nitrogen, nano zinc and nano copper**

metabolically assimilated as proteins, amino acids, etc. as per the plant's need.

Nano nitrogen contains nanoscale nitrogen particles (18-30 nm) which have more surface area (10,000 times over 1 mm urea prill) and number of particles (55,000 nitrogen particles over 1 mm urea prill). Nano nitrogen particles with pore size (20 nm) can easily penetrate through cell wall and reach up to plasma membrane. Large size particles (20 - 50 nm) can penetrate through stomatal pores. They are also transported via phloem cells through plasmodesmata (40 nm diameter) to other plant parts. They can bind to carrier proteins through aquaporin, ion channels, and through endocytosis and metabolized inside the plant cell. Thus, when applying nanoscale particle like nano nitrogen through foliar application, it leads to more efficient absorption and penetration of nitrogen in-

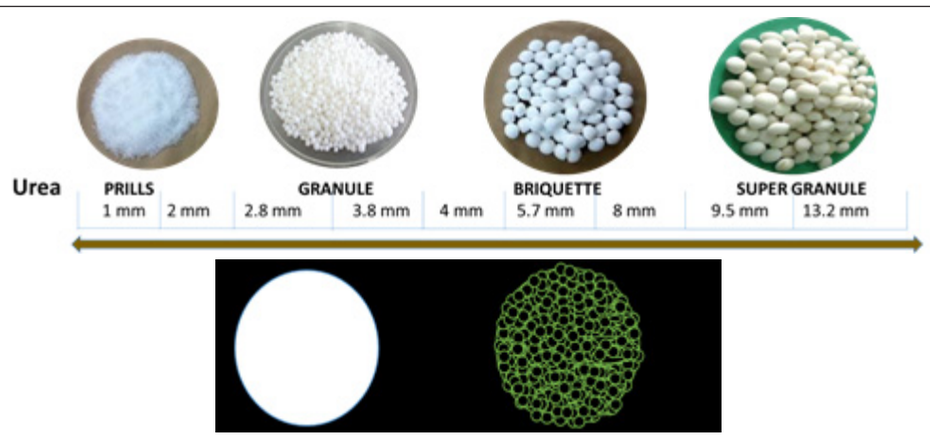


**Figure 6. Nanoscale advantage - dynamics of size, shape and mode of action**

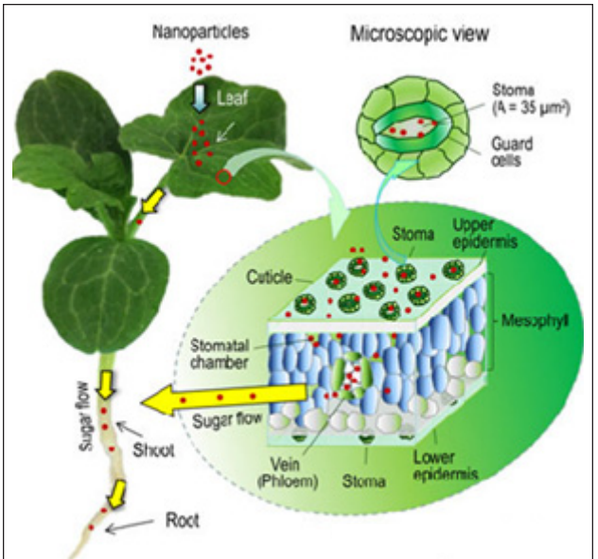


**Figure 7. Entry, transport and translocation of nanoscale particles inside the plant system (Source: Wang et al., 2013)**

side the plant system. It enhances metabolic processes, promotes meristematic activities leading to higher apical growth and leaf photosynthetic area. The composite effect of all these activities ultimately leads to higher yields and lower nitrogen deficiency inside the plant systems.

Foliar application of nano nitrogen to crops two times in a season fulfils its nitrogen requirement in above-ground tissues. It also triggers and induces mechanisms inside the plant for achieving the desired nitrogen levels such as in amino acids/protein content, chlorophyll content, nucleic acid, etc. Uptake of nitrogen and other nutrients is also increased due to improved soil organic matter (SOM) and microbial activity in the rhizosphere.

For better results, 500 mL bottle acre$^{-1}$ of nano nitrogen has to be sprayed two times at critical growth stages of the crop at initial growth stage and at pre-flowering stage. Benefit of 500 mL bottle of IFFCO nano nitrogen can potentially replace a bag of urea besides, providing benefit of better soil-air-water in perpetuity. IFFCO nano nitrogen can be applied safely to all type of crops, such as cereals, pulses, vegetables, fruit crops, turf, grasses and oilseed crops,

*2. Nano Zinc and Nano Copper*

Zinc is essentially required by the plants, animals and human beings for their proper growth and development. Humans require Zn through their diet drawn directly or indirectly from plants. Similarly, Cu is also one of the eight essential plant micronutrients, required for plant metabolic activities and healthy seed production. Copper deficiency can lead to increased susceptibility to pathogenic fungal and bacterial diseases, which can cause significant yield losses. Plants meet their Zn and Cu requirements from soils but because of increasing micronutrient deficiencies, bulk fertilizers are being applied to meet crop demand of these nutrients. Current fertilizer options are not efficient because of their poor use efficiency in soil.

Primary aim of nano zinc and nano copper is to substitute their conventional fertilizer analogues which have use efficiency between 2-5 %, increase crop productivity, and enhance its quality through agronomic fortification. Furthermore, nano zinc also helps plant to take up more P, leads to better physiological growth, and brings uniformity in shape and size of fruits. Similarly, nano copper builds innate immunity of crops against harmful fungal and bacterial pathogens which affects their overall growth and development. When nano zinc and nano copper are sprayed on the leaves because of small size they can be easily absorbed by the plant either directly or through stomatal openings. On entering through the leaves, these are distributed to plant parts through phloem translocation and metabolically assimilated as per the plant's need.

For better results, nano zinc or nano copper are sprayed two times at critical growth stages of the plant, first during initial growth stages and second at the pre-flowering stage with rate of application being 2-4 mL per tree of water. Nano zinc and nano copper can be mixed together during spray, if needed; else, they can be used separately. IFFCO nano zinc and nano copper can be used for all the crops such as legumes, cereals, oilseeds, vegetables and fruit.

***Multi location - Multi Crop 'On Station' and 'On Farm' Trials of Nano-fertilizers***

IFFCO launched nanotechnology-based indigenous nano products – nano nitrogen, nano zinc and nano copper on 3rd November, 2019 and simultaneously, undertook 11,000 farmers' field trials (FFTs) and "On Station" trials in collaboration with 22 State Agricultural Universities (SAUs)/Research institutes. Experimental trials undertaken during *rabi / zaid* 2019-20 in different crops like paddy, wheat, mustard, maize, tomato, cabbage, cucumber, capsicum, onion and states have recorded encouraging results. Summary of State Agricultural Universities / ICAR- KVK trials indicate that nano nutrient can enhance farmer's crop yields, besides effecting substantial savings on subsidised bulk fertilizer applications **(Figure 8).**

Trials conducted with SAUs/Research Institutes indicate that 50% urea reduction is possible with foliar application of nano nitrogen. All the growth and yield contributing characters were maximum and

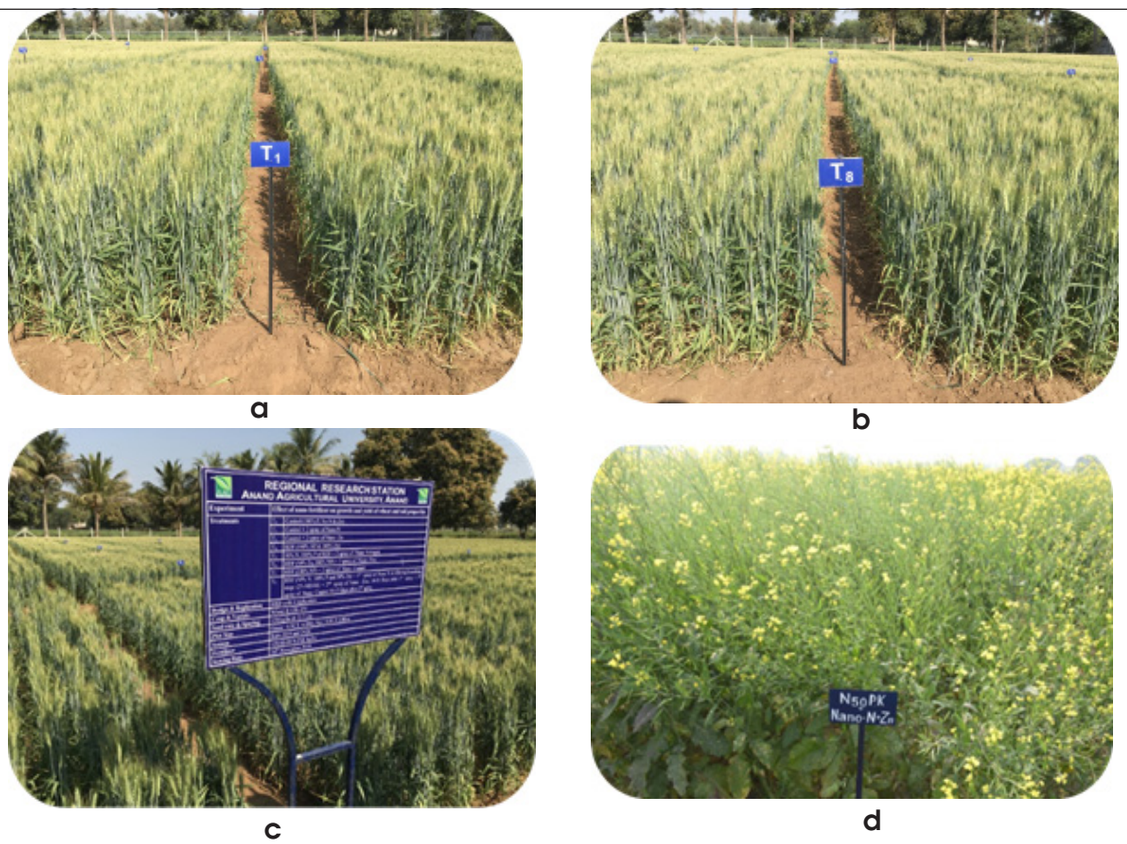


**Figure 8. Comparative photograph of RDF and 50% RDF + nano-N sprays a,b); nano trials in State Agricultural Universities and Research Institutes (c,d)**

significantly superior in treatments receiving 2 sprays of nano nitrogen or alternate combination sprays of nano nitrogen, nano zinc and nano copper with 50% reduction in nitrogen and zinc wherever recommended. ICAR-Indian Agricultural Research Institute, New Delhi states that nano fertilizers (alone or in combination) when applied with graded doses of fertilizers can lead to up to 50% reduction in the fertilizer nitrogen. Curtailing of 25% nitrogen fertilizer in wheat and 50% nitrogen fertilizer in mustard is possible with the two sprays of nano nitrogen. Similar or better results have been conveyed by other research institutes and SAUs. More number of effective tillers, higher growth and biomass yields and grain and straw yield have been recorded in treatments receiving nano- fertilizer application.

Mahatma Phule Krishi Vidyapeeth, Rahuri evaluated nanoproducts on onion crop and found that nano nitrogen and nano zinc increased yield even when their conventional counterpart application dose was reduced by 50% and Nano Copper improved the fruit quality. Economic benefits *i.e.* BCR of nanofertilizer application have to be seen in terms of extra yield achieved along with reduction in fertilizer usage and direct – indirect benefits on the reduction of soil-air-water pollution level.

***Multi location- Multi Crop - Farmer Field Trials (FFTs) of Nanofertilizers***

Farmer field trials have confirmed that IFFCO nano nitrogen leads to reduction in urea usage and better economics for the farmers. 8719 successful Farmer Field Trials – FFTs on 94 crops conducted in close supervision with ICAR- KVKs across 28 States / UTs were recorded **(Figure 9).** In farmer field trials average 7-8% higher crop yields have been recorded with 50% less of urea application.

Results of 600 on-farm trials with 8 crops conducted during winter season in different districts of Rajasthan have proved that the quantity of urea being applied by the farmers to supply nitrogen to the crops can be successfully reduced to half **(Table 3**). The yields obtained with 50% less nitrogen plus 2 sprays of nano nitrogen in standing crops gave yields higher than that applied in most of the 8 crops tested in these trials. Apart from this, effect of the nano-zinc and nano-copper was also evaluated. As the deficiencies of


**Figure 9. Photographs of farmer field trials conducted in close supervision in major crops and cropping systems of India**

these micronutrients are not universal like nitrogen, the significant responses to these nano-fertilizers depend on the magnitude of deficiency of specific micronutrient(s) and the nature of the crops.

Results of 730 field demonstrations conducted in different districts of Uttar Pradesh on farmers' fields with 12 crops proved that with the use of nano nitrogen, the quantity of urea being applied by the farmers to supply nitrogen to their crops can be successfully reduced to half **(Table 3**). The yields obtained with 50% less nitrogen as compared to the N applied under farmers fertilizer practice (FFP) and applying 2 sprays of nano nitrogen in standing crops gave yields higher than FFP in most of the crops tested in these demonstrations. Apart from this, effect of nano zinc and nano copper was also evaluated. As the deficiencies of micronutrients are not universal like N, positive responses to these nanofertilizers depended on the magnitude of the deficiency of specific nutrient Zn or Cu and the nature of the crops.

These results clearly establish that with application of nanofertilizers, the NUE can be significantly enhanced as revealed by 50% saving on urea through 2 sprays of nano nitrogen. Nano-fertilizers are considered as a novel approach towards saving of nutrients, in particular nitrogen, and for protecting the

**Table 3. Effect of nano fertilizers on crops (Table derived from Yogendra Kumar et al., 2020a and 2020b)**

| Crop (Data in parenthesis are number of trials) | Parameters | Farmer fertilizer practice (FFP) | FFP -50% N +2 sprays of nano nitrogen | FFP + 2 sprays of nano zinc | FFP + 2 sprays of nano copper | FFP(-50% N)+ 1 spray of nano nitrogen + 1 spray of nano zinc + 1 spray of nano copper |
|---|---|---|---|---|---|---|
| Wheat (480) | Lowest yield (kg ha$^{-1}$) | 2250 | 2400 | 2370 | 2370 | 2380 |
| | Highest yield (kg ha$^{-1}$) | 6410 | 6760 | 6610 | 6580 | 6875 |
| | Mean yield (kg ha$^{-1}$) | 4330 | 4580 | 4490 | 4475 | 4628 |
| | Response over FFP (kg ha$^{-1}$) | - | 250 | 160 | 145 | 297.5 |
| | Per cent increase over FFP | - | 5.77 | 3.7 | 3.35 | 6.87 |
| | Net return over FFP (Rs. ha$^{-1}$) | - | 4813 | 3080 | 2791 | 5727 |
| Barley (9) | Lowest yield (kg ha$^{-1}$) | 3200 | 3380 | 3300 | 3250 | 3350 |
| | Highest yield (kg ha$^{-1}$) | 5260 | 5620 | 5730 | 5790 | 5900 |
| | Mean yield (kg ha$^{-1}$) | 4230 | 4500 | 4515 | 4520 | 4625 |
| | Response over FFP (kg ha$^{-1}$) | - | 270 | 285 | 290 | 395 |
| | Per cent increase over FFP | - | 6.38 | 6.74 | 6.86 | 9.34 |
| | Net return over FFP (Rs. ha$^{-1}$) | - | 4118 | 4346 | 4423 | 6024 |
| Maize (4) | Lowest yield (kg ha$^{-1}$) | 4100 | 4300 | 4400 | 4100 | 4500 |
| | Highest yield (kg ha$^{-1}$) | 5500 | 6000 | 5700 | 5550 | 6000 |
| | Mean yield (kg ha$^{-1}$) | 4800 | 5150 | 5050 | 4825 | 5250 |
| | Response over FFP (kg ha$^{-1}$) | - | 350 | 250 | 25 | 450 |
| | Per cent increase over FFP | - | 7.29 | 5.21 | 0.52 | 9.38 |
| | Net return over FFP (Rs. ha$^{-1}$) | - | 6160 | 4400 | 440 | 7920 |
| Chickpea (27) | Lowest yield (kg ha$^{-1}$) | 1437 | 1566 | 1498 | 1466 | 1677 |
| | Highest yield (kg ha$^{-1}$) | 2500 | 2700 | 2650 | 2600 | 2650 |
| | Mean yield (kg ha$^{-1}$) | 1969 | 2133 | 2074 | 2033 | 2164 |
| | Response over FFP (kg ha$^{-1}$) | - | 165 | 106 | 65 | 195 |
| | Per cent increase over FFP | - | 8.36 | 5.36 | 3.28 | 9.91 |
| | Net return over FFP (Rs. ha$^{-1}$) | - | 8019 | 5143 | 3144 | 9506 |
| Urdbean (3) | Lowest yield (kg ha$^{-1}$) | 1650 | 1850 | 1925 | 1750 | 1975 |
| | Highest yield (kg ha$^{-1}$) | 1700 | 1850 | 2000 | 1800 | 2150 |
| | Mean yield (kg ha$^{-1}$) | 1675 | 1850 | 1963 | 1775 | 2063 |
| | Response over FFP (kg ha$^{-1}$) | - | 175 | 288 | 100 | 388 |
| | Per cent increase over FFP | - | 10.45 | 17.16 | 5.97 | 23.13 |
| | Net return over FFP (Rs. ha$^{-1}$) | - | 9975 | 16388 | 5700 | 22088 |
| Mustard (70) | Lowest yield (kg ha$^{-1}$) | 1100 | 1200 | 1170 | 1120 | 1180 |
| | Highest yield (kg ha$^{-1}$) | 4200 | 4300 | 4500 | 4200 | 4600 |
| | Mean yield (kg ha$^{-1}$) | 2650 | 2750 | 2835 | 2660 | 2890 |
| | Response over FFP (kg ha$^{-1}$) | - | 100 | 185 | 10 | 240 |
| | Per cent increase over FFP | - | 3.77 | 6.98 | 0.38 | 9.06 |
| | Net return over FFP (Rs. ha$^{-1}$) | - | 4425 | 8186 | 443 | 10620 |
| Potato (187) | Lowest yield | 13250 | 15000 | 14000 | 14000 | 16000 |
| | Highest yield | 61200 | 64300 | 61800 | 61800 | 62700 |
| | Mean | 32298 | 35414 | 33568 | 33824 | 34798 |
| | Response over FFP, kg ha$^{-1}$ | - | 3117 | 1270 | 1526 | 2500 |
| | % Increase over FFP | - | 9.65 | 3.93 | 4.72 | 7.74 |
| | Net Return over FFP, Rs. ha$^{-1}$ | - | 31165 | 12702 | 15259 | 24997 |
| Lentil (5) | Lowest yield (kg ha$^{-1}$) | 625 | 680 | 665 | 660 | 650 |
| | Highest yield (kg ha$^{-1}$) | 2019 | 2056 | 2032 | 2038 | 2024 |
| | Mean yield (kg ha$^{-1}$) | 1677 | 1715 | 1696 | 1696 | 1689 |
| | Response over FFP (kg ha$^{-1}$) | - | 37 | 19 | 19 | 12 |
| | Per cent increase over FFP | - | 2.23 | 1.11 | 1.13 | 0.72 |
| | Net return over FFP (Rs. ha$^{-1}$) | - | 1795 | 893 | 912 | 576 |

environment.

**Prospects of IFFCO Nano Nitrogen, Nano Zinc and Nano Copper**

IFFCO nano nitrogen, nano zinc and nano copper are in sync with OECD testing guidelines (TGs) and "Guidelines for Testing of Nano Agri inputs (NAIPs) and Food Products released by the Department of Biotechnology, Government of India. Harvested produce of crops applied with IFFCO nano nitrogen, nano zinc and nano copper have been found to be fit for consumption with no adverse effect. These are safe for application, both to the user and for the environment. These have other incremental benefits such as these are cost-effective and can be applied in rainfed and dry land agriculture as well as in protected cultivation. These are also compatible with most of the agrochemicals, biostimulants and specialty fertilizers.

Independently, nano nitrogen, nano zinc and nano copper have also been proactively tested for bio-efficacy- biosafety- toxicity and environment suitability by NABL-accredited and GLP-certified laboratories. IFFCO nano-fertilizers meet all the current national and international guidelines related to nanotechnology or nanoscale agri-inputs. It is for the first time in the world that nano nitrogen is being introduced to the farmers. With inclusion of nano-fertilizers in FCO 1985, their production will be further scaled up by IFFCO at industry level so that farmers can ultimately benefit from the boon of nanotechnology. It will be a step in the direction of self-reliance in terms of 'ATMANIRBHAR BHARAT' and 'ATMANIRBHAR KRISHI' because of nano-fertilizers.

**Epilogue**

Agriculture is the backbone of the Indian economy and hence is accountable for consumption of majority of renewable and non-renewable resources besides providing food security to its masses. Reduction in fertilizer application has cascading effect in improvement of overall economy and environment resilience. Nanotechnology-based solutions have more relevance for countries like India where resource conservation has to be seen in the light of its increasing population which is next only to China. Increasing consumer awareness regarding traceability of food and environment friendliness of farm operations and agri-inputs requires to revisit agriculture with novel and innovative solutions like nano-fertilizers.

Nanotechnology has varied applications. It is on record that more than 1200 nano-tech based commercial products have found place as different product variants in consumer and industrial space around the world. Nano products have definitive advantage in terms of size, shape, quantity and efficacy. They can address many constraints faced at the level of scale and scope in perspective of environment and sustainability. Benefits of application of nanotechnology in agriculture have to be realised as an 'informed choice' rather than an ongoing research perspective.

Novelty of nano-fertilizers lies in their unique composition and properties. Their applications in small quantities and their significant impacts have to be seen in terms of enhanced bioavailability of nutrients due to triggering of alternative pathways inside the plant system, increase in rhizospheric microbial population which ultimately results in better crop response through more availability of nutrients. It has practical application in organic or natural farming where nutritional requirement of crops can be effectively met through targeted and slow release application without disturbing the distinct agro-ecology. Nano-fertilizer application can be further streamlined as per crop uptake and removal studies over a period of time so that they can be effectively integrated in the package of practices of different crops and states.

Nitrogen pollution has emerged as a major factor influencing global environment pollution and thus it should be targeted for reduction in a phased manner. In fact, reduction of nitrogen has become a matter of collaborative effort all over the world for better environment and survival of life forms. Nano products especially IFFCO nano nitrogen should be viewed in this context. Foliar application of nano-fertilizers calls into focus efficient spray technologies with agritech solutions such as drones, electrostatic sprayers, so that farmers are able to merge them as per their existing farming practices.

Nano-fertilizers have to be looked in totality as an option to address the challenges being faced by modern day agriculture. It is high time that the nano-fertilizers are introduced as an 'informed choice' to address persistent limitations plateauing sustainability and profitability of agriculture.

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**References and Further Readings**

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