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Liquid Nano-Urea: An Emerging Nano Fertilizer Substitute for Conventional Urea

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Abstract

Farmers are mostly dependent on urea fertilizer to meet the nitrogen requirement of different crops. Further, they are applying urea in an indiscriminate manner and this is causing degradation of soil and imbalance in fertilization leading to high cost of cultivation and low/stagnant production and productivity. Granular/Prilled urea is readily soluble in water leading to leaching, denitrification and volatilization losses resulting in low nitrogen use efficiency and environmental pollution. Liquid Nano urea developed by Indian Farmers' Fertilizer Cooperative Limited (IFFCO) as a substitute to urea to meet the nitrogen requirement of crops especially during critical growth stages. It is applied as a foliar spray, helps in efficient absorption and penetration of nitrogen into the leaves and reaches plant parts where nitrogen is required and release nutrients in a controlled manner, thereby reducing wastage into the environment. Further, it improves physiological traits of crops especially under drought stress conditions. Nano urea due to its high surface area, more solubility and less size might help for different metabolic reactions, resulting in improved yields and quality parameters and reduced wastage of fertilizers.

1. Introduction

Plant growth, vigour and yields are dependent upon the availability of essential nutrients. There are number of ways mineral nutrients are transferred from the soil and other sources to the plant. These can be natural, synthetic, recycled wastes or a range of biological products including microbial inoculants. The majority of nutrient input to agriculture comes from commercial mineral fertilizers. The total global consumption of nitrogen, phosphorous and potash fertilizers in 2016 was 198.1 million metric tonnes at an average rate of 100 kg of nutrients ($N+P_2O_5+K_2O$) per hectare of arable area

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(World fertilizer trends and outlook to 2020, summary report, FAO, 2017). Five countries namely China, United States of America, India, Brazil and France accounts for 61% of the total global fertilizer consumption (World fertilizer trends and outlook to 2020, Summary report, FAO, 2017). Nitrogenous fertilizers take the foremost place among fertilizers since the deficiency of nitrogen in the soil is the major limiting factor that affects crop yield. Crops respond to nitrogen better than other nutrients as it is an essential nutrient for plant growth, development and reproduction. Nitrogen is an essential constituent of chlorophyll, protoplasm and enzymes resulting in improved quality parameters. Most of the farmers use urea fertilizer for fulfilment of nitrogen requirement of crops. Nevertheless, for decades, the nutrient use efficiency of conventional fertilizers, such as for nitrogen (30-35%), phosphorus (15-20%) potassium (35-40%) and sulphur (8-10%) have remained low (Subramanian et al., 2015).

Wheat was the main crop receiving N fertilizers, with 18.2% of global use, followed by maize with 17.8% and rice with 15.2%. Other cereals accounted for 4.7% of the world total nitrogen fertilizer requirement (Patrick et al., 2017). Despite nitrogen being one of the most abundant elements on earth, nitrogen deficiency is probably the most common nutritional problem affecting crops worldwide. More than 80% of the fertilizers used in this country are made up of nitrogenous fertilizers, particularly urea (Anonymous, 2020).

2. Conventional Urea

Urea is the most widely used solid N fertilizer in the world, It is highly soluble, dry material used in many ways to provide N nutrition for plant growth. Production of urea fertilizer involves controlled reaction of ammonia gas (NH_3) and carbon dioxide (CO_2) with elevated temperature and pressure, the molten urea is formed into spheres with specialized granulation equipment or hardened into a solid prill while falling from a tower (Figure 1). N in urea becomes plant-available when converted to ammonium (NH_4^+) and then nitrate (NO^{3-}). Urea can be used as a starter, broadcast or top dress application and can be used in fertilizer mixes (dry or liquid). Advantages of urea are its high N content (46%), relatively low cost per unit of N, and rapid conversion to plant-available N. The high N content of urea makes it efficient to transport to farms and apply to fields. Conventional granular urea is one of the most important nitrogenous fertilisers in India, with a high nitrogen content of 46%, and is available at one of the lowest market prices of about Rs. 242 per 45 kg bag after government subsidy. Urea usage accounts for more than 82% of the nitrogenous fertilizers applied to crops. Government of India is facing subsidy burden on fertilizers especially for supply of urea fertilizer to farmers at affordable prices, In Union Budget 2022-23, the government has allocated a Rs. 67,187 lakh crore for urea (Anonymous, 2022).

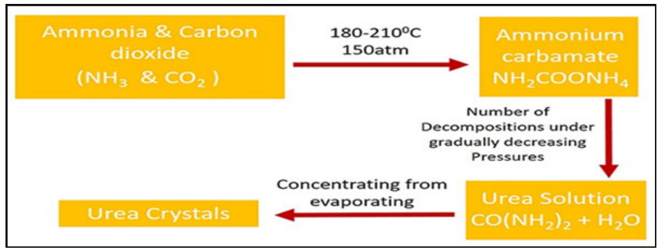

Figure 1: Urea manufacturing process

2.1. *Properties of urea*

➢ It is the most concentrated solid nitrogenous fertilizer, containing 46% N

➢ It is a white crystalline substance readily soluble in water

➢ It absorbs moisture from the atmosphere and has to be kept in moisture proof containers. It is readily converted to ammoniacal and nitrate forms in the soil

➢ The nitrogen in urea is readily fixed in the soil in an ammoniacal form and is not lost in drainage

➢ Urea sprays are readily absorbed by plants

➢ It may be applied at sowing or as a top-dressing

➢ It is suitable for most crops and can be applied to all soils

2.2. *Losses of Urea fertilizer after application*

Nitrogen fertilizer management is challenging due to the many factors that influence fertilizer nitrogen (N) after it is applied. Excessive application of N fertilizers beyond crop demand has resulted in undesirable consequences of degradation of soil, water, and air quality. These include soil acidification, N leaching in groundwater, and emissions of nitrous oxide (N_2O), a potent greenhouse gas that contributes to global warming. If urea is surface applied and not incorporated (either by rain or tillage), N losses to the air as ammonia can approach 40% of the applied N. In addition, a rapid pH increase after application caused by hydrolysis of urea can result in ammonia release that can damage seedlings if the urea is applied too close to the seed. If urea is used as a band-applied starter, the planter should be carefully checked to ensure placement is not closer than 2 inches beside and below the seed. Conversion of ammonium to nitrate results in the formation of hydrogen ions (H^+), so, like most N fertilizers, repeated urea applications will cause a reduction in soil pH over time. Application of higher dosage of urea in the agriculture sector to increase the crop production, leads to soil nitrogen reactions leading to nitrogen fertilizer losses *viz.*, surface runoff, leaching, denitrification, ammonia volatilization (Figure 2) and contaminating the soil, water reservoirs, groundwater, polluting the environment through greenhouse gas emissions and increasing the input costs of farmers, which is a major challenge for global agriculture.

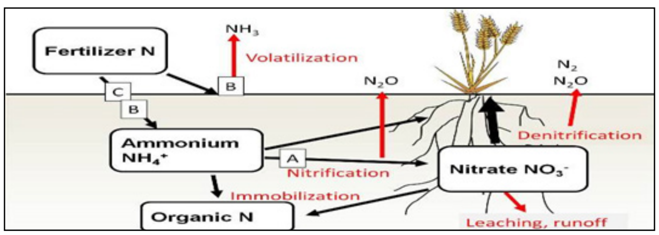

Figure 2: Soil nitrogen reactions leading to nitrogen fertilizer losses

3. Liquid Nano- Urea

Chemical fertilizer needs could be substituted by introducing organic sources *viz.*, farm yard manure, vermicompost, crop residues and vermicompost and Nano fertilizers. In this context, IFFCO has introduced its nanotechnology-based product i.e., liquid Nano-urea fertilizer, which is the alternative to urea fertilizer to meet the nitrogen requirement during growth stages of the crop. Nano-structured fertilizers are characterized by high surface area owing to smaller size of nano particles (1-100 nm) and have high reactivity, solubility in water and enhance the fertilizer response, crop yield and quality parameters with nutrient use efficiency while minimizing the cost of production and the potential negative effects associated with overdosing which reduces the frequency of the application, thus, contribute towards agricultural sustainability (Kottegoda et al., 2011).

IFFCO introduced the first Nano Urea, a breakthrough solution for the drawbacks observed while using urea. The innovative product was designed in Kalol, Gujarat, at IFFCO's Nano Biotechnology Research Center (NBRC). Nano urea (liquid) has been notified under Fertilizer Control Order , 1985 (FCO, 1985) Government of India. As per specifications of IFFCO Nano urea – liquid (nano nitrogen), the particle size is less than 100 nm (Table 1). It contains 4% N and has a shelf-life of about 2 years. It has a zeta potential >30 and is stable. India has become the first country globally to start commercial production of Nano Urea. Kalol plant has been set up by Indian Farmers' Fertilizer Cooperative Limited (IFFCO) with an investment of Rs. 175 crore for manufacturing and bottling of nano urea (Figure 3).

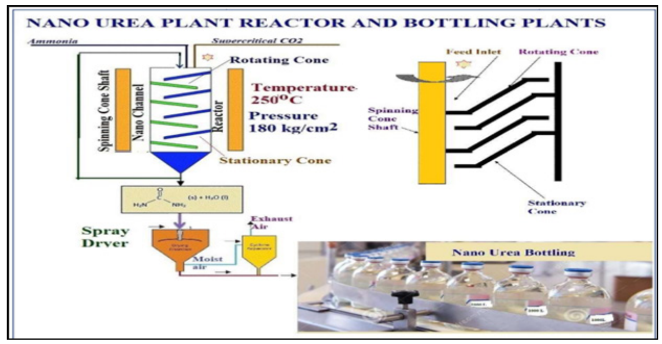

Figure 3: Nano urea manufacturing process

One bottle of Nano-urea (500 ml) is equivalent to a bag of urea fertilizer (45 kg), which is 10% lower cost than a bag of conventional urea. To evaluate this product, IFFCO conducted farmer field trials (FFT's) and multilocation trials on multi crops, concluded that it can replace the use of urea granules by 50 % (Kumar et al., 2020a). It can bring down the import of urea fertilizer, reduce the government's subsidy burden, reduce the transportation, storage and usages of urea fertilizer subsequently lower the costs of nitrogen fertilizer.

3.1. Liquid Nano urea: How it works

Nano urea (Liquid) contains 4 % Nano scale nitrogen particles. These particles have a small size (20-50 nm); more surface area and number of particles per unit area than conventional urea. Nano particles can easily penetrate through the cell wall or through leaf stomatal pores. After entering the plant, they are transported to other plant parts via phloem cells, plasmodesmata (40nm diameter) or can bind to carrier proteins through aquaporin, ion channels, and through endocytosis (Figure 4). Upon penetration, these nanoparticles reach plant parts where nitrogen is required and release nutrients in a controlled manner, thereby reducing wastage into the environment. Nano-Urea in plants 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

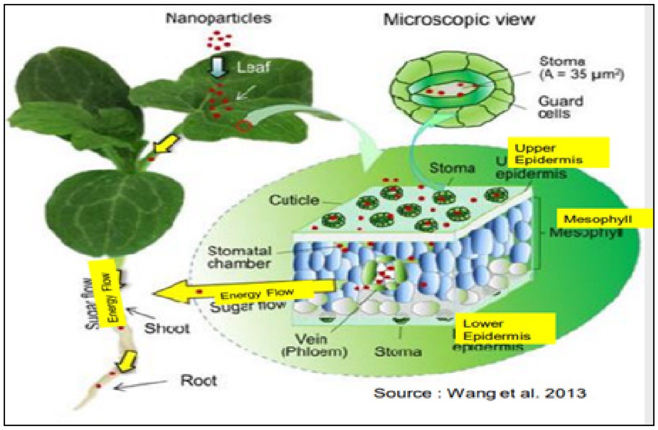

Figure 4: Entry, transport and translocation of nanoscale particles inside the plant system (Wang et al. 2013)

3.2. Dosage and time of application of Liquid Nano- Urea

Nano Urea – liquid (nano nitrogen) is sprayed @ 2 to 4 ml l^{-1} of water depending on the crop nitrogen requirement, crop canopy development and amount of water required for the standing crop. It is sprayed at critical crop growth stages when crop canopy is suitably developed for proper intake of foliar nutrients. First spray of nano urea is undertaken at 30-35 days after germination or 20-25 days after transplanting and the second spray either at 20-25 days after 1st spray or at one week before flowering. Number of sprays and spray concentration were synchronized as per the crop N requirement.

3.3. Results from field trials conducted through use of Liquid Nano-Urea

Results of field demonstrations conducted in different districts of Uttar Pradesh on farmers' fields through IFFCO proved that with the application of liquid Nano urea, the quantity of conventional urea to meet recommended dose of nitrogen can be reduced to half (Table 1). The yields obtained in wheat, maize, chickpea and mustard increased to 5.77 %, 7.29%, 8.36% and 3.77% respectively under farmer's field trials with 50% less nitrogen as compared to the N applied under farmers fertilizer practice (FFP) and applying two sprays of Nano nitrogen in standing crops. Similar results were also obtained from the field trials in farmer's field conducted through IFFCO on use of liquid Nano urea (Nano- N) across locations revealed that two foliar applications at

Table 1: Effect of liquid nano urea fertilizer on crops (Table derived from Yogendra Kumar et al., 2020a and 2020b)

Crop (Data in parenthesis are number of trials)	Parameters	Farmer fertilizer practice (100% N Through conventional urea)	FFP-50% N+Two sprays of Nano urea at critical stages of crop
Wheat (480)	Average yield (kg ha^{-1})	4330	4580
	Response over FFP(kg ha^{-1})		250
	Percent increase over FFP (%)		5.77
	Net return over FFP(Rs ha^{-1})		4813
Maize (4)	Average yield (kg ha^{-1})	4800	5150
	Response over FFP (kg ha^{-1})		350
	Increase over FFP (%)		7.29
	Net return over FFP (Rs ha^{-1})		6160
Chickpea (27)	Average yield (kg ha^{-1})	1969	2133
	Response over FFP (kg ha^{-1})		165
	Increase over FFP (%)		8.36
	Net return over FFP (Rs ha^{-1})		8019
Mustard (70)	Average yield (kg ha^{-1})	2650	2750
	Response over FFP (kg ha^{-1})		100
	Increase over FFP (%)		3.77
	Net return over FFP (Rs ha^{-1})		4425

critical growth stages of crops like rice, wheat, maize, tomato, cucumber and capsicum led to a 50% reduction in the application rate of conventional urea fertilizer and also caused increase in the yield in range of 3-23% in wheat, 5-11% in tomato, 3-24% in paddy, 2-15% in maize, 5% in cucumber, and 18% in capsicum (Kumar et al., 2021).

4. Liquid Nano Urea vs. Conventional Urea

The size of one Nano urea liquid particle is 30 nanometre and compared to the conventional granular urea it has about 10,000 times more surface area to volume size and important characteristics and differences between liquid Nano-urea and conventional urea were enlisted in Table 2. Nano urea has also been tested for biosafety and toxicity according to norms followed in India and the international guidelines developed by OECD (The Organisation for Economic Co-operation and Development), which are adopted and accepted globally.

Table 2: Differences between liquid nano urea and conventional urea

Characteristics	Nano urea	Conventional urea
Year of Invention	2021	1823
Technology	Nano- technology	Conventional method
Particle size	32 nm	1 mm
Use efficiency (%)	85-90	30-40
Price (Rs.)	240/- per bottle (500 ml)	266.50/- per bag (45 kg)
Storage area requirement	Very less area	Very high area
Pollution	No	Air, water and soil
Vaporization	No	Yes
Soil residual	No	Yes
Effect on soil	Enhance quality	Acidifies soil
Availability in plant	Throughout the life cycle	3-4 days
Effect on crop maturity	Maturity on time	Early maturity
Intake medium	Direct through leaves	Through roots
Method of use	Only for foliar spray	Soil application as basal and top dressing and foliar spray

5. Advantages of Liquid Nano Urea

Nano Urea is a breakthrough product that uses nanotechnology to suffice the plant's needs for Nitrogen. Some of the benefits are depicted in Figure 5 and detailed through points

Figure 5: Nano urea advantages

- Nano Urea is applied @ 1250 ml ha^{-1} at initial growth stage and before flowering, When sprayed on leaves initially it gets absorbed easily and also enters through stomata and other pores
- It is translocated and metabolically assimilated as proteins, amino acids etc. as per the plant's need. Reduces the amounts of traditional urea needed by half or more. Produces more with fewer resources: One bottle of Nano Urea (500 ml) has the same efficacy as one bag of urea
- Environmentally friendly product that can improve soil, air, and water quality, so assisting in addressing global warming issues and reaching UN SDGs (United Nations Sustainable Development Goals)
- It's less costly than traditional urea. Farmers' input costs are reduced, resulting in increased income. Increases crop output, soil health and produce nutritional quality

6. Limitations

- It is recommended only for foliar application to meet the nitrogen requirement of crops during active growth stages of crop
- Crop response to liquid Nano urea was found meagre as compared to conventional nitrogen fertilizers
- Additional labour cost for foliar application
- Not popular as conventional urea among the farming community

7. Conclusion

Nano urea is a sustainable option for farmers towards smart agriculture and combat climate change. Its application increases nitrogen availability to crop by more than 80% resulting in higher Nutrient Use efficiency, In addition to this, nano urea helps in minimizing the environmental footprint by reducing the loss of nutrients from agriculture fields in the form of leaching and gaseous emissions which used to cause environmental pollution and climate change. The new form of urea would prove to be a boon for the sector as farmers would get high yield at a reduced cost of fertilisers.

8. Future Research Thrust Areas

• Liquid Nano-Urea can lead to better crop harvests with minimal environment footprint. For this, extensive field trials and lab testing's need to be conducted to ascertain efficacy, biosafety- bio toxicity of liquid Nano urea

• Most of the results of use of liquid nano urea are from farmers field trials conducted for one season, the credibility of results are not dependable, hence there is need for taking up field trials for multiple seasons or cropping system mode at ICAR and university research stations under supervision of scientific experts to obtain valid results

• There is need for validation whether to use of Liquid Nano-Urea as a substitute or supplement for conventional urea to increase nitrogen use efficiency and crop yields

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