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NANO UREA A STEP TOWARDS PRECISION AND SUSTAINABLE AGRICULTURE : A REVIEW

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ABSTRACT

Fertilizers are at the foundation of our modern society, without which we would not be able to feed and sustain a majority of the world population. Among 17 major nutrients, nitrogen (N) is one of the major limiting nutrients, is essential for healthy plant growth, yield and quality. Furthermore, the leaves of plants that receive sufficient nitrogen have a dark, blue-green color, which promotes photosynthesis and results in vigorous vegetative growth. Therefore, N fertilizer is usually applied in large quantity to increase crop production to achieve self-sufficiency in food production in many developing countries across the world. As of now, just 30-50 per cent of nitrogen from urea is utilized by plants in farms while the rest goes waste due to quick chemical transformation because of leaching contaminates soil and water bodies, and losses due to volatilization that causes emissions of nitrous oxide in the atmosphere leading to air pollution and global warming. Also, the synthetic fertilizers used extensively in crop production typically have low nutrient use efficiency (NUE) values. Hence, there is a need for a more innovative fertilizer approach that can increase the productivity of agricultural systems and be more environmentally friendly than synthetic fertilizers. In order to boost NUE, decrease fertilizer waste, reduce soil residual N, and lower cultivation costs, nano urea is the key instrument in precise nutrient management. Therefore, keeping in view the aforementioned fact, we reviewed the recent development and potential benefits derived from the use of nano urea (NUs) in modern agriculture.

***Keywords*:** Nano fertilizer, nitrogen, nano urea, precision agriculture, sustainability, nutrient use efficiency (NUE) etc.

Introduction

Due to climate change, an increased human population, decreased fertile lands and freshwater resources, food production and distribution are under an increased and continuous stress at a global scale (Usman *et al.*, 2020). This challenge could be addressed with technological advancements coupled with significant modifications to existing global food production systems (Dwivedi *et al.*, 2016; Shang *et al.*, 2019). Nutrient management has played an important role in achieving self-sufficiency in food-grain production, but the conventional application of the fertilizers to increase productivity and profitability has brought about higher consumption of the nutrients, which ultimately leads to low nutrient use efficiencies, lower profits and increased environmental issues (Pampolino *et al.*, 2012). Currently, modern agriculture is heavily supported by the use of high rates of agrochemicals; in 2019, the global production of synthetic fertilizers amounted to 188.2 MT, whereas the current consumption of pesticides is about 4 MT in agricultural fields (Kah *et al.*, 2019; FAO, 2020). It is expected that to feed 9.6 billion people by 2050 this amount of agrochemicals will be increased in the near future (FAO 2017, Diatta *et al.*, 2020, Seleiman *et al.*, 2020). Since the 1950s, nitrogen (N) fertilizers have been vital for supporting the growing human population, playing an even more significant role in recent decades. Annually, nearly 120 million tonnes of nitrogen are applied to agricultural fields (FAO, 2017). Furthermore, as the global population has continued to grow, so has our reliance on synthetic nitrogen fertilizers, without considering the contribution from organic sources (Erisman *et al*., 2008) and this trend does not seem to be waning. Synthetic chemical fertilizers are used for the optimal growth and productivity of crops, but, at present, adopted agricultural practices have not been particularly successful to simultaneously enhance plant nutrient uptake, nutrient use efficiency (NUE), and crop productivity (Seleiman *et al*., 2020 ; Adnan *et al*., 2020). In most cases, synthetic fertilizers used in extensive agriculture have low NUE values (Guo *et al*., 2020) e.g., the NUE values of the three most basic macronutrients, i.e., nitrogen (N), phosphorus (P), and potassium (K), are low at 30-35 per cent, 18-20 per cent, and 35-40 per cent, respectively (Subramanian *et al*., 2015), which shows that more than half of the broadcasted fertilizers in the fields are lost and do not reach their targeted sites due to different factors such as photolysis, hydrolysis, leaching, and microbial immobilization and degradation (Green and Beestman 2007). A low NUE can lead to the intensive use of synthetic fertilizers to increase crop production (Guo *et al*., 2018) however, in the long term, this intensive application of synthetic fertilizers can result in severe environmental risks such as air pollution, degradation of soil, water eutrophication, and groundwater pollution (Seleiman *et al*., 2020). Higher release levels of synthetic fertilizers than plant uptake levels or changes of the forms of nutrients into those which are not bioavailable to plants are typically the main result of low NUE values. Additionally, the over-application of synthetic fertilizers enhances the cost of their production and decreases the profit margin of farmers (Diatta *et al*., 2020; Seleiman *et al*., 2020). Low NUE values (Chippa *et al*., 2017) and increased environmental risks (Czymmek *et al*., 2020) related to the use of more synthetic fertilizers has been a long-term limitation to achieve sustainability in agriculture (Diatta *et al*., 2020; Preetha and Balkrishan, 2017). However, despite their necessity, our dependency on nitrogen fertilizers has shifted the natural balance, leading to many damaging and long lasting environmental and ecological consequences. Sustainable agriculture with a high productivity is crucial to alleviate the perils of hunger and increase food security. Therefore, sustainability in agriculture can be achieved through the implementation and utilization of innovative techniques (Shang *et al*., 2019) that could enhance global food production while also protecting natural and environmental resources (Arora, 2018). Additionally, recent studies have suggested that nanotechnology may have a potential for modifying the current synthetic framework utilized in modern agriculture systems (Prasad *et al*., 2019) by increasing the efficiency of novel agrochemicals (Kerry *et al*., 2017) and providing solutions for environmental and agricultural problems (Usman *et al*., 2020). Thus, research regarding the use of nanoparticles (NPs) has gained attention among agricultural researchers in recent years (Kah *et al*., 2019; Kerry *et al*., 2017; Seleiman *et al*., 2020). From a sustainable agriculture perspective, nanotechnology has the potential to develop new innovative types of fertilizers such as nano fertilizers (NFs) like nano urea to increase global food production to feed the increasing world population (Diatta *et al*., 2020; Seleiman *et al*., 2020; Feregrino Perez and Lopez, 2018).

Sources of nitrogen uptake in plants

Most non legume cropping systems need more nitrogen inputs. Nitrogen fertilizers provide nitrogen in two main forms ammonium (NH_4^+) and nitrate (NO_3^-), can be used by crops (Sergei 2012; James 2013). The N fixation can be accomplished by natural means like lightning and/or processes including the Haber-Bosch that is used to produce fertilizers such as urea and other chemical fertilizers (Havlin *et al*., 2014). Among all N fixation processes, bacterial nitrogen fixation (BNF) is the most common one in plants. Due to their property to fix atmospheric N and accumulate a great quantity of N in their organs, legumes serve as bio-fertilizers in crop production systems (Peter *et al*., 2002). Accordingly, a leguminous crop when applied as green manure in the soil confers the subsequent non- legume crops with a huge quantity of sources comprising nitrogen and carbon (Stagnari *et al*., 2017). The N in soils exists in two forms: (i) organic and (ii) inorganic nitrogen (Weil and Brady 2017) are as follows:

Organic nitrogen (N)

The organic form of soil N is represented by compounds such as amino acids, amino sugars, proteins and more resistant N compounds such as humus. This organic N in soil (mostly in hydrolysable form) is gradually mineralized and converted into mineral N through the process of aminization, ammonification and nitrification, thus ultimately rendering N available to plants. Manure, compost, crop residues, green manure, bio-fertilizer and several waste materials are the organic source of soil N. Amino acids, proteins and polypeptides are the most common organic constituents of living organisms including plants (Gonzalez *et al*. 2005).

Inorganic nitrogen (N):

The inorganic forms of N are represented by ammonium (NH_4^+), ammonia (NH_3), nitrate (NO_3^-)

and nitrite (NO_2^-) which can be utilized by the plants as plant root absorb N from the soil in the form (NO_3^-) and (NH_4^+). N in its inorganic forms remains available to plants and microorganisms or could move downward in the soil along with the movement of water. By contrast, the majority of the N in the soil remains unavailable to plants due to its organic form (Havlin *et al*., 2014). The N that is absorbed by plants or any other living organism is incorporated into soil organic matter after the death and subsequent decomposition of the organisms. Nitrate is the dominant form of N in aerobic soil, while N remains predominantly as ammonium in case of anaerobic soils (Sqrensen and Sessitsch 2007). Beyond crops demand excessive and continuous application of N fertilizers to non-legume crops led to undesirable consequences. For economic and environmental reasons, nitrogen fertilizers should be utilized more efficiently as much as possible in agriculture production. Therefore, if all of the nitrogen applied to the soil is taken up by the plants and soil, there would be none left to escape into the environment. Therefore, Nitrogen use efficiency (NUE) is more essential for agriculture development and environmental protection. Therefore, optimum nitrogen application to soil can improve the current status of soil, which increased the plant metabolism and its production.

Nano urea an alternate to conventional urea

The major way to supplement nitrogen is with urea. Crops effectively use the basal dose of urea, but as they progress, it becomes more difficult to top dress, which also reduces efficiency. Therefore, effective method of fertilization that increases the availability of nutrients, particularly nitrogen, is the foliar application of urea as nano urea, a novel technology that is emerging in the area of fertilizer management for nutrient management in precision agriculture with matching the crop growth stage for nutrient and provide nutrient throughout the crop growth period. It is produced from nanotechnology to improve the efficiency of the nutrients of the crops by utilizing the special characteristics of nanoparticles with a range of nano dimensions from 1 to 100 nm (Suppan, 2017). Nano urea contains nano scale nitrogen particles 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). Average physical size of nano urea particles is in the range of 20-50 nm and contains 4 per cent nitrogen by weight in its nano form (Dwivedi *et al*., 2016). Also the small size (20-50 nm) nano urea increases its bio availability to crop by more than 80 per cent resulting in higher nutrient use efficiency. Although, in the management aspects, efforts have made to increase the efficiency of applied fertilizer with the help of nano clays and zeolites and restoration of soil fertility by releasing fixed nutrients (Jyothi and Hebsur 2017). Up to the optimum applied doses and concentrations, nitrogen-based nano-fertilizers increase crop growth and production. However, if concentrations are higher than the optimum, they can limit crop growth and yield. Nano scale fertilizers have the potential to act as a catalyst for plant growth and can enhance the exchange of plant gases and root efficiency. Furthermore, due to the slowness and control of nutrient release, nano fertilizers are able to increase the availability of nutrients in the root zone (De Rose *et al*., 2010).

Nano urea can release their nutrients at a slow and steady pace, either when applied alone or in combination with synthetic or organic fertilizers. They can release their nutrients in 40-50 days, while synthetic fertilizers do the same in 4-10 days. Reports have shown that to produce 1.0 mg of grain, approximately 27 kg of NPK per hectare was needed during the early 1970s, while 109 kg of NPK per hectare was needed to achieve the same productivity in 2008 (Heffer & Homme 2012). It varies with the climate and the types of soil and plants of a particular area. Thus, it is of paramount importance to develop innovative fertilizers that can release their nutrients in a slow and steady way in order to increase crop yield, improve quality, and improve the overall sustainability of agricultural systems.

The combine application of traditional and nanoparticle mineral fertilizers may create a continuous nutritional balance for the different growth stages of the plant, may help in reduction in the use of chemical fertilizers and the creation of a better environment for nutrient absorption in the plant. Therefore, it promotes clean and green technology as its industrial production is neither energy intensive nor resource consuming. In addition to this, it 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 also it is a sustainable option for farmers towards smart agriculture and combat climate change.

Mechanism of nano urea (NU)/ nano-fertilizer (NF) uptake by plants

It is very important to investigate the uptake and movement of NU/ NFs from soil into plants, because such information can give an idea of suitable applications for NFs to plants. For instance, if NU/ NFs prefer transport through the xylem, then the optimal application of NFs is through an irrigation system. Meanwhile, if NFs move through the phloem, then an exogenous application is recommended and suitable (Pitambara and Shukla, 2019). The composition, size of NFs, the physiology of plants, and the pore diameter (5-20 nm) of the cell wall (Rico *et al.*, 2011) affect the transportation and accumulation of nutrients released from NFs in plants.

Nitrogen (N), considered the most important mineral nutrient for plants, is a basic part of several amino acids, proteins, DNA (deoxyribonucleic acid), ATP (adenine triphosphate), chlorophylls, and structural units of cells. Most of the metabolic functions and regulatory pathways in plants depend on adequate amounts of N. Plants uptake N in the forms of NO_3 and $NH+_4$ (Seleiman *et al.*, 2020 & Peertha and Balrishan 2017).

When sprayed on leaves, nano urea easily enters through stomata and other openings and is assimilated by the plant cells. It is easily distributed through the phloem from source to sink inside the plant as per its need. Unutilized nitrogen is stored in the plant vacuole and is slowly released for proper growth and development of the plant. Due to the ultra-small size and surface properties, the nano urea liquid gets absorbed by plants more effectively when sprayed on their leaves. Nano urea provide more surface area for different metabolic reactions in the plant which increase rate of photosynthesis and produce more dry matter and yield of the crop.

Furthermore, aside from improving yield, apart from being cost-effective, nano urea liquid also promises to provide a sustainable solution for plant nutrition as despite lower usage than its current version, it provides higher nutrient efficiency for crops while reducing soil, water and air pollution. Nano urea feed the crop plants gradually in a controlled manner in contradiction to rapid and spontaneous release of nutrients from chemical fertilizers. Nano urea is more efficacious in terms of nutrients absorption and utilization owing to considerably lesser losses in the form of leaching and volatilization. Within the plant, nanoparticles may pass through plasmodesmata that result in effective delivery on nutrient to sink sites. Comparatively higher solubility and diffusion impart superiority to nano fertilizers over conventional synthetic fertilizers.

Nano urea by Indian Farmer's Fertilizer Cooperative (IFFCO) Limited

In a breakthrough, the Indian farmer's fertilizer cooperative (IFFCO) limited launched the nano urea liquid, a nutrient to provide nitrogen to plants as an alternative to the conventional urea. IFFCO nano urea is the only nano fertilizer approved by the Government of India and included in the Fertilizer Control Order (FCO) and has been tested on more than 90 crops across 11,000 locations in collaboration with Indian Council of Agricultural Research ICAR)- Krishi Vigyan Kendras (KVKs), research institutes, state agriculture universities and progressive farmers of India. It contains 40,000 ppm of nitrogen in a 500 ml bottle which is equivalent to the impact of nitrogen nutrient provided by one bag of conventional urea. IFFCO has priced nano urea at Rs 240 per 500 ml bottle for the farmers, which is 10 per cent cheaper than the cost of a bag of conventional urea. Conventional urea is effective 30-40 per cent in delivering nitrogen to plants, while the effectiveness of the nano urea liquid is over 80 per cent. Also, the prills /granular urea are not only costly for the producer but may be harmful to humans and the environment.

Application of nano urea in the crops

Mix 2 to 4 ml of nano urea in one liter of water and spray on crop leaves at active growth stages. For best results apply 2 foliar sprays 1st spray at active tillering / branching stage i.e. 30-35 days after germination or 20-25 days after transplanting. 2nd spray 20-25 days after 1st spray or before flowering in the crop. Don't cut nitrogen applied through straight/ complex fertilizer at the basal stage. For effective results number of sprays of nano urea can be increased depending upon crop and its nitrogen requirement. Also avoid the spray of the during morning or evening hours avoiding dew and if rain occurs within 12 hours of the spray of nano urea, it is advised to repeat the spray. Nano urea can easily be mixed with bio stimulants, and it is recommended to use a face mask and gloves while spraying on the crop. Also store in a dry place avoiding high temperature and keep away from the reach of children and pets.

Conclusion

According to the problem of environmental pollution and hunger dilemma of the growing population of the world, it seems that the use of nano-urea can not only reduce environmental pollution, eutrophication, pollution of groundwater and diseases caused by overusing of conventional urea prills/ granular, but also due to smaller particle diameters, with more penetration into the roots and leaves of plants can improve the physiological traits and yield of crops. Therefore, it is recommended to replace nano-urea with conventional fertilizers, especially in sandy soils due to the possibility of more leaching of conventional urea fertilizer and groundwater pollution.

Future studies must be focused on the safety, bioavailability, and toxicity of different NFs/ NU used for agricultural production. Furthermore, bio-synthesized or green synthesized nano-biofertilizers and NFs should be explored in order to further increase yields in sustainable agriculture.

Disclosure statement

The authors declare they have no conflict of interest.

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