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Nano-urea for Vegetable Cultivation in Coastal West Bengal

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Nano-fertilisers has come up to curtail the use of inorganic fertilisers and reduce the antagonistic effects of fertilizers on the environment. A field experiment was laid out under the randomised block design (RBD) in coastal West Bengal, India during *kharif* season of 2022 to examine the efficacy of IFFCO nano-urea in okra (*Abelmoschus esculentus*) cultivation. The treatments were T_1 = no fertiliser; T_2 = recommended fertiliser dose @ 90:45:45 kgha^{-1}:: N:P_2O_5:K_2O; T_3 = 1/3N urea, PK + 1/3N urea + 1/3 N nano-urea on equivalent basis (nano); T_4 = 1/3N urea, PK + 1/3N nano + 1/3 N nano; T_5 = 1/3N nano, PK + 1/3N nano + 1/3 N nano. Nitrogen was applied in three split doses whereas P and K were applied as basal. The plant vigour was recorded at 50 days after sowing using Trimble Green Seeker. T_2 and T_3 recorded significantly higher normalised difference vegetation index (NDVI) values, and T_1 recorded the lowest. Maximum okra yield was recorded in T_2 whereas 44.7%, 18.5%, 38.1% and 41.2% yield reductions were recorded in T_1, T_3, T_4, and T_5, respectively. Fruit nitrogen content was also maximum in T_2 (2.31% on a dry weight basis). The nitrate content in leachate was maximum in T_2 (1.22 mg L^{-1}) as compared to nano urea treated plots (0.74-0.85 mg L^{-1}).The results of GHG measurement showed that the N_2O emission decreased to 0.79-1.71 mg m^{-2} day^{-1} with nano-urea in comparison to 2.85 mg m^{-2} day^{-1} with conventional prilled urea. The field experiment showed that there was a yield penalty in case of nano-urea application but it has environmental benefits in terms of minimum nitrate level in leachate and low N_2O emissions than the conventional urea application.

(***Key words:*** *Coastal West Bengal, Ecofriendly, Nano-fertilisers, Nano-urea, Okra*)

Nanotechnology deals with nanoparticles (NPs) working through manipulation, characterisation and manufacturing of materials at the nanometer scale that ranges from 1 to 100 nm with different physiochemical properties than bulk materials (He *et al.*, 2019). Eco-friendly technologies are becoming progressively important in modern agricultural applications as an alternative to traditional fertilisers and pesticides and nanotechnology offers an alternative solution to overcome the disadvantages of conventional agriculture. NPs improved physical, chemical, and biological properties and functions due to their expanded surface area to volume ratio, high reactivity, tuneable pore size, desired particle morphology and stability in the environment (Bhardwaj *et al.*, 2022; Singh *et al.*, 2023). Nanofertilisers are anticipated to improve crop growth and development due to their greater nutrient use efficiency and ability to directly enter the cell through cell wall pores (Lv *et al.*, 2019). These fertilisers can spread like a powder or a liquid with a diameter of <100 nm and are expected to check nutrient losses, as they may synchronise the release of nutrients with the uptake by the crop (Lv *et al.*, 2019; Singh *et al.*, 2021).

A large portion of inorganic fertilisers added to the soil are lost and become unavailable to plants. For example, 40-70%, 80-90% and 50-90% of nitrogen (N), phosphorus (P) and potassium (K) fertilisers are lost and/or fixed in soils, resulting in economic losses (Ombódi and Saigusa, 2000). Therefore, more fertilisers are added to soils to compensate for lost fertilisers, negatively affecting soil nutrient balance (Baruah and Dutta, 2009).

The traditional nutrient application to the soil has

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several drawbacks in terms of nutrient availability to plants. Therefore, foliar application is the most efficient method of correcting nutrient deficiencies and increasing crop yield and quality (Semida *et al.*, 2021). In addition, it also reduces environmental contamination and increases nutrient use efficacy by decreasing the amount of fertiliser applied to the soil (Abou-El-Nour, 2002; Schwab *et al.*, 2015). Eichert *et al.* (2008) and Pérez-de-Luque (2017) found that nano-coated substances with asize greater than 10 nm improve penetration across stomata. Nano-fertilisers have a large surface area, a high sorption capability, and regulate release kinetics to specific sites, making them a smart delivery system (Rameshaiah *et al.*, 2015; Solanki *et al.*, 2015). Nano-carriers often deliver nutrients at the right time and in the right place (El-Saadony *et al.*, 2021).

Though several benefits have been recognised for nano-fertiliser, its use so far has been limited largely to controlled environments of laboratories, greenhouses, and institutional research experiments. The use of urea-based nanoparticles is now advocated to be used in agricultural fields to supplement nitrogen (Kiran and Samal, 2021). Recently in India, nano-urea developed by IFFCO has been explored at a field research scale to aid in providing required nitrogen and increasing the efficacy of several crops such as finger millet (Samanta *et al.*, 2022), wheat, barley, maize, chickpea, uradbean, mustard, potato, tomato and lentil (Kumar *et al.*, 2020, 2021; Tiwari *et al.*, 2021). The use of various nano-fertilisers has an exceptional impact on crop production not only through reducing fertilizer costs but also by reducing emission risks. Crop growth, yield, quality, and nutrient use efficiency are all improved by nano-fertilisers.

Soils in coastal West Bengal are heavy textured with low available nitrogen, low to medium available phosphorus and high available potassium contents and the coastal land resources are vulnerable to various processes of land degradation like salinisation, water logging, drainage congestion, etc. (Mandal *et al.*, 2019). Nutrient management is one of the important strategies for boosting the production potential of the region. Excessive precipitation renders coastal soils to have low N retention capacity and high N losses upon application of readily available N fertiliser. Nitrogen leaching and run-off, most of which arise from N fertiliser application, are major pathways of N losses during crop growing season. Nitrogen fertilisers release nitrate (NO_3^-) which is a highly water-soluble form of nitrogen and pollute surface and ground water. The enrichment of surface water bodies with lost plant nutrients also results in algal bloom and eutrophication. Nitrous oxide (N_2O), as a potent greenhouse gas, is the main contributor to global warming from crop growing season and along with economic benefit, environmental impacts are also an important consideration of N management strategies (Shen *et al.*, 2022), particularly for the climatically vulnerable coastal region.

The real advantage would come from the increased efficiency of macronutrients and with the use of nano-fertilizers for macronutrients, as reduced amounts of these nutrients only would lead to significant environmental benefits such as reduced nitrate in leaching and run-off water, and reduced N_2O emissions. Optimisation of doses in their case may be highly important because just size-based or uptake-efficiency-based assumptions may not suffice to meet crop requirements as there is a threshold amount of nutrient (especially macro) that a plant would need to meet the productivity goal. Otherwise, the application of less than needed amounts might lead to the mining of that macro-nutrient from the soil unless the supply comes from a complimentary source such as biological fixation or through *in-situ* crop residue recycling or *ex-situ* application of organic matter/ manures (Bhardwaj *et al.*, 2022). The biased fertiliser application favouring macro-nutrients has also led to the deficiency of essential micro-nutrients because the food brings to the dining table what it is fed in the field (Chhipa, 2017; Zulfiqar *et al.*, 2019). The imbalances in the soil negatively impact the growth, yield, and nutritional quality of food (Sharma *et al.*, 2020).

Against this background, a field experiment was conducted to assess the efficacy of nano-urea for vegetable cultivation in coastal West Bengal and to provide a sustainable N management strategy for vegetable production considering crop productivity and environmental protection.

MATERIALS AND METHODS

Experiment site and climate

The field experiment was established at ICAR-Central Soil Salinity Research Institute (CSSRI), Regional Research Station, Canning Town (22° 18′ 10.8″ N Latitude, 88° 39′ 58.4″ E Longitude, elevation 3.52 m msl), located in the eastern coast of India. The site is a part of the Indian Sundarbans region. The climate of the region is moist sub-humid with hot summer and mild winter. The mean maximum air temperature during summer (March, April and May) ranges from 32.9-34.8°C. The mean minimum temperature during winter (December, January and February) ranges from 13.2-16.6°C. The region receives a mean annual rainfall of 1821 mm, out of that, monsoon months (June-September) contributed 74.4% (1355 mm) to the annual rainfall, whereas pre-monsoon (March-May) and post-monsoon (October-February) months contributed 13.1% and 12.5% of the annual rainfall, respectively. Pre-and post-monsoon rainfall meets up 45 and 51% of the evapotranspiration (ET_0), whereas there was 2.7 times surplus rainfall than ET_0 during monsoon months (Mandal *et al.*, 2019). During the crop growing period from 1st June to 31st October 2022, a total of 1240 mm rainfall was received. The soil at the site had a heavy texture with 48% clay, 19% sand, and 33% silt, deep and free from gravels and hardpan (fine, mixed hyperthermic *Fluvaquentic Endoaquepts* as per USDA soil classification). Soils have an aquic moisture regime. The top soil pH varied from 6.7 to 7.8, $EC_{1:2}$ was 0.55 dS m^{-1} and the average bulk density was 1.54 Mg m^{-3}. The soil was medium in organic C (0.6 %) and low in available N (111 kg ha^{-1}) intermediate in available P (or Olsen P) (22 kg ha^{-1}) and high in available K (or Ammonium acetate extractable K) (509 kg ha^{-1}).

IFFCO Nano urea

IFFCO has recently developed a nano-urea in liquid form having particle size 20-50 nm, containing 4% nitrogen by weight (w/v) in its nano form and compared to the conventional granular urea, it has about 10000 times more surface area to volume size (Baboo, 2021). When sprayed on leaves nano-urea easily enters through stomata and other openings and is as similated by the plant cell and distributed through the phloem from source to sink inside the plant as per its need. One 500 mL bottle of nano-urea was considered equivalent to one bag of 50 kg prilled urea to meet the nitrogen requirement of the crop. A mixture of 2-4 mL nano urea per litre of water is recommended to spray on crop leaves at active growth stages.

Experimental design and field management

The experiment was conducted in a randomised complete block design with three replications during during *kharif* season of 2022. Each experimental plot was 2.7 m × 5.4 m. The treatments were T_1 = no fertilizer; T_2 = recommended fertilizer dose (RDF) @ 90:45:45 kg/ha:: $N:P_2O_5:K_2O$; T_3 = 1/3N as prilled urea, P and K as RDF + 1/3N as prilled urea having 46% N (w/w) + 1/3 N nano-urea on an equivalent basis (nano); T_4 = 1/3N as prilled urea, P and K as RDF + 1/3N nano + 1/3 N nano; T_5 = 1/3N nano, P and K as RDF + 1/3N nano + 1/3 N nano. Nitrogen was applied in three split doses during 14 days, 31 days and 49 days after sowing (DAS). Prilled urea was applied to soil and nano-urea was mixed @ 2 ml L^{-1} of water and applied as a foliar spray. All treatments were supplied with the same amount of phosphorus @ 45 kg P_2O_5 ha^{-1}as single super phosphate and potassium @ 45 kg K_2O ha^{-1} as muriate of potash, both of which were applied as basal fertiliser at 14 DAS. The basal and topdressing fertilisers were applied directly to the surface soil. The seeds of okra (also known as Lady's finger or bhendi, *Abelmoschus esculentus*, variety Bindu hybrid) were sown on 1st June 2022 at 45 cm × 45 cm spacing and green okra harvesting was done from July end till the end of October.

Soil and plant sampling and analysis

Composite soil samples were collected from each of the plots from 0-20 cm depth after ten days of harvesting of the crop during mid-November and the soil samples were sun-dried passed through a 2 mm sieve and stored for different analyses. Available soil N was determined by the alkaline $KMnO_4$ method (Subbaiah and Asija, 1956), which measures easily oxidisable N. Soil pH and electrical conductivity (EC) were measured by pH and conductivity meter. The normalised difference vegetation index (NDVI) values of the crop canopy were recorded with a Trimble® Green Seeker® hand held crop-sensing system. Representative samples of green okra fruits were collected from each plot and dried at 60°C in a desiccator and analysed for total N by digesting plant samples using the semi-Kjeldahl method (Bremner and Mulvaney, 1982). Leaching and run-off samples were collected at a depth of 30 cm using a porous cup with a diameter of 2 mm installed in experimental plots and nitrate in leachate was analysed using a spectrophotometer. N_2O emissions were determined by the closed-chamber method. For each N_2O flux measurement, four gas samples were drawn at 10-minute intervals from 09:00-12:00 (Mandal *et al.*, 2021) and measured with a gas chromatograph (7890A, Agilent Technologies, Santa Clara, CA, USA).

RESULTS AND DISCUSSION

The plant vigour was recorded during 50 days after sowing using Trimble Green Seeker and the treatments T_2 and T_3 recorded significantly higher NDVI values (0.873 and 0.853, respectively) while T_1 and T_5 recorded the lowest (0.817 and 0.817, respectively) (Table 1). Plant vigour is directly proportional to the rate of application of nitrogen and significantly lower plant height and pale green colourrelated to typical nitrogen deficiency symptom was noticed in T_1 and T_5 treatments. There was a significant increase in the fruit yield of okra with the application of fertiliser N and the magnitude of the increase ranged from 10.10 to 18.30 t ha^{-1}. Maximum okra yield was recorded in T_2 (18.30 t ha^{-1}), whereas 44.7%, 18.5%, 38.1% and 41.2% yield reductions were recorded in T_1, T_3, T_4, and T_5, respectively (Table 1). Fruit nitrogen content was also maximum in T_2 (2.32% as dry weight basis) (Table 1) and it was least in T_1 (2.08%) and T_5 (2.17%) treatments. The lower dose of N fertiliser application leads to lower uptake of nitrogen, as has been recorded in lower fruit nitrogen content.

The nitrate content in leachate and run-off collected during the months of August and September in the porous cup was analysed and its concentration varied from 0.68 to 1.22 mg L^{-1} and maximum nitrate content in leachate was recorded in T_2 (1.22 mg L^{-1}) where the recommended dose of nitrogen as prilled urea was applied compared to nano-urea treated plots (0.74-0.85 mg L^{-1}) (Table 2). The N_2O flux was assessed using the static chamber gas chromatography method and there was no increase in N_2O flux immediately after the application of nano-urea. The flux was measured after three days of nitrogen application at 52 days after sowing and T_1, T_2, T_3, T_4 and T_5 recorded N_2O flux 28, 119, 71.2, 52.9 and 33.3 µg m^{-2} h^{-1}, respectively (Fig. 1). Mohanraj *et al.* (2017, 2019) reported two studies with a significant decrease in greenhouse gas (GHG) emissions in rice soil with the use of nano zeolite-based nitrogenous fertiliser containing NO_3^- and NH_4^+ forms of N. Their result of GHG measurements showed that the N_2O emission decreased to 0.88 mg m^{-2} day^{-1} with nano-fertilizers in comparison to 1.67 mg m^{-2} day^{-1} with conventional ammonium sulfate. In our study N_2O emission decreased to 0.79-1.71 mg m^{-2} day^{-1} with nano-urea in comparison to 2.85 mg m^{-2} day^{-1} with conventional prilled urea. Analysis of post-harvest soil samples showed that available soil nitrogen content was lowest in treatment where no N fertiliser as well as only nano-urea was applied (T_1 and T_5) which indicate the mining of nitrogen from soils due to plant uptake in those treatments (Table 2).

Table 1. *Effect of nano-urea and conventional urea on NDVI, Yield and fruit N content for okra cultivation*

Treatments	NDVI	Yield (t ha^{-1})	Fruit N content (% dry weight)
T1	0.817	10.11	2.08
T2	0.873	18.30	2.32
T3	0.853	14.91	2.30
T4	0.823	11.33	2.21
T5	0.817	10.77	2.17
Least significant difference (LSD) (p =0.05)	0.033	1.04	0.17

The field experiment results showed that there was yield reduction in the case of nano-urea application but it has environmental benefits in terms of minimum nitrate level in leachate and less N_2O emissions than the conventional prilled urea application and there is a need to look after the application doses for nano-urea. Singh *et al.* (2023) evaluated urea nanoparticles developed by TERI, India for maize and rice in the fields of Punjab Agricultural University and recommended that nano-

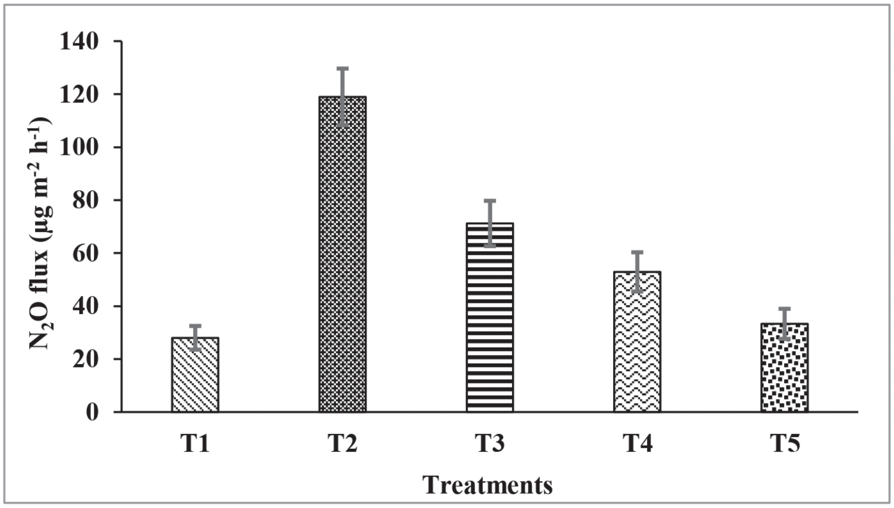

Fig. 1. *N_2O flux after three days of nitrogen application (Error bars represent standard errors; n = 3)*

Table 2. *Effect of nano-urea and conventional urea application on soil pH, EC, NO_3^- leachate and soil available nitrogen under okra cultivation*

Treatments	Soil pH	Soil $EC_{1:2}$ (dS m^{-1})	NO_3^- content in leachate (mg L^{-1})	Soil available N (kg ha^{-1})
T1	6.38	0.54	0.68	77.0
T2	6.04	0.66	1.22	138.6
T3	6.51	0.64	0.85	123.2
T4	6.38	0.64	0.78	107.8
T5	6.15	0.48	0.74	92.4
Least significant difference (LSD) (p =0.05)	NS	NS	0.18	19.2

urea can safely reduce a minimum of 25% of the recommended dose of the conventional urea fertiliser. The TERI nano-urea contains 40% N and application was carried out @ 1250 mL ha^{-1}. This study was carried out to explore if IFFCO nano urea can replace one or two top dressings of fertiliser N, but our results showed that recommended doses of N with three split applications of conventional urea still gave the highest yield for okra and there was a yield reduction whenever it was supplemented with nano-urea. Also, there was a mining of soil nitrogen as well as a lesser level of fruit N, wherever nano-urea or no N was applied. The IFFCO nano urea contains 4% N by weight, which means one bottle of 500 mL contains just 20 g N. In our experiment, N was applied @ 90 kg ha^{-1} in three equal splits, which is equivalent to 652 mL nano-urea in each application. Also, we applied @ 2 mL L^{-1} of nano-urea which is equivalent to 1000 mL nano-urea mixed with 500 L water for spraying one hectare of land in each application. The claim from IFFCO that one 500 mL bottle of nano urea would be equivalent to one bag of regular urea fertiliser may misguide the farmers to maintain the yield level of the crops. Coastal farmers generally apply less fertilisers than in other regions as climatic risk is always associated with coastal agriculture. The recommended fertiliser doses (RDF) for the coastal agro-ecological region are generally less than in other agro-eco regions and it considers total nutrient removal from soils by the crop. Farmers sometimes apply more than the recommended fertilizer doses to earn the premium price, particularly for vegetables and in such cases, nano-urea may help to apply extra fertilizer amount beyond the RDF. However, replacing RDF for nitrogen through IFFCO nano urea may lead to mining of soil N as well as deficiencies of essential nutrients in foods.

The results of the field experiment indicated that there was a yield penalty with nano-urea application but it offers environmental benefits in terms of reducing nitrate levels in leachate as well as less N_2O emission compared to conventional urea application. However, there is a need to look after the application doses for nano-urea.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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