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NUTRIENT USE EFFICIENCY, NUTRIENT UPTAKE AND ECONOMICS AS INFLUENCED BY INTEGRATING NANO-UREA IN NITROGEN MANAGEMENT OF MAIZE UNDER RAINFED CONDITIONS

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ABSTRACT

A fixed plot field experiment was conducted to assess the economic and nutrient competency of conventional urea with nano-urea (novel fertilizer) in a predominant crop of maize in Northeast region of India. The study was conducted to evaluate the Nutrient use efficiency as influenced by integrating nano-urea in the nitrogen management of maize. Higher nutrient uptake by the crop was observed under 75% RDN (3 split conventional urea) + Two nano urea spray which was on par with 100% RDN (3 split conventional urea). Similarly, nutrient use efficiency parameters like nitrogen use efficiency (NUE), agronomic efficiency (AE) were found highest in 75% RDN (3 split conventional urea) + Two nano urea spray. Partial Nitrogen Balance (PNB), and N recovery efficiency were observed under 50% RDN (3 split conventional urea) + Two Nano urea spray which was on par with 75% RDN (3 split conventional urea) + Two nano urea spray. While recommended concentration of nano spray (4%) had significant impact on the growth and yield parameters due to increased availability of N within the plant system. Foliar sprays of the nano fertilizer at critical crop growth stages either alone or in combination have been found to increase crop yields even at reduced levels of application of their conventional analogues. This paper reviews the efficacy and benefits of these nano fertilizers in increasing the nutrient use efficiency (NUE) and crop productivity and sustainability and profitability of major crop production systems. Furthermore, the application of 75% RDN+ two nano-urea exhibited 49.7% higher economic yield compared to control plot. This indicates that application of foliar spray of nano-urea with 75% RDN+ two nano urea spray is a soil-supportive production approach. More interestingly, two foliar sprays of nano-urea curtailed nitrogen load by 25% without any yield penalty. This study examines the effectiveness and advantages of these nano fertilizers in raising crop productivity and nutrient usage efficiency (NUE), as well as the sustainability and financial success of significant agricultural production systems.

Key words : Nutrient uptake, Nitrogen Use Efficiency (NUE), Agronomic efficiency (AE), Partial Nitrogen Balance (PNB), N recovery efficiency.

Introduction

Maize is the third most important cereal crop in India after rice and wheat and is grown in a wide range of environments, extending from extreme semi-arid to sub-humid and humid regions (which predominantly occupies 82 percent of the area under cultivation in the *kharif* season). It accounts for around 10 percent of total food grain production in the country. India produced 31.65 million tons in an area of 9.86 million hectares in 2020-21 with a productivity of 3195 kg/ha (GoI, 2022), whereas in 2021-22, maize production was 33.62 million tons. (Anonymous, 2022). In the North-eastern region (NER) of India, maize is the second most important food grain after rice. The crop has multiple uses as food, feed, fuel, etc. Maize has special significance in the region as a concentrate feed ingredient for poultry, fish, pig, and cattle.

Presently, demands for green cob and popcorn are continuously increasing among the people of the region.

Nitrogen continues to be the "kingpin" of the nutrient kingdom and its management is a critical issue to be addressed across the globe including in India. It plays a key role in photosynthetic activity, and crop yield and significantly increases agriculture production (50%), being a constituent of protein, it increases the food value as well. The atmosphere carries 78% N_2 gas which is hardly possible for plants to use while biological N fixers facilitate N cycling in agroecosystems. In mineral soil, organic matter possesses 98% N and more than 90% of the arable soils are found deficient in available N (Brady and Weil, 2008). Since a major portion of added N got lost through leaching, volatilization, and denitrification, the N use efficiency of crops hardly exceeds 30-35% (Ladha *et al.*, 2005). Increasing costs of fertilizers, low yield benefits, multiple nutritional deficiencies and environmental pollution are important concerns (Singh, 2018). Nitrogen usage every year, 115 million tons in the world every year 16.48 million tons in India every year. These fertilizers are expected to check nutrient losses, as they may synchronize the release of nutrients with the uptake by the crop (Singh *et al.*, 2021; Lv *et al.*, 2019).

Nano fertilizers 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). Nano-fertilizers and nanocomposites can be used to control the release of nutrients (De Rosa *et al.*, 2010) from the fertilizer granules to improve nutrient use efficiency while preventing the fixation or loss of nutrients to the environment (Subramanian and Tarafdar, 2009) and supply with a range of nutrients in desirable proportions (Datta, 2011). Zeolite and nano-porous zeolite are used as slow-release fertilizers in farming (Ramesh *et al.*, 2010). Zeolite incorporated urea, potassium sulphate and calcium hydroxyapatite as a slow-release nano-fertilizer and increased availability for 60 days (Kottegoda *et al.*, 2011). Sarkar (2011) synthesized clay polymer nutrient nanocomposite using crystalline and non-crystalline components of soil clays increasing biomass yield. The nanocomposite was fabricated using nano clays and zeolite for maize as a slow-release fertilizer which regulated N availability for up to 45-49 days (Sharmila, 2010). Nano fertilizers are slow-release fertilizers that are good alternatives to traditional fertilizers for supplying nutrients to the soil gradually and in a regulated manner. The disadvantages are lack of production and availability of nano fertilizers in required quantities. This limits the wider scale adoption of nano-fertilizers as a source of plant nutrients, Lack of standardization in the formulation process. Since no studies have been carried out to evaluate the effect of nano urea fertilization on maize under rainfed conditions of north eastern hill region, India. These issues are compelling for developing suitable and environment-friendly agri-inputs with higher nutrient use efficiency and benefit-to-cost ratio value with reduced negative impacts on the quality of produce, natural resources, and environment (Zulfiqar *et al.*, 2019).

Materials and Methods

A field trial was conducted during the *Kharif* season 2022-23 at the Andro research field, Central Agricultural University, Imphal. The experimental field's soil had a Clayey texture and a pH of 5.68 with available nitrogen (262.24 kg ha^{-1}), available phosphorus (27.37 kg ha^{-1}), available potassium (273.72 kg ha^{-1}) and organic carbon (1.36%), it was medium fertile. Maize variety HQPM- 5 (hybrid) was sown with an 18-20 kg ha^{-1} seed rate. The seeds were dibbled with the help of a hand in pre-irrigated plots at a depth of 5 cm with spacing 60×25 cm. After sowing the seeds were covered with a thin layer of soil firmly and the field was irrigated immediately. The experiment was placed out in randomized block design replicated thrice with ten treatments *viz.*, T_1: Control (only P and K), T_2: 100% RDN (3 split conventional urea), T_3: 75% RDN (3 split conventional urea) + One nano urea spray, T_4: 75% RDN (3 split conventional urea) + Two nano urea spray, T_5: 50% RDN (3 split conventional urea) + One nano urea spray, T_6: 50% RDN (3 split conventional urea) + Two Nano urea spray, T_7: 33% RDN (only basal conventional urea) + Two nano urea spray, T_8: 66% RDN (2 split conventional urea) + One nano urea spray, T_9: 33%RDN (only basal conventional urea) + Two foliar spray of 2% conventional urea, T_{10}: 66% RDN (2 split conventional urea) + One foliar spray of 2% conventional urea. RDF- 120:60:60 N:P:K kg/ha. Recommended nano urea @ 1250 ml/ha/spray. 3 Split at Basal, 25 DAS, and 45 DAS. All the treatments will be furnished with recommended doses of P and K. Present experiment was conducted to study nutrient use efficiency and nutrient uptake by crop as influenced by integrating nano-urea in nitrogen management of maize under rainfed conditions. The observations recorded nutrient uptake and nutrient use efficiency. The data were analyzed using standard statistical techniques.

Weather and climatic condition

Imphal has a subtropical climate and monsoon season often begins from June and extends up to September and retreats from October onwards. The winter is experienced from the month of November upto February. Imphal valley receives a lot of rain from June to September with an average annual rainfall of about 1881 mm. The meteorological data recorded at ICAR Research Complex for NEH Region, Manipur center, Lamphelpet, Imphal for the period of experimentation illustrated graphically in Fig. 1.

The average minimum and maximum temperatures recorded during the period under review were 19.94^{0}C and 29.52^{0}C, respectively. The highest (148.4mm) and lowest (5.4 mm) monthly rainfall was received in the month of July and November, respectively. However, the total rainfall received during the course of the research was 494 mm. The average relative humidity in the 700h and 1300h were 87.04% and 59.2% respectively. The average sunshine recorded was 6.28 hours.

Quality parameters

Crop samples at harvest were used for nutrient analysis. These samples were dried and ground to a fine powder using a Willey mill and used for the analysis of the uptake of nutrients by crop.

Nitrogen content (%) and uptake (kg ha^{-1}) in grain and stover

Nitrogen content (%) in the grain and stover were assessed by the micro kjeldhal method (Jackson, 1967) using a Kelplus N analyzer after digesting the samples with H_2SO_4 and H_2O_2 (Piper, 1966). For calculation of nutrient uptake in grain and stover, the respective percent content of nitrogen in grain and stover were analyzed separately and was multiplied by corresponding dry matter yield to estimate the nitrogen uptake.

Nutrient use efficiency parameters

Nitrogen Use Efficiency (Martinez-Feria *et al*., 2018)

Most basic form nitrogen use efficiency can be described from the plant uptake (%) of total available nitrogen (applied nitrogen + soil mineral nitrogen).

Nitrogen Use Efficiency (NUE)

$$= \frac{\text{Nitrogen uptake by the plant}}{\text{Rate of fertilizer nitrogen applied + Soil N}}$$

Agronomic Efficiency (AE) (Dobermann, 2007)

Agronomic Efficiency is the additional grain yield produced due to the application of nutrients over unfertilized control per unit of nutrient applied. It is expressed in Kg/kg.

Agronomic efficiency (AE)

$$= \frac{\text{Grain yield in fertilized plot} - \text{Grain yield in unfertilized plot}}{\text{Rate of fertilized nitrogen applied}}$$

Nitrogen harvest index (NHI) (Moll *et al*., 1982)

Nitrogen Harvest index is the ratio of nitrogen uptake by grain (or economic yield) to total nutrient uptake. It can also be expressed in percentage.

Nitrogen Harvest Index =

$$\frac{\text{Nitrogen uptake by grain}}{\text{Total nitrogen uptake by biological yeild}}$$

Partial Nitrogen Balance (PNB) or Nitrogen Removal Ratio (Dobermann, 2007)

Partial Nitrogen Balance is the ratio of nutrient uptake by grain to nutrient applied. PNB value more than 1 is considered as nutrient mining from soil and less than 1 is considered as excessive application of nutrient.

Partial Nitrogen Balance =

$$\frac{\text{Nitrogen uptake by the plant}}{\text{Rate of fertilizer nitrogen applied}}$$

Nitrogen recovery efficiency (Dobermann, 2007)

The percentage of fertilizer N that is taken up by the plant, accounting for background soil N levels, also sometimes referred to as apparent recovery.

Nitrogen recovery efficiency (NRE) =

$$\frac{\text{Nitrogen uptake in treated plot} - \text{Nitrogen uptake in control plot}}{\text{Rate of fertilizer N applied.}} \times 100$$

Results and Discussion

Effect on nutrient uptake

Data pertaining to nutrient uptake is presented in Table 1. Maximum N uptake by grain (kg/ha) was recorded under 75% RDN (3 split conventional urea) + Two nano urea spray (T_4) (119.03 kg/ha). This was followed by 100% RDN (3 split conventional urea) (T_2) (116.27 kg/ha). Control (only P and K) (T_1) (52.19 kg/ha) noticed minimum N uptake by grain (kg/ha). Whereas, N uptake by stover (kg/ha) was recorded higher under 100% RDN (3 split conventional urea) (T_2) (67.93 kg/ha), which was on par with (T_4) (67.07), (T_6) (65.61), (T_3) (62.63), (T_8) (60.92), (T_{10}) (58.95) and (T_7) (54.20). Lower N uptake by stover (kg/ha) was recorded with control (only P and K) (T_1) (37.29 kg/ha). This might be due to a lack of supply of nitrogen, and poor vegetative growth and root growth leading to less uptake of nutrients in control plot. Similar results were observed with Adhikari *et al.* (2014).

Effect of nutrient use parameters

Higher nitrogen use efficiency was recorded under 75% RDN (3 split conventional urea) + two nano urea

Table 1 : Nutrient uptake by crop and nitrogen use efficiency parameters and as influenced by integrating nano-urea in nitrogen management of maize under rainfed conditions.

Treatments	NUE (%)	AE (kg/kg)	PNB	NRE (%)
T_1: Control (only P and K)	-	-	-	-
T_2: 100% RDN	48.20[abc]	34.49[cd]	1.37[g]	78.93[cd]
T_3: 75% RDN + One nano urea spray	45.30[bcd]	35.53[c]	1.77[ef]	77.86[cd]
T_4: 75% RDN + Two nano urea spray	52.84[a]	47.73[b]	2.07[de]	107.35[b]
T_5: 50% RDN + One nano urea spray	41.12[d]	35.23[c]	2.21[cd]	71.66[cd]
T_6: 50% RDN + Two nano urea spray	50.76[ab]	52.87[a]	2.73[b]	123.42[a]
T_7: 33% RDN + Two nano urea spray	43.51[cd]	45.12[b]	3.29[a]	104.98[b]
T_8: 66% RDN + One nano urea spray	45.76[bcd]	34.72[c]	1.96[def]	83.90[c]
T_9: 33% RDN + Two 2% urea spray	39.75[d]	34.93[cd]	2.48[bc]	69.22[cd]
T_{10}: 66% RDN + One 2% urea spray	42.77[cd]	29.67[d]	1.67[fg]	67.94[d]
SE (m) ±	2.09	1.66	0.11	5.44
CD (P=0.05)	6.27	4.98	0.33	16.31

Table 2 : Economics as influenced by integrating nano urea in nitrogen management under rainfed conditions.

Treatments	Cost of cultivation (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	B:C	Return per day (Rs/ha)
T_1: Control (only P and K)	43513	82478	38965	1.90	319
T_2: 100% RDN	49868	163676	113808	3.28	933
T_3: 75% RDN + One nano urea spray	48842	145219	96378	2.97	790
T_4: 75% RDN + Two nano urea spray	49772	166754	116982	3.35	959
T_5: 50% RDN + One nano urea spray	47253	123954	76701	2.62	629
T_6: 50% RDN + Two nano urea spray	48184	144714	96531	3.00	791
T_7: 33% RDN + Two nano urea spray	47372	117887	70515	2.49	578
T_8: 66% RDN + One nano urea spray	48440	136968	88528	2.83	726
T_9: 33% RDN + Two 2% urea spray	46326	116744	70418	2.52	577
T_{10}: 66% RDN + One 2% urea spray	47922	134869	86947	2.81	713
SE (m) ±	-	4293	4293	0.09	35
CD (P=0.05)	-	12870	12870	0.27	105

B:C- Benefit-cost ratio

spray (T_4) (52.84%) (Table 1), which was on par with 50% RDN (3 split conventional urea) + two nano urea spray (T_6) (50.76%) and 100% RDN (3 split conventional urea) (T_2) (48.20%), respectively. Reduction of particle size results in increased specific surface area and number of particles per unit area of a fertilizer that provide more opportunity to contact of nano-fertilizer which leads to more penetration and uptake of the nutrient and thus results in high nutrient use efficiency (Liscano *et al.*, 2000).

Agronomic efficiency (AE) was noticed to be significantly higher under 50% RDN (3 split conventional urea) + two nano urea spray (T_6) (52.87 kg/kg). This was followed by 75% RDN (3 split conventional urea) + two nano urea spray (T_4) (47.73 kg/kg), which was on par with 33% RDN (only basal conventional urea) + two nano urea spray (T_7) (45.12 kg/kg). Agronomic efficiency provides information regarding the effect of applied fertilizer on production and quantifies productivity due to added nutrients. Higher values of AE imply that further enhancement in nutrient input will not give a positive crop response (Dobermann, 2007).

Whereas, Partial Nitrogen Balance (PNB) was noticed higher under 33% RDN (only basal conventional urea) + two nano urea spray (T_7) (3.29), which was on par with (T_6) (2.73), (T_9) (2.48), (T_5) (2.21) and (T_4) (2.07).

Nitrogen recovery efficiency was maximum under 50% RDN (3 split conventional urea) + two nano urea spray (T_6) (123.42). This was followed by 75% RDN (3 split conventional urea) + two nano urea spray (T_4) (107.35) which was on par with 33% RDN (only basal conventional urea) + two nano urea spray (T_7) (104.98). These results were confirmed by Manikandan and Subramanian (2016).

Economics

Maximum gross return was noticed under (T_4) 75% RDN with two nano urea spray (166754 Rs/ha) and which

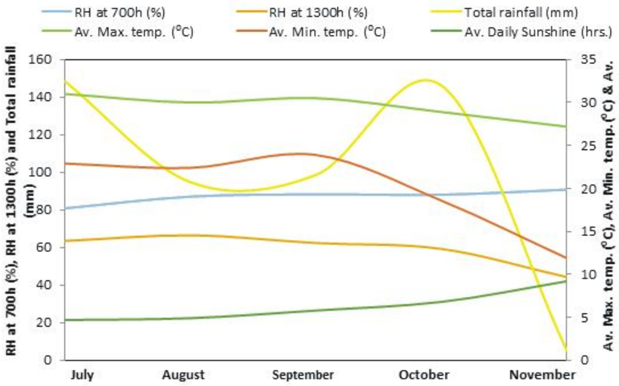

Fig. 1 : RH at 700h (%), RH at 1300h (%), Total rainfall (mm), Av. Max. temp. (p C), Av. Min. temp. (p C) & Av. Daily Sunshine (hrs.), during the period of Experimentation (July 2022 to November 2022).

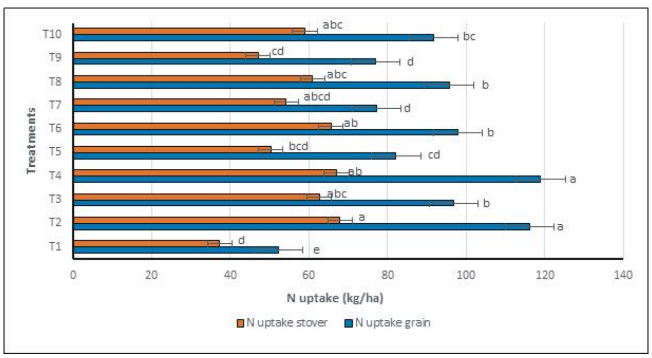

Fig. 2 : N uptake grain (kg/ha), and N uptake stover (kg/ha) as influenced by integrating nano urea in nitrogen management of maize under rainfed conditions. The bars display standard errors.

was at par with (T_2) 100% RDN (163676 Rs/ha). This was followed by (T_3) (145219 Rs/ha), (T_6) (144714 Rs. / ha), T_8 (136968 Rs/ha), (T_{10}) (134869 Rs/ha) (T_5) (123954 Rs/ha) T_7 (117887 Rs/ha) and T_9 (116744 Rs/ha). Minimum gross return was recorded under T_1, control (82478 Rs/ha).

Similarly, the maximum net return was noticed under T_4, 75% RDN with two nano urea sprays (116982 Rs/ ha) which was at par with T_2, 100% RDN (113808 Rs/ ha). This was followed by T_6 (96531 Rs. /ha), T_3 (96378 Rs/ha), T_8 (88528 Rs/ha), T_{10} (86947 Rs/ha), T_5 (76701 Rs/ha), T_7 (70515 Rs/ha) and T_9 (70418 Rs/ha), respectively. Minimum net return was recorded under T_1, control (38965 Rs/ha).

Likewise, the maximum B:C was noticed under T_4, 75% RDN with two nano urea sprays (3.35) and which was at par with T_2, 100% RDN (3.27). This was followed by T_6 (3.00), T_3 (2.97), T_8 (2.83), T_{10} (2.81) T_5 (2.62), T_9 (2.52), and T_7 (2.49), respectively. Minimum gross return was recorded under T_1, control (1.90).

Equally, the highest return per day was recorded under T_4, 75% RDN with two nano urea sprays (959 Rs/ day) and which was at par with T_2, 100% RDN (933 Rs/ day). This was followed by T_6 (791 Rs/day), T_3 (790 Rs/ day), T_8 (726 Rs/day), T_{10} (713 Rs/day) T_5 (629 Rs/day), T_7 (578 Rs/day) and T_9 (577 Rs/day) and respectively. Minimum gross return was recorded under T_1, control (319 Rs/day).

The gross returns, net returns, and benefit-to-cost ratio were lowest in the absolute control group due to insufficient nutrient supply, resulting in lower yields and returns. In contrast, basal application of conventional fertilizers and foliar application of nano fertilizers met the nutrient needs adequately, leading to higher yields and returns. These findings are consistent with the results reported by Rawat (2017) and Sankar *et al.* (2020).

Conclusion

Based on the findings, it can be inferred that nutrient uptake and use efficiency were higher with 75% RDN (3 split conventional urea) plus two nano urea sprays (T_4), comparable to 100% RDN (3 split conventional urea) (T_2). Nano fertilizers enhance nutrient bioavailability by activating alternative pathways and enzymes, increasing root biomass and rhizospheric microbial population. Synchronizing nano fertilizer application with crop demand is a sustainable strategy. A 4% nano spray concentration yielded 49.7% higher output and 33.3% higher net returns. Nano urea also increased efficiency, saving 25% nitrogen fertilizer without negatively impacting soil properties or the microenvironment. Thus, nano urea spraying benefits hilly ecosystems by boosting yields and reducing chemical fertilizer use, thereby minimizing environmental nitrogen accumulation.

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