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Effect of Different Levels of Nitrogen and Foliar Spray of Super Nano Urea on Soil Properties and Economics of Maize in Typic Haplustepts

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Abstract

The present study was undertaken during the *kharif* season of 2024 at the Instructional Farm of the Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan. The experiment consisted of eleven treatments involving different combinations of fertilizers and Super Nano Urea (SNU). Each treatment was replicated three times and arranged in a Randomized Block Design. The application of treatment T_7 (100% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS) recorded highest soil microbial population (bacteria, fungi and actinomycetes) and enzymatic activities *viz.,* dehydrogenase and alkaline phosphatase activity at harvest which was statistically at par with treatment T_6 (100% N + 2 spray of SNU at 25 DAS and 40 DAS) and T_5 (100% N + 1 spray of SNU at 55 DAS). Similarly, the maximum available nitrogen, phosphorus, potassium, and DTPA-extractable zinc in post-harvest soil were also recorded under treatment T_7 (100% N + 3 sprays of SNU at 25 DAS, 40 DAS, and 55 DAS). Economic analysis revealed that the maximum net returns (Rs. 118813 ha^{-1}) were recorded under T_7 (100% N + 3 sprays of SNU at 25, 40 and 55 DAS) which was found at par with T_6 (100% N + 2 sprays of SNU at 25 and 40 DAS). However, the highest benefit-cost ratio (3.36) was recorded under T_6, indicating better economic efficiency of the treatment.

Keywords: Super nano urea, Microbial population, Nitrogen, Dehydrogenase activity, BC ratio

Introduction

Maize (*Zea mays* L.), a member of the Poaceae family, is the third most extensively cultivated crop globally and is well adapted to dry and semi-arid regions (Shahzad *et al.,* 2020). It is grown across diverse agro-climatic conditions and can be cultivated throughout the year. Maize is a major source of nutrient-rich food for nearly 200 million people worldwide, and its significance is expected to increase as the global population surpasses 8 billion by 2025. It accounts for approximately 15% of total protein and 20% of the caloric intake required by humans, underscoring its vital role in global food and nutritional security. The average yield of maize is 5823.8 kg ha^{-1} and currently it has grown on 197 million hectares worldwide (FAOSTAT, 2022). In Rajasthan, maize is predominantly cultivated during the kharif season, especially in the Mewar, Wagad, and Hadoti regions, largely under rainfed conditions. Due to its high yield potential, maize is popularly known as 'queen of cereals'. Maize is the third most important food grain crop in India after wheat and rice (Mahapatra *et al.,* 2018; Suganya *et al.,* 2020). At the global level, India accounts for nearly 4% of the total maize growing area and about 2% of overall production, with the crop ranking fourth in cultivated area and seventh in production within the country. Maize is an important cereal crop cultivated in more than 170 countries worldwide.

Although maize has high yield potential, its actual productivity is often limited by various constraints, with inadequate soil nutrient availability a major factor. Maize demand large amounts of nitrogen (N) and phosphorus (P), with nitrogen being especially critical. A key approach to reducing the gap between current and future production is ensuring that nutrients are applied in the right amounts, at the right time, and from suitable sources. Nitrogen is a vital nutrient for maize and plays a major role, as it forms an integral part of amino acids, nucleic acids, chlorophyll, ATP, and plant hormones. Nitrogen availability affects several vital biological processes in plants, including water and nutrient uptake, transport through the xylem, storage in vacuoles, photosynthesis, carbon and nitrogen metabolism, and protein production. Given the significant role of nitrogen in promoting plant vegetative growth, its price and availability often lead to both misuse and over application (Li *et al.,* 2017). However, even when supplied in sufficient amounts, nitrogen frequently becomes limited in the soil because it is prone to losses through processes like volatilization, denitrification and leaching (Nduwimana *et al.,* 2020; Meena *et al.,* 2021).

The excessive and indiscriminate use of chemical fertilizers over the past five decades has negatively affected both the quality and quantity of agricultural production. With rising chemical fertilizer costs and global energy challenges, nanofertilizers are emerging as a promising alternative for supplying nutrients to crops. Combining nanofertilizers with conventional fertilizers in appropriate proportions can help improve crop yield while preserving soil health. To promote sustainable agriculture, the use of slow-release nitrogen fertilizers, such as nanofertilizers, has become increasingly important. Nanotechnology has been applied across agriculture in areas like production, processing, storage, packaging, and transport. Its potential includes controlled nutrient release, improving soil and rhizosphere properties, enhancing nutrient transport, conserving soil and water, treating water, and remediating soil and groundwater pollution. Nanofertilizers provide nutrients in a precise and balanced way, improving nutrient use efficiency (NUE). Nano urea usually contains 4% nitrogen, has an approximate shelf life of two years, and exhibits a zeta potential greater than 30. Due to the high surface area-to-volume ratio of nanofertilizers, they are readily absorbed by plants (Al-Juthery *et al.,* 2018). When nano urea is applied to leaves, it can efficiently enter through stomata and other openings and is readily transported into plant cells via apoplastic and symplastic pathways. Nanotechnology, in this way, offers a promising large-scale alternative to conventional nitrogen fertilizers (Madzokere *et al.,* 2021). Nano urea reduces the environmental impact of agriculture by minimizing nutrient losses through leaching and gaseous emissions, which contribute to pollution and climate change. It also improves soil health by enhancing aggregation, carbon sequestration, and water retention, while releasing nutrients in response to plant needs and environmental conditions.

Materials and Methods

The present investigation was carried out during *kharif* season of 2024, at the Instructional Farm, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan. This region falls under Agro-climatic Zone IVa, known as the sub-humid Southern Plains. This region has a subtropical climate with mild winters and moderately warm summers, accompanied by relatively high humidity. The area receives an average annual rainfall of 644.33 mm. The soil of the experimental field has a clay loam texture. The experiment was conducted in a Randomized Block Design comprising 11 treatments with three replications. The variety of crop used in the experiment was PHM-6. The details of the treatment are given in Table 1. The fertilisers (N:P:K:Zn) were applied at the recommended doses (90:60:40:25 kg ha^{-1}) using Urea, SSP, MOP, and ZnSO4.7H2O, respectively, as per the package of practices for this crop in this region. Full dose of P, K and Zn and half of the recommended dose

Table 1. Treatment details

Treatments	
T_1	0% N
T_2	100% N
T_3	0% N + 2 spray of SNU at 25 DAS and 40 DAS
T_4	0% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS
T_5	100% N + 1 spray of SNU at 55 DAS
T_6	100% N + 2 spray of SNU at 25 DAS and 40 DAS
T_7	100% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS
T_8	75% N + 1 spray of SNU at 40 DAS
T_9	75% N + 2 spray of SNU at 40 DAS and 55 DAS
T_{10}	50% N + 2 spray of SNU at 25 DAS and 40 DAS
T_{11}	50% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS

of N were applied at the time of sowing, and the remaining half dose of N was applied in two split doses as top dressing. The composition of Super Nano Urea used in the experiment was 4% Nitrogen (N), with a recommended foliar application rate of 4 mL L^{-1} in water. The experimental data were statistically analyzed by using the ANOVA technique as described by Cochran and Cox (1963). The significance of treatment differences was tested by F-test and critical difference (CD) was calculated at 5% level of significance.

Results and Discussion

Soil physical properties

The data on the effects of different nitrogen levels and foliar application of super nano urea on soil physical properties are presented in Table 2. The data shows that the different treatments of nitrogen levels and super nano urea did not show any significant effect on different physical properties of soil *viz.,* bulk density, particle density and porosity. The absence of a significant effect may be due to the experiment's relatively short duration, which may not have been sufficient for nutrient applications to produce noticeable changes in the soil's physical structure. Physical properties of soil are mainly determined by inherent factors such as texture, mineral composition, and long-term organic matter, which are not easily altered by short-term fertilizer use. In addition, nitrogen and nano-urea primarily influence plant growth and microbial activity rather than directly altering soil aggregation, so their effects on broader soil physical characteristics may be minimal (Bronick and Lal, 2005). Similar findings also reported by (Nibin *et al.,* 2019) and (Khardia *et al.*, 2022).

Soil chemical properties

The data presented in Table 3 shows that the different treatment comprising varying nitrogen levels and foliar spray of super nano urea did not show any significant effect on soil physico-chemical properties of soil such as pH, EC and OC. This could be attributed to the soil's natural buffering capacity, which helps maintain stability and resists changes. Soil pH tends to remain stable as it is largely governed by the nature of the parent material and the soil's buffering capacity, which makes it relatively unresponsive to short-term fertiliser applications (Brady and Weil, 2008). Organic carbon content in soil is mainly influenced by the long-term addition and breakdown of organic matter, and applications of inorganic or nano-fertilizers are usually inadequate to cause noticeable changes in OC levels (Lal, 2005). Similar results were also reported from (Naderi and shahraki, 2013) and (Rani *et al.,* 2019).

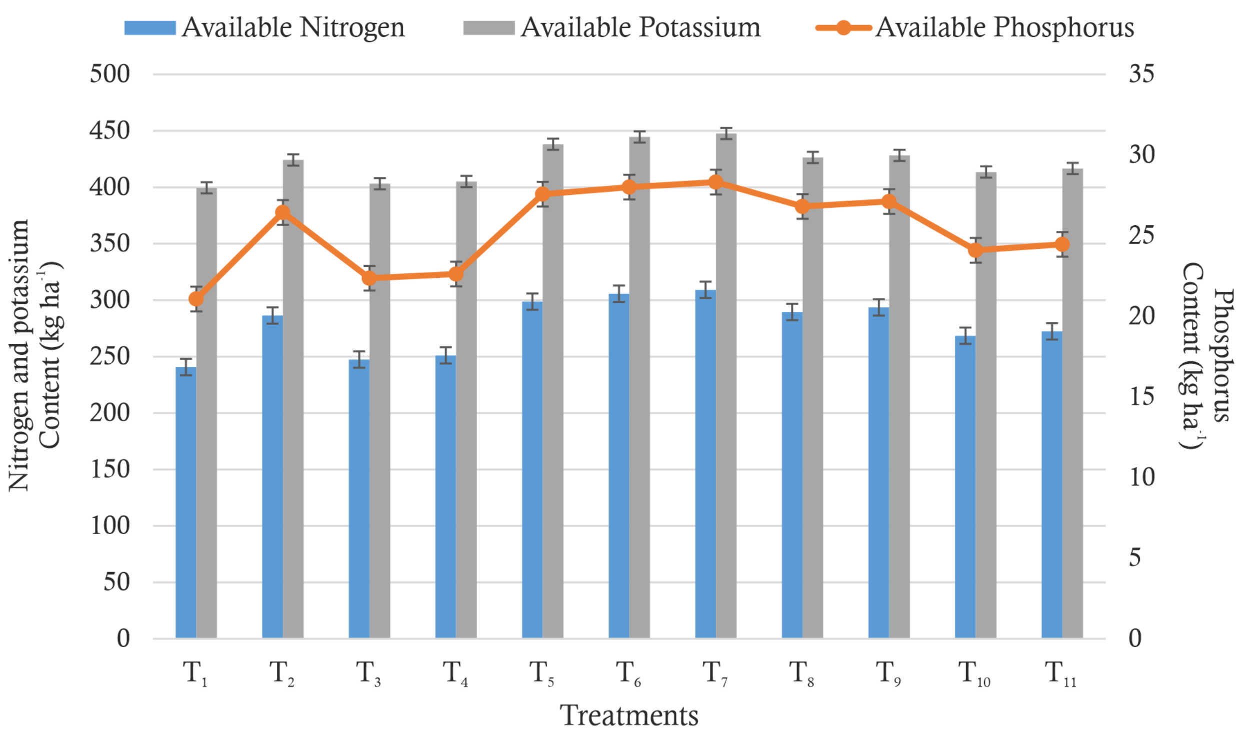
However, the data illustrated in Figure 1 and 2 shows that the amounts of available nitrogen,

Table 2. Effect of different levels of nitrogen and foliar spray of super nano urea on the physical properties of soil after harvest

Treatment		Bulk density ($Mg\ m^{-3}$)	Particle density ($Mg\ m^{-3}$)	Porosity (%)
T_1	0% N	1.33	2.39	44.36
T_2	100% N	1.32	2.36	44.04
T_3	0% N + 2 spray of SNU at 25 DAS and 40 DAS	1.35	2.35	42.56
T_4	0% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	1.36	2.39	43.09
T_5	100% N + 1 spray of SNU at 55 DAS	1.35	2.39	43.47
T_6	100% N + 2 spray of SNU at 25 DAS and 40 DAS	1.32	2.37	44.28
T_7	100% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	1.31	2.38	44.96
T_8	75% N + 1 spray of SNU at 40 DAS	1.35	2.38	43.21
T_9	75% N + 2 spray of SNU at 40 DAS and 55 DAS	1.31	2.36	44.48
T_{10}	50% N + 2 spray of SNU at 25 DAS and 40 DAS	1.32	2.35	43.81
T_{11}	50% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	1.34	2.37	43.46
SEm±		0.02	0.03	0.97
CD (p=0.05)		NS	NS	NS

Table 3. Effect of different levels of nitrogen and foliar spray of super nano urea on the chemical properties of soil after harvest

Treatment		pH	EC (dS m^{-1})	OC (%)
T_1	0% N	8.29	0.33	0.61
T_2	100% N	8.26	0.36	0.64
T_3	0% N + 2 spray of SNU at 25 DAS and 40 DAS	8.28	0.33	0.63
T_4	0% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	8.25	0.34	0.63
T_5	100% N + 1 spray of SNU at 55 DAS	8.29	0.37	0.67
T_6	100% N + 2 spray of SNU at 25 DAS and 40 DAS	8.28	0.37	0.68
T_7	100% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	8.24	0.38	0.69
T_8	75% N + 1 spray of SNU at 40 DAS	8.26	0.35	0.64
T_9	75% N + 2 spray of SNU at 40 DAS and 55 DAS	8.25	0.35	0.65
T_{10}	50% N + 2 spray of SNU at 25 DAS and 40 DAS	8.27	0.34	0.64
T_{11}	50% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	8.26	0.35	0.65
	SEm±	0.13	0.01	0.02
	LSD (p=0.05)	NS	NS	NS



*SEm± : N= 5.25, P= 0.38, K= 6.56
*CD(P=0.05): N= 15.50, P= 1.13, K= 19.34

Fig. 1 Effect of different levels of nitrogen and foliar spray of super nano urea on available macronutrient content of soil after harvest

phosphorus, potassium and DTPA extractable zinc in soil after harvest of maize crop were significantly enhanced with the application of different levels of nitrogen and foliar spray of super nano urea. The significantly highest available nitrogen (309.1 kg ha^{-1}), phosphorus (28.3 kg ha^{-1}), potassium (447.6 kg ha^{-1}) and DTPA extractable zinc (0.82 mg kg^{-1}) were recorded in treatment T_7 (100% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS) which was at par with treatment T_6 (100% N + 2 spray of SNU at 25 DAS and 40 DAS) and T_5 (100% N + 1 spray of

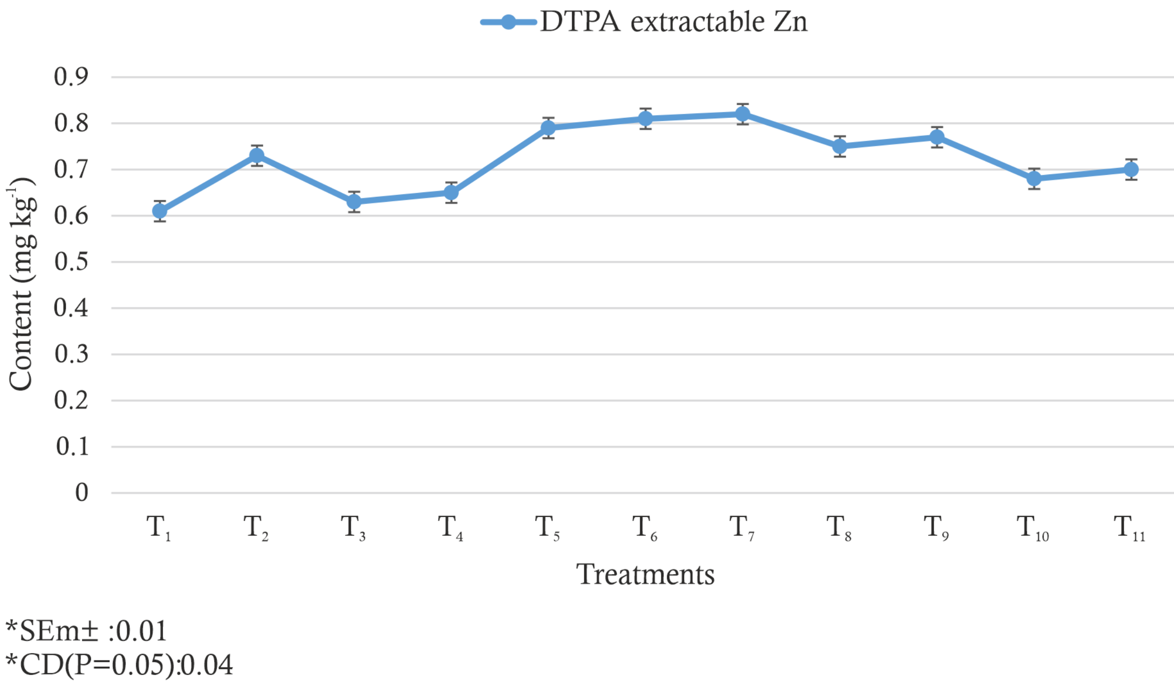


Fig. 2 Effect of different levels of nitrogen and foliar spray of super nano urea on DTPA extractable Zn content of soil after harvest

SNU at 55 DAS) and significantly superior over all other treatments. The lowest amount of all these nutrients was recorded in treatment T_1 (0% N). The increase in soil-available nitrogen is primarily due to the addition of nitrogen through both conventional and nano-urea fertilisers, which enhance specific biogeochemical processes, such as nitrification and ammonification, leading to the build-up of soil-available nitrogen (Raliya *et al.,* 2018). As nano-fertilisers release nutrients gradually, they also contribute to humic substances and root exudates, providing additional carbon and nitrogen sources for soil microorganisms, and they also minimise nutrient losses through leaching, volatilisation, and fixation by enabling the controlled and synchronised release of nutrients in accordance with crop demand. The nano-sized particles possess a high surface area and enhanced adsorption capacity, which improve nutrient retention in the rhizosphere and thereby increase the availability of both macro and micronutrients in the soil (Raliya *et al.,* 2018; Dimkpa *et al.,* 2020). Although, the higher amount of DTPA extractable zinc was due to application of zinc fertilizer ($ZnSO_4.7H_2O$) along with the nano fertilizer which improves its efficiency by enhancing microbial properties in the soil. A study conducted by (Naderi and Shahraki, 2013) shows that the application of nanofertilizers improves solubility and dispersion of insoluble nutrients in soil, reduces nutrient fixation by soil and increases bioavailability. Similar findings were reported by Nibin *et al.* (2019), Rani *et al.* (2019), Meena et al. (2021), and Raut et al. (2024).

Soil biological properties

The research findings of the experiment showed that different levels of nitrogen and foliar spray of super nano urea significantly enhanced soil biological properties, viz., soil microbial population and enzymatic activities such as dehydrogenase and alkaline phosphatase, at harvest, as presented in Tables 4 and 5. The highest soil microbial population and enzymatic activities were recorded with the application of treatment T7 (100% N + 3 sprays of SNU at 25 DAS, 40 DAS, and 55 DAS), which was significantly superior to the other treatments, including T_1 (0% N). However, it was statistically at par with treatment T_6 (100% N + 2 spray of SNU at 25 DAS and 40 DAS) and T_5 (100% N + 1 spray of SNU at 55 DAS).

Nano-fertilizers enhance microbial growth by supplying nutrients in readily available forms, thereby increasing microbial biomass and

Table 4. Effect of different levels of nitrogen and foliar spray of super nano urea on soil microbial population after harvest

Treatments		Microbial population in soil (cfu g^{-1} soil)		
		Bacteria (1×10^6)	Fungi (1×10^4)	Actinomycetes (1×10^5)
T_1	0% N	54.35	22.35	32.39
T_2	100% N	61.39	28.32	37.83
T_3	0% N + 2 spray of SNU at 25 DAS and 40 DAS	55.49	23.12	33.25
T_4	0% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	55.65	23.49	33.78
T_5	100% N + 1 spray of SNU at 55 DAS	64.70	30.75	38.77
T_6	100% N + 2 spray of SNU at 25 DAS and 40 DAS	66.35	31.18	39.48
T_7	100% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	66.45	31.27	39.52
T_8	75% N + 1 spray of SNU at 40 DAS	62.68	29.45	38.04
T_9	75% N + 2 spray of SNU at 40 DAS and 55 DAS	62.85	29.98	38.23
T_{10}	50% N + 2 spray of SNU at 25 DAS and 40 DAS	58.86	25.85	35.44
T_{11}	50% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	59.12	26.76	35.98
	SEm±	1.22	0.39	0.28
	LSD (p=0.05)	3.59	1.15	0.81

Table 5. Effect of different levels of nitrogen and foliar spray of super nano urea on soil enzymatic activity after harvest

Treatments		Enzyme activities in soil	
		Dehydrogenase (μg TPF g^{-1} soil 24 hr^{-1})	Alkaline phosphatase activity (μg PNP g^{-1} soil hr^{-1})
T_1	0% N	10.75	132.6
T_2	100% N	12.23	143.3
T_3	0% N + 2 spray of SNU at 25 DAS and 40 DAS	11.04	134.5
T_4	0% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	11.25	135.2
T_5	100% N + 1 spray of SNU at 55 DAS	12.81	149.9
T_6	100% N + 2 spray of SNU at 25 DAS and 40 DAS	13.05	152.3
T_7	100% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	13.15	153.2
T_8	75% N + 1 spray of SNU at 40 DAS	12.59	145.7
T_9	75% N + 2 spray of SNU at 40 DAS and 55 DAS	12.41	146.6
T_{10}	50% N + 2 spray of SNU at 25 DAS and 40 DAS	11.76	139.5
T_{11}	50% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	11.90	140.3
	SEm±	0.25	2.227
	LSD (p=0.05)	0.74	6.571

enzymatic activities in soil. Improved availability of nutrients such as N, P, K, and Zn stimulates microbial metabolism and creates a favorable environment for soil microorganisms (Paul and Clark, 1996). The significant increase in dehydrogenase activity observed in the present study indicates enhanced microbial oxidative activity and overall biological health of soil. Likewise, higher alkaline phosphatase activity may be attributed to increased mineralization of organic phosphorus and improved phosphorus dynamics under integrated nutrient management practices. The combined application of conventional and nano-fertilizers also reduces nutrient losses through leaching, thereby improving nutrient use efficiency and supporting soil biological activity (Luo *et al.,* 2015). Similar findings were also reported by (Nibin *et al.*, 2019), (Meena *et al.*, 2021), and (Khardia *et al.*, 2022).

Economics

The data pertaining to net returns and benefit-cost (B:C) ratio as influenced by different nitrogen levels and SNU sprays are presented in Table 6. The results revealed that net returns and B:C ratio increased significantly under different treatments.

Table 6. Effect of different levels of nitrogen and foliar spray of super nano urea on soil economics of maize

Treatment	Net returns (Rs ha^{-1})	Benefit-cost ratio
T_1 0% N	57807	1.76
T_2 100% N	98750	2.91
T_3 0% N + 2 spray of SNU at 25 DAS and 40 DAS	62449	1.84
T_4 0% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	66765	1.94
T_5 100% N + 1 spray of SNU at 55 DAS	109917	3.19
T_6 100% N + 2 spray of SNU at 25 DAS and 40 DAS	116961	3.36
T_7 100% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	118813	3.35
T_8 75% N + 1 spray of SNU at 40 DAS	103626	3.03
T_9 75% N + 2 spray of SNU at 40 DAS and 55 DAS	105176	3.04
T_{10} 50% N + 2 spray of SNU at 25 DAS and 40 DAS	82658	2.40
T_{11} 50% N + 3 spray of SNU at 25 DAS, 40 DAS and 55 DAS	87127	2.50
SEm±	3710	0.11
LSD (p=0.05)	10944	0.31

The significantly higher net returns (Rs. 118813 ha^{-1}) were recorded under T_7 (100% N + 3 sprays of SNU at 25, 40 and 55 DAS), which was found at par with T_6 (100% N + 2 sprays of SNU at 25 and 40 DAS) (Rs. 116961 ha^{-1}). However, T_6 recorded the highest benefit-cost ratio (3.36), which was marginally higher than T_7 (3.35).

Among the treatments, T_6 proved to be the most economical and efficient, achieving maximum profitability with comparatively fewer foliar sprays than T_7, thereby reducing additional cultivation costs. The lower net returns (Rs. 57807 ha^{-1}) and B:C ratio (1.76) were recorded under T_1 (0% N), indicating poor crop performance under nitrogen-deficient conditions. The results clearly suggest that the integrated application of recommended nitrogen, along with two sprays of SNU, significantly improved the economic returns and profitability of the crop. Similar findings were also reported by (Al-Juthery *et al.*, 2018), (Raut *et al.*, 2024), and (Rani *et al.,* 2019).

Conclusion

Based on the findings of the present investigation, it can be concluded that the application of different nitrogen levels and Super Nano Urea (SNU) sprays markedly improved soil nutrient availability, soil biological properties and economic returns of the crop. The combined use of conventional nitrogen fertilizer and SNU enhanced the availability of N, P, K and Zn along with microbial population and enzymatic activities, thereby improving soil health and nutrient use efficiency. Among the treatments, T_7 (100% N + 3 sprays of SNU at 25, 40, and 55 DAS) recorded the highest net returns, whereas the highest benefit-cost ratio was observed under T_6 (100% N + 2 sprays of SNU at 25 and 40 DAS). However, T_6 also remained statistically on par with T_7 in net returns and proved more economical due to lower cultivation costs and one fewer foliar spray. Therefore, the application of 100% recommended nitrogen, along with two sprays of SNU at 25 and 40 DAS, may be considered an efficient and economically viable nutrient management practice for improving soil health, nutrient use efficiency, and crop profitability under the prevailing agro-climatic conditions.

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