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Research Article

Foliar spray of urea and nano-urea in yield and economics of maize (*Zea mays* L.)

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Abstract
Applying urea is becoming more and more rapidly rising worldwide; nonetheless, the present study aimed to investigate the influence of using nitrogen fertilizer in the soil application in conjunction with foliar spraying of urea and nano-urea on the yield and economics of maize (Syngenta NK 6802) crop during rabi season of 2024. The experiment was laid out in a Randomized Block Design with seven treatments T_1 : 100 % RDF, T_2 : 75% RDF, T_3 : 75% RDF + foliar spray of urea @ 0.5% at knee height and tasselling stage, T_4 : 75% + RDF foliar spray of urea @ 1% at knee height and tasselling stage, T_5 : 75% RDF + foliar spray of nano-urea @ 0.2% at knee height and tasselling stage, T_6 : 75% RDF + foliar spray of nano-urea @ 0.3% at knee height and tasselling stage, T_7 : 75% RDF + foliar spray of nano-urea @ 0.4% at knee height and tasselling stage. Among the treatment 4 recorded significantly highest Plant height (139.83 cm), TDMP (94.32 g), Cob length (19 cm), Number of grains per row (24.67), Number of rows per cob (14.43), Stover yield (8636 kg/ha), Grain yield (6415 kg/ha), Gross return (₹ 166910.91), Net return (₹ 124169.68) and B: C ratio (2.91) as well as improving nutrient uptake and its efficiency. Therefore, the phenology, growth, yield, and profitability of maize and nitrogen fertiliser applications have been structured as per this combination of uptake to avoid losses by leaching and crop response.

Keywords: Economics, Foliar spray, Grain yield, Maize, Nano-urea, Urea

INTRODUCTION

Maize (*Zea mays* L.) is one of the most versatile emerging crops having wider adaptability under changing agro-climatic conditions. It is popularly known as the queen of cereals because it has the highest genetic yield potential among cereals. Every part of the maize plant is primarily used to feed livestock, and corn is a versatile grain with a wealth of uses. Maize is grown in more than 166 global countries, including tropical, subtropical, and temperate regions. Globally, it is cultivated in an area of nearly 205 mha with a production of 1210 metric tons and productivity of 5878 kg/ha (FAOSTAT 2021). The rapidly growing population creates a demand for food and a need to minimize the yield gap of maize crops (Nduwimana, 2020). Farmers affected by the price volatility of sugarcane, turmeric, and vegetables were shifting to maize cultivation (Rajalakshmi *et al*., 2020). The post-green revolution era faces a challenge due to the excessive utilization of fertilizers, complicated by the growing global population, emphasizing the need for increased quantities of chemical fertilizers, particularly nitrogen fertilizer in maize crops. Applying nutrients at the right time from the right concentration is the most important strategy for achieving the potential yield of maize crops. As a primary source of plant nutrients, nitrogen is vital to the plant system's protein, chlorophyll content, enzyme content, and enzyme activity

(Pan *et al*., 2021). In urea, nitrogen use efficiency generally ranges from 30 to 50% in moist soil (Singh, 2016). The efficiency of urea can reach around 50.61% when applied through foliar spray at optimal rates combined with proper soil moisture levels (Awwad *et al*., 2018).

Urea is the most nutrient used as a commercial nitrogen fertilizer for increasing crop productivity. However, their imbalanced application has environmental and ecological consequences. When applied at the right time, split doses of nitrogen application can reduce environmental pollution and improve yield by increasing nutrient usage efficiency. Optimizing nutrient utilization, especially nitrogen, requires containing neem-coated urea in conventional crop cultivation practices. The losses of nitrogen by soil application in maize through leaching (NO_3) and gas emissions (NH_4 and N_2O) are the leading causes of environmental pollution and climate change (Nair *et al*., 2020). Recent advancements in agricultural technology have led to the development of innovative practices such as foliar spraying of urea. Foliar application involves spraying nutrients directly into plant leaves, facilitating rapid absorption and minimizing nutrient leaching compared to soil application. The application of nitrogen through foliar spray emerges as a potentially more efficient alternative (Mahil and Kumar, 2019). The present research aimed to assess the impact of foliar spray of urea and nano-urea on the growth, yield and economic viability of maize (Syngenta NK 6802) cultivation.

MATERIALS AND METHODS

Field and experimental details

The research study was investigated during the rabi season of the year 2024 at the research field of SRM College of Agricultural Sciences, Baburayanpettai, Tamil Nadu, India (12^o 23'22" N latitude 79^o 44' 36" E longitude). The soil texture of the field was clay in nature with neutral soil reaction (pH 7.5), high in organic carbon (1.2%), low in available nitrogen (138 kg/ha), medium in available phosphorous (10 kg/ha) and low in available potassium (120 kg/ha). The Maize hybrid Syngenta NK 6802 seeds were sown on 4th March 2024 with a recommended seed rate of 25 kg/ha at spacing (60cm × 25cm). The various agronomic practices and other management practices apart from the treatment were performed according to the package and practices of Tamil Nadu Agricultural University, and Crop Production Guide (tnau.ac.in/site/research/wp-content/uploads/sites/60/2020/Agriculture-CPG-2020. pdf), Coimbatore, Tamil Nadu, India.

Treatment details

The experiment was designed in RBD (Randomized Block Design), with seven treatments and triplicate. The treatments used are T_1 : 100 % RDF, T_2 : 75% RDF, T_3 : 75% RDF + foliar spray of urea @ 0.5% at knee height and tasselling stage, T_4 : 75% + RDF foliar spray of urea @ 1% at knee height and tasselling stage, T_5 : 75% RDF + foliar spray of nano-urea @ 0.2% at knee height and tasselling stage, T_6 : 75% RDF + foliar spray of nano-urea @ 0.3% at knee height and tasselling stage, T_7 : 75% RDF + foliar spray of nano-urea @ 0.4% at knee height and tasselling stage. Growth and yield parameters of the maize plant were recorded every 15 days after sowing. The treatments were imposed based on critical stages of crop growth.

Statistical analysis

The data were collected from the research plot area and analysed based on "Analysis of variance" (ANOVA). Overall differences were tested by the "F" test of significance at a 5% ($p \leq 0.05$) level, as suggested by Gomez and Gomez (1984). The figures were constructed using the data analysis tool pack of Microsoft Excel 365. Statistical analysis was conducted using R (version 4.2.2) with R-studio (version 2022.12.0+353) and the "Agricole" package.

RESULTS AND DISCUSSION

Plant height and total dry matter production

During the 2024 rabi season, nitrogen application, that T_4: 75% RDF + foliar spray of urea @1 % at knee height and tasselling stage significantly ($p \leq 0.05$) enhanced growth parameters of plant height (139.83 cm), Total Dry Matter Production (94.32 g), Nutrient uptake of nitrogen (95.25 kg in grain and 46.45 kg in fodder), phosphorous (26.79 kg in grain and 13.87 kg in fodder) and potassium (35.14 kg in grain and 94.07 kg in fodder) in straw and grains, compared to other nitrogen application treatments mentioned in Table 1. The relationship between plant height, total dry matter production, and nutrient uptake of nitrogen, phosphorus, and potassium in maize significantly influences overall yield. However, these indices were more prominent under nitrogen fertilizer combined soil application with a foliar spray of urea. Nitrogen is a key constituent of the plant's photosynthetic organ, which helps to improve the chlorophyll content, enzyme content and enzymatic activity of plant leaves, as reported by Nasar *et al.* (2020).

Also, the study highlights that increasing plant height correlates with enhanced total dry matter and nutrient uptake, which is essential for optimal maize growth. Such findings emphasize the need for an integration of soil and foliar application approach to cultivation that prioritizes both plant morphological traits and soil nutrient management as reported by Arshad (2021). According to Tollenaar *et al.* (1984), optimal growing conditions and plant population density are crucial, as excessively dense plantings can inhibit growth due to competition for nutrients and sunlight. Therefore, managing these factors can maximize total dry matter and positively yield outcomes. (Reddy *et al*., 2024) mentioned nitrogen fertilizer is crucial for maize production, but higher doses can result in environmental concerns.

Nutrient uptake of nitrogen

In this study, the application of foliar fertilizers in the T_4 : 75% RDF + foliar spray of urea 1% at knee height and tasselling stage has gained attention as a potent strategy to improve nutrient uptake efficiency and reduce losses associated with soil application as well as foliar application. Foliar spraying involves delivering nutrients directly to plant leaves, allowing for rapid absorption and utilization by crops. Such research has demonstrated that replacing mineral nitrogen fertilizers with nitrogen derived from maize straw can significantly improve nitrogen (Arshad, (2021). Also, the integrated application of nitrogen in soil and foliage has enhanced root growth and the efficiency of nitrogen. Various nitrogen application strategies improve maize productivity and demonstrate an effective method of nitrogen applied through foliar to mitigate leaching and encourage robust crop growth, as reported by Martins *et al*. (2017)

Nutrient uptake of phosphorous

Foliar applications combined with soil treatments have shown promising results in improving phosphorus uptake among maize. Significant results of the experiments indicated that T_4 : 75% RDF + foliar spray of urea 1% at knee height and tasselling registered the highest nutrient in grains and straw compared to other treatments. According to Alim *et al.* (2023), the significance of phosphorus for root development and overall plant health cannot be overstated. Some researchers have highlighted instances where urea, when phosphorus is applied in soil, enhances phosphorus accessibility, which is vital during the flowering and grain-filling stages. Thus, applying urea foliar spray may facilitate enhanced phosphorus absorption, contributing positively to the soluble protein content and quality of maize grains Wierzbowska *et al.* (2022).

Nutrient uptake of potassium

Potassium is essential in various physiological activities, including enzyme activation and water regulation. The use of foliar with soil application of urea has also been associated with significantly increased potassium uptake in maize. The results of the experiments indicated that treatment T_4 : 75% RDF + foliar spray of urea 1% at knee height and the tasselling stage registered the highest nutrient content in maize compared to other treatments. Ali *et al*. (2016) have shown that soil applications improve nitrogen absorption and correlate with enhanced potassium content in maize. This improvement can lead to better drought resistance and overall plant vigor, suggesting that foliar application is particularly advantageous where soil potassium levels are low.

Yield parameters

The yield parameters, *viz,* cob length (19 cm), number of rows per cob (14.43), number of grains per row

Table 1. Growth and nutrient of maize influenced by foliar application of urea and nano-urea

Treatment		Plant height (cm)	TDMP (g)	N		P		K	
				Grain	Fodder	Grain	Fodder	Grain	Fodder
T_1	100% RDF	135.23	91.83	90.82	43.77	22.86	11.96	31.51	85.69
T_2	75% RDF	128.40	84.45	64.64	40.79	14.88	9.83	21.13	68.00
T_3	75% RDF + FSU 0.5% at knee height and tasselling stage	139.00	93.95	93.60	44.72	24.79	12.70	33.53	90.78
T_4	75% RDF + FSU 1% at knee height and tasselling stage	139.83	94.32	96.25	46.45	26.79	13.87	35.14	94.07
T_5	75% RDF + FSNU 0.2% at knee height and tasselling stage	129.86	86.91	84.22	42.52	20.91	10.02	26.09	76.98
T_6	75% RDF + FSNU 0.3% at knee height and tasselling stage	131.40	88.19	86.75	43.25	21.89	10.63	27.62	80.50
T_7	75% RDF + FSNU 0.4% at knee height and tasselling stage	133.23	90.38	87.73	43.96	22.86	11.12	29.14	83.50
F-test		871.41***	8.91***	376.32**	22.65**	54.33**	90.45**	48.45**	161.58**
SE (m)		0.15	1.23	0.56	0.37	0.51	0.15	0.68	0.69
CD (p≤0.05)		0.46	3.79	1.85	1.28	1.76	0.53	2.37	2.35

Description: RDF= Recommended dose of fertilizer, FSU= Foliar Spray of Urea, FSNU= Foliar Spray of Nano-Urea, TDMP= Total Dry Matter Production.

Table 2. Yield and yield attributes of maize influenced by foliar application of urea and nano-urea

Treatment		Cob Length (cm)	No. of rows/cob (nos.)	No. of grain/row (nos.)	100 seed weight (g)	Stover yield (kg)	Grain yield (kg)
T_1	100% RDF	17.4	14.22	24.00	26.72	6084	8453
T_2	75% RDF	14.1	13.66	20.67	25.13	4502	8116
T_3	75% RDF + FSU 0.5% at knee height and tasselling stage	18.4	14.39	24.27	26.80	6239	8556
T_4	75% RDF + FSU 1% at knee height and tasselling stage	19	14.43	24.67	27.01	6415	8636
T_5	75% RDF + FSNU 0.2% at knee height and tasselling stage	15.2	13.89	23.87	26.24	5783	8293
T_6	75% RDF + FSNU 0.3% at knee height and tasselling stage	15.4	13.93	24.00	26.41	5884	8333
T_7	75% RDF + FSNU 0.4% at knee height and tasselling stage	16.5	14.02	24.13	26.53	5978	8383
F-test		179.24***	1870.94**	8.77***	NS	19.02***	21.36***
SE (m)		0.13	0.01	0.45	-	39.68	187.94
CD (p≤0.05)		0.41	0.02	1.40	-	122.27	579.11

(24.67), grain yield (8636 kg/ha) and stover yield (6415 kg/ha)) were statistically analysed and mentioned in Table 2. The treatment T4 : 75% RDF + foliar spray of urea @1% at knee height and tasselling stage was observed to have the highest value in the yield parameters. The treatment T_2 : 75% RDF with the lowest growth parameters was recorded at the knee height and tasselling stage.

Specifically, a treatment involving a 75% recommended nitrogen rate coupled with a foliar spray of urea at specific growth stages remarkable grain yield and overall plant development results. The effective incorporation of these practices can lead to increased productivity and sustainability in maize cultivation practices. This indicates a growing preference for urea in agricultural practices aimed at optimizing maize yield, as Samui *et al*. (2022) reported.

Also, some research highlights the effectiveness of foliar spray urea in improving maize growth. Specifically, applying 75% recommended nitrogen dose combined with urea at a concentration of 1% during key growth stages resulted in superior growth and yield attributes and suggests that urea might enhance nutrient uptake efficiency in maize crops (Nayak *et al*., 2022). Also, existing studies have shown the relationship between nitrogen application rate on crop photosynthetic characteristics, nitrogen utilization rate, and crop yield (Shah *et al.,* 2021).

Economics of maize

The cost of cultivating maize varies widely and is influenced by various factors such as labour, fertilizers, and the inputs utilized in the production process, as mentioned in Table 3. In the treatment T_4 : 75% RDF + foliar spray of urea 1% at knee height and tasselling stage ₹ 42741.24 (493.85 USD) the lowest was seen in treatment T_2 : 75 % RDF ₹ 42331.24 ($ 489.00 USD). Gross returns from maize are notably high, reflecting the crop's substantial profitability potential. Studies indicate that farmers can achieve substantial gross earnings, often in the T_4 : 75% RDF + foliar spray of urea 1% at knee height and tasselling stage ₹ 166910.91 ($ 1929.00 USD) and the lowest was seen in treatment T_2 : 75 % RDF ₹ 120234.93 ($ 1388.92 USD). Net returns for maize producers remain robust, averaging in treatment T_4 : 75% RDF + foliar spray of urea 1% at knee height and tasselling stage ₹ 124169.68 ($ 1434.85 USD) and the lowest was seen in treatment T_2: 75 % RDF ₹ 77903.69 ($ 900.00 USD). The benefit-cost ratio for maize cultivation is a crucial metric, revealing the economic viability of growing this crop. The B: C ratio for maize often exceeds, indicating profitability in the treatment T_4 : 75% RDF + foliar spray of urea 1% at knee height and tasselling stage (2.91) and the lowest was seen in treatment T_2 : 75 % RDF (1.84). This study indicates that combining soil and foliar application methods can improve grain yields and enhance farmers' economic returns also advocates the necessity of incorporating foliar urea spray into sustainable maize cultivation practices. By improving nutrient efficiency and enhancing overall crop yield, foliar spraying can lead to higher productivity while minimizing environmental impacts typically associated with conventional fertilization methods.

Such practices align with modern agricultural strategies aimed at sustainable and responsible farming (Arunkumar *et al*., 2024). The combined treatment (T_4) of 75% RDF + foliar spray of urea 1% at knee height and tasselling stage influence the yield and economics of maize cultivation. The findings indicate that this treatment enhances productivity and provides farmers with cost savings, leading to improved economic outcomes. According to Alim *et al*. (2023) and Sanaullah *et al.* (2020), integrating these application methods can optimize returns, making it a highly beneficial practice in modern agriculture.

Table 3. Economics of maize as influenced by foliar application of urea and nano-urea

Treatments		Economics of maize			
		Cost of Cultivation	**Gross return (₹)**	**Net return (₹)**	**B: C ratio**
T_1	100% RDF	43145.00	158691.05	115546.05	2.68
T_2	75% RDF	42331.24	120234.93	77903.69	1.84
T_3	75% RDF + FSU 0.5% at knee height and tasselling stage	42686.24	162570.82	119884.58	2.81
T_4	75% RDF + FSU 1% at knee height and tasselling stage	42741.24	166910.91	124169.68	2.91
T_5	75% RDF + FSNU 0.2% at knee height and tasselling stage	42851.24	151231.35	108380.11	2.53
T_6	75% RDF + FSNU 0.3% at knee height and tasselling stage	43181.24	153716.77	110535.53	2.56
T_7	75% RDF + FSNU 0.4% at knee height and tasselling stage	43291.24	156035.12	112743.88	2.60

Conclusion

The application of foliar spray of urea in maize cultivation has demonstrated significant benefits in enhancing plant growth, improving yield, and optimizing nitrogen use efficiency. In the present findings, foliar feeding cum soil-applied nitrogen fertilizer had the adoption of treatment T_4: 75% RDF + foliar spray of urea @1% at knee height and the tasselling stage had significantly the highest plant height and grain yield improved quality and quantity of maize. The findings highlight the importance of adopting an integrated approach to nutrient management that combines foliar and soil-applied fertilizers in treatment 4 (75% RDF + foliar spray of urea @1% at knee height and the tasselling stage). This integrated methodology boosts plant height and total dry matter production and maximizes nitrogen, phosphorus, and potassium uptake, leading to significant improvements in maize yield, yield attributes and quality. This significantly impacted the economics of maize cultivation, particularly in terms of cost of cultivation, gross returns, net returns and the benefit-to-cost (B:C) ratio. Specifically, trials have reported gross returns and net returns exceeding with appropriate foliar treatments, thereby underscoring the economic viability of using soil application with foliar sprays of urea in maize (Syngenta NK 6802) production

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Conflict of Interest

The authors declare that they have no conflict of interest.

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