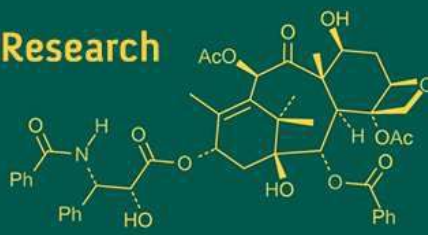


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Effect of plant density and nano-urea-based nitrogen management on physiological growth and nitrogen use efficiency of sweet corn

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Abstract

Optimizing plant density and nitrogen management is essential for improving physiological performance and nitrogen use efficiency in sweet corn (*Zea mays* L. *saccharata*). A field experiment was conducted during the summer seasons of 2024 and 2025 to evaluate the effects of plant density and nano-urea-based nitrogen management on physiological growth parameters and nitrogen use efficiency of sweet corn. The experiment was laid out in a split-plot design with three plant densities (60 × 20 cm, 50 × 20 cm and 45 × 20 cm) as main-plot treatments and six nitrogen management practices, including conventional prilled urea and reduced nitrogen levels supplemented with nano-urea or prilled urea sprays, as sub-plot treatments. Results showed that plant density significantly influenced crop physiological behaviour; closer spacing (45 × 20 cm) enhanced crop growth rate at later stages and increased nitrogen uptake, apparent nitrogen recovery and partial factor productivity due to higher biomass production, while wider spacing recorded higher absolute growth rate and net assimilation rate, indicating better individual plant efficiency. Relative growth rate was higher under wider spacing at the initial stage but shifted towards closer spacing at later stages. Among nitrogen management practices, application of 75% nitrogen through prilled urea supplemented with nano-urea improved physiological growth parameters, nitrogen uptake, apparent nitrogen recovery and agronomic nitrogen use efficiency over 100% recommended nitrogen, while partial factor productivity was highest under 50% nitrogen supplemented with nano-urea. The study demonstrates that integrating optimum plant density with nano-urea-based nitrogen management enhances physiological efficiency and nitrogen utilization in sweet corn.

Keywords: Nano urea, plant density, sweet corn, nue, cgr, rgr

Introduction

Sweet corn (*Zea mays* L. *saccharata*) is a high-value maize crop grown mainly for its tender and sweet kernels, which are consumed as a vegetable. Due to its good taste, nutritional value and increasing preference among urban and health-conscious consumers, the cultivation of sweet corn is expanding rapidly in many parts of India (Swapna *et al.*, 2020) [11]. Unlike grain maize, sweet corn requires careful agronomic management, as small changes in crop growth and nutrient availability can strongly influence cob development and marketable yield. Among the various management practices, plant density and nitrogen nutrition play a key role in determining crop performance.

Plant density directly affects the availability of light, water and nutrients to individual plants. Closer spacing increases the number of plants per unit area and generally enhances total biomass production and crop growth rate, but it may reduce growth of individual plants due to competition (Sai and Umesha 2022) [9]. On the other hand, wider spacing allows better growth of individual plants by providing more space and resources, but often results in lower yield per hectare because of reduced plant population. Therefore, selecting an appropriate plant density is important to achieve a balance between individual plant growth and overall crop productivity in sweet corn.

Nitrogen is the most important nutrient required for maize growth, as it is a major component of chlorophyll, proteins and enzymes involved in photosynthesis and plant development.

Adequate nitrogen supply promotes leaf area development, dry matter accumulation and efficient assimilate production. However, nitrogen use efficiency in maize is often low when conventional fertilizers such as prilled urea are used. Large losses of nitrogen through leaching and volatilization reduce fertilizer efficiency, increase production costs and pose environmental risks. Improving nitrogen availability to crops while reducing these losses is therefore a major challenge in modern agriculture.

In recent years, nano-fertilizers have emerged as a promising option for improving nutrient use efficiency. Nano-urea is a nano-sized nitrogen fertilizer that releases nutrients slowly and can be absorbed effectively through foliar application. Its small particle size allows better penetration into plant tissues, resulting in improved nitrogen availability at critical growth stages (Upadhyay *et al.*, 2023) [12]. Studies have shown that combining nano-urea with reduced doses of conventional nitrogen fertilizers can improve crop growth and nitrogen recovery in cereals (Kaviyazhagan *et al.*, 2022) [13]. However, understanding how such practices influence crop physiological behaviour is equally important for developing efficient nutrient management strategies.

Physiological growth parameters such as crop growth rate, absolute growth rate and net assimilation rate help explain how plants convert light and nutrients into biomass under different management practices. Similarly, nitrogen use efficiency indicators, including nitrogen uptake, apparent nitrogen recovery and agronomic efficiency, provide useful information on how effectively applied nitrogen is utilized by the crop. Despite their importance, limited research is available on the combined effects of plant density and nano-urea-based nitrogen management on physiological growth and nitrogen use efficiency of sweet corn, particularly under the agro-climatic conditions of western Uttar Pradesh. Therefore, the present study was conducted to evaluate the effect of plant density and nano-urea-based nitrogen management on physiological growth parameters and nitrogen use efficiency of sweet corn. The findings of this study are expected to provide useful insights for improving crop productivity while promoting efficient and sustainable nitrogen management.

Methods and Materials

The field trials were conducted during the summer seasons of 2024 and 2025 at the Agronomy Research Farm of Narain (P.G.) College, Shikohabad, Firozabad district, Uttar Pradesh, India (27.10° N latitude, 78.59° E longitude; 163 m above mean sea level). The region falls under the western plain zone of Uttar Pradesh and has a subtropical climate. The soil of the experimental field was sandy loam in texture, slightly alkaline in reaction (pH 7.74), low in organic carbon (0.41%) and low in available nitrogen (188.4 kg ha⁻¹), while available phosphorus (20.5 kg ha⁻¹) and potassium (261.3 kg ha⁻¹) were medium. The electrical conductivity of the soil was 1.87 dS m⁻¹. Soil samples were collected before sowing and analyzed using standard procedures.

The experiment was laid out in a split-plot design with three plant densities (S₁-60 cm × 20 cm, S₂-50 cm × 20 cm and S₃-45 cm × 20 cm) to the main plots and 6 nitrogen treatments (N₁: No Nitrogen, N₂: N_{100%}, N₃: N_{75%} through prilled urea + 2 sprays Nano-N @ 4 aml litre⁻¹ at 25 and 50 DAS each coincide with split doses of prilled urea application, N₄: N_{75%} through prilled urea + 2% prilled urea spray at 25 and 50

DAS each coincide with split doses of prilled urea application, N₅: N_{50%} through prilled urea + 2 sprays Nano-N @ 4ml litre⁻¹ at 25 and 50 DAS each coincide with split doses of prilled urea application and N₆: N_{50%} through prilled urea + 2% prilled urea spray at 25 and 50 DAS each coincide with split doses of prilled urea application) allocated to the sub-plots. A sweet corn hybrid 'Sugar-75' was sown manually following recommended agronomic practices. Phosphorus and potassium were applied as basal doses, while nitrogen through prilled urea was applied in split doses according to the treatments. Foliar sprays were applied using a hand sprayer, and uniform crop management practices were followed throughout the season.

Physiological growth parameters, including crop growth rate (CGR), relative growth rate (RGR), absolute growth rate (AGR) and net assimilation rate (NAR), were calculated for the period from 25-50 DAS and 50 DAS to harvest using standard growth analysis formulas based on dry matter accumulation and leaf area measurements. Plant samples were oven-dried to constant weight for growth analysis. Total nitrogen uptake was determined from nitrogen concentration in grain and stover multiplied by their respective yields. Nitrogen use efficiency indices such as apparent nitrogen recovery, agronomic nitrogen use efficiency and partial factor productivity were computed using standard methods (Dobermann 2007). The recorded data were subjected to analysis of variance appropriate for a split-plot design, and treatment means were compared using the critical difference test at the 5% level of significance. Statistical analysis was performed separately for each year.

Results and Discussion

Physiological parameters

Plant density significantly influenced most physiological growth parameters of sweet corn. Crop growth rate (CGR) during the early growth period (25-50 DAS) did not differ significantly among plant densities shown in Table 1. However, during the later growth stage (50 DAS to harvest), CGR was significantly higher under the closest spacing of 45 × 20 cm (S₃) compared to 50 × 20 cm (S₂) and 60 × 20 cm (S₁). The higher CGR at later stages under S₃ may be attributed to increased plant population per unit area, resulting in greater leaf area development and more efficient interception of solar radiation, which enhanced dry matter accumulation on an area basis. Absolute growth rate (AGR), relative growth rate (RGR) and net assimilation rate (NAR) were significantly higher under wider spacing (S₁), indicating superior individual plant growth efficiency due to reduced inter-plant competition for light, nutrients and moisture. Thus, closer spacing favoured population growth and biomass accumulation per unit area, whereas wider spacing improved physiological efficiency at the individual plant level. Sai and Umsha (2022) [9] recorded higher crop growth rate (CGR) and relative growth rate (RGR) at plant spacing 45 × 15 cm. Similar results were observed by Layek *et al.*, (2012) [15] and Rajput *et al.*, (2017) [17].

Nitrogen management practices exerted a pronounced effect on physiological growth parameters (Table 1 & 2). Application of 75% nitrogen through prilled urea supplemented with two foliar sprays of nano-urea (N₃) recorded the highest CGR, RGR, AGR and NAR, and was distinctly superior to 100% recommended nitrogen through prilled urea (N₂). The improvement in physiological performance under N₃, despite reduced basal nitrogen,

indicates more efficient nitrogen availability and utilization. Treatments receiving reduced prilled urea combined with nano-urea consistently outperformed their corresponding prilled urea spray treatments, whereas the control (N₁) recorded the lowest values due to nitrogen deficiency. Enhanced growth under nano-urea application may be attributed to improved nitrogen absorption through foliar pathways, higher chlorophyll content and increased

photosynthetic efficiency. The increase of these indices with N levels was also reported by Kaviyazhagan *et al.*, (2022)^[3] and Reddy *et al.*, (2022)^[8] also confirm superiority of LAI, CGR, AGR, Relative Growth Rate and NAR with the application of 25% N as granular urea (GU) at basal + 25% as nano urea at 4 leaf stage + 25% N as nano urea on 8 leaf stage+ 25% N as nano urea at tasseling stage than other treatment combinations.

Table 1: Effect of Plant Density and Nitrogen (Prilled Urea, Nano Urea & Prilled Urea Spray) on CGR and RGR at different growth stages

Treatments	CGR (g m ⁻² day ⁻¹)				RGR (mg g ⁻¹ day ⁻¹)			
	25-50 DAS		50-harvest DAS		25-50 DAS		50-harvest DAS	
	2024	2025	2024	2025	2024	2025	2024	2025
Plant Density								
60 cm × 20 cm (S ₁)	11.17	11.32	11.07	11.25	75.71	75.67	22.20	22.24
50 cm × 20 cm (S ₂)	12.12	12.28	12.17	12.38	68.87	68.81	21.84	21.89
45 cm × 20 cm (S ₃)	12.39	12.55	13.68	13.92	64.57	64.51	23.06	23.13
SE(m)	0.334	0.338	0.287	0.292	1.364	1.364	0.068	0.068
CD at 5%	NS	NS	1.011	1.029	4.810	4.811	0.239	0.238
Nano Urea Foliar Application								
N ₁ -N ₀ Nitrogen	7.76	7.86	8.47	8.61	62.25	62.18	22.58	22.64
N ₂ -N _{100%}	14.04	14.22	14.81	15.05	70.03	69.94	22.70	22.75
N ₃ -N _{75%} through prilled urea + 2 sprays Nano-N @ 4 ml litre ⁻¹ at 25 & 50 DAS	16.23	16.45	16.52	16.79	79.68	79.60	22.88	22.92
N ₄ -N _{75%} through prilled urea + 2% prilled urea spray at 25 and 50 DAS	11.10	11.25	11.77	11.96	65.58	65.53	22.40	22.44
N ₅ -N _{50%} through prilled urea + 2 sprays Nano-N @ 4 ml litre ⁻¹ at 25 and 50 DAS	13.17	13.36	13.47	13.73	75.72	75.87	22.68	22.76
N ₆ -N _{50%} through prilled urea + 2% prilled urea spray at 25 and 50 DAS	9.06	9.17	8.81	8.96	65.03	64.86	20.97	21.02
SE(m)	0.507	0.513	0.417	0.424	2.171	2.170	0.102	0.102
CD at 5%	1.448	1.466	1.191	1.212	6.205	6.202	0.292	0.292

Table 2: Effect of Plant Density and Nitrogen (Prilled Urea, Nano Urea & Prilled Urea Spray) on AGR and NAR at different growth stages

Treatments	AGR (g plant ⁻¹ day ⁻¹)				NAR (mg day ⁻¹ cm ⁻²)			
	25-50 DAS		50-harvest DAS		25-50 DAS		50-harvest DAS	
	2024	2025	2024	2025	2024	2025	2024	2025
Plant Density								
60 cm × 20 cm (S ₁)	1.341	1.359	1.329	1.350	0.885	0.862	0.307	0.299
50 cm × 20 cm (S ₂)	1.216	1.229	1.217	1.238	0.752	0.747	0.278	0.276
45 cm × 20 cm (S ₃)	1.157	1.130	1.231	1.252	0.695	0.677	0.298	0.293
SE(m)	0.016	0.020	0.017	0.016	0.016	0.021	0.005	0.005
CD at 5%	0.056	0.071	0.061	0.055	0.057	0.075	0.019	0.017
Nano Urea Foliar Application								
N ₁ -N ₀ Nitrogen	0.807	0.817	0.875	0.889	0.600	0.595	0.231	0.229
N ₂ -N _{100%}	1.448	1.469	1.518	1.541	0.842	0.838	0.341	0.338
N ₃ -N _{75%} through prilled urea + 2 sprays Nano-N @ 4 ml litre ⁻¹ at 25 & 50 DAS	1.667	1.682	1.684	1.713	0.999	0.940	0.371	0.357
N ₄ -N _{75%} through prilled urea + 2% prilled urea spray at 25 and 50 DAS	1.222	1.154	1.197	1.219	0.722	0.739	0.287	0.293
N ₅ -N _{50%} through prilled urea + 2 sprays Nano-N @ 4 ml litre ⁻¹ at 25 and 50 DAS	1.354	1.375	1.379	1.404	0.865	0.825	0.312	0.299
N ₆ -N _{50%} through prilled urea + 2% prilled urea spray at 25 and 50 DAS	0.930	0.941	0.899	0.914	0.635	0.632	0.224	0.222
SE(m)	0.025	0.031	0.032	0.023	0.021	0.021	0.006	0.006
CD at 5%	0.072	0.090	0.091	0.064	0.060	0.060	0.016	0.016

Nitrogen uptake, Nutrient use efficiency

Plant density significantly influenced total nitrogen uptake and all nitrogen use efficiency parameters of sweet corn during both years (Table 3). Total nitrogen uptake increased significantly with increasing plant density and was highest under 45 × 20 cm spacing (S₃), which recorded 103.15 and 107.06 kg ha⁻¹ during 2024 and 2025, respectively, and was significantly superior to 50 × 20 cm (S₂) and 60 × 20 cm (S₁). The higher nitrogen uptake under S₃ can be attributed to greater biomass production and higher plant population per unit area, which enhanced cumulative nitrogen demand and absorption. Apparent nitrogen recovery also increased significantly with closer spacing and was highest under S₃ (34.95% in 2024 and 34.78% in 2025), indicating improved

utilization of absorbed nitrogen under higher plant density. Agronomic nitrogen use efficiency differed significantly among plant densities; however, the highest value was recorded under S₃ during 2024, while during 2025, S₂ recorded marginally higher agronomic NUE than S₃, indicating year-wise variation in nitrogen response. Partial factor productivity was significantly higher under closer spacing and was maximum under S₃ (25.29 and 25.89 kg kg⁻¹ during 2024 and 2025, respectively), reflecting more efficient conversion of applied nitrogen into economic yield at higher plant population. Overall, the results demonstrate that closer spacing improved nitrogen uptake and most efficiency indices on a per-hectare basis. Similar results

were reported by Upadhyay *et al.*, (2023) ^[12] and Saklani and Pal (2023) ^[10].

Nitrogen management practices exerted a highly significant effect on nitrogen uptake and nitrogen use efficiency indices shown in Table 3. Application of 75% nitrogen through prilled urea supplemented with two foliar sprays of nano-urea (N₃) recorded the highest total nitrogen uptake, apparent nitrogen recovery and agronomic nitrogen use efficiency, and was significantly superior to 100% recommended nitrogen through prilled urea (N₂). Partial factor productivity was highest under N₅ (50% nitrogen + nano-urea), followed by N₃, indicating greater productivity per unit of applied nitrogen under reduced nitrogen doses. In contrast, sole application of prilled urea and prilled urea

spray treatments showed lower efficiency, while the unfertilized control recorded the lowest values for all parameters. These results demonstrate that integration of nano-urea with reduced prilled urea markedly improves nitrogen uptake and use efficiency in sweet corn. Similar results were observed by Muchhadiya *et al.*, (2024) ^[6] in sweet corn, Bindhani *et al.*, (2007) ^[1] in baby corn and Kumar (2009) ^[4] in sweet corn with increased uptake of nitrogen at higher N levels. Upadhyay *et al.*, (2023) ^[12] concluded that grain/seed N uptake was significantly influenced by different treatments of nano-urea and highest grain/seed N uptake was noted under N_{100%} PK + nano-urea sprays followed by N_{75%} PK + nano-urea and N_{100%} PK respectively.

Table 3: Effect of Plant Density and Nitrogen (Prilled Urea, Nano Urea & Prilled Urea Spray) on total nitrogen uptake and nitrogen use efficiency

Treatments	Total N uptake (kg/ha)		Apparent Recovery of N		Agronomic NUE		Partial Factor Productivity	
	2024	2025	2024	2025	2024	2025	2024	2025
Plant Density								
60 cm × 20 cm (S ₁)	92.83	96.81	29.36	31.02	9.78	10.25	24.15	24.83
50 cm × 20 cm (S ₂)	98.03	103.91	32.81	34.16	9.69	10.58	24.19	25.71
45 cm × 20 cm (S ₃)	103.15	107.06	34.95	34.78	9.96	8.90	25.29	25.89
SE(m)	1.427	0.567	0.421	0.391	0.043	0.142	0.174	0.229
CD at 5%	5.035	2.000	1.484	1.381	0.151	0.499	0.613	0.808
Nano Urea Foliar Application								
N ₁ -N ₀ Nitrogen	64.88	68.44	0.00	0.00	0.00	0.00	0.00	0.00
N ₂ -N _{100%}	118.89	123.87	44.34	45.32	10.38	10.37	22.43	23.09
N ₃ -N _{75%} through prilled urea + 2 sprays Nano-N @ 4 ml litre ⁻¹ at 25 & 50 DAS	133.08	138.63	57.36	59.06	16.54	16.58	32.57	33.52
N ₄ -N _{75%} through prilled urea + 2% prilled urea spray at 25 and 50 DAS	93.13	97.60	33.34	34.12	8.91	8.88	23.76	24.56
N ₅ -N _{50%} through prilled urea + 2 sprays Nano-N @ 4 ml litre ⁻¹ at 25 and 50 DAS	100.51	105.04	44.20	45.35	13.96	14.01	38.00	39.40
N ₆ -N _{50%} through prilled urea + 2% prilled urea spray at 25 and 50 DAS	77.52	81.97	15.01	16.06	9.06	9.62	30.52	32.29
SE(m)	1.042	1.319	0.507	0.560	0.156	0.160	0.387	0.375
CD at 5%	2.979	3.770	1.450	1.601	0.445	0.457	1.106	1.071

Conclusion

The study clearly demonstrated that plant density and nano-urea-based nitrogen management significantly influenced physiological growth and nitrogen use efficiency of sweet corn. Closer spacing (45 × 20 cm) enhanced crop growth rate and nitrogen uptake due to higher plant population, while wider spacing improved individual plant efficiency. Application of 75% nitrogen through prilled urea supplemented with nano-urea sprays markedly improved nitrogen uptake, recovery and use efficiency over conventional fertilization. Thus, integration of optimum plant density with nano-urea-based nitrogen management offers an efficient and sustainable strategy for improving nitrogen utilization in sweet corn.

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