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Shivashankar K
Department of Agronomy,
University of Agricultural Sciences
Dharwad, Karnataka, India

MP Potdar
Department of Agronomy,
University of Agricultural Sciences
Dharwad, Karnataka, India

Aishwarya Golshetti
Department of Agronomy, College
of Agriculture, V C Farm, Mandya,
University of Agricultural Science,
Bangalore, Karnataka, India

DP Biradar
Department of Agronomy,
University of Agricultural Sciences
Dharwad, Karnataka, India

Corresponding Author:
Shivashankar K
Department of Agronomy,
University of Agricultural Sciences
Dharwad, Karnataka, India

Yield and nutrient uptake dynamics of irrigated rabi maize (*Zea mays* L.) under graded nitrogen regimes

Shivashankar K, MP Potdar, Aishwarya Golshetti and DP Biradar

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Abstract

Maize is an increasingly important cereal crop globally, and its cultivation during the Rabi season is gaining prominence due to favorable climatic conditions and higher yield potential under irrigation. Nitrogen (N) is a pivotal macronutrient that dictates the overall growth, development, and sink capacity of the crop. To optimize nitrogen recommendations and maximize productivity, a field experiment was conducted during the Rabi 2020-21 season at the Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad. The study evaluated the impact of graded levels of nitrogen on maize, employing a Randomized Complete Block Design (RCBD) with nine treatments (ranging from 0 to 200% of the Recommended Dose of Nitrogen, incremented by 25%). The findings revealed that yield attributes were significantly enhanced by elevated nitrogen levels. The application of 200% RDN recorded maximum cob length (17.4 cm), cob diameter (4.71 cm), grains per row (35.2), grains per cob (574.8), test weight (33.2 g), and grain yield per cob (194.4 g). Consequently, this treatment yielded the highest grain (9485.7 kg ha⁻¹) and straw (11485.6 kg ha⁻¹), alongside the highest total NPK uptake (213.2, 58.3, and 172.9 kg ha⁻¹, respectively). However, the 175% and 150% RDN applications demonstrated statistical parity with the 200% RDN across major yield parameters, underscoring their effectiveness for sustainable Rabi maize production.

Keywords: Rabi maize, graded nitrogen, yield attributes, nutrient uptake, harvest index

Introduction

Maize (*Zea mays* L.) is the third-most significant cereal crop globally, ranking just after wheat and rice. Often heralded as the "Queen of Cereals" due to its remarkably high genetic yield potential, maize serves multifaceted roles as a staple food for millions, an essential livestock feed, and a vital industrial raw material. While traditional maize cultivation in India is predominantly rainfed during the Kharif season, there has been a paradigm shift towards Rabi season cultivation. Cultivating maize during the Rabi season offers distinct agronomic advantages, including assured irrigation, mild temperatures, abundant solar radiation, and a significantly lower incidence of pests and diseases. These favorable environmental factors collectively result in a notably higher productivity potential compared to the Kharif crop.

To realize the elevated yield potential of modern maize hybrids during the Rabi season, meticulous nutrient management is indispensable. Among the essential macronutrients, nitrogen (N) is the most critical and universally yield-limiting factor in maize production. Nitrogen is fundamentally integrated into plant metabolism as a primary structural component of amino acids, proteins, nucleic acids, and chlorophyll. It directly influences vegetative canopy development, photosynthetic rate, and the subsequent translocation of assimilates to the developing grain sink. Despite its physiological importance, the application of generic, blanket nitrogen recommendations often fails to harness the full genetic potential of highly responsive maize hybrids under intensive Rabi cultivation. Furthermore, poor nitrogen management poses dual challenges. Sub-optimal nitrogen application severely curtails canopy expansion, prematurely accelerates leaf senescence, and restricts grain filling, thereby incurring heavy yield penalties. Conversely, the indiscriminate and excessive application of nitrogen fertilizer leads to diminished Nitrogen Use Efficiency (NUE) and escalates the risk of severe environmental hazards, including nitrate leaching and greenhouse gas emissions. Striking a precise balance is therefore a paramount concern for sustainable agricultural intensification.

In light of these considerations, standardizing the nitrogen dosage is a pressing necessity. Comprehensive field studies evaluating the systematic progression of nitrogen levels are crucial to identifying the optimal application rate that maximizes yield without compromising environmental or economic sustainability. Consequently, the present investigation was specifically designed and executed to evaluate the comprehensive impact of graded levels of nitrogen application on the growth dynamics, yield attributes, final crop yield, and nutrient uptake patterns of irrigated maize during the Rabi season.

Materials and Methods

Site Description and Soil Characteristics: The field experiment was conducted during the Rabi 2020-21 cropping season at the Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad. Geographically, the experimental site is situated in the Northern Transition Zone (Zone-8) of Karnataka at 15° 26' N latitude and 75° 01' E longitude. Prior to the initiation of the experiment, comprehensive soil sampling was conducted. The soil of the experimental site was identified as a medium black soil with a slightly alkaline pH of 7.68 and a safe electrical conductivity of 0.31 dS m⁻¹. Baseline fertility analysis revealed that the soil was low in organic carbon content (0.46%) and available nitrogen (232.4 kg ha⁻¹), medium in available phosphorus (28.5 kg P₂O₅ ha⁻¹), and high in available potassium (384.2 kg K₂O ha⁻¹).

Experimental Design and Treatment Details: The experiment was systematically laid out using a Randomized Complete Block Design (RCBD) with three replications. The study evaluated nine specific treatments comprising graded levels of nitrogen. The treatments spanned from an absolute control to highly intensified nitrogen regimes: T1 (Absolute control - 0 kg N ha⁻¹), T2 (25% RDN), T3 (50% RDN), T4 (75% RDN), T5 (100% RDN), T6 (125% RDN), T7 (150% RDN), T8 (175% RDN), and T9 (200% RDN). The Recommended Dose of Nitrogen (RDN) for the region under irrigated conditions was established at 150 kg N ha⁻¹, complemented by 65 kg P₂O₅ and 65 kg K₂O ha⁻¹.

Crop Husbandry and Fertilizer Application: The highly responsive maize hybrid, NK-6240, was selected for the study. Sowing was carried out on December 10, 2020, maintaining a strict spacing geometry of 60 cm between rows and 20 cm between plants. To isolate the effect of nitrogen, a uniform basal dose of phosphorus (as Single Super Phosphate) and potassium (as Muriate of Potash) was applied to all experimental plots, exclusively omitting the absolute control. Nitrogen fertilizer (supplied as Urea) was applied in a carefully scheduled split-dose regimen to synchronize with the critical crop demand phases: 10% was applied as a basal dose, followed by top-dressings of 20% at 20 Days After Sowing (DAS), 30% at 35 DAS, 30% at 50 DAS, and the final 10% at 65 DAS. Standard plant protection measures, including the application of Emamectin Benzoate 5% SG for the management of fall armyworm, were adopted uniformly to ensure a healthy crop stand. The crop was harvested upon physiological maturity on April 10, 2021.

Data Collection and Statistical Analysis: Five representative plants from each net plot were randomly tagged to record critical yield attributing parameters, including cob length, cob diameter, number of rows per cob, number of grains per row, grains per cob, and test weight (100-seed weight). Grain and straw yields were recorded on a net plot basis and subsequently extrapolated to kilograms per hectare (kg ha⁻¹). Furthermore, destructive plant

sampling was conducted at harvest to quantify the total accumulation and partitioning of macronutrients (N, P, and K) in both grain and straw tissues using standard laboratory protocols. The collected experimental data were statistically analyzed using the analysis of variance (ANOVA) technique as outlined by Gomez and Gomez (1984) ^[2], with treatment means differentiated at a 5% level of significance.

Results and Discussion

Yield Attributes

The yield attributing traits of Rabi maize were significantly augmented by the graded application of nitrogen. The application of 200% RDN registered the most superior yield attributes, specifically achieving maximum cob length of 17.4 cm, cob diameter of 4.71 cm, and test weight of 33.2 g. This was closely followed by the 175% RDN treatment, which recorded a cob length of 16.9 cm, cob diameter of 4.54 cm, and test weight of 32.2 g, demonstrating a strong statistical parity. Furthermore, critical sink-capacity indicators peaked under the 200% RDN regime, recording 35.2 grains per row, 574.8 grains per cob, and a grain yield per cob of 194.4 g. The absolute control exhibited the poorest structural development, registering significantly lower yield parameters including a cob length of 8.8 cm, cob diameter of 3.50 cm, and grain yield per cob of 55.9 g. This profound improvement in cob parameters under higher nitrogen levels can be attributed to the continuous and abundant availability of nitrogen during the critical stages of cob initiation and silking. Enhanced nitrogen assimilation boosts leaf area and chlorophyll synthesis, promoting an extended period of active photosynthesis and total dry matter production (Ramachandiran *et al.*, 2016; Kumar *et al.*, 2019) ^[7, 4]. These results are in close conformity with the findings of Mohapatro and Shankar (2022) ^[6], who reported that sufficient nitrogen supply significantly maximizes yield attributes like cob length, grains per cob, and test weight.

Crop Yield, Shelling Percentage, and Harvest Index

The grain and stover yields closely mirrored the positive trends observed in the yield attributes. The 200% RDN treatment culminated in the highest grain yield of 9485.7 kg ha⁻¹ and a straw yield of 11485.6 kg ha⁻¹. This performance was statistically on par with the 175% RDN application (9171.3 kg ha⁻¹ grain; 11381.6 kg ha⁻¹ straw) and the 150% RDN application (8653.4 kg ha⁻¹ grain; 11366.2 kg ha⁻¹ straw). The absolute control exhibited the poorest yield outcome, producing only 2875.0 kg ha⁻¹ of grain and 4753.7 kg ha⁻¹ of straw, highlighting the crop's heavy reliance on external N supplementation. The shelling percentage and harvest index reached their maximums with 200% RDN at 82.2% and 45.0% respectively. The substantial yield leap at higher nitrogen doses is a direct consequence of a robust vegetative framework that supports high dry matter accumulation and highly efficient resource partitioning into the economic yield. Similar yield responses to high nitrogen doses in maize have been extensively documented by Bushong *et al.* (2016) ^[1] and Jyothsna *et al.* (2021) ^[3], who observed that optimized N levels support higher grain yields and extended grain-filling.

Nutrient Uptake Dynamics at Harvest

Graded levels of nitrogen profoundly influenced not only the uptake of nitrogen but also the concurrent accumulation of phosphorus and potassium in both grain and straw. Plants receiving 200% RDN recorded the maximum total nitrogen uptake of 213.2 kg ha⁻¹, which partitioned into 159.7 kg ha⁻¹ in the grain and 53.5 kg ha⁻¹ in the straw. Concurrently, this high-nitrogen treatment maximized the total uptake of phosphorus at

58.3 kg ha⁻¹ and potassium at 172.9 kg ha⁻¹. The 175% RDN treatment remained highly competitive and statistically similar, showcasing an efficient nutrient extraction pattern with a total N uptake of 205.0 kg ha⁻¹, total P uptake of 56.3 kg ha⁻¹, and total K uptake of 168.8 kg ha⁻¹. The lowest total nutrient extraction was recorded in the absolute control (56.7 kg ha⁻¹ N, 17.3 kg ha⁻¹ P, and 60.8 kg ha⁻¹ K). The synergistic effect of nitrogen on extensive root proliferation enables a larger soil volume to be

explored, thus enhancing the overall nutrient foraging capacity of the crop and increasing the concentration and accumulation of P and K alongside N. This synergistic nutrient extraction and accumulation mechanism is well-supported by previous research by Lawal *et al.* (2018) [5] and Jyothsna *et al.* (2021) [3], who highlighted that optimal nitrogen nutrition enhances nutrient uptake, use efficiency, and total nitrogen accumulation in maize.

Table 1: Yield attributes of maize as influenced by graded levels of nitrogen during *rabi*

Treatments	Cob length (cm)	Cob diameter (cm)	No of rows per cob	No of grains per row	Test weight (g)	No of grains per cob	Grain yield per cob (g)
T ₁ -Absolute control	8.8 ^e	3.50 ^d	14.4 ^b	17.2 ^d	20.3 ^f	249.2 ^f	55.9 ^e
T ₂ - 25% of RDN	10.7 ^d	3.72 ^{cd}	14.8 ^{ab}	21.4 ^c	21.3 ^{ef}	318.1 ^e	71.6 ^e
T ₃ - 50% of RDN	11.8 ^d	3.98 ^{bcd}	15.2 ^{ab}	24.2 ^c	22.2 ^{ef}	371.0 ^d	82.2 ^e
T ₄ - 75% of RDN	14.8 ^c	4.04 ^{bc}	15.2 ^{ab}	30.6 ^b	24.8 ^{c e}	466.0 ^c	121.9 ^d
T ₅ - 100% of RDN	15.2 ^c	4.32 ^{ab}	15.6 ^{ab}	31.4 ^b	28.6 ^{bcd}	491.4 ^{bc}	139.3 ^{cd}
T ₆ - 125% of RDN	15.5 ^{bc}	4.35 ^{ab}	15.6 ^{ab}	32.4 ^{ab}	28.7 ^{bc}	507.5 ^{bc}	151.3 ^c
T ₇ - 150% of RDN	15.9 ^{abc}	4.44 ^{ab}	16.0 ^{ab}	33.2 ^{ab}	30.8 ^{ab}	536.0 ^{ab}	161.1 ^{bc}
T ₈ - 175% of RDN	16.9 ^{ab}	4.54 ^a	16.0 ^{ab}	34.8 ^a	32.2 ^{ab}	573.5 ^a	186.6 ^{ab}
T ₉ - 200% of RDN	17.4 ^a	4.71 ^a	16.4 ^a	35.2 ^a	33.2 ^a	574.8 ^a	194.4 ^a
S.Em.±	0.5	1.5	0.6	1.2	1.0	22.1	6.4

Table 2: Grain yield, straw yield harvest index and shelling percentage of maize as influenced by graded levels of nitrogen during *rabi*

Treatments	Yield (kg ha ⁻¹)			Harvest index (%)	Shelling percentage (%)
	Cob	Grain	Straw		
T ₁ -Absolute control	3964.7 ^e	2875.0 ^f	4753.7 ^g	37.3 ^b	72.2 ^b
T ₂ - 25% of RDN	5323.2 ^e	3894.9 ^{ef}	6142.9 ^f	38.8 ^{ab}	73.1 ^b
T ₃ - 50% of RDN	7042.8 ^d	5163.8 ^{de}	7634.8 ^e	40.3 ^{ab}	73.4 ^{ab}
T ₄ - 75% of RDN	8285.8 ^{cd}	6220.1 ^{cd}	8833.9 ^d	41.3 ^{ab}	75.2 ^{ab}
T ₅ - 100% of RDN	9298.0 ^{bc}	7087.2 ^{bc}	9691.3 ^{cd}	42.2 ^{ab}	76.2 ^{ab}
T ₆ - 125% of RDN	10157.7 ^{ab}	7877.2 ^{ab}	10461.8 ^{bc}	43.0 ^{ab}	77.6 ^{ab}
T ₇ - 150% of RDN	10753.3 ^{ab}	8653.4 ^{ab}	11366.2 ^{ab}	43.3 ^{ab}	80.4 ^{ab}
T ₈ - 175% of RDN	11190.7 ^a	9171.3 ^a	11381.6 ^{ab}	44.6 ^a	82.1 ^a
T ₉ - 200% of RDN	11661.0 ^a	9485.7 ^a	11485.6 ^a	45.0 ^a	82.2 ^a
S.Em.±	485.4	509.5	304.8	0.02	2.6

Table 3: Nutrient uptake of maize at harvest as influenced by graded levels of nitrogen during *rabi*

Treatments	N uptake (kg ha ⁻¹)			P uptake (kg ha ⁻¹)			K uptake (kg ha ⁻¹)		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T ₁ -Absolute control	39.3 ^g	17.4 ^g	56.7 ^f	7.6 ^g	9.7 ^f	17.3 ^g	19.6 ^g	41.1 ^f	60.8 ^g
T ₂ - 25% of RDN	55.2 ^{fg}	24.1 ^f	79.3 ^f	10.5 ^{fg}	12.5 ^e	23.0 ^f	6.6 ^{fg}	53.3 ^e	79.8 ^f
T ₃ - 50% of RDN	74.5 ^{ef}	30.7 ^e	105.3 ^e	14.1 ^{ef}	15.8 ^d	29.9 ^e	35.5 ^{ef}	66.6 ^d	102.2 ^e
T ₄ - 75% of RDN	97.1 ^{de}	37.3 ^d	134.4 ^d	17.5 ^{de}	19.4 ^c	36.9 ^d	3.1 ^{de}	77.3 ^c	120.4 ^d
T ₅ - 100% of RDN	111.7 ^{cd}	41.6 ^c	153.2 ^{cd}	20.7 ^{cd}	21.3 ^c	41.9 ^c	49.3 ^{cd}	85.9 ^b	135.2 ^c
T ₆ - 125% of RDN	127.7 ^{bc}	46.2 ^b	174.0 ^{bc}	22.9 ^{bc}	24.6 ^b	47.6 ^b	55.4 ^{bc}	93.5 ^b	148.9 ^b
T ₇ - 150% of RDN	140.1 ^{ab}	52.1 ^a	192.2 ^{ab}	25.5 ^{ab}	28.1 ^a	53.6 ^{ab}	61.9 ^{ab}	102.6 ^a	164.5 ^a
T ₈ - 175% of RDN	152.4 ^{ab}	52.6 ^a	205.0 ^a	27.6 ^{ab}	28.8 ^a	56.3 ^a	65.5 ^{ab}	103.4 ^a	168.8 ^a
T ₉ - 200% of RDN	159.7 ^a	53.5 ^a	213.2 ^a	28.5 ^a	29.7 ^a	58.3 ^a	68.2 ^a	104.7 ^a	172.9 ^a
S.Em.±	8.3	1.3	8.2	1.5	0.7	1.6	3.6	2.7	4.4

Conclusion

It can be conclusively stated that optimizing nitrogen management is paramount for exploiting the genetic yield potential of irrigated Rabi maize. The application of graded nitrogen levels significantly improved the source-sink dynamics, growth, and nutrient extraction. While the 200% RDN application numerically maximized all yield attributes, crop yields, and nutrient uptake parameters, the 175% and 150% RDN applications generated statistically comparable and highly competitive outcomes. Therefore, higher nitrogen regimes distinctly favor the robust performance of maize during the Rabi season.

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