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Performance of maize cultivars under varied nitrogen levels in the rainfed Shivalik foothills of Jammu and Kashmir

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Abstract

Field trials were conducted during the kharif seasons of 2019, 2020 and 2021 at the Research Farm of the Advanced Centre for Rainfed Agriculture (ACRA), Sher-e-Kashmir University of Agricultural Sciences and Technology (SKUAST)-Jammu, Rakh Dhiansar, to investigate the performance of maize cultivars under rainfed conditions of the Shivalik foothills of Jammu and Kashmir. The experimental treatments included two maize cultivars, Mansar and Jammu Maize Composite-3 (JMC-3), evaluated at 4 nitrogen (N) levels: 0, 60, 75 and 90 kg ha^{-1}. The study was laid out in a split-plot design with three replications to ensure statistical accuracy, where N levels were assigned to the main plots and maize cultivars were assigned to subplots. The results showed that the maize composite JMC-3 had a pronounced and significant influence on both growth and yield parameters compared with the Mansar variety. Regarding nutrient management, an N level of 90 kg ha^{-1} yielded significantly higher values for growth, yield attributes and overall grain yield; however, these results were statistically at par with the N level of 75 kg ha^{-1}. Economic analysis also showed that higher N levels improved net returns and the B:C ratio, with JMC-3 showing superior economic performance. Consequently, this study concluded that the JMC-3 maize composite can be successfully cultivated by increasing the N dose to 75 kg ha^{-1}. This agronomic strategy is recommended for achieving higher productivity and profitability under the specific rainfed sub-montane conditions of the Jammu region.

Keywords: JMC-3; maize; nitrogen; rainfed agriculture; sub-tropics; yield attributes

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1. Introduction

Maize (*Zea mays* L.) is a versatile, adaptable crop that thrives under diverse environmental conditions. Globally, it is recognised as the "queen of cereals" because of its exceptional yield potential. Cultivated in over 166 countries, maize spans tropical, subtropical and temperate zones from sea level to 3000 m altitude, showcasing its remarkable flexibility. It is cultivated on nearly 203.4 million hectares, producing 1210 million tonnes and yielding 5949 kg ha^{-1} worldwide, with wide diversity in soil, climate, biodiversity and management practices (1). India produced approximately 37.66 million tonnes of maize on approximately 10.97 million hectares (2). Maize is predominantly grown during the kharif season, covering over 85 % of the cultivated area. It is the third most important crop in India, after rice and wheat. Globally, India was the fifth-largest producer of maize in 2020, according to the FAO and its share of world maize production was approximately 2.59 %. Generally, maize can be grown where annual precipitation exceeds 750 mm and rainfall is well distributed during the growing period. Sandy loam to loam soil with good organic matter and moisture-holding capacity supports optimum crop growth and development. Furthermore, balanced, scheduled nutrient application is important for nutrient management and plays a crucial role in increasing crop production and quality. Plant development and yield formation depend on the balanced availability of nutrients such as N, P, K, Zn, S and Mg. However, nitrogen (N) is essential for optimum plant growth and its deficiency reduces crop growth and yield (3, 4).

In the Union Territory of Jammu and Kashmir, maize is the major staple crop and is cultivated on

315.80 thousand hectares, covering almost all districts of J&K. The leading maize-producing districts of J&K are Kupwara, Baramulla, Budgam, Anantnag, Doda, Rajouri, Poonch, and Udhampur. In terms of production and yield, Kupwara ranks first among maize-producing districts. During the kharif season, maize is grown and approximately 85 per cent of the area under its cultivation is rainfed (5, 6). It is widely cultivated in both undulating rainfed sub-montane tracts (kandi) and plain areas. Maize prospers in well-drained sandy and loamy soils. It needs 30 °C for germination, growth and development and about 20 °C at ripening. As a heavy nutrient feeder and an exhaustive crop, maize requires adequate manuring even under good soil fertility conditions. However, it has a wider adaptability and can be grown under a wide range of climatic conditions. Crops require sufficient moisture and temperature from planting until the termination of the flowering period. Maize is very sensitive to the amount and distribution of rainfall, which is crucial for maize production. Maize cannot tolerate water stagnation even for a few hours; however, rainfall between 500 and 790 mm during its vegetative period supports proper growth and development. Moisture deficit conditions during flowering drastically reduce maize grain yield.

Optimum nutrient application, especially N, is required in maize and determines yield and quality. Nitrogen is an essential nutrient required for protein synthesis, cell multiplication and differentiation. It helps form chlorophyll pigment, enhancing photosynthesis and thus plays a significant role during the vegetative and reproductive phases of a crop. Nitrogen status mainly influences biochemical processes in plants and its imbalance disrupts or alters various physiological processes. Nitrogen contributes 1–4 % of dry matter (DM) and increases the translocation of reserve photosynthates, as well as the uptake of other essential nutrients in plants. Excessive N application or its deficit reduces maize productivity; therefore, optimal N supplementation is key to improving maize productivity under low-fertility, rainfed conditions. Nitrogen application mainly determines maize yield components, as it is a key nutrient for biochemical reactions that enhance source-to-sink capacity (3, 4, 7). Yield declines under low N status because less assimilate is partitioned from source to sink, as reflected in smaller leaf area, reduced light interception and lower photosynthetic activity (4, 8). Crop production can be enhanced by applying N at higher rates and at appropriate times, which plays a prominent role in overall productivity by improving yield-attributing traits. Previous studies also state that increasing N application enhances crop productivity and helps avoid yield penalties (4, 7–10). Nitrogen boosts photosynthesis, aiding the translocation of produced assimilates to different sink parts, such as the number of cobs per plant, cob length (CL), cob diameter and number of grains per cob (GPC) (4, 7, 9, 11, 12). Plant height (PH), number of leaves per plant, leaf area index (LAI), DM production, fodder yield and nutrient uptake increased with higher N application rates, which determines overall maize productivity (4, 8–10). In rainfed areas, N deficiency is a major constraint that limits maize productivity. Various N levels can affect maize growth, yield and quality. Understanding maize cultivar performance under different N levels is crucial for optimising N use, improving yields and ensuring food security in the rainfed regions of Jammu and Kashmir. This study evaluated maize cultivars' responses to different N levels under rainfed conditions to identify N-efficient cultivars and inform nutrient management strategies.

2. Materials and Methods

Field experiments were conducted during the kharif seasons of 2019 to 2021 at the Research Farm of the Advanced Centre for Rainfed Agriculture (ACRA), Rakh Dhiansar of Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir (UT). The experimental site was located at 32° 39” N 74° 53” E at an elevation of 332 m above mean sea level (amsl). The Shivalik foothills have a subtropical climate, characterised by hot, dry summers, cold, dry winters and a humid monsoon from June to September. The study area recorded total seasonal rainfall of 535.6, 546.2 and 405.9 mm during the 2019, 2020 and 2021 kharif seasons, respectively. The soil of the experimental field was categorised as Inceptisol of the Alluvial group with sandy-loam texture, low available N, medium phosphorus (P), low potash, pH (6.62) and low organic carbon (0.23 %). The experiment used a split-plot design with three replicates. Main plot treatments consisted of N levels (0, 60, 75 and 90 kg ha^{-1}) and maize cultivars (Mansar and JMC-3) were assigned to subplots. Each plot measured 6 m × 4 m. The maize crop was sown during the onset of the monsoon and harvested at physiological maturity during the kharif seasons of 2019 to 2021. Seeds of the maize cultivars Mansar and Jammu Maize Composite-3 (JMC-3) were procured from the Maize Breeding Research Sub-station, Poonch, SKUAST-Jammu. Jammu Maize Composite-3 is a yellow-grain variety distinguished by its small leaf angle, semi-drooping leaf attitude and canico-cylindrical ear shape. It shows moderate resistance to *Turcicum* and *Maydis* leaf blights while maintaining a nutritional profile of 10.3 % protein and 62.11 % starch. In contrast, Mansar is a well-adapted composite widely favoured by local farmers for its stable performance across varying soil types and a maturity duration that fits effectively into the regional maize-wheat cropping systems. While Mansar generally exhibits lower growth and yield attributes than JMC-3, its high resilience in low-input environments makes it a reliable option for the rainfed "Kandi" belt. The recommended nitrogen-phosphorus-potassium (NPK) dose was 60:40:20 kg ha^{-1}, applied as urea, diammonium phosphate (DAP) and muriate of potash (MOP). Half the N dose and the full dose of P

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and K were applied at sowing and the remaining half dose of N was applied when the crop reached the knee-height stage. Atrazine 50 % WP was applied as a pre-emergence treatment at the recommended dose of 1.0 kg active ingredient (a.i.) ha^{-1} within three days of sowing to ensure early-season weed control. This was followed by a post-emergence application of tembotrione at 120 g a.i. ha^{-1} and manual hand weeding during the earthing-up operation to maintain a weed-free environment throughout the critical growth stages. However, we carried out other agronomic practices throughout the growing season as per the package and practices of SKUAST-Jammu.

Standard procedures were followed to record growth and yield parameters at various phenophases. Crop growth observations included PH (cm) and DM accumulation (q ha^{-1}) at the knee-high, tasseling, silking and physiological maturity stages. Yield attributes recorded at harvest included CL (cm), cob girth (CG) (cm), number of GPC and seed index (100-seed weight in grams). Total productivity was determined by measuring the grain and stover yields (q ha^{-1}). We conducted post-harvest soil analysis for pH, organic carbon (%) and available NPK content (kg ha^{-1}). Additionally, economic indices, specifically net returns (Rs ha^{-1}) and the benefit-cost (B:C) ratio were calculated, to evaluate treatment profitability.

3. Results and Discussion

Growth parameters: Plant height and dry matter accumulation

The experimental results indicated that N application and maize cultivar significantly influenced PH at all phenophases (Table 1). Jammu Maize Composite-3 consistently showed superior vertical growth compared with Mansar. While PH increased with N levels up to 90 kg ha^{-1}, the difference between 75 and 90 kg N ha^{-1} was statistically at par. This growth response likely reflects N's critical role in chlorophyll synthesis and internode elongation. Higher N availability stimulates rapid cell division and expansion, providing a robust vegetative framework. Earlier studies also reported significant height increases in specific cultivars under varying N levels (3, 13). A separate study showed that optimising N levels is essential for maximising growth parameters in cereal crops (4), while another study found that nitrogenous fertilisation significantly affects leaf area and plant stature through enhanced metabolic activity (7).

Dry matter production showed a steady upward trend from the knee-high stage to physiological maturity (Table 2). This surge in biomass is attributed to peak leaf-area expansion, which maximises solar radiation interception and photosynthetic rate. Nitrogen at 75 kg ha^{-1} significantly increased DM over 60 kg ha^{-1}, but higher rates did not yield further gains (14). This plateau suggests that under rainfed conditions, moisture is limiting, a pattern corroborated by a previous study that found N use efficiency depends heavily on the balance between nutrient supply and environmental conditions (15). Other studies also noted that DM accumulation is restricted when N levels exceed the soil's moisture-carrying capacity (8, 16).

Yield-attributing characteristics

Yield-contributing traits, including CL, CG and GPC, were significantly higher in JMC-3 than those in Mansar (Table 3). Nitrogen levels up to 90 kg/ha improved these attributes but remained statistically at par with 75 kg ha^{-1}. Physiologically, this is attributed to enhanced photosynthetic capacity and efficient source-to-sink partitioning (4). Optimal N status reduces the anthesis-silking interval, promoting better grain filling. A similar trend was reported in another study, which noted that yield components such as 1000-grain weight and kernels per cob are highly sensitive to N levels (7). A separate study emphasised that balanced N supplementation is key to optimising cob development (15), as N plays a vital role in floral initiation and seed set (3).

Grain and stover yield productivity

Maximum grain and stover yields were achieved at 90 kg N ha^{-1}, comparable to 75 kg N ha^{-1} (Table 3). Higher N availability enhances source-to-sink capacity, leading to better grain weight and CG (3, 12). Jammu Maize Composite-3 showed statistically higher productivity than Mansar, likely because of its superior genetic efficiency in N uptake under moisture-stressed, rainfed conditions. Another study reported that nutrient-mediated biomass partitioning directly drives increased maize yield (4). Conversely, the yield penalty observed in lower-N plots was attributed to reduced LAI, which curtails photoassimilate production (7). It was further suggested that stover yield follows a similar linear-to-plateau response to N (17).

Post-harvest soil nutrient status

Nitrogen application significantly influenced the residual soil fertility. The highest residual NPK levels were recorded at 90 kg N ha^{-1}, which was statistically comparable to that at 75 kg N ha^{-1} (Table 4). This trend suggests that higher fertilisation rates help maintain the soil nutrient pool (15). The parity between 75 and 90 kg N ha^{-1} suggests that the 75 kg N ha^{-1} rate provides a balanced nutrient removal-to-retention ratio. This is essential for sustaining the soil health of the rainfed tract (18). As other investigators reported, long-term application of fertiliser at varying doses significantly affects soil chemical properties (3). It was further suggested that site-specific N management is crucial for avoiding nutrient leaching while maintaining soil productivity (4, 18).

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Table 1. Effect of maize varieties and different levels of nitrogen on plant height of maize at various growth stages (pooled data of three years)

Treatment	Plant Height (cm)			
	Knee high	Tasseling	Silking	Harvest
Varieties				
V_1 Mansar	53.66	170.43	174.90	189.4
V_2 JMC-3	55.75	176.51	180.18	193.7
CD (5 %)	1.61	1.57	1.92	2.60
Nitrogen levels				
N_0 Control	49.9	163.56	170.46	179.4
N_1 60 kg ha^{-1}	54.3	169.50	173.74	191.1
N_2 75 kg ha^{-1}	56.7	179.52	182.50	196.1
N_3 90 kg ha^{-1}	57.8	181.29	183.46	199.7
CD (5 %)	2.27	2.22	2.72	3.68

Table 2. Effect of maize varieties and different levels of nitrogen on dry matter accumulation in maize at various growth stages (pooled data of three years)

Treatment	Dry matter accumulation (q ha^{-1})			
	Knee high	Tasseling	Silking	Maturity/Harvest
Varieties				
V_1 Mansar	15.08	32.59	51.16	68.84
V_2 JMC-3	17.15	36.75	57.68	77.62
CD (5 %)	1.07	1.53	2.40	3.23
Nitrogen levels				
N_0 Control	10.17	21.56	33.86	45.55
N_1 60 kg ha^{-1}	16.09	36.15	56.75	76.36
N_2 75 kg ha^{-1}	18.87	39.99	62.78	84.46
N_3 90 kg ha^{-1}	19.33	40.96	64.31	86.53
CD (5 %)	1.51	2.16	3.39	4.57

Table 3. Effect of maize varieties and different levels of nitrogen on yield attributes, yield and economics of maize (pooled data of three years)

Treatment	Cob Length (cm)	Cob girth (cm)	No. of grains per cob	Seed Index (g)	Grain yield (q ha^{-1})	Stover yield (q ha^{-1})	Net Returns (Rs ha^{-1})	B: C ratio	RWUE
Varieties									
V_1 Mansar	14.9	13.2	249	20.0	22.78	46.06	29858	2.39	5.34
V_2 JMC-3	15.8	13.8	281	21.9	25.87	51.75	36334	2.68	6.05
CD (5 %)	0.59	0.54	12.5	0.84	1.05	2.29			
Nitrogen levels									
N_0 Control	13.5	11.8	201	18.5	14.75	30.80	14844	1.81	3.45
N_1 60 kg ha^{-1}	15.5	13.3	258	20.2	25.28	51.08	34603	2.58	5.94
N_2 75 kg ha^{-1}	16.1	14.1	294	22.1	28.21	56.26	40768	2.85	6.61
N_3 90 kg ha^{-1}	16.3	14.8	306	22.9	29.05	57.48	42169	2.88	6.79
CD (5 %)	0.84	0.77	17.7	1.19	1.49	3.24			

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Table 4. Effect of maize varieties and different levels of nitrogen on soil properties after harvest

Treatment	pH	Organic Carbon (%)	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potash (kg ha^{-1})
Varieties					
V_1 Mansar	6.58	0.25	175.1	14.9	120.5
V_2 JMC-3	6.59	0.26	179.2	15.4	123.8
CD (5 %)	NS	NS	NS	NS	NS
Nitrogen levels					
N_0 Control	6.61	0.21	164.5	13.5	115.1
N_1 60 kg ha^{-1}	6.60	0.25	175.3	14.9	120.2
N_2 75 kg ha^{-1}	6.57	0.28	182.3	15.8	124.9
N_3 90 kg ha^{-1}	6.56	0.29	186.5	16.4	128.5
CD (5 %)	0.02	0.019	7.81	0.60	6.76

Economics

Higher levels of N fertilisation showed better economics, as the 90 kg ha^{-1} dose gave higher net returns and a higher B:C ratio than 60 kg N ha^{-1}, though it was comparable to 75 kg N ha^{-1} (Table 3). This is attributed to differences in grain and stover yields offsetting input costs (5, 15, 19). Among composites, JMC-3 recorded a higher B:C ratio. Previous studies on hybrid and composite performance have well documented these economic benefits of optimised N levels (3, 7). These results align with another study that found medium-to-high N doses maximise profitability in winter maize systems (20).

4. Conclusion

The present study signifies the importance of maize crop in sub-montane rainfed areas of Jammu. Maize composite JMC-3 showed pronounced significance for robust growth and higher yield and responded significantly to higher levels of N application. Incremental increases in N levels significantly enhanced PH, DM accumulation, yield components and economic returns. The application of 75 kg ha^{-1} N was statistically comparable to 90 kg ha^{-1}, indicating an optimal N dose that maximises productivity while minimising input costs. Moreover, soil nutrient levels increased with higher N application, highlighting the advantages of balanced nutrient management. Further, it can be concluded that cultivating the JMC-3 maize composite with a N application rate of 75 kg ha^{-1} is an effective agronomic strategy to enhance maize productivity and profitability in rainfed Shivalik foothill conditions of Jammu and Kashmir.

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Authors' contributions

BS, APS, VG, JK, RS[1], AS, PS, VK and RS[2] conceived and designed the study. BS, APS, JK and RS[1] carried out the field experimentation, material preparation, and primary data collection. BS, RS[1], and JK performed the statistical analysis and interpreted the results. BS, APS, AS, VG, PS and RS[2] wrote the first draft of the manuscript. All the authors have read and approved the final manuscript. [RS[1] - Rohit Sharma and RS[2] - Rohit Singh]

Compliance with ethical standards

Conflict of interest

The authors have no conflicts of interest to declare.

Ethical issues

None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT to improve the language and readability of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the final content of the publication.

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