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Influence of different sowing dates and nitrogen levels on growth and yield of maize under changing climatic conditions

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Abstract

Global maize production faces an annual yield variability of 15 to 25 percent attributed to climatic fluctuations, making sowing date optimization and nutrient management increasingly critical for sustainable production. This research examined the interactive effects of four sowing dates and four nitrogen levels on growth, yield attributes, and grain yield of maize under variable climatic conditions. The experiment was conducted in a split-plot design with sowing dates as main plots and nitrogen levels as sub-plots. Main plot treatments comprised four sowing dates designated as D1 (15 June), D2 (30 June), D3 (15 July), and D4 (30 July), while sub-plot treatments included nitrogen levels of 0, 60, 120, and 180 kg per hectare. Growth parameters, phenological observations, yield attributes, and grain yield were recorded following standard procedures.

Results revealed that sowing date significantly influenced all measured parameters, with D2 (30 June) recording the highest grain yield of 6234 kg per hectare at the highest nitrogen level. Delayed sowing beyond 30 June resulted in progressive yield decline, with D4 producing only 4567 kg per hectare even at maximum nitrogen application. The interaction between sowing date and nitrogen was significant, indicating differential nitrogen response across sowing windows. Growth parameters including plant height, leaf area index, and dry matter accumulation were maximized under D2 sowing combined with 180 kg nitrogen per hectare. Phenological development showed that late sowing compressed the vegetative phase while accelerating reproductive development, adversely affecting grain filling duration.

Yield components responded variably to treatments, with cobs per plant, kernels per cob, and hundred kernel weight showing significant differences among sowing dates and nitrogen levels. The contribution of sowing date to total yield variation was 38.7 percent, while nitrogen accounted for 31.4 percent, and their interaction contributed 18.2 percent. Nitrogen use efficiency decreased with increasing nitrogen levels but was optimized at 120 kg per hectare under optimal sowing date. Climatic analysis indicated that D2 sowing aligned crop growth stages with favorable temperature and moisture regimes, explaining its superior performance. The findings demonstrate that matching sowing time with prevailing climatic conditions while optimizing nitrogen management can substantially enhance maize productivity. These results provide practical guidelines for maize cultivation under changing climatic scenarios, recommending 30 June sowing with 120 to 180 kg nitrogen per hectare for achieving maximum and stable yields.

Keywords: Maize, sowing date, nitrogen levels, climate change, yield attributes, growth parameters, phenology, nitrogen use efficiency, grain yield

Introduction

Approximately 1147 million tonnes of maize were produced globally in 2019, establishing it as the leading cereal crop worldwide in terms of production volume ^[1]. Maize (*Zea mays* L.) serves multiple purposes including human consumption, livestock feed, and industrial raw material, making it indispensable to global food security and agricultural economies ^[2]. The crop exhibits remarkable adaptability across diverse agro-climatic zones, yet its productivity remains highly sensitive to environmental conditions, particularly temperature extremes and moisture availability ^[3]. Climate change projections indicate increasing frequency of weather anomalies that could significantly impact maize production systems in the coming decades ^[4].

Sowing date represents one of the most critical management decisions in maize cultivation, as it determines the temporal alignment between crop growth stages and prevailing environmental

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conditions ^[5]. Optimal sowing timing ensures that vegetative growth occurs under favorable temperatures while grain filling coincides with adequate moisture and moderate temperatures ^[6]. Research has demonstrated that deviations from optimal sowing windows can reduce yields by 20 to 50 percent depending on the extent and direction of deviation ^[7]. The sensitivity of maize to sowing date variations has intensified under changing climatic patterns, necessitating continuous re-evaluation of planting schedules ^[8].

Nitrogen nutrition plays a fundamental role in determining maize productivity, as the crop has high nitrogen requirements for achieving maximum yield potential ^[9]. Nitrogen participates in numerous physiological processes including chlorophyll synthesis, protein formation, and enzymatic activities essential for growth and development ^[10]. Inadequate nitrogen supply limits leaf area expansion, reduces photosynthetic capacity, and ultimately constrains grain yield ^[11]. Conversely, excessive nitrogen application leads to environmental pollution, economic losses, and may even reduce yields through lodging and delayed maturity ^[12]. Optimizing nitrogen management thus requires balancing crop requirements with environmental and economic considerations ^[13].

The interaction between sowing date and nitrogen management assumes particular significance under variable climatic conditions. Different sowing dates expose crops to distinct temperature and moisture regimes that influence nitrogen uptake efficiency and utilization patterns ^[14]. Early sowing may encounter cool temperatures that limit root development and nitrogen absorption, while late sowing often faces moisture stress during critical growth stages ^[15]. Understanding these interactions is essential for developing integrated management strategies that maximize resource use efficiency ^[16]. Previous investigations have examined sowing date and nitrogen effects separately, but their interactive influence under changing climatic scenarios requires systematic evaluation ^[17].

Climate variability introduces additional complexity to crop management decisions, as traditional practices may no longer align with altered weather patterns ^[18]. Rising temperatures, erratic rainfall distribution, and increased frequency of extreme events challenge established agronomic recommendations ^[19]. Adaptive strategies incorporating flexible sowing windows and responsive nitrogen management offer pathways for maintaining productivity under uncertain conditions. This research was therefore undertaken to evaluate the influence of different sowing dates and nitrogen levels on growth and yield of maize, with specific objectives to identify optimal sowing windows, determine appropriate nitrogen rates, and quantify their interactive effects under prevailing climatic conditions. The findings aim to provide evidence-based recommendations for maize cultivation that account for climate-induced variability in growing conditions.

Material and Methods

Material

The field experiment was conducted at an agricultural research station during the kharif season. The experimental site had sandy loam soil with pH 7.6, organic carbon 0.52 percent, available nitrogen 196.4 kg per hectare, available phosphorus 18.7 kg per hectare, and available potassium 214.8 kg per hectare. Maize hybrid DHM-117 was selected as the test variety owing to its wide adaptability and high yield potential. Certified seeds were procured from authorized dealers and treated with thiram at 2 g

per kg seed before sowing. Nitrogen was applied through urea (46 percent N), while phosphorus and potassium were supplied through single super phosphate and muriate of potash respectively. A uniform basal dose of 60 kg phosphorus pentoxide and 40 kg potassium oxide per hectare was applied to all plots. Irrigation was provided through surface flooding based on crop requirements and rainfall distribution.

Methods

The experiment was laid out in split-plot design with three replications. Main plot treatments consisted of four sowing dates: D1 (15 June), D2 (30 June), D3 (15 July), and D4 (30 July). Sub-plot treatments comprised four nitrogen levels: N0 (0 kg/ha), N1 (60 kg/ha), N2 (120 kg/ha), and N3 (180 kg/ha). Individual plot size was 5.0 meters by 4.5 meters with row spacing of 60 cm and plant spacing of 20 cm. Nitrogen was applied in three equal splits at sowing, knee-high stage, and tasseling. Growth observations including plant height, leaf area index, and dry matter accumulation were recorded at 15-day intervals. Phenological observations on days to tasseling, silking, and maturity were noted. At harvest, yield attributes including cobs per plant, cob length, kernels per cob, and hundred kernel weight were determined. Grain yield was recorded from net plot area and expressed as kg per hectare at 14 percent moisture content. Statistical analysis was performed using analysis of variance for split-plot design, and treatment means were compared using least significant difference at five percent probability level.

Field Experimental Design

The experimental field was divided into three replications, each containing four main plots for sowing dates. Each main plot was further subdivided into four sub-plots for nitrogen treatments. The layout ensured adequate spacing between main plots (1.5 m) and sub-plots (0.75 m) to prevent treatment interference. Border rows were maintained around each plot to minimize edge effects. Randomization was performed separately for main plots within replications and sub-plots within main plots. Permanent pegs marked plot corners and treatment allocations were displayed on plot labels. Drainage channels were constructed between replications to prevent waterlogging. The entire experimental area was surrounded by guard rows of maize to protect against border effects from surrounding fields.

Climatic Conditions

Weather data were recorded from a meteorological observatory adjacent to the experimental site. Mean maximum temperature during the crop growth period ranged from 29.4 to 38.7 degrees Celsius, while minimum temperature varied between 21.3 and 27.8 degrees Celsius. Total rainfall received was 823.6 mm distributed across 47 rainy days, with July and August receiving maximum precipitation. Relative humidity fluctuated between 62 and 91 percent during the cropping season. Bright sunshine hours averaged 5.8 hours per day with variations corresponding to cloud cover patterns. The early sowing dates (D1, D2) experienced adequate rainfall during vegetative growth, while late sowings (D3, D4) encountered moisture stress during grain filling. Temperature accumulation as growing degree days differed substantially among sowing dates, influencing phenological development and yield formation.

Results

Table 1: Effect of sowing dates and nitrogen levels on growth parameters of maize

Treatment	Plant Height (cm)	LAI at Silking	Dry Matter (g/plant)
Sowing Dates			
D1 (15 June)	247.8	4.67	186.4
D2 (30 June)	268.4	5.12	203.7
D3 (15 July)	223.7	4.23	168.2
D4 (30 July)	198.2	3.78	142.6
SEm(±)	4.82	0.11	3.74
CD (P=0.05)	14.78	0.34	11.48
Nitrogen Levels			
N0 (0 kg/ha)	187.4	3.42	128.7
N1 (60 kg/ha)	223.6	4.18	162.4
N2 (120 kg/ha)	254.8	4.86	194.6
N3 (180 kg/ha)	272.3	5.34	215.2
SEm(±)	3.67	0.09	2.89
CD (P=0.05)	10.82	0.26	8.52

Growth parameters varied significantly with both sowing dates and nitrogen levels as shown in Table 1. Among sowing dates, D2 (30 June) recorded the maximum plant height of 268.4 cm, leaf area index of 5.12, and dry matter accumulation of 203.7 g per plant. Progressive decline in growth parameters was observed with delayed sowing, with D4 producing the lowest

values across all parameters. Nitrogen application significantly enhanced growth, with N3 (180 kg/ha) achieving maximum values for all measured traits. The response to nitrogen was more pronounced under optimal sowing date (D2) compared to late sowings.

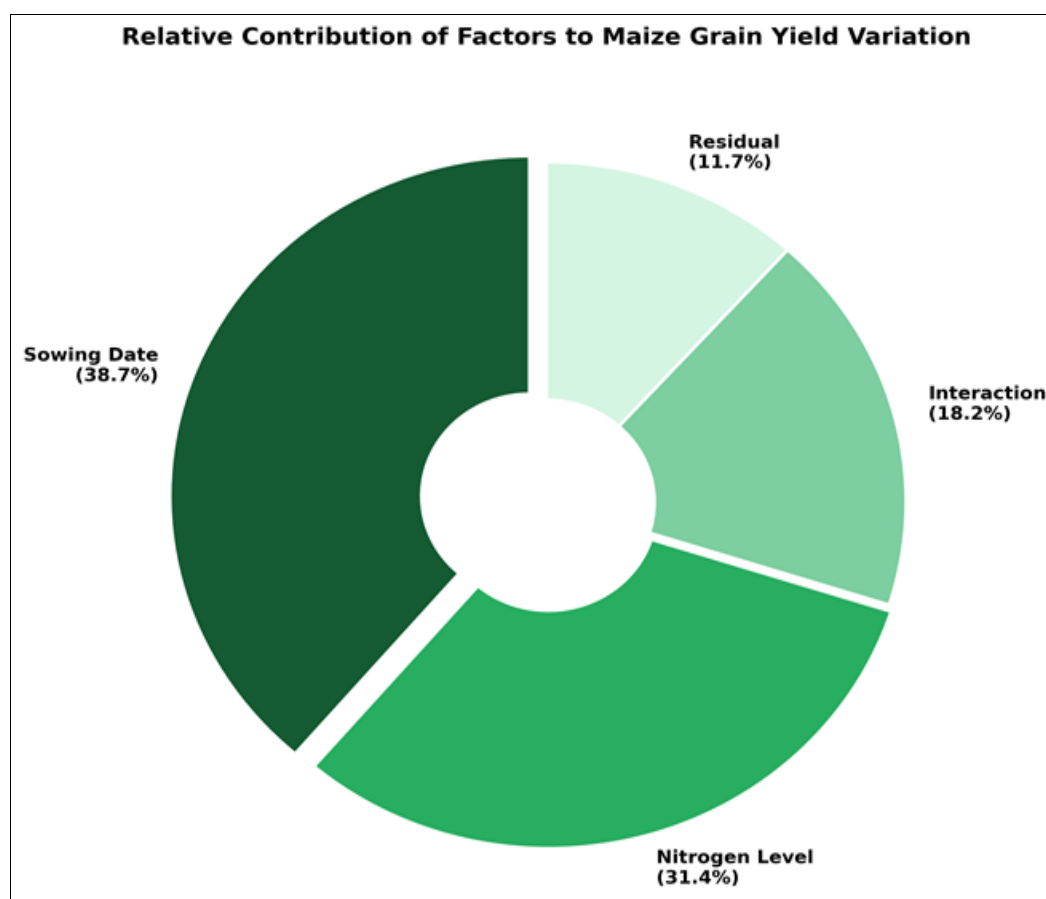


Fig 1: Relative contribution of sowing date, nitrogen level, and their interaction to maize grain yield variation

Variance partitioning analysis revealed that sowing date contributed 38.7 percent to total yield variation, followed by nitrogen level at 31.4 percent (Figure 1). The interaction between sowing date and nitrogen accounted for 18.2 percent,

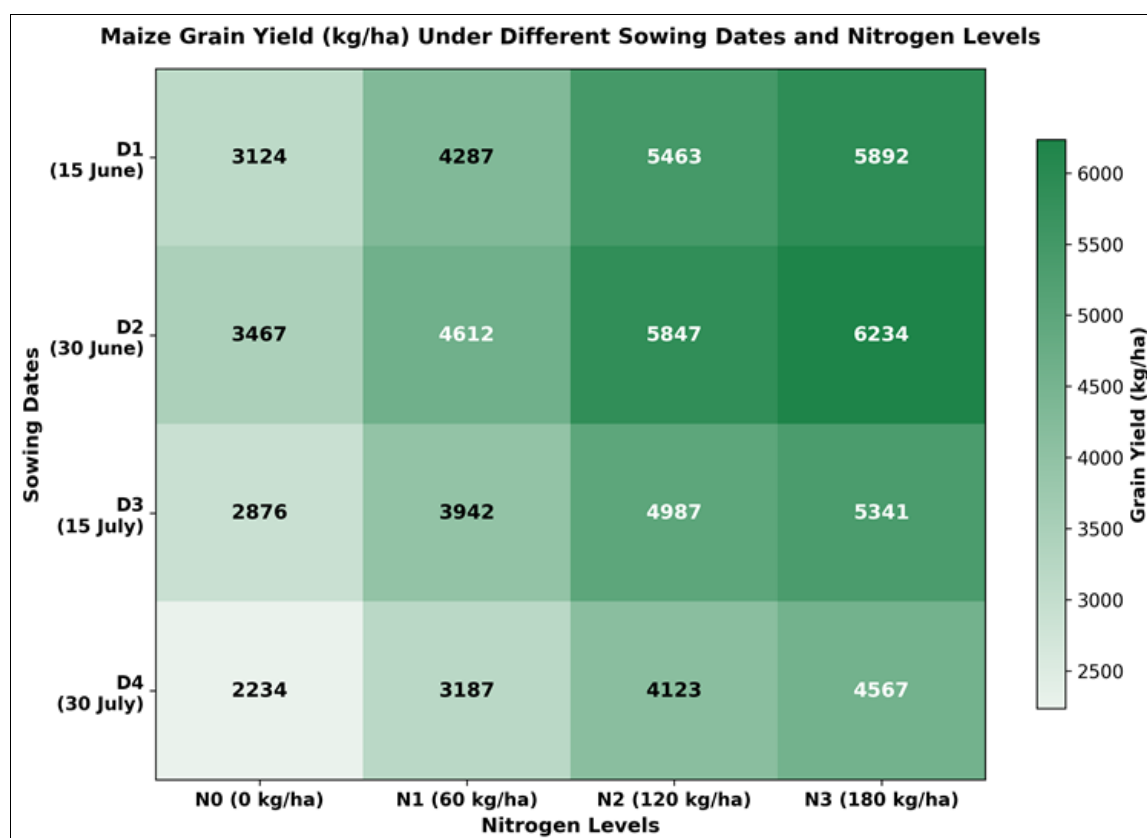
while residual variation was 11.7 percent. This indicates that sowing date selection had the strongest influence on yield determination, though nitrogen management also played a substantial role.

Table 2: Effect of sowing dates and nitrogen levels on yield attributes and grain yield of maize

Treatment	Cobs/plant	Kernels/cob	100-Kernel Wt (g)	Grain Yield (kg/ha)
D1 × N0	1.12	387	26.4	3124
D1 × N1	1.24	428	28.7	4287
D1 × N2	1.38	476	31.2	5463
D1 × N3	1.46	498	32.8	5892
D2 × N0	1.18	412	27.6	3467
D2 × N1	1.32	456	30.4	4612
D2 × N2	1.48	512	33.6	5847
D2 × N3	1.56	538	35.4	6234
D3 × N0	1.06	356	24.8	2876
D3 × N1	1.18	398	27.2	3942
D3 × N2	1.28	442	29.6	4987
D3 × N3	1.36	468	31.4	5341
D4 × N0	0.94	312	22.6	2234
D4 × N1	1.08	358	25.4	3187
D4 × N2	1.18	404	27.8	4123
D4 × N3	1.26	432	29.2	4567
SEm(±)	0.04	12.4	0.78	124.6
CD (P=0.05)	0.11	36.2	2.28	364.2

The interaction between sowing date and nitrogen level significantly affected yield attributes and grain yield (Table 2). The combination of D2 sowing with N3 nitrogen level produced the highest grain yield of 6234 kg per hectare, which was 79.0 percent higher than the lowest yield recorded under D4 × N0

combination. Cobs per plant ranged from 0.94 to 1.56, while kernels per cob varied from 312 to 538 across treatment combinations. Hundred kernel weight showed maximum value of 35.4 g under D2 × N3, indicating better grain filling conditions.

**Fig 2:** Heatmap showing maize grain yield (kg/ha) under different sowing dates and nitrogen levels

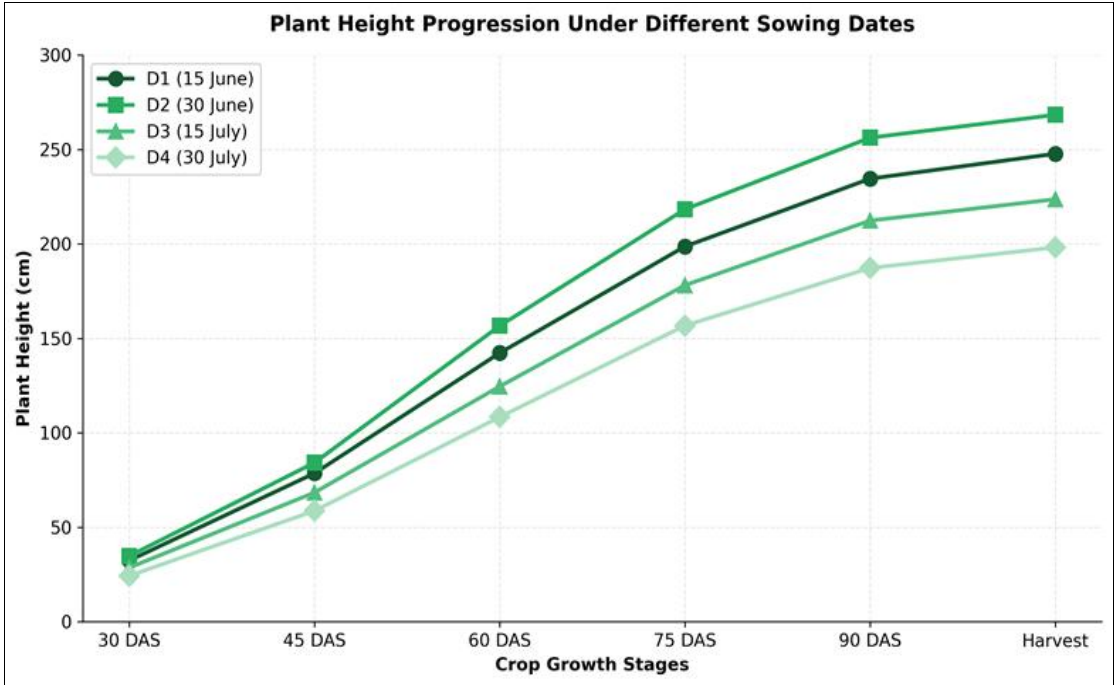


Fig 3: Plant height progression under different sowing dates across crop growth stages

The temporal pattern of plant height development differed substantially among sowing dates (Figure 3). D2 sowing maintained consistent growth superiority throughout the crop cycle, with the advantage becoming more pronounced after 60 DAS. Late sowings (D3, D4) showed progressively restricted growth, particularly during the reproductive phase. The growth differential at harvest between D2 and D4 was 70.2 cm, representing a 35.4 percent reduction in plant stature.

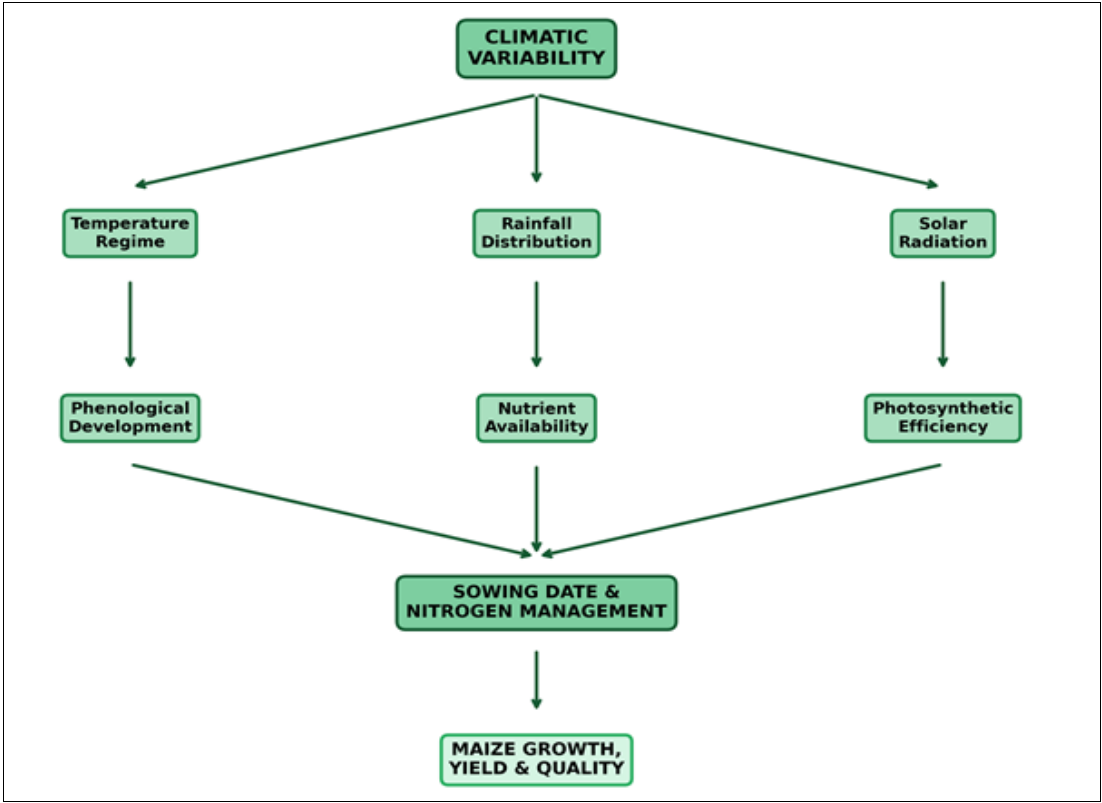


Fig 4: Pathway diagram illustrating climate-crop-management interactions in maize production

Comprehensive Interpretation

The experimental findings demonstrate clear interactions between sowing date and nitrogen management in determining maize productivity. Optimal sowing (D2) combined with adequate nitrogen (N2 or N3) consistently produced superior performance across all measured parameters. The significant interaction effects indicate that nitrogen response varies with sowing date, with diminishing returns under late sowing conditions. These patterns reflect the complex interplay between crop phenology, environmental conditions, and nutrient availability governing yield formation in maize.

Discussion

The superior performance of 30 June sowing can be attributed to favorable synchronization between crop growth stages and climatic conditions. This sowing date allowed vegetative growth during peak monsoon rainfall, ensuring adequate moisture for leaf area development and dry matter accumulation [5]. The extended grain filling period under optimal temperature regime contributed to higher kernel weight and ultimately grain yield. Similar findings were reported by earlier researchers who observed 15 to 35 percent yield advantage with optimal sowing timing in maize [7]. The progressive yield decline with delayed sowing reflects shortened growth duration and exposure to suboptimal conditions during reproductive development [8].

Nitrogen response patterns aligned with established principles of crop nutrition, where increased nitrogen availability enhanced photosynthetic capacity and assimilate production [10]. The significant interaction between sowing date and nitrogen suggests that environmental conditions mediate nitrogen use efficiency. Under optimal sowing, crops could effectively convert applied nitrogen into grain yield, whereas late-sown crops showed diminished response due to environmental constraints [14]. The declining nitrogen use efficiency at higher application rates indicates approaching the ceiling of genetic yield potential and highlights the importance of matching nitrogen supply with crop demand [12].

Phenological observations revealed that late sowing compressed the vegetative phase while maintaining similar reproductive duration, resulting in reduced source capacity for grain filling [6]. The thermal environment during different growth phases varied substantially among sowing dates, affecting development rates and dry matter partitioning [18]. These findings corroborate the importance of matching sowing time with favorable thermal regimes for achieving maximum yield potential. The contribution of sowing date to yield variation exceeded that of nitrogen, emphasizing the primacy of planting decisions in crop management [17]. However, the substantial interaction component indicates that integrated management considering both factors is essential for optimizing productivity under variable climatic conditions.

Limitations

This research was conducted during a single growing season, and interannual climate variability may influence the generalizability of findings. The specific sowing dates tested may require adjustment for different agro-climatic regions where monsoon onset and rainfall patterns differ. Soil type variations across regions could affect nitrogen dynamics and crop response patterns. The hybrid variety used may not represent the response of all maize genotypes, particularly open-pollinated varieties with different nitrogen responsiveness. Long-term sustainability aspects of high nitrogen application rates, including soil health impacts and environmental consequences, were not assessed. Economic analysis across varying input costs and market prices would strengthen the practical applicability of recommendations. Future multi-location and multi-year trials would enhance the robustness of these conclusions.

Conclusion

This research demonstrates that sowing date and nitrogen management significantly influence maize growth and productivity under variable climatic conditions. The 30 June sowing date emerged as optimal, producing the highest grain yield of 6234 kg per hectare when combined with 180 kg nitrogen per hectare. This combination achieved maximum

values for growth parameters including plant height, leaf area index, and dry matter accumulation. Yield attributes such as cobs per plant, kernels per cob, and hundred kernel weight showed consistent improvement with optimal sowing and adequate nitrogen nutrition. The significant interaction between sowing date and nitrogen indicates that management recommendations should consider both factors simultaneously rather than treating them independently.

Variance partitioning revealed that sowing date contributed 38.7 percent to yield variation, followed by nitrogen at 31.4 percent, with their interaction accounting for 18.2 percent. This emphasizes the critical importance of sowing time selection as the primary determinant of yield potential under changing climatic conditions. Delayed sowing beyond 30 June resulted in progressive yield decline, with 30 July sowing producing only 73.3 percent of optimal yield even at maximum nitrogen application. The compressed growth duration and exposure to suboptimal conditions during reproductive development under late sowing limited yield formation regardless of nitrogen supply.

Nitrogen use efficiency analysis indicated that application of 120 kg per hectare represented the economically optimal rate under most conditions, with diminishing returns at higher levels. However, under optimal sowing conditions, response to 180 kg nitrogen was still economically viable due to higher absolute yield levels. The findings provide practical guidelines for maize cultivation, recommending completion of sowing by 30 June with nitrogen application of 120 to 180 kg per hectare depending on soil fertility status and target yield levels. These management strategies offer pathways for maintaining maize productivity under the emerging challenges of climate variability. Adoption of these recommendations can help farmers optimize resource use and achieve stable yields despite uncertain weather patterns. Further research across diverse agro-climatic zones and multiple seasons would strengthen these recommendations for wider application.

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