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Exploring *Kharif* maize productivity through agronomic management

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Abstract

A field experiment was conducted during the *kharif* seasons of 2021 and 2023 to evaluate the performance of maize under varying sowing windows, plant population densities, and genotypes. The study aimed to optimize both grain and stover yield by matching environmental resource availability with crop demand. Results indicated that normal sowing time (S_1) achieved the highest pooled grain yield (6501 kg ha^{-1}) and stover yield (10970 kg ha^{-1}), with progressive delays leading to significant reductions. Increasing plant density up to $133,333 \text{ plants ha}^{-1}$ (P_1) via paired-row planting significantly enhanced cumulative biomass and grain yields (pooled grain yield of 5889 kg ha^{-1}), effectively compensating for individual plant competition. Among genotypes, the late-maturing hybrid BIO-9682 (G_3) outperformed the grain yield (5442 kg ha^{-1}) and stover yield (10114 kg ha^{-1}), mid-late (ADV-756) and early (BIO-605) alternatives.

Keywords: Weather variability, population density, paired-row planting, grain yield, Stover yield

Introduction

Maize (*Zea mays* L.) is a foundational global cereal providing food, feed, and industrial resources, predominantly cultivated during the monsoon-dependent *kharif* season in tropical regions. However, climate change-induced weather variability, characterized by thermal fluctuations and erratic rainfall, increasingly threatens productivity by disrupting critical phenology (Swetha Sree *et al.*, 2018; Sab *et al.*, 2020) ^[13, 18]. Physiologically, grain production peaks when source capacity matches kernel sink demand; weather stresses compromise this balance by restricting leaf area expansion, dry matter production, and photo-assimilate translocation. Consequently, delayed sowing exposes the crop to unfavourable microclimates, significantly compressing the vegetative growth phase and driving down final grain and stover biomass yields (Girijesh *et al.*, 2011; Leela Rani *et al.*, 2013; Jajoria *et al.*, 2020) ^[6, 10, 12].

Strategic agronomic management offers a vital defence against these climate risks through the integration of optimized planting schedules, population densities, and genotypes. Aligning the sowing window with ideal seasonal weather ensures optimal thermal conditions during flowering and grain-filling. Adjusting plant population structures such as high-density, paired-row configurations maximizes solar radiation capture and cumulative biomass while mitigating individual plant resource competition (Sannagoudar & Murthy, 2018 ^[14]; Alimuddin *et al.*, 2020; Bernhard & Below, 2020) ^[2, 3]. Because density responses are highly dependent on genetic maturity groups, pairing these spatial arrangements with late-maturing cultivars extends the vegetative phase to maximize dry matter accumulation (Jat *et al.*, 2019 ^[11]; Sab *et al.*, 2020) ^[13]. Ultimately, quantifying these synergistic Genotype $\times$ Environment $\times$ Management ($G \times E \times M$) interaction effects provides a resilient, multi-factor framework to optimize spatial-temporal resource efficiency and stabilize *kharif* maize yields (Singh *et al.*, 2022) ^[17]. Hence, optimization of agronomic factors like plant population density and genotype selection is essential to maximize spatial and temporal resource capture. This study evaluates the combined impacts of sowing times, population densities, and maturity-group genotypes to establish best management configurations for maize productivity

Materials and Methods

Field trials were executed across two experimental seasons (2021 and 2023) using a structured layout to evaluate three main treatment factors: weather variability via four sowing schedules viz., normal sowing (S_1), 10 days after normal sowing time (S_2), 20 days after normal sowing time (S_3), and 30 days after normal sowing time (S_4); three plant population densities viz., high density (P_1 : 133,333 plants ha^{-1} using paired-row planting at $60 \times 90 \times 10$ cm), intermediate density (P_2 : 111,111 plants ha^{-1} using single-row planting at 60×15 cm), and low density (P_3 : 83,333 plants ha^{-1} using single-row planting at 60×20 cm); and three maturity-group genotypes viz., early-maturing BIO-605 (G_1), mid-late ADV-756 (G_2), and late-maturing BIO-9682 (G_3). At harvest, the grain and stover yield were recorded, and a subsequent pooled analysis was performed to determine stable cross-seasonal trends across the treatments.

The soil of the experimental field was medium black with clayey texture and was slightly alkaline in nature (2021: 7.82 and 7.71 soil pH) Soil EC was 00.34 dSm^{-1} in 2021 and 0.39 dSm^{-1} in 2023, low in available nitrogen (2021: 210.8 and 2023: 215.3 kg ha^{-1}), medium in available phosphorus (2021: 15.7 and 2023: 17.4 kg ha^{-1}) and high in available potassium (2021: 17.7 and 2023: 17.4 kg ha^{-1}). medium in organic carbon (2021: 0.34 and 2023: 0.62 g kg^{-1}). The total rainfall during *Kharif* 2021 season was 790.3 mm of rainfall over 40 rainy days and during 2023 it was 600.5 mm, approximately 89% of the normal 673.2 mm over 29 rainy days.

Yield studies

The rate of translocation of photosynthates from source to sink during the reproductive stage directly drives maize grain yield. Yield depends on the balance between source capacity (leaf area and dry matter) and sink demand (developing kernels). When the source capacity matches sink demand, grain production increases. Changes in either side alter the final harvest.

Grain yield

The data on grain yield of maize (kg ha^{-1}) as influenced by the different treatments are presented in Table 1. Mean grain yield of maize was 5174 and 4551 kg ha^{-1} during 2021 and 2023, respectively. In pooled analysis it was 4863 kg ha^{-1} .

Weather variability

Weather variability created through different sowing time significantly influenced the maize grain yield. Normal sowing time (S_1) recorded the highest grain yield during both 2021 and 2023 (6734 and 6268 kg ha^{-1} , respectively), accordingly it recorded the highest grain yield in pooled analysis (6501 kg ha^{-1}) and was found to be significantly superior over the subsequent delayed sowings. Delaying maize sowing time by 10 (S_2), 20 (S_3), and 30 (S_4) days past the normal schedule (S_1) led to progressive and significant reductions in grain yield. The lowest grain yield was produced in the most delayed sowing (S_4) during both years and the pooled analysis (3156, 2578 and 2867 kg ha^{-1} , respectively). Each 10-day step lowered the final grain yield compared to the time before it because each step progressively missed the best weather window for the crop to grow, flower, and make grain. The grain yield reduction of maize due to delayed sowing was to the extent of 5%, 35% and 53% in 2021; 9%, 42% and 59% in 2023 and 7%, 38% and 56% in pooled analysis, in the crop sown after 10, 20 and 30 days after normal sowing, respectively.

Crop economic yield is a function of dry matter production and how well the crop translocate and accumulate it in yield

attributing traits. Yielding ability of a crop is reflections of yield attributing characters. Superior yield level with normal sowing was due to relatively better expression of vegetative and reproductive attributes that enabled the crop to express the inherent potential to the maximum as compared to later sowings, especially 20-day and 30-day delay, where crop growing period was also notably squeezed limiting potential output. Other authors Girijesh *et al.* (2011) ^[6], Leela Rani *et al.* (2013) ^[12], Swetha Sree *et al.* (2018) ^[18], Sab *et al.* (2020) ^[13], Shingne *et al.* (2020) ^[15]. and Sharma *et al.* (2022) ^[16]. have also reported reductions in yield attributes and yield of *kharif* maize with delayed sowing due to less favourable weather variables.

Population density

Maize grain yield increased with increase in population density. The highest plant population density of 133333 plants ha^{-1} (P_1 : paired row planting at $60 \times 90 \times 10$ cm) achieved maximum grain yield of maize during both years (6286 and 5492 kg ha^{-1} , respectively) and in pooled analysis (5889 kg ha^{-1}). It was significantly more over population densities of 111111 plants ha^{-1} (P_2 : single row planting at 60×15 cm) and 83333 plants ha^{-1} (P_3 : single row planting at 60×20 cm). The lowest population density (P_3) yielded the least amount of grain during both years (3949 and 3495 kg ha^{-1} , respectively) and in pooled analysis (3722 kg ha^{-1}). Intermediate population density (P_2) yielded significantly higher amount of grain than the lowest density (P_3) during both years (5288 and 4666 kg ha^{-1} , respectively) and in pooled analysis (4977 kg ha^{-1}).

Higher plant population density increased the cumulative number of ears and biological mass per unit area. Even though individual plant yield may have decreased due to competition for vital resources, the gains from a greater number of plants or harvested ears per unit area significantly outweighed the lower output per individual plant, maximizing overall grain yield per hectare through high cumulative spatial efficiency. The aforesaid results are in agreement with the outcome of Bharud *et al.* (2014) ^[5], Honnappa (2016) ^[7], Sannagoudar and Murthy (2018) ^[14], Akil *et al.* (2019) ^[1], Alimuddin *et al.*, (2020) ^[2], Bernhard and Below (2020) ^[3]. and Singh *et al.* (2022) ^[17].

Genotype

All the maize genotypes differed from each other for grain yield ha^{-1} . Grain yield increased with extended maturity period of maize genotype during both years. Accordingly, during 2021 and 2023, late maturing genotype, BIO-9682 (G_3) recorded significantly higher grain yield (5784 and 5100 kg ha^{-1} , respectively) than the mid-late genotype, ADV-756, G_2 (5150 and 4521 kg ha^{-1} , respectively) and early genotype BIO-605, G_1 (4589 and 4033 kg ha^{-1} , respectively). Similar trend of genotype wise grain yield was observed in pooled analysis ($5442 > 4836 > 4311 \text{ kg ha}^{-1}$).

Grain yield in maize relies heavily on key traits like grains per row, total grains per cob, and test weight. Genetic differences drive variations in these traits. The superior grain yield of late genotype BIO-9682 primarily stemmed from stronger expression of yield components as compared to medium ADV-756 and early BIO-605. Hossein *et al.* (2014) ^[8], Jadhav *et al.* (2015) ^[9], Jat *et al.* (2019) ^[11], Jajoria *et al.* (2020) ^[10], Sab *et al.* (2020) ^[13]. and Bhakne *et al.* (2023) ^[4]. also found highly significant differences among different maturity group genotypes for yield contributing traits and grain yield which strongly support the present finding.

Interaction

Interaction effects of weather variability x population density ($S \times P$) and weather variability genotype ($S \times G$) significantly

influenced grain yield during 2021, 2023 and in pooled analysis. Remaining interaction effects were statistically not significant.

Weather variability and population density (S X P) interaction

Data presented in Table (1a) indicated that interaction effect of normal sowing time and highest population density of 133333 plants ha⁻¹ at paired row planting 60-90X10 cm (S₁P₁) recorded significantly higher grain yield during 2021(8124 kg ha⁻¹), 2023(7526 kg ha⁻¹) and in pooled analysis (7825 kg ha⁻¹). However, it was statistically on par with S₂P₁ interaction only during both years but proved significantly superior to other treatment combinations during both years and when pooled. The lowest grain yield was observed in treatment interaction of most delayed sowing with lowest population density (S₄P₃) during both years and when pooled. Normal sowing time combined with high plant density of 133333 plants ha⁻¹ under adequate spatial arrangement in paired rows maximizes resource capture and grain yield per unit area, offsetting any reduction in individual plant yield potential through a superior number of productive ears per hectare, while a slight 10-day delay sustained similar high-density compensatory growth potential before severe environmental or developmental constraints set in. Whereas, lower densities or further delayed sowings restrict source-sink capacity and yield output.

Weather variability and genotypes (S X G) interaction

Data in Table 18 (b) revealed that the interaction effect normal on time sowing with late-maturing genotype (S₁G₃) recorded significantly higher grain yield over other treatment interactions during 2021, 2023 and when pooled (7575, 7123 and 7349 kg ha⁻¹, respectively). Treatment interaction S₄G₁ recorded the lowest grain yield during both years and when pooled (2719, 2323 and 2521 kg ha⁻¹, respectively), being at par with S₄G₂ and S₄G₃ interactions during 2023 season. Pairing normal on-time sowing with a late-maturing maize genotype maximizes grain yield as this interaction provides an optimal growing duration, efficient resource capture, and favorable thermal conditions during critical grain-filling stages compared to delayed planting or earlier-maturing alternatives.

Stover yield

Maize stover yield is the total aboveground non-grain biomass (leaves, stalks, and tassels) at harvest. It directly relies on the cumulative development of key vegetative growth parameters over the entire crop season. Better early and middle growth leads to a higher total stover weight per hectare. Data on stover yield of maize as influenced by different treatments have been set out in Table 1. The mean straw yield of maize during 2021, 2023 and the in the pooled analysis was 9632, 8936 and 9284 kg ha⁻¹, respectively.

Weather variability

Stover yield (kg ha⁻¹) of maize was significantly influenced by weather variability due to sowing times during both years. In 2021, normal sowing time and 10 days after normal sowing time being at par with each other produced significantly higher stover yield (S₁:11238 and S₂:11064 kg ha⁻¹, respectively) over the subsequent delayed sowings by 20 and 30 days after normal sowing time (S₃: 9219 and S₄: 7005 kg ha⁻¹, respectively). Similar trend with respect to stover yield was noticed in 2023 and in pooled analysis. Normal sowing and sowing 10 days later comparatively provide a longer and more favourable growth

period. This boosts plant height, leaf area, and dry matter. Subsequent delayed sowings (S₃ and S₄) expose the crop to less favourable seasonal weather conditions, shortening the active vegetative growth period. Similar results were also observed Moosavi *et al.* (2012), Vikhe (2016), Prasad *et al.* (2017), Jajoria *et al.*, (2020) ^[10], Sab *et al.* (2020) ^[13]. and Sahu *et al.* (2024)

Population density

Differences in maize stover yield due to different plant population densities were significant. Stover yield of maize was significantly increased with increase in population density in both 2021 and 2023 seasons and in pooled analysis also. The highest population density (P₁: 133333 plants ha⁻¹) with paired row planting at 60-90 x 10 cm proved significantly superior and produced maximum stover yield (2021: 11574; 2023: 10780 and pooled: 11177 kg ha⁻¹) followed by P₂ (111111 plants ha⁻¹) with single row planting at 60 x 15 cm distance (2021: 9932; 2023: 8988; pooled: 9460 kg ha⁻¹) and the least stover yield was recorded in P₃ (83333 plants ha⁻¹) with single row planting at 60 x 20 cm (2021: 7389; 2023: 7038, pooled: 7214 kg ha⁻¹). This could be attributed to the fact that higher plant population captures more solar radiation and utilizes growth resources more efficiently per unit area, and more efficient spatial distribution in paired row layout minimizes shaded leaves between rows and higher population density maximizes the total number of stalks harvested. These results are in conformity with findings of Norwood (2001), Abuzar *et al.* (2011), Sannagoudar and Murthy (2018) ^[14], Marahatta (2021) and Singh *et al.* (2022) ^[17].

Genotype

Differences in stover yield due to different maturity group genotypes were significant. During both years, stover yield was significantly more with longer maturity period of the genotype. Thus, significantly higher stover yield was produced in late maturing genotype. BIO-9682(G₃) during 2021, 2023 and in pooled data (10488, 9739 and 10114 kg ha⁻¹, respectively) as compared to the medium duration genotype ADV-756 (G₂: 9586, 8872, 9229 kg ha⁻¹, respectively) and early duration genotype BIO-605 (G₁:8820, 8196 and 8508 kg ha⁻¹, respectively). Genotype ADV-756 also yielded significantly higher stover than BIO-605 genotype. This could be because longer durations allow for extended growth periods and higher cumulative dry matter accumulation. Similar results were recorded by Nik *et al.* (2010), Jadhav *et al.* (2015) ^[9], Jat *et al.* (2019) ^[11], Sab *et al.* (2020) ^[13].

Interaction

Interaction effects of weather variability with population density (SxP) during 2023 and pooled analysis, weather variability with genotype (SxG) during both years and pooled analysis were significant in respect of stover yield.

Weather variability and population density (S X P) interaction

Data given in Table (1a) indicated that interaction effect of normal sowing time and highest population density of 133333 plants ha⁻¹ (S₁P₁) recorded significantly higher stover yield during 2023(8124 kg ha⁻¹), 2023(12858 kg ha⁻¹) and in pooled analysis (13163 kg ha⁻¹). However, it was statistically on par with S₂P₁ interaction and significantly superior to other treatment combinations during both 2023 and when pooled. The lowest stover yield was observed in treatment interaction of most delayed sowing with lowest population density (S₄P₃) during 2023 and when pooled.

Weather variability and genotype (S X G) interaction

Data presented in Table 1(d) revealed that the interaction effect S_1G_3 i.e. normal sowing time with late-maturing genotype BIO-9682 recorded significantly higher stover yield over other treatment interactions during 2021, 2023 and when pooled (12750, 12436 and 12593 kg ha⁻¹, respectively). Interaction of

most delayed sowing time and early maturing genotype (S_4G_1) recorded the lowest stover yield during both years and when pooled (6680, 6196 and 6438 kg ha⁻¹, respectively), being at par with S_4G_2 and S_4G_3 interactions during both years and when pooled.

Table 1: Grain yield and stover yield, as influenced by different treatments during 2021 and 2023

Treatment	Grain yield (kg ha ⁻¹)			Stover yield (kg ha ⁻¹)		
	2021	2023	Pooled	2021	2023	Pooled
Weather variability						
S ₁ - Normal sowing time	6734	6268	6501	11238	10703	10970
S ₂ - 10 days after normal sowing	6397	5706	6052	11064	10415	10739
S ₃ - 20 days after normal sowing	4410	3653	4032	9219	8226	8723
S ₄ - 30 days after normal sowing	3156	2578	2867	7005	6399	6702
SE(m)±	80	111	74	198	239	191
CD (P=0.05)	276	384	255	686	827	662
Population density						
P ₁ - 60-90x10 (133333 pl ha ⁻¹)	6286	5492	5889	11574	10780	11177
P ₂ - 60X15 (111111 pl ha ⁻¹)	5288	4666	4977	9932	8988	9460
P ₃ - 60x20 (83333 pl ha ⁻¹)	3949	3495	3722	7389	7038	7214
SE(m)±	47	87	57	142	123	105
CD (P=0.05)	141	262	170	425	368	315
Genotype						
G ₁ - BIO - 605	4589	4033	4311	8820	8196	8508
G ₂ - ADV - 756	5150	4521	4836	9586	8872	9229
G ₃ - BIO - 9682	5784	5100	5442	10488	9739	10114
SE(m)±	77	81	70	178	142	132
CD (P=0.05)	218	232	199	508	404	376
Interaction						
SXP						
SE(m)±	94	175	114	284	246	210
CD (P=0.05)	281	523	340	NS	736	629
SXG						
SE(m)±	153	163	140	357	284	264
CD (P=0.05)	436	463	397	1016	808	752
PXG						
SE(m)±	133	141	121	309	246	229
CD (P=0.05)	NS	NS	NS	NS	NS	NS
SE(m)±	266	282	242	618	492	458
CD (P=0.05)	NS	NS	NS	NS	NS	NS
GM	5174	4551	4863	9632	8936	9284

Table 1: (a) Grain yield as influenced by S X P interaction during 2021, 2023 and in pooled analysis

Weather variability / Population density	Grain yield (kg ha ⁻¹)								
	2021			2023			Pooled		
	P ₁ 60-90x10 (133333 ha ⁻¹)	P ₂ 60X15 (111111 ha ⁻¹)	P ₃ 60x20 (83333 ha ⁻¹)	P ₁ 60-90x10 (133333 ha ⁻¹)	P ₂ 60X15 (111111 ha ⁻¹)	P ₃ 60x20 (83333 ha ⁻¹)	P ₁ 60-90x10 (133333 ha ⁻¹)	P ₂ 60X15 (111111 ha ⁻¹)	P ₃ 60x20 (83333 ha ⁻¹)
S ₁ - Normal sowing time	8124	6968	5110	7526	6443	4835	7825	6706	4972
S ₂ - 10 days after normal sowing	7905	6362	4925	6883	5723	4512	7394	6043	4718
S ₃ - 20 days after normal sowing	5230	4599	3402	4347	3821	2791	4788	4210	3096
S ₄ - 30 days after normal sowing	3885	3224	2359	3213	2678	1844	3549	2951	2102
S.E(m)±	94			175			114		
CD (P=0.05)	281			523			340		

Table 18: (b) Grain yield as influenced by S X G interaction during 2021, 2023 and in pooled analysis

Weather variability / Genotype	Grain yield (kg ha ⁻¹)								
	2021			2023			Pooled		
	G ₁ BIO - 605	G ₂ ADV - 756	G ₃ BIO -9682	G ₁ BIO - 605	G ₂ ADV - 756	G ₃ BIO -9682	G ₁ BIO - 605	G ₂ ADV - 756	G ₃ BIO -9682
S ₁ - Normal sowing time	6060	6567	7575	5535	6146	7123	5797	6357	7349
S ₂ - 10 days after normal sowing	5586	6193	7411	5075	5487	6556	5331	5840	6984
S ₃ - 20 days after normal sowing	3992	4530	4709	3198	3750	4011	3595	4140	4360
S ₄ - 30 days after normal sowing	2719	3309	3440	2323	2701	2712	2521	3005	3076
S.E(m)±	153			163			140		
CD (P=0.05)	436			463			397		

Table 1: (c) Stover yield as influenced by S X P interaction during 2023 and in pooled analysis

Weather variability / Population density	Stover yield (kg ha ⁻¹)					
	2023			Pooled		
	P ₁ 60-90x10 (133333 ha ⁻¹)	P ₂ 60X15 (111111 ha ⁻¹)	P ₃ 60x20 (83333 ha ⁻¹)	P ₁ 60-90x10 (133333 ha ⁻¹)	P ₂ 60X15 (111111 ha ⁻¹)	P ₃ 60x20 (83333 ha ⁻¹)
S ₁ - Normal sowing time	12858	11013	8238	13163	11299	8450
S ₂ - 10 days after normal sowing	12660	10317	8267	13051	10624	8543
S ₃ - 20 days after normal sowing	9833	8011	6834	10400	8858	6910
S ₄ - 30 days after normal sowing	7771	6612	4815	8094	7061	4952
S.E(m)±	246			210		
CD (P=0.05)	736			629		

Table 1: (d) Stover yield as influenced by S X G interaction during 2021, 2023 and in pooled analysis

Weather variability Genotype	Stover yield (kg ha ⁻¹)								
	2021			2023			Pooled		
	G ₁ BIO - 605	G ₂ ADV - 756	G ₃ BIO - 9682	G ₁ BIO - 605	G ₂ ADV - 756	G ₃ BIO - 9682	G ₁ BIO - 605	G ₂ ADV - 756	G ₃ BIO - 9682
S ₁ - Normal sowing time	9975	10989	12750	9415	10258	12436	9695	10624	12593
S ₂ - 10 days after normal sowing	9893	11017	12282	9381	10369	11494	9637	10693	11888
S ₃ - 20 days after normal sowing	8732	9190	9735	7793	8330	8555	8263	8760	9145
S ₄ - 30 days after normal sowing	6680	7150	7186	6196	6531	6471	6438	6840	6828
S.E(m)±	357			284			264		
CD (P=0.05)	1016			808			752		

Conclusion

To maximize both grain and stover yield in *kharif* maize, maintaining a normal on-time sowing schedule is paramount. Farmers can successfully mitigate early 10-day sowing delays and individual resource competition by adopting high-density paired-row planting configurations (133,333 plants ha⁻¹ at 60-90 × 10 cm). Furthermore, choosing a late-maturing genotype like BIO-9682 optimizes resource capture window efficiencies, ensuring maximum expression of agronomic yield traits

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