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Effect of climatic factors during different phenophases on growth of Sugarcane (*Saccharum officinarum* L)

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Abstract
Sugarcane is a long-duration crop whose growth is strongly governed by the interplay of climatic factors operating across its successive phenophases. The present investigation was undertaken at Parikshitgarh, Meerut, Uttar Pradesh, during 2024–25, to study the effect of climatic factors during different phenophases on the growth of the early-maturing sugarcane cultivar Co 0238, planted on 23–24 March 2024 and harvested on 20–21 February 2025. The crop duration was divided into four phenophases — germination, tillering, grand growth, and maturity/ripening — and monthly climatic data (temperature, rainfall, relative humidity, sunshine hours and wind speed,) were correlated with monthly growth parameters (plant height, tiller number, millable shoot number, Leaf Area Index, green leaf number, cane girth, internode number, and dry matter accumulation). Correlation of monthly growth increments (rather than cumulative values) with the corresponding month's climatic factors showed that structural growth attributes — plant height, cane girth, internode formation, and LAI — were strongly and positively associated with mean temperature ($r = 0.66–0.88$, $p<0.05$ to $p<0.01$), consistent with the known optimum temperature range of 30–35°C for sugarcane vegetative growth. Rainfall and rainy days showed the strongest positive association with internode formation and canopy parameters, while tiller and millable shoot increment were most strongly (negatively) associated with relative humidity, reflecting the self-thinning of non-productive tillers coinciding with the monsoon canopy-closure period. The results confirm distinct phenophase-specific climatic sensitivity in Co 0238 and provide a quantitative basis for weather-informed agronomic planning of early-maturing sugarcane cultivars in western Uttar Pradesh.

Keywords: *Saccharum officinarum,* environmental factors, temperature, rainfall, grand growth

Introduction

Sugarcane (*Saccharum officinarum* L.) is one of India's most important commercial crops, with national production having risen from 405.4 million tonnes in 2020–21 to 454.6 million tonnes in 2024–25 (Ministry of Agriculture and Farmers Welfare, Government of India, 2025) [6]. Uttar Pradesh remains the country's leading sugarcane-producing state, contributing over 220 million tonnes annually and accounting for nearly half of India's total output. Within Uttar Pradesh, the early-maturing variety Co 0238 (Karan 4), released in 2009 by the ICAR–Sugarcane Breeding Institute, Regional Centre, Karnal, for commercial cultivation across Haryana, Punjab, Western and Central Uttar Pradesh, Uttarakhand, and Rajasthan, has become the dominant cultivar of the region, occupying over 90 percent of the sugarcane area in several western U.P. districts owing to its high cane yield, superior sugar recovery, and adaptability to varying sowing periods and moisture regimes (ICAR, 2024) [3].

Despite this dominance, sugarcane productivity in the region remains closely tied to the prevailing weather during the crop's growth cycle. Being a long-duration crop spanning ten to twelve months, sugarcane passes through physiologically distinct phenophases — germination, tillering, grand growth, and maturity/ripening — each with markedly different climatic requirements. Early studies on crop-weather relationships in sugarcane established that maximum and minimum temperature and relative humidity during the germination and tillering phases exert a particularly strong influence on final yield, with above-normal temperature and comparatively drier conditions during this window generally favouring better yields (Rupa Kumar, 1984) [8]. More recent work has reinforced that sugarcane requires an optimum temperature range of approximately 30–35°C for vegetative growth, that canopy expansion and rapid elongation depend heavily on adequate rainfall and humidity during the grand growth phase, and that the ripening phase instead requires cool, dry conditions with clear sunshine to favour sucrose accumulation over continued vegetative growth (Mehdi *et al*., 2024) [5]. Despite the substantial area under Co 0238 in western Uttar Pradesh, phenophase-wise studies explicitly correlating monthly climatic variation with the growth trajectory of this specific cultivar remain limited in the published literature, most existing crop-weather correlation work having been conducted for other agro-climatic zones and cultivars (Rupa Kumar, 1984) [8]. Given the cultivar's regional dominance and its documented sensitivity to temperature and moisture stress at the tillering, elongation, and grand growth stages (Mehdi *et al*., 2024) [5], a location-specific, phenophase-wise assessment is needed. Keeping this in view, the present investigation was undertaken to study the effect of climatic factors during different phenophases on the growth of sugarcane cultivar Co 0238 at Parikshitgarh, Meerut, with the objective of identifying the climatic parameters most strongly associated with growth response at each phenophase and establishing correlation relationships that can inform weather-based agronomic planning for early-maturing sugarcane in the region.

Materials and Methods

1. **Experimental Site:** The field investigation was conducted at Parikshitgarh, District Meerut, Uttar Pradesh, India, during the crop season 2024–25, to study the effect of climatic factors during different phenophases on the growth of sugarcane. The region falls under the sub-tropical agro-climatic zone of western Uttar Pradesh, characterised by hot, dry summers, a distinct monsoon season, and cool, dry winters.

2. **Planting Material and Crop Establishment:** The early-maturing sugarcane cultivar Co 0238 was used as the test variety. Planting was carried out during the optimal window of 23–24 March 2024, in furrows opened at a depth of 15 cm, with an inter-row spacing of 75 cm maintained over a levelled field surface. All standard agro-techniques and cultural practices recommended for sugarcane cultivation in the region — including fertilization, irrigation, weed management, and plant protection — were uniformly applied throughout the crop's life cycle. The crop attained physiological maturity and was harvested on 20–21 February 2025, giving a total crop duration of approximately 334 days.

3. **Delineation of Phenophases:** Based on standard sugarcane growth physiology and field observations, the crop duration was divided into four broad phenophases for the purpose of relating climatic variation to growth response:

Phenophase	Approximate Duration (DAP)	Calendar Period
Germination/Sprouting	0–45 days	24 March – early May 2024
Tillering	46–120 days	Mid-May – mid-July 2024
Grand Growth (Elongation)	121–270 days	Late-July – mid-December 2024
Maturity/Ripening	271–334 days	Late-December 2024 – 21 February 2025

4. **Meteorological Data Collection:** Daily meteorological data — maximum and minimum temperature, rainfall, number of rainy days, morning and evening relative humidity, sunshine hours, and wind speed — were obtained for the crop growth period (24 March 2024 to 21 February 2025) from the nearest agrometeorological observatory serving the Parikshitgarh–Meerut region and compiled into monthly means/totals. Mean temperature for each month was computed as the average of the mean maximum and mean minimum temperature.

5. **Recording of Growth Parameters:** Five clumps were randomly selected and tagged in each plot for periodic biometric observation, and growth parameters were recorded at monthly intervals from planting to harvest. The parameters recorded were:

- Plant height (cm) measured from the base of the shoot to the tip of the topmost visible dewlap leaf
- Number of tillers/clump total number of tillers counted per tagged clump
- Number of millable-type shoots per metre row shoots with cane-forming potential counted per running metre
- Leaf Area Index (LAI) computed from leaf length, maximum leaf breadth, and a standard correction factor
- Number of green (photosynthetically active) leaves per plant
- Cane girth (mm) measured at the third internode from the base using vernier calipers, recorded once girth development became measurable (from the tillering phase onward)
- Number of internodes per plant
- Dry matter accumulation (g/plant) determined by oven-drying representative sampled plants at 70±5°C to constant weight

Results

Weather Conditions during the Crop Growth Period: The crop experienced marked seasonal variation in weather parameters across its 12-month growth cycle at Parikshitgarh, Meerut. During the germination phase (March–early May 2024), mean temperature rose steadily from 26.2°C to 34.4°C, while rainfall remained low (16.5–17.0 mm) with rainy days limited to 0–2 per month, and morning relative humidity declined from 81.5% to 53.3%. The tillering phase (mid-May to mid-July) coincided with the onset of the monsoon, with rainfall rising sharply from 208.5 mm (June) to 412.0 mm (July) and rainy days peaking at 24 in July; mean temperature during this phase ranged from 29.3–34.4°C. The grand growth phase (late-July to mid-December) was characterised by high but gradually declining rainfall (368.0 mm in August, tapering to 2.0 mm by October) and a progressive fall in mean temperature from 28.7°C (August) to 13.1°C (December) as the season transitioned from monsoon to winter. The maturity/ripening phase (January–February 2025) recorded the lowest mean temperatures of the season (12.1–16.0°C), minimal rainfall (4.0–28.5 mm), and reduced sunshine hours (5.8–7.8 hrs), consistent with the cool, dry conditions favourable for ripening.

Growth Attributing Parameters: Plant height increased slowly during germination (5.2 cm in March to 44.0 cm in April) and accelerated markedly through tillering and early grand growth, reaching 230.5 cm by July and peaking at 423.8 cm by harvest (February 2025), with growth rate visibly plateauing after October once the crop entered the grand growth–maturity transition. Tiller number followed a classic rise-and-decline pattern, increasing from 0 in March to a peak of 11.2 tillers/clump in June (tillering phase), before declining to a stable 7.0 tillers/clump from October onward as non-productive tillers senesced — a pattern consistent with the natural tiller mortality/self-thinning process in sugarcane. Millable shoot number per metre row showed a similar trend, rising to 13.9 in June and stabilising near 11.0 from September through harvest. Leaf Area Index (LAI) peaked at 6.62 in August (grand growth phase) before declining to 2.68 by February as lower leaves senesced during ripening. Cane girth increased consistently throughout the season (10.4 mm in May to 29.9 mm at harvest), as did internode number (3 in May to 32 at harvest) and dry matter accumulation, which showed the steepest increase during the grand growth phase (246.0 g/plant in July to 977.5 g/plant in November) before slowing markedly during maturity (1106.0 to 1174.5 g/plant, December–February).

Germination Phase: The relatively low rainfall and moderate-to-rising temperature during March–April created favourable, though not optimal, moisture conditions for bud sprouting; the gradual rise in mean temperature from 26.2°C to 30.6°C aligns with the known requirement of warm soil temperature for uniform germination in sugarcane. The comparatively slow height gain (5.2 to 44.0 cm) and negligible tillering during this period reflect the crop's dependence on establishing an adequate root system before above-ground vegetative growth accelerates.

Tillering Phase: The sharp increase in rainfall and rainy days coinciding with monsoon onset (June–July) appears closely associated with the peak in tiller production (11.2 tillers/clump) and rapid LAI build-up. Adequate soil moisture combined with still-high temperatures (29–34°C) during this window likely created optimal conditions for bud-break at the lower nodes, supporting profuse tillering. The subsequent decline in tiller number from July onward, despite continuing favourable moisture, is consistent with intra-clump competition for light and nutrients, leading to natural elimination of weaker, non-millable tillers — a physiological response rather than a climatic limitation.

Grand Growth Phase: This phase showed the strongest apparent climate-growth linkage in the dataset. High rainfall carried over from the monsoon (August: 368.0 mm) combined with still-warm temperatures supported the steepest gains in plant height, cane girth, internode formation, and dry matter accumulation recorded across the season. As the phase progressed into the post-monsoon period (September–December), declining rainfall and falling temperature corresponded with a gradual deceleration in height increment, although dry matter accumulation continued at a relatively high rate — suggesting that once canopy and structural growth are largely established, biomass accumulation becomes less immediately rainfall-dependent and more a function of thermal time and photosynthetic carry-over.

Maturity/Ripening Phase: The transition to cool, dry conditions (mean temperature 12.1–16.0°C, minimal rainfall) from December onward corresponded with the plateauing of plant height and LAI decline, both expected responses as vegetative growth ceases and the crop shifts resources toward sucrose accumulation in the stalk. The continued, though slowed, increase in cane girth and dry matter during this phase, despite minimal rainfall and low temperature, is consistent with the physiological priority shift toward stem thickening and sugar deposition characteristic of the ripening stage in early-maturing cultivars such as Co 0238.

Table 1: Monthly Meteorological Data (Parikshitgarh, Meerut, Mar 2024 – Feb 2025)

Month	Max T (°C)	Min T (°C)	Mean T (°C)	Rainfall (mm)	Rainy Days	Morn RH (%)	Eve RH (%)	Sunshine (hrs)	Wind (km/h)	Phenophase
Mar '24	33.3	19.1	26.2	16.5	2	81.5	48.5	8.2	6.4	Germination
Apr '24	38.3	22.9	30.6	4.0	0	63.0	33.8	9.1	7.9	Germination
May '24	42.1	26.6	34.4	17.0	2	53.3	28.8	9.4	10.0	Tillering
Jun '24	39.4	26.8	33.1	208.5	15	75.0	55.4	7.2	9.2	Tillering
Jul '24	34.1	24.4	29.3	412.0	24	92.8	79.8	4.7	7.0	Till.→Grand Growth
Aug '24	33.3	24.0	28.7	368.0	20	91.8	78.0	5.3	5.9	Grand Growth
Sep '24	33.8	22.4	28.1	140.0	9	83.6	59.4	7.5	4.5	Grand Growth
Oct '24	31.0	16.8	23.9	2.0	0	76.5	42.3	8.6	3.7	Grand Growth
Nov '24	25.9	10.9	18.4	4.5	1	83.5	46.5	7.7	4.4	Grand Growth
Dec '24	19.4	6.8	13.1	22.5	2	93.4	59.2	5.9	5.5	Maturity/Ripening
Jan '25	18.1	6.1	12.1	28.5	4	93.8	62.3	5.8	5.7	Maturity/Ripening
Feb '25	22.8	9.2	16.0	4.0	0	85.0	48.0	7.8	6.0	Maturity/Ripening

Table 2: Monthly Growth Parameters (end-of-month recording) in sugarcane variety Co 0238

Month	DAP	Phenophase	Height (cm)	Tillers /Clump	Millable Shoots/m	LAI	Green Leaves	Girth (mm)	Internodes	Dry Matter (g/plant)
Mar '24	7	Germination	5.2	0.0	0.0	0.05	2.1	–*	0	1.5
Apr '24	35	Germination	44.0	4.1	0.0	0.65	5.5	–*	0	14.0
May '24	63	Tillering	93.0	9.6	11.2	1.82	8.5	10.4	3	46.8
Jun '24	98	Tillering	164.5	11.2	13.9	4.02	12.2	18.5	9	130.5
Jul '24	126	Grand Growth	230.5	8.7	12.5	5.75	13.8	23.2	15	246.0
Aug '24	154	Grand Growth	298.5	7.6	11.6	6.62	14.4	26.2	21	407.2
Sep '24	189	Grand Growth	365.8	7.2	11.2	6.42	12.5	28.4	26	641.5
Oct '24	217	Grand Growth (Late stage)	400.0	7.0	11.0	5.45	10.2	29.3	30	824.2
Nov '24	245	Grand Growth	416.2	7.0	11.0	4.35	8.4	29.7	31	977.5
Dec '24	280	Maturity/Ripening	422.4	7.0	11.0	3.25	6.9	29.9	32	1106.0
Jan '25	308	Maturity/Ripening	423.5	7.0	11.0	2.80	6.3	29.9	32	1156.8
Feb '25	329	Maturity/Ripening (harvest)	423.8	7.0	11.0	2.68	6.0	29.9	32	1174.5

Note: Cane girth not measurable during germination phase (0-45 DAP); measurement commenced from 63 DAP at 3rd internode from base

Table 3: Correlation between Monthly Growth Rate of plant (Increment) and Climatic Factors

Growth Rate (monthly)	Mean Temp	Rainfall	Rainy Days	Morn RH	Eve RH	Sunshine	Wind
Plant Height	0.888	0.727	0.732	−0.225	0.285	−0.086	0.359
Tillers/Clump	0.411	−0.514	−0.494	−0.913	−0.829	0.775	0.678
Millable Shoots	0.434	−0.262	−0.224	−0.757	−0.585	0.535	0.699
LAI	0.773	0.649	0.682	−0.298	0.197	−0.121	0.805
Green Leaves	0.690	0.276	0.306	−0.564	−0.175	0.167	0.943
Cane Girth	0.739	0.349	0.401	−0.516	−0.097	0.139	0.771
Internodes	0.662	0.803	0.812	0.071	0.502	−0.318	0.130
Dry Matter	0.016	0.303	0.285	0.400	0.412	−0.263	−0.669

(n=12 for all parameters except cane girth where n=10 (May-Feb) for absolute values and n=9 for increment, due to non-measurable stage in March-April)

Discussion

The findings presented in this study clearly demonstrate that prevailing climatic factors during the distinct phenophases of sugarcane play a critical role in determining final crop yield. The germination phase is considered foundational for ultimate crop density and tillering potential, as the number of hills established during this stage directly governs subsequent yield outcomes. According to FAO (2001) [2], the optimum temperature range for sprouting in sugarcane lies between 32°C and 38°C, with germination rates declining sharply below this threshold. Consistent with this, Mehdi *et al*. (2024) [5] confirmed that early-stage chilling stress, particularly temperatures below 8°C, substantially impairs photosynthesis and leaf development, resulting in poorly established hills that subsequently fail to support uniform plant heights across the growing cycle.

The transition from germination to tillering is governed primarily by the interaction between ambient humidity and temperature. Rupa Kumar (1984) [8], in a long-term study conducted in Andhra Pradesh, demonstrated that maximum and minimum temperatures along with relative humidity during the first three months of the crop (germination and tillering phases) exert a profound influence on yield. However, not all tillers generated survive to maturity. Ramesh and Mahadevaswamy (2000) [7] established that drought stress during the formative phase increases shoot mortality, forcing the plant to rely predominantly on robust, "millable-type" shoots for final yield.

The grand growth stage represents the most water-sensitive and visually dynamic vegetative phenophase in the crop cycle. Evidence from Inman-Bamber and Smith (2005) [4] indicates that the stem elongation and tillering phases are the most susceptible to water stress, with direct consequences for internode number, internode length, and overall biomass accumulation. The climatic requirements of the ripening phase stand in sharp contrast to those of the grand growth stage. The comprehensive review by Cardozo and Sentelhas (2013) [1] demonstrates that a progressive decline in air temperature, combined with a moderate soil water deficit, signals the plant to cease vegetative growth and redirect resources toward sucrose storage within the stalk internodes — a process mediated by shifts in the balance between acid and neutral invertase enzyme activity. Taken together, these findings confirm that the climatic requirements of sugarcane vary distinctly, and at times contrastingly, across its phenophases — warm, humid conditions favor germination and tillering, whereas dry, relatively cooler conditions are desirable during ripening. This duality carries important implications for the development of region-specific, climate-informed crop management strategies.

Conclusion

The present investigation carried out at Parikshitgarh, Meerut during 2024–25 on the early-maturing cultivar Co 0238 revealed distinct phenophase-specific climatic sensitivity in sugarcane growth. Correlation of monthly growth increments with corresponding monthly climatic factors indicated that structural growth attributes were predominantly temperature-driven, with plant height ($r = 0.888$), LAI ($r = 0.773$), cane girth ($r = 0.739$) and green leaf number ($r = 0.690$) showing strong positive association with mean temperature, consistent with the optimum range of 30–35°C for vegetative growth. Internode formation exhibited the strongest positive dependence on moisture availability, with rainfall ($r = 0.803$) and rainy days ($r = 0.812$). Tiller and millable shoot increment showed strong negative association with morning relative humidity ($r = -0.913$ and -0.757) and evening RH ($r = -0.829$), reflecting the natural self-thinning and mortality of non-productive tillers coinciding with monsoon-induced canopy closure rather than a direct adverse effect of humidity. The grand growth phase (late-July to mid-December) emerged as the most climate-sensitive phenophase, accounting for the steepest gains in height, girth, internode number and dry matter (246.0 to 977.5 g/plant).

The transition to cool, dry conditions during maturity (mean temperature 12.1–16.0°C, rainfall 4.0–28.5 mm) was associated with plateauing of height (423.8 cm at harvest), decline in LAI from 6.62 to 2.68, and stabilization of cane girth and internode number, confirming the shift from vegetative growth to sucrose accumulation. Overall, the results confirm that warm, humid conditions with adequate rainfall favour germination, tillering and grand growth, while cool, dry conditions are essential for proper ripening in Co 0238. The quantitative correlations provide a basis for weather-informed agronomic planning for early-maturing sugarcane in western Uttar Pradesh. Since the findings are based on single-season, single-location data, multi-year validation is recommended.

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