



International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

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www.agronomyjournals.com

2024; 7(10): 440-445

Received: 12-08-2024

Accepted: 19-09-2024

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Effect of sowing dates on the accumulation of GDD and heat use efficiency in Kharif maize cultivars

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DOI: <https://doi.org/10.33545/2618060X.2024.v7.i10f.1786>

Abstract

Maize is a crucial cereal crop from the Poaceae family and it is the third most important globally following wheat and rice. In India, maize ranks alongside rice and wheat due to its rapid growth, high yield potential and diverse applications. This study conducted at Acharya Narendra Deva University of Agriculture & Technology during the kharif season of 2022, investigated the impact of sowing dates and maize cultivars on crop growth and yield. The experiment utilized a Split Plot Design (S.P.D.) with three sowing dates (June 5th, June 15th and June 25th) and three cultivars (Kanchan, Sonari (Shweta) and AQH-4) on a silty loam soil with low organic carbon, nitrogen, sulphur and phosphorus but medium in potash. The study revealed that maize sown on July 5th took the longest to mature. Delayed sowing consistently reduced the duration of all growth stages vegetative growth, flowering, fertilization and grain filling. Specifically, the period from sowing to maturity decreased by approximately 5 days in vegetative growth, 4-5 days in flowering and fertilization and 10-12 days in grain filling. Among cultivars, AQH-04 required 5 additional days to mature compared to Kanchan at the July 25th sowing, indicating that cultivar choice affects development duration. The reduction in growing degree days (GDD) and heat use efficiency (HUE) with later sowing dates was attributed to higher maximum temperatures and reduced rainfall, which forced quicker physiological maturity and led to lower yields. The July 5th sowing environment had the highest HUE (0.67 g/m²/°C days), indicating superior efficiency in converting thermal energy into biomass. This study provides insights for improving planting strategies and cultivar selection to enhance maize productivity in the region.

Keywords: High yield, GDD, maturity, maximum temperature and heat use efficiency

Introduction

Maize belonging to the family Poaceae, is the third most important cereal crop globally, following wheat and rice. It holds significant agricultural value in India, alongside rice and wheat, due to its rapid growth, high yield potential, ease of cultivation, industrial applications and nutritional properties. Maize is often referred to as the "Queen of Cereals" due to its adaptability to diverse environmental conditions and its remarkable production capacity (Choudhari & Channappagouda, 2015) ^[1].

Apart from its consumption as food by humans and animals, maize serves various industrial purposes. It is a valuable source of raw materials for numerous industrial products, including starch, protein, oil, alcoholic beverages, food sweeteners, pharmaceuticals, cosmetics and biofuels. Maize is utilized in more diverse ways than any other cereal, making it increasingly important in several countries. Maize grains have high nutritional value, comprising approximately 72% starch, 10% protein, 4.8% oil, 5.8% fiber and 3% sugar (Rafiq *et al.*, 2010) ^[6].

The top three uses of maize in the world are for feed (61%), food (17%) and industry (22%) as 83% of its production used in feed, starch and bio-fuel industries. Additionally, more than 3000 goods are produced directly or indirectly using maize, offering numerous opportunities for value addition. It is a major force behind the global agricultural economy due to its many uses (ICAR-Indian Institute of Maize Research. 2020-21).

Over the past 40 years the total global area sown under maize has increased by about 40 percent

and production has doubled. The maize is cultivated throughout the year in all states of the country for various purposes including grain, fodder, green cobs, sweet corn, baby corn, pop corn in peri-urban areas. Currently, nearly 1147.7 million MT of maize is being produced together by over 170 countries from an area of 193.7 million ha with an average productivity of 5.75 t/ha (FAOSTAT, 2020) [4].

The United States is the largest maize producer globally, accounting for 31.08% of the total production, followed by China (23.42%), Brazil (9.27%), the European Union (5.89%), Argentina (4.49%), Ukraine (3.22%), India (2.8%), Mexico (2.25%), South Africa (1.48%) and other countries (16.45%) (Statistical Yearbook, 2020).

In India, maize cultivation occurs in both the Kharif (monsoon) and Rabi (winter) seasons. Approximately 85% of maize is cultivated during the Kharif, summer and spring seasons, while the remaining 15% is grown in the Rabi season. The major maize-producing states, contributing to 85% of total production, include Karnataka (16.45%), Madhya Pradesh (11.37%), Maharashtra (10.91%), Tamil Nadu (8.63%), West Bengal (7.76%), Rajasthan (7.20%), Bihar (7.06%), Andhra Pradesh (6.19%), Uttar Pradesh (5.72%), Telangana (5.55%) and other states (13.15%) (Directorate of Economics and Statistics, 2021).

In Uttar Pradesh, maize cultivation is carried out for both human consumption and fodder purposes. Maize is grown in all three seasons of the year: Kharif, Rabi and summer. In 2019-20, the maize cultivation area was 0.77 million hectares, with a production of 1.80 million tons and a productivity of 2331 kg/ha. In 2020-21, the area decreased slightly to 0.73 million hectares, with a production of 1.69 million tons and a productivity of 2323 kg/ha (Directorate of Economics and Statistics, 2021).

In agricultural practices, growing degree days (GDD) are commonly used to represent heat units. GDD is calculated by subtracting a base or threshold temperature from the average temperature of a given day. The base temperature refers to the minimum temperature required for plant growth initiation, which varies among plant species. For maize, the base temperature is typically 10 °C. Maize is cultivated in diverse conditions, with a preference for warmer temperate zones and humid subtropical regions. The ideal temperature range for maize growth is between 22 to 32 °C during the day and 16.7 to 23.3 °C at night. Extreme temperatures below 5 °C or above 32 °C negatively affect plant growth (Vanaja *et al.*, 2017) [9].

Key meteorological factors like temperature, rainfall, relative humidity, evaporation and sunlight hours are the primary determinants of maize development. The effect of temperature on crops is accounted through the concept of the heat unit, which is based on the fact that crops need certain amount of temperature requirement for the completion of each stage of their ontogeny. Depending on the temperature at each growth phase and the cultivar, sowing dates varied according to the GDD requirements of different maize cultivars. The radiative and thermal conditions during maize's growth are altered by variations in the planting date. Changes in sowing dates have a direct impact on temperature and photoperiod, which has a significant impact on the phasic development and dry matter partitioning. Very early sowing exposes the crop to a high risk of crop failure due to erratic rainfall distributions associated with the start of the rainfall season. In contrast with late sowing dates, the crop is vulnerable to early rainfall cessation before it fully matures. Therefore, it is essential to strike a balance between reducing the risk of sowing too early and ensuring the crop is planted early enough to develop before the end of the season

(Dadapeer *et al.*, 2020) [2].

Materials and Methods

Location of experimental site

The experiment was carried out at Student's Instructional Farm of Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya (U.P.) during kharif season 2022. It is situated on Faizabad-Raibareilly road at the distance of 42Km from Ayodhya district head quarter. The geographically experimental site lies at latitude 26° 54' north, longitude 81° 82' East and altitude of 113 meter from mean sea level in the Indo-Gangetic alluvium of Eastern Uttar Pradesh.

Climatic condition of the experimental site

Geographically, this region falls under sub-tropical climate. The annual rainfall of this region is about 1100 mm of which 85% received during the South-West monsoon (mid-June to end of September). The winters are cold and dry. The hot winds blow from South-West to North-East direction during summers. The average weekly maximum and minimum temperatures during the crop growth period ranged from 30.3 °C to 36.7 °C and 14.8 °C to 27.5 °C, respectively. The average relative humidity ranged between 72.08% to 86.90% and bright sunshine between 1.4 to 9.0 hours.

Soil of the experimental fields

According to triangular method of soil classification recognized by International Society of Soil Science, the soil of the field may texturally be classified as silty loam, while low in organic carbon, nitrogen, sulphur and phosphorus but medium in potash contents.

Details of treatments

The experimental design used was a Split Plot Design (S.P.D.). It consisted of nine treatment combinations, which included three different sowing dates: 5th June (G1), 15th June (G2) and 25th June (G3). Additionally, three cultivars were used in the investigation, namely Kanchan, Sonari (Shweta) and AQH-4.

Heat unit (Growing degree days):

The concepts of growing degree days were developed assuming that there is a direct and linear relationship between crop growth and temperature. Growing degree days (GDD) at different phenological stages were calculated by using following formula:

$$GDD = \sum_{i=1}^n \text{heat unit (HU)}$$

Where,

1, 2, 3, ...n is number of days and

$$\text{Heat unit} = \frac{T_{\text{max}} + T_{\text{min}}}{2} - (T_b)$$

Where, T_b is the base temperature

Base Temperature is 10 °C.

Where,

T_{max} = Daily maximum temperature (°C)

T_{min} = Daily minimum temperature (°C)

T_b = Base temperature (10 °C for maize)

Heat use efficiency (g/m²/°day)

Heat use efficiency (HUE) is the dry matter production per unit of heat unit use by the crop. Heat used efficiency (HUE) may be calculated as following.

$$\text{HUE} = \frac{\text{Total dry matter (g/m}^2\text{)}}{\text{Heat Unit (}^\circ\text{days)}}$$

Results and Discussion**No of days taken to different phenophases**

The study observed that maize crop sown on July 5th took the longest time to reach maturity (Table-1 and fig. 1). As sowing was delayed, the number of days to maturity consistently decreased. This reduction was observed across various growth stages, including vegetative growth, flowering, fertilization and grain filling. Specifically, from the first sowing (G1) to the third (G3) there was a reduction of about 5 days in vegetative growth, 4-5 days in flowering and fertilization and 10-12 days in the grain filling and maturity period.

Among the cultivars, AQH-04 took a relatively longer duration to mature compared to Kanchan in the 25th July sowing. This delay amounted to 5 days. It suggests that the choice of cultivar can also impact the duration of crop development and maturity.

The primary reason for this shortened duration in later sowings was the increased maximum temperatures and reduced rainfall during the grain filling and maturity stages. These conditions forced the maize plants to reach physiological maturity more quickly. The study supports the hypothesis that shorter reproductive and grain development periods lead to lower yields. Additionally, delayed sowing resulted in fewer accumulated heat units due to lower ambient temperatures and increased water stress. This further shortened the growing period, negatively impacting maize yield. Overall, the study highlights the importance of optimal sowing dates and cultivar selection to maximize maize yield by taking advantage of favourable growing conditions and avoiding stress during critical growth stages. The results match with Vanaja *et al.*, (2017) [9].

Table 1: No. of days taken to different phenophases of kharif maize cultivars as affected by Crop growing environments:

Treatments	Days Taken to Different Phenophases						
	Emergence	Knee high stage	Tasseling	Silking	Milking	Dough stage	Maturity
5 th July (32 °C)							
Kanchan	4	31	42	51	60	74	96
Sonari (Shweta)	4	33	44	53	64	75	97
AQH-04	4	37	47	57	69	78	99
15 th July (31.5 °C)							
Kanchan	5	32	41	50	58	71	92
Sonari (Shweta)	5	34	43	51	60	73	95
AQH-04	5	36	46	55	62	74	97
25 th July (30.5 °C)							
Kanchan	5	30	40	46	57	70	86
Sonari (Shweta)	5	32	42	50	59	72	88
AQH-04	5	34	44	52	60	76	91

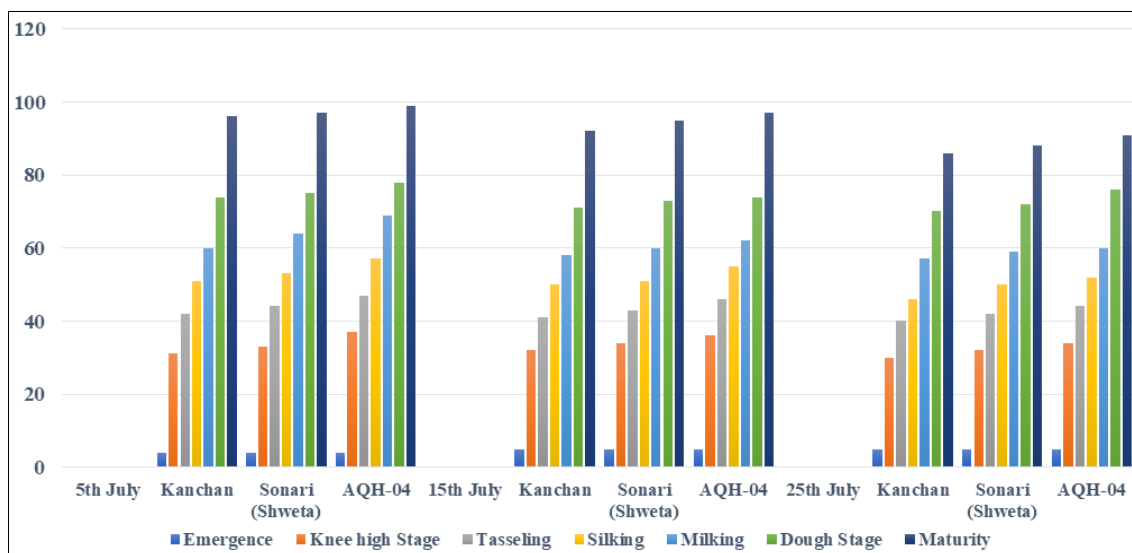


Fig 1: Days taken to different phenophases of kharif maize cultivars as affected by Crop growing environments

Heat Unit/GDD

The study investigated the growing degree days (GDD) required for maize to reach various phenophases, finding that these requirements varied with planting dates. The GDD needed for physiological maturity ranged from 1652.6 to 1935.05 °C days across different crop-growing environments. Later sowing dates

accumulated fewer GDD due to shorter growing periods caused by increased moisture stress and higher minimum temperatures compared to the July 5th sowing (Table 2 and fig. 2). Delayed sowing dates significantly impacted maize phenology, shortening all growth stages and reducing GDD, especially during the grain-filling period.

Crop-Growing Environments and Cultivars

- **July 5th Environment:** AQH-04 recorded the highest heat unit requirement, needing 1935.05 °C days from sowing to maturity. This indicates AQH-04 took the longest to reach maturity under this specific environment.
- **July 25th Environment:** Kanchan recorded the lowest heat unit requirement, needing 1652.6 °C days from sowing to maturity. This suggests Kanchan reached maturity relatively faster compared to other cultivars in this environment.

The accumulated heat unit requirements, represented as GDD or

°C days, reflect the cumulative thermal energy received by the crops from sowing to maturity. This measurement considers the effect of temperature on crop development and helps understand differences in crop duration and maturity under various crop-growing environments and cultivars.

Based on the findings, early sowing of maize hybrids is recommended for this area. Maize sown on July 5th achieved higher grain yield, GDD and heat use efficiency (HUE) for all hybrids compared to later sowing dates. Among the hybrids, AQH-04 produced better grain yields than other cultivars.

Table 2: Accumulated heat unit requirement at different phenophases of Kharif maize cultivars influenced by Crop growing environments: (GDD)

Sowing Date	Accumulated Heat Unit (°C days) Requirement at Different Phenophases						
	Emergence	Knee high Stage	Tasseling	Silking	Milking	Dough Stage	Maturity
Kanchan							
05-July-22	82	636.25	850.25	1062.75	1200.00	1470.15	1878.05
15-July-22	105	642.00	818.5	991.75	1150.75	1390.4	1784.55
25-July-22	103	593.00	784.25	903.75	1105.7	1350.1	1652.6
Sonari (Shweta)							
05-July-22	82	677.5	892.25	1062.75	1280.75	1485.4	1896.55
15-July-22	105	684.0	854.5	1011.75	1189.65	1423.65	1843.55
25-July-22	103	629.5	823.75	982.15	1145.7	1388.1	1684.3
AQH-04							
05-July-22	82	754.25	950.25	1139.75	1378.15	1541.9	1935.05
15-July-22	105	723.0	912.5	1091.75	1229.5	1443.15	1875.8
25-July-22	103	666.5	865.0	1021.75	1163.9	1462.3	1729.1

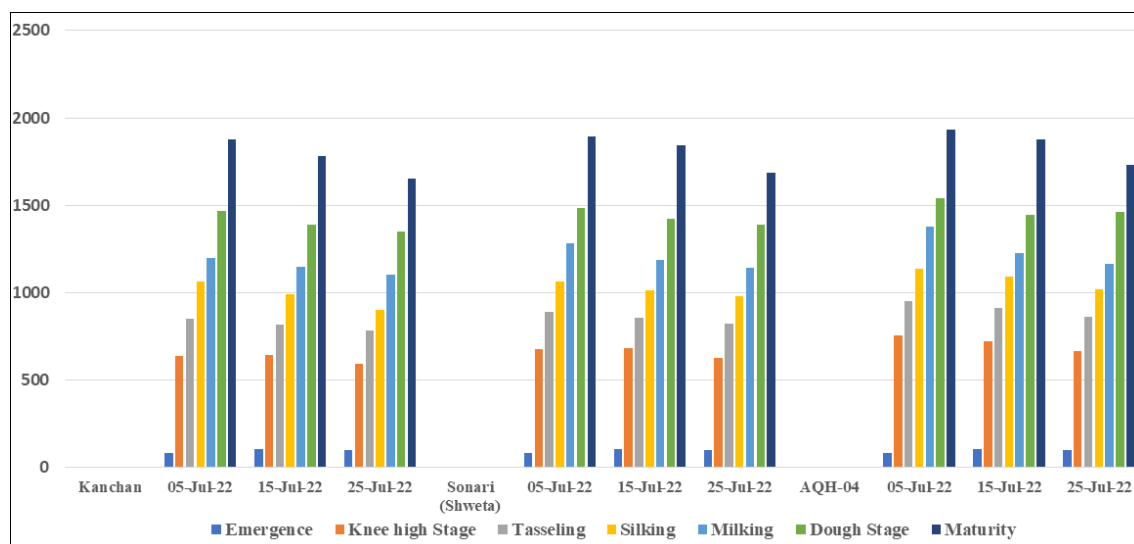


Fig 2: Accumulated heat unit requirement at different phenophases of Kharif maize cultivars influenced by Crop growing environments (GDD)

Heat use efficiency

The study found that total dry matter per plant was significantly affected at all stages of crop growth. The highest dry matter per plant was consistently observed in crops sown on June 5th across all stages. A progressive decrease in total dry matter per plant was noted with each subsequent delay in sowing (Table 3 and fig. 3). This decline is likely due to early-sown crops better exploiting climatic conditions and soil moisture during critical growth stages. Additionally, a higher leaf area index in early-sown crops likely provided more photosynthetic area, contributing to greater dry matter accumulation. Early sowing also benefited from more growing degree days and higher heat use efficiency.

Specifically, dry matter production per unit of heat was higher at all growth stages for crops sown on June 5th compared to later sowings. The table details the heat use efficiency (HUE)

requirements for Kharif maize at various growth phases, considering environmental and moisture factors.

Crop Growing Environment

- **July 5th:** The highest HUE from sowing to maturity was recorded, with a value of 0.67. This suggests that the environment on this date was most efficient in converting thermal energy into biomass production.
- **July 25th:** The lowest HUE from sowing to maturity was recorded, with a value of 0.60, indicating less efficiency in utilizing thermal energy for biomass production.

Cultivars

AQH-04: Exhibited the highest HUE among the three cultivars, with a value of 0.66, indicating superior efficiency in converting thermal energy into biomass.

Sonari (Shweta): Had an HUE value of 0.62, making it more efficient than Kanchan but less so than AQH-04.

Kanchan: Recorded an HUE value of 0.60, the lowest among the three cultivars. The table also provides HUE values for specific phenophases such as Emergence, Knee High Stage, Tasseling, Silking and Maturity, for both different growing

environments and cultivars. This indicates the effectiveness of thermal energy utilization for biomass production during these specific growth stages. These findings underscore the impact of both crop growing environments and cultivar selection on heat use efficiency, offering valuable insights into optimizing thermal energy conversion into biomass production during the growth of Kharif maize.

Table 3: Heat use efficiency of Kharif maize cultivars as affected by Crop growing environments

Treatments	Heat use efficiency (g/m ² /°C days)				
	Emergence	Knee high Stage	Tasseling	Silking	Maturity
Crop Growing Environment					
5 th July (32°C)	0.16	0.20	0.29	0.58	0.67
15 th July (31.5 °C)	0.14	0.18	0.27	0.54	0.63
25 th July (30.5 °C)	0.13	0.17	0.26	0.51	0.60
Cultivars					
Kanchan	0.12	0.15	0.25	0.50	0.60
Sonari (Shweta)	0.13	0.16	0.26	0.54	0.62
AQH- 04	0.15	0.20	0.28	0.57	0.66

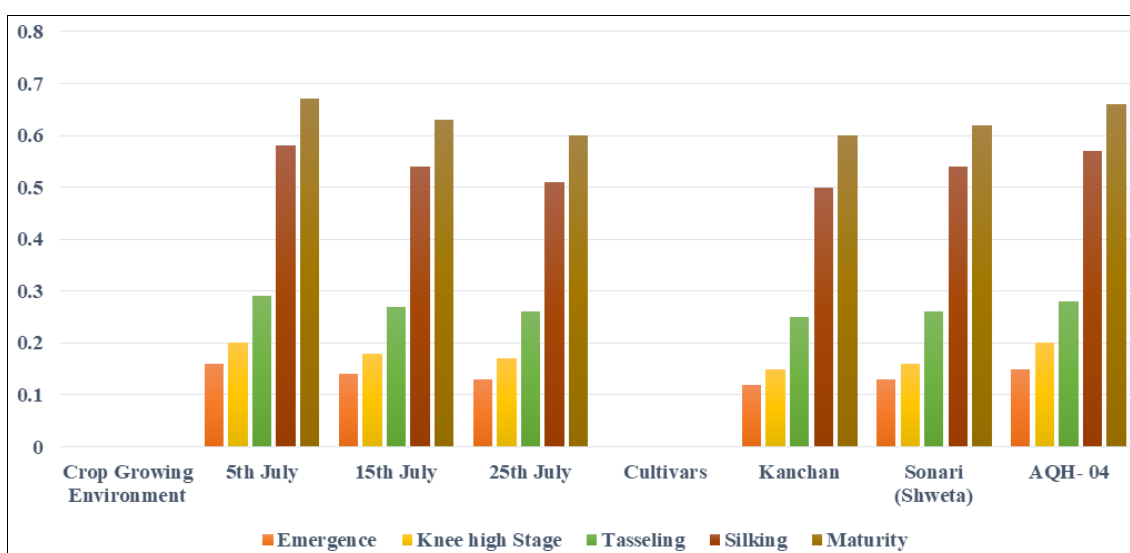


Fig 3: Heat use efficiency of Kharif maize cultivars as affected by Crop growing environment

Relationship between dry matter accumulation and growing degree day of different crop growing environments and cultivars in kharif maize: A study observed a linear relationship between heat units (Growing Degree Days or GDD) and dry matter accumulation at different growth stages of the kharif maize crop (Table-4 and fig. 4). As heat units increased, dry matter accumulation also increased. The highest heat unit demand was recorded on the first sowing date (July 5th), while

the lowest was on the third sowing date (July 25th). This suggests that maize sown on July 5th achieved higher GDD and heat use efficiency (HUE) for all hybrids compared to later sowing dates. Later sowing dates experienced fewer GDD due to shorter growing periods, increased moisture stress and higher minimum temperatures. Delayed sowing dates significantly affected maize phenology, shortening all growth stages and reducing GDD, particularly during the grain-filling period.

Table 4: Relationship between dry matter accumulation and growing degree day of different crop growing environments and cultivars in kharif maize

Growing Degree Days (°C days)	Dry Matter Accumulation (g/m ²)
1652.6	1014.9
1684.3	1072.0
1729.1	1158.8
1784.5	1318.5
1843.5	1396.7
1875.8	1501.7
1878.05	1549.4
1896.5	1646.0
1935.05	1761.2

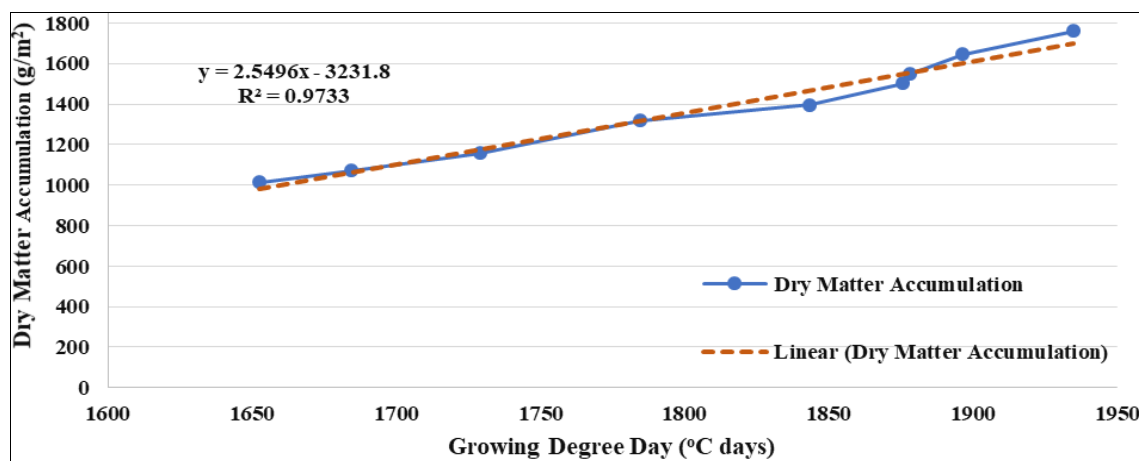


Fig 4: Relationship between dry matter accumulation and growing degree day of different crop growing environments and cultivars in kharif maize.

Conclusion

This study highlights the significant impact of sowing dates on the phenology, growth stages and productivity of maize. Delayed sowing dates were found to shorten all growth stages and reduce the growing degree days (GDD), particularly affecting the grain-filling period. As a result, early sowing of maize hybrids is strongly recommended for farmers in the studied area to maximize yield and optimize heat use efficiency (HUE). Maize sown on July 5th demonstrated the highest grain yield, GDD and HUE across all hybrids compared to later sowing dates. Among the maize hybrids, AQH-04 produced the best grain yields, showcasing its suitability for early sowing in this environment. The required GDD for physiological maturity ranged from 1652.6 to 1935.05 °C days, with later sowing dates accumulating fewer GDD due to shorter growing periods caused by increased moisture stress and higher minimum temperatures. The July 5th sowing environment had the highest HUE requirement (0.67 g/m²/ °C days), indicating greater efficiency in converting thermal energy into biomass production. The July 15th and July 25th sowing environments had progressively lower HUE requirements (0.63 and 0.60 g/m²/ °C days, respectively). In summary, early sowing, particularly around July 5th, is advantageous for achieving higher yields and better heat use efficiency in maize cultivation. This study provides valuable insights for optimizing planting schedules and selecting appropriate maize hybrids to enhance productivity in the region.

Acknowledgments

I am profoundly grateful to God for this opportunity. I also extend my heartfelt thanks to my teachers, parents and friends for their unwavering support. Additionally, the authors express their gratitude to the university for providing the facilities necessary to conduct this research.

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