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Research Paper

Effect of sowing dates and nitrogen management on thermal time requirement and heat use efficiency of *Rabi* maize in Odisha

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ABSTRACT

Rapid climate changes are imperative and it is crucial to evaluate and find ways that work for nitrogen (N) fertilizer management with appropriate sowing dates to prevent critical growth stages from being impacted by changing climatic conditions. Considering this, a field experiment was carried out in the *Rabi* season of 2023-24 at the Post Graduate Research Farm of Centurion University of Technology and Management, Odisha. The experiment was laid out in a split-plot design with different sowing dates and nitrogen split applications at different times with varying proportions. The main plots consisted of four sowing dates and four nitrogen split applications were considered in sub-plots. Results revealed that the early sown crop (31st October) took a higher number of days and heat units to attain various phenophases. Maize sown on 31st October consumed maximum heat units of 1750 °C days and the significantly highest heat use efficiency (HUE) of 3.56 kg ha^{-1} °C day^{-1} for grain yield compared to minimum heat units (1665°C days) and the significantly lowest HUE of 2.81 kg ha^{-1} °C day^{-1} for 15th December sown crops. Among split applications of nitrogen, treatment consisting of 25% N basal+25% N prior to knee high + 25% N at knee high +25% N at tasseling recorded the highest HUE (3.55 kg ha^{-1} °C day^{-1}). The sowing of maize crop on 31st October with 25% N basal+25% N prior to knee high + 25% N at knee high +25% N at tasseling have been found to be the most efficient for heat utilisation.

Keywords: Heat units, Heat use efficiency, Nitrogen management, Phenology, Sowing dates

Maize (*Zea mays* L.), a highly significant cereal crop with the broadest adaptability and highest genetic yield potential is an essential staple food for humans (Singh *et al.,* 2024). It requires less water than rice or wheat and its short growth cycle makes it ideal for spring and *Rabi* seasons. This has led to increased popularity among farmers and corporations due to its high yield potential (Biswas *et al.,* 2024). Temperature is a quintessential factor for crop production and directly influences the production and quality of produce (Girijesh *et al.,* 2011; Hatfield and Prueger, 2015). The growing degree days (GDD) are an important meteorological parameter used to relate crop growth and yield to climatic conditions prevailing during the crop growing period. Crop sown on various dates and managed differently in terms of nitrogen at different stages of crop growth generates ample information to determine the optimal choice with logical explanation (Sharangi and Roychowdhury, 2014). Maize can harness solar energy more effectively and tolerate higher temperatures up to a critical limit due to its C_4 plant characteristics. Heat stress refers to temperatures that exceed a specific threshold, leading to irreversible damage to crop growth and development. Both high and low temperatures can disrupt this process. Elevated temperatures can lead to various changes in the morphological, anatomical, physiological and biochemical aspects of maize. The heat use efficiencies can be used effectively for yield forecasting. Therefore, there is need to determine the growing degree days (GDD), helio-thermal units (HTU) and heat use efficiency (HUE) of *rabi* maize under different sowing environments and nitrogen management in Odisha.

MATERIALS AND METHODS

Experiment details

The field experiment was carried out during *Rabi* 2023-24 at Post Graduate Research Farm, M. S. Swaminathan School of

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Agriculture, CUTM, Odisha, India. It was carried out in split plot design with four sowing dates *i.e.* S_1- October 31st, S_2 -November 15th, S_3 - November 30th and S_4- December 15th in main plots and four nitrogen split applications *i.e.* N_1-50 % N as basal + 50% at knee-high; N_2- 33 % N as basal + 33% at knee-high + 33 % at tasselling; N_3- 25 % N as basal + 25% prior to knee-high + 25% at knee-high + 25% at tasselling; N_4- 25 % N as basal + 25% at knee-high + 25% at tasselling+ 25% at silking in subplots. The experiment was replicated thrice.

The number of days taken to reach various growth stages of the crop, such as knee-high, tasselling, silking and physiological maturity (identified by around 90% of plants displaying yellowing cobs, ready for harvest) was visually observed and recorded as the number of days to attain these phenophases. During the harvest, productivity was evaluated by taking the grain and stover yields from the net plot. Furthermore, daily high and low temperatures, as well as the number of sunshine hours, were recorded from the agrometeorological observatory during the entire growth season. This extensive data gathering offered important information on the environmental factors influencing crop growth and productivity.

Heat units

The growing degree days (GDD) were calculated taking 10 °C as base temperature for maize (Kaur *et al.,* 2019; Leela Rani *et al.,* 2012).

$$GDD = \Sigma \left[(T_{max} + T_{min}) / 2 - T_{base} \right]$$

Where, GDD - Growing degree days (°C day), T_{max} - Daily maximum temperature (°C), T_{min} - Daily minimum temperature (°C), T_{base} - Base temperature (°C)

The helio-thermal units (HTU) was calculated by the given formula

HTU = Growing Degree Days (GDD) × Bright sunshine hours (°C day hours)

The heat use efficiencies (HUE) for grain and biomass yield were calculated as the following equation

Heat use efficiency for grain (kg ha^{-1}°C day^{-1})

= (Grain yield (kg ha^{-1})) / (GDD (°C day))

Heat use efficiency for biomass (kg ha^{-1}°C day^{-1})

= (Biomass (kg ha^{-1})) / (GDD (°C day))

RESULTS AND DISCUSSION

Crop phenology

The phenological stages of maize were affected by both sowing dates and nitrogen split applications (Table 1). Among the sowing dates, early sown crop (31st October) took significantly less number days to attain knee high (29) as well as tasseling (58) and silking (62) compared to late sown crop (15th December), which took (33) days for knee high, (62) tasseling and (67) silking, respectively. However, early sown crop recorded significantly more number of days to attain physiological maturity (117 days) compared to (103 days) taken by late sown crop. In early sowing, this might be due to the optimum temperature during the vegetative stage, which hastened the crop growth and resulted in less number of days taken to attend up to the silking stage and lower temperatures during the grain filling, which slowed down the growth rate and provided a longer grain filling period and more duration to reach to physiological maturity. For late sown maize crop, there was forced maturity due to an increase in temperature during the grain filling period which resulted in the lowest duration of the crop (103 days). Similar results were also recorded with Nilesh (2013). The timing of nitrogen application also affected the number of days taken to attend various phenological stages. The treatment consisting of 25% N basal + 25% at knee-high + 25% at tasselling + 25% at silking recorded significantly maximum number of days (33, 62, 66 and 112) to attain knee-high, tasseling, silking and physiological maturity, respectively compared to other split applications. This could indicate that a more sustained nitrogen supply prolongs the growth period, allowing for more gradual development. Early sowing and more split application of nitrogen tend to prolong the growth period, while delayed sowing and nitrogen application in lesser splits shortened it (Kaur *et al.,* 2019).

Growing degree days (GDD)

The accumulation of heat units required for maize to reach different growth stages, as influenced by both sowing dates and nitrogen split application is presented in Table 2. The crop sown on October 31st attained the significantly highest accumulated GDD (1750 °C day) to reach physiological maturity. In contrast, crop sown late on December 15th required only (1665 °C day). This indicates that earlier sowing allowed for a longer growing period and higher heat unit accumulation, which can potentially enhance crop development and yield. These results are in accordance with Abbas *et al.,* (2020) and Shrestha *et al.,* (2016). Split application of 25% N as basal + 25% at knee-high + 25% at tasseling + 25% at silking attained the significantly highest GDD (1736 °C day) and the significantly lowest GDD (1671°C) was recorded by application of nitrogen as 50 % N basal + 50% knee-high. By applying nitrogen splits at critical growth stages, such as knee high, tasseling and silking, can significantly improve nitrogen use efficiency and consequently, GDD utilization reported by Mueller *et al.,* (2017).

Helio-thermal units (HTU)

The early sown (31st October) maize consumed the significantly highest helio thermal units (5879 °C Day hours) to attain physiological maturity as compared to November 15th (5475 °C day hours); November 30th (5405 °C day hours) and December ١٥th (4071°C day hours) sown crops (Table 3). The relationship between sowing dates and thermal units is crucial, crops sown earlier attain an advantage of longer growing periods, accumulating more HTUs and leading to better biomass production. The late-sown crops reduced thermal accumulation, resulting in lower efficiency and yield reported by Mehta and Dhaliwal (2020). Among nitrogen split applications, 25% N as basal + 25% at knee-high + 25% at tasseling + 25% at silking consumed the significantly highest helio thermal units (5207 °C day hours) to attain physiological maturity as compared to 25% N basal + 25% prior to knee-high + 25% at

Table 1: Number of days taken to various phenological stages of maize as influenced sowing dates and nitrogen split applications

Treatments	Knee high	Days to tasseling	Days to silking	Physiological maturity
Sowing dates				
31st October	29	58	62	117
15th November	32	61	65	112
30th November	32	61	65	108
15th December	33	62	67	103
S.Em. ±	0.44	0.85	0.88	1.53
CD at 5 %	1.54	2.93	3.18	5.3
Nitrogen split application				
50 % N basal + 50% knee-high	30	59	63	108
33 % N basal + 33% at knee-high + 33 % at tasselling	31	60	64	110
25 % N basal + 25% prior to knee-high + 25% at knee-high + 25% at tasselling	32	61	65	110
25 % N basal + 25% at knee-high +25% at tasselling+ 25% at silking	33	62	66	112
S.Em. ±	0.55	0.96	0.98	1.74
CD at 5 %	1.83	3.37	3.56	6.02

Table 2: Growing degree days (°C day) accumulated at different stages of maize as influenced by date of sowing and nitrogen split application

Treatments	Knee high	Days to tasseling	Days to silking	Physiological maturity
Sowing dates				
31st October	440	840	903	1750
15th November	449	849	910	1701
30th November	490	855	923	1692
15th December	491	873	951	1665
S.Em. ±	5.8	10.6	19.7	21.1
CD at 5 %	20.1	36.7	68.4	73.1
Nitrogen split application				
50 % N basal + 50% knee-high	450	830	899	1671
33 % N basal + 33% at knee-high + 33 % at tasselling	460	848	913	1696
25 % N basal + 25% prior to knee-high + 25% at knee-high + 25% at tasselling	473	859	929	1705
25 % N basal + 25% at knee-high + 25% at tasselling+ 25% at silking	486	880	947	1736
S.Em. ±	5.6	10.3	15.6	20.6
CD at 5 %	16.5	30.2	45.7	60.2

knee-high + 25% at tasseling (5207°C day hours) and 33% N basal + 33% at knee-high + 33% at tasseling (5189 °C day hours). The significantly lowest helio thermal units (5184 °C day hours) were recorded by the application 50% N basal + 50% knee-high to attain physiological maturity. The crops have specific growth stages where nitrogen demand peaks and optimal HTU accumulation during these stages can enhance the effectiveness of split nitrogen applications (Fayaz *et al.,* 2022).

Heat use efficiency (HUE)

Early sown maize (31st October) attained the significantly highest heat use efficiency of (3.56 and 7.35 kg °C day^{-1}) for grain and biomass, respectively compared to late sown (15th December) maize, which recorded the significantly lowest heat use efficiency (2.81 and 4.89 °C day^{-1}) for grain and biomass, respectively (Table 4). HUE tends to increase up to a certain point with earlier sowing dates, after which it might decline due to exposes of crop to higher temperatures, which led to stress and reduced growth. Similar results were reported by Sattar *et al.,* (2023). Among different nitrogen split application, application of nitrogen as 25 % N basal + 25% prior to knee-high + 25% at knee-high + 25% at tasselling attained the significantly highest heat use efficiency of 3.55 and 7.01 °C day^{-1} for grain and biomass, respectively compared to other split applications. More number of nitrogen split applications might have significantly enhanced the heat use efficiency in crops by improving nitrogen uptake, reducing losses and optimizing timing relative to

Table 3: Accumulated helio-thermal units (°C day hr) at different stages of maize as influenced by sowing dates and nitrogen split application.

Treatments	Knee high	Days to tasseling	Days to silking	Physiological Maturity
Sowing dates				
31st October	3201	5778	7098	5879
15th November	3252	5934	7420	5475
30th November	3444	6134	7692	5405
15th December	4014	6293	7939	4071
S.Em. ±	43.1	74.92	93.5	64.6
CD at 5 %	149.4	259.2	323.7	223.7
Nitrogen split application				
50 % N basal + 50% knee-high	3345	5827	7372	5184
33 % N basal + 33% at knee-high + 33 % at tasselling	3427	6029	7416	5189
25 % N basal + 25% prior to knee-high + 25% at knee-high + 25% at tasselling	3521	6040	7616	5207
25 % N basal + 25% at knee-high + 25% at tasselling+ 25% at silking	3619	6244	7745	5250
S.Em. ±	42.1	73.1	91.3	63.1
CD at 5 %	123.0	213.5	266.7	184.3

Table 4: Heat use efficiency (°C day hr) of maize as influenced by sowing dates and split nitrogen application

Treatments	Grain yield (kg ha^{-1})	Biomass (kg ha^{-1})	Heat use efficiency (kg °C day^{-1})	
			Grain yield	Biomass
Sowing dates				
31st October	6230	12853	3.56	7.35
15th November	5713	11753	3.35	6.92
30th November	5479	11122	3.24	6.58
15th December	4678	8144	2.81	4.89
S.Em. ±	121	248.6	0.04	0.09
CD at 5 %	418.8	860.5	0.16	0.31
Nitrogen split application				
50 % N basal + 50% knee-high	4887	9694	2.92	5.80
33 % N basal + 33% at knee-high + 33 % at tasselling	5633	11013	3.32	6.49
25 % N basal + 25% prior to knee-high + 25% at knee-high + 25% at tasselling	6051	11949	3.55	7.01
25 % N basal + 25% at knee-high + 25% at tasselling+ 25% at silking	5530	11215	3.18	6.45
S.Em. ±	114.8	222.	0.04	0.08
CD at 5 %	335.3	648.2	0.12	0.23

crop needs. Similar findings were observed by Marahatta (2021).

Correlation study

Simple Pearsons correlation (r) between grain and biological yield (Fig. 1) with crop duration and various heat utilization parameters such as GDD, HTU and HTUE of *Rabi* maize was found to be positively correlated with each other.

CONCLUSION

The study concluded that sowing of *Rabi* maize on 31st October along with four split applications of nitrogen (25 % N basal + 25% prior to knee-high + 25% at knee-high + 25% at tasselling) proved to be the best one in improving heat use efficiency. Such management approaches can be employed to successfully control the effects of climate change on maize to maintain agricultural yield sustainability and food security.

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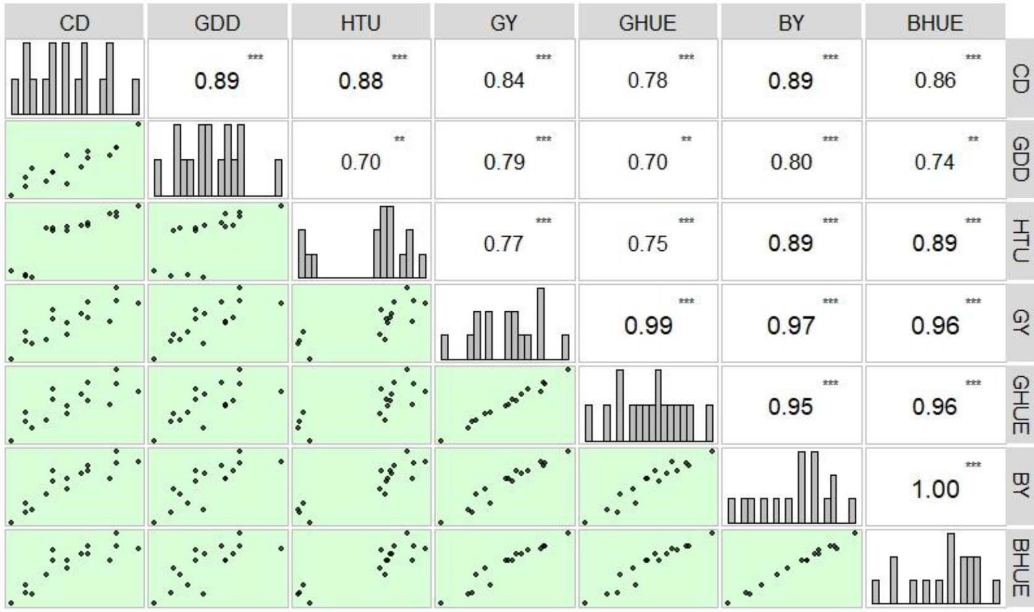

Fig 1: Correlation study to depict the inter-trait relationship among yield and various heat use parameters

(Note: CD- Crop duration, GDD- Growing degree days, HTU- Helio-thermal units, GY- Grain yield, GHUE- Grain heat use efficiency, BY- Biomass yield and BHUE- Biomass heat use efficiency)

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