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Research Article

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Estimation of water stress in maize hybrid PMH-13 from stress degree days measurements

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ABSTRACT

A split-plot field experiment was performed to estimate water stress in maize cultivar PMH-13 which was grown using two different nitrogen levels: N_1=150 kg ha^{-1} and N_2=120 kg ha^{-1}, each having four irrigation treatments based on IW/CPE ratios of 2.0 (I_1), 1.5 (I_2), 1.2 (I_3) and 1.0 (I_4), respectively. In the present study, three replications for each treatment have been employed to examine the impact of various irrigation treatments and nitrogen application on crop stress and yield. Among the four irrigation treatments, I_4 exhibited the highest SDD, whereas I_2 had the lowest value. Higher frequency of irrigation in I_1 and I_2 resulted in a reduction of crop stress due to the maintenance of higher soil moisture. Nitrogen application increased yield and reduced SDD. Thus, the irrigation strategy with IW/CPE ratio of 2.0 with nitrogen application of 150 kg ha^{-1} is observed to be most appropriate to reduce stress and maximize the yield of PMH-13.

KEYWORDS: Water stress, Maize, Stress degree days, Crop water deficit index

INTRODUCTION

Agriculture is the occupation for around two-thirds of the people in India. It is a major sector that provides not only food grains but also essential raw materials for various industrial products. The country's expansive geography supports the broadest range of crops to be cultivated on its land both edible or not across the three major cropping seasons in India, namely, rabi, kharif, and zaid. This intricate cycle of agriculture plays an extremely important role in sustaining millions of livelihoods and thereby contributing to the economic development of the nation. Amidst the agricultural belt of India comes Punjab, one of the vital contributors to the nation's food production. The fertile soil of this region has been put to work for years to get a rich yield of crops, with a significant place in the agricultural tapestry occupied by maize. In a world facing the consequences of climate change, understanding the dynamics of water absorption in plants becomes critical for ensuring food security and sustainable agricultural practices in the heartland of Punjab. Pimentel (1991) findings highlight the anticipated consequences of global warming on agriculture and food production, emphasizing a general increase in temperatures and a corresponding reduction in rainfall and water availability, particularly in temperate regions. The relationship between a plant's water status and canopy temperature underscores the significant influence of environmental factors on crop health. Leaves and canopies of crop plants experience temperature variations based on energy exchange through radiation, convection, and transpiration. Singh and Kanemasu (1983) study emphasizes the impact of factors such as wind speed, solar radiation, soil moisture, and surrounding air temperature on the leaf temperature of specific plant types.

In the realm of predictive modeling, various canopy temperature-based indices, such as stress degree days (SDD), Crop Water Deficit Index (CWDI), etc come into play which serve as valuable tools for assessing crop water consumption, and growth by statistically accumulating temperature variances. This method, as elucidated by Idso *et al.* (1977), offers a practical approach to gauge both the water requirements of crops and their overall growth patterns. Consequently, the integration of these temperature-based indices presents a promising avenue for effective irrigation water management strategies in agriculture.

Studies have demonstrated that transpiration significantly reduces the temperature of leaves (Tanner, 1963; Gates, 1964; Slatyer & Bierhuizen, 1964; Pallas *et al.*, 1967; Van Bavel & Ehrler, 1968). As water deficits develop in the leaves, stomata gradually close, leading to an increase in leaf temperature. Leaf temperature (T_l) and canopy temperatures (T_c) are linked to the level of water stress in plants (Millard *et al.*, 1978). Other temperature-based indicators of water stress in plants include leaf minus air temperature (T_l - T_a) and canopy minus air temperature (T_c - T_a), both of which have been reported to be associated with plant water stress (Van Bavel & Ehrler, 1968).

Temperature acts as a fundamental environmental factor influencing biological processes. Stress degree days (SDD) serve as a useful indicator for assessing both the timing and quantity of irrigation required for a particular crop, as outlined by Idso *et al*. (1977).

Maize (*Zea mays* L.) holds a significant position as the third most vital food crop in India, followed by rice and wheat. Maize acts as the primary source material for a wide range of industries which includes oil, protein, food sweeteners, pharmaceuticals, starch, textiles, gums, cosmetics, alcoholic beverages, and the paper industry. Maize cultivation is integral to Punjab's agriculture, contributing significantly to the state's economy and food security as indicated by Gulati *et al.* (2021). Despite its resilience and adaptability, the impact of global warming poses challenges to maize production. Changes in temperature and precipitation patterns affect crop growth and may impact the region's underground water table. Understanding these dynamics is crucial for devising sustainable strategies to ensure the continued prosperity of maize cultivation in Punjab amid evolving environmental conditions. It is important to note that an adequate supply of soil nitrogen has the potential to increase the protein content in maize grains (Zhang *et al.*, 2020). Moreover, the improvement of irrigation practices can lead to a substantial enhancement in the growth and yield characteristics of maize, as evidenced by Kumar (2018).

MATERIALS AND METHODS

The research experiment was conducted on the leaf samples of PMH-13, a maize crop variety that was sown on June 16, 2022, at the research farm, more precisely, at Tube well no: 2, under the Department of Soil Science at Punjab Agricultural University (PAU) in Ludhiana, situated at 30°53' N latitude, 75°47' E longitude, and has an altitude of 246 meters above sea level. PMH-13 is a maize hybrid recommended by PAU, and has a maturation period of 97 days. This hybrid was introduced in 2021. It features tall plants with moderately high ear placement, dark green and broad leaves, a medium and open tassel, and long conico-cylindrical ears with light orange flint grains. Its average yield is expected to be around 24.0 quintals per acre, and it exhibits moderate resistance to maydis leaf blight, charcoal rot, and maize stem borer. A split-plot arrangement as shown in Figure 1 was used for different levels of irrigation and nitrogen treatments for this experiment. The data was collected for all the field plots consisting of two levels of nitrogen and four irrigation treatments. There were 24 plots each of size (5.6 x 3 m)^2 out of which twelve plots have the nitrogen content of N_1 =150 kg ha^{-1} and the other twelve plots have the nitrogen content of N_2 =120 kg ha^{-1}. The twelve plots with the same nitrogen content were further divided into four categories (each with three replications R_1, R_2 and R_3) having different irrigation regimes i.e., based on IW/CPE ratio of 2.0 (I_1), 1.5 (I_2), 1.2 (I_3), and 1.0 (I_4). According to Prihar *et al.* (1976), the IW/CPE ratio signifies the proportion of irrigation water (IW) and cumulative pan evaporation (CPE) to determine irrigation timing based on the relation between crop evapotranspiration and pan evaporation.

DETERMINATION OF STRESS DEGREE DAYS (SDD)

Stress Degree days (SDD) defined as:

$$SDD= T_c - T_a \quad (1)$$

where T_c (T_a) is canopy (air) temperature. It has been used as a tool to monitor the various parameters related to plant growth in this paper. The stress degree days concept was originally developed by Idso *et al.* (1977) to develop a crop water stress index. For the experiment performed here, the canopy temperature is calculated using a hand-held Fluke 62 Max Digital IR Thermometer with an accuracy of ±2 °C, 28°×28° field of view, and temperature range of −30 °C + 350 °C. The temperature is taken during mid-day (1200-1400 h). SDD is evaluated from 62th day to 85th day after sowing. In the present study, the SDD value was calculated from the tasseling stage until the blistering stage. The calculation of SDD during the tasseling stage is important as it is marked as a critical reproductive stage in the growth of maize crops and it marks the transition to the reproductive phase. It is crucial for successful pollination and determining crop yield. Additionally, it is a sensitive period for environmental stress and therefore, guides the timing of various agricultural management practices.

RESULT AND DISCUSSION

The SDD values were calculated for the different stages of crop growth for all treatments and their replications. The tasseling

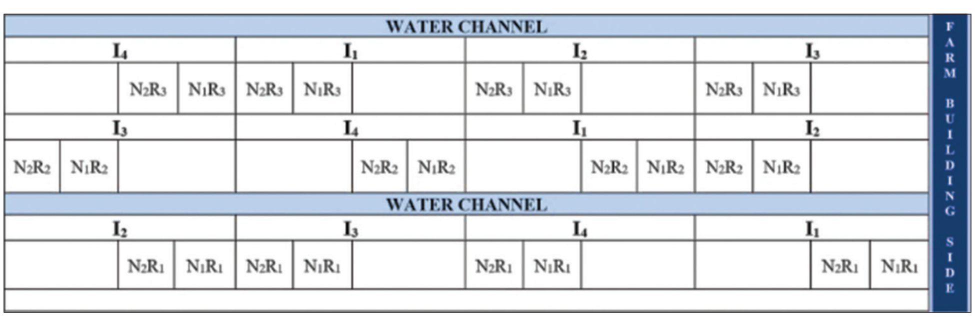

Figure 1: Layout plan of nitrogen and irrigation treatments of maize cultivar PMH-13

stage corresponds to the 62nd day from the sowing of the crop till the 67th day while the silking stage lasts from the 68th day to the 71st day followed by the blistering stage from the 72th day to the 85th day.

Figures 2 to 9 depict the distribution of SDD over various days of sowing across different treatment conditions. Each graph illustrates the SDD values for different replicates and also includes the mean value, indicated by a dotted line. These visual representations provide a comprehensive overview of how stress degree days vary over time in response to the different experimental conditions. This series of figures offers valuable insights into the relationship between treatments and stress degree.

It has been observed that the crop experienced different levels of stress on different days depending on environmental conditions as shown in Figure 10. Here, SDD for a particular treatment is calculated by averaging the value obtained from its three replications. N_1I_4 has experienced maximum stress at the blistering stage as compared to other irrigation treatments with same nitrogen level while N_2I_4 has highest stress among various irrigation treatments with same nitrogen level as illustrated in Figure 11 and Table 1.

In the blistering stage, maximum stress is observed in irrigation level I_4 followed by I_3 while I_2 have minimum SSD value. In I_1 and I_2 treatments, more frequent irrigation maintains the higher soil moisture and favorable crop microclimate. These factors resulted in lowering the difference between canopy and air temperature.

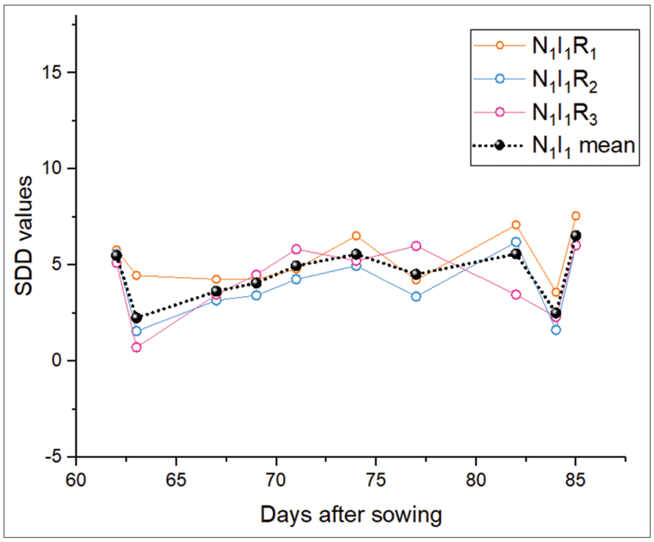

Figure 2: Days after sowing (DAS) vs SDD for treatment N_1I_1. The three replications (R_1, R_2, R_3) are shown in open circles while their average value is represented using solid circles

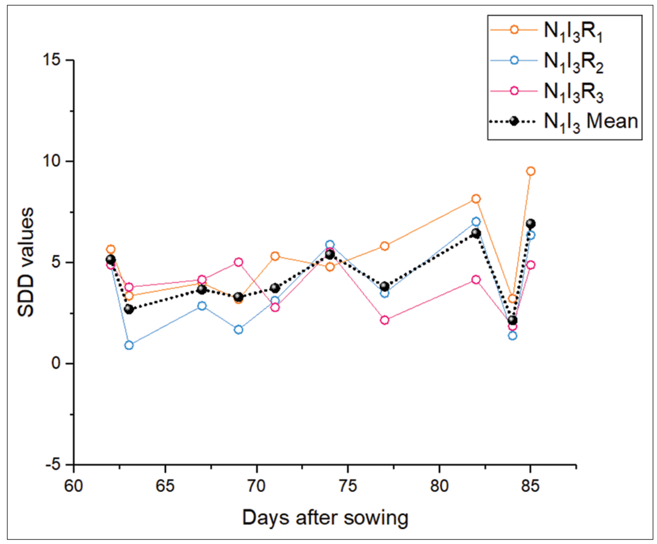

Figure 4: Days after sowing (DAS) vs SDD for treatment N_1I_3. The three replications (R_1, R_2, R_3) are shown in open circles while their average value is represented using solid circles

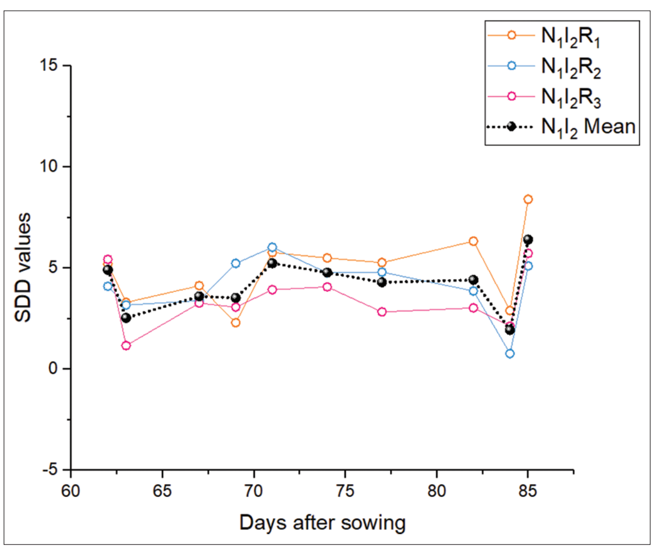

Figure 3: Days after sowing (DAS) vs SDD for treatment N_1I_2. The three replications (R_1, R_2, R_3) are shown in open circles while their average value is represented using solid circles

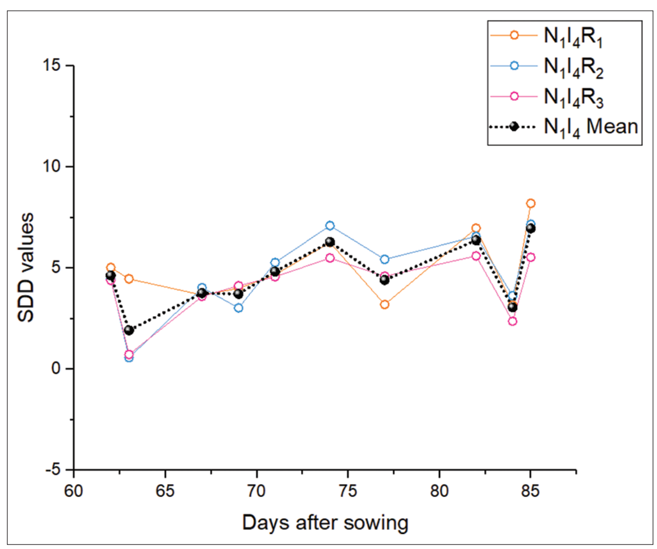

Figure 5: Days after sowing (DAS) vs SDD for treatment N_1I_4. The three replications (R_1, R_2, R_3) are shown in open circles while their average value is represented using solid circles

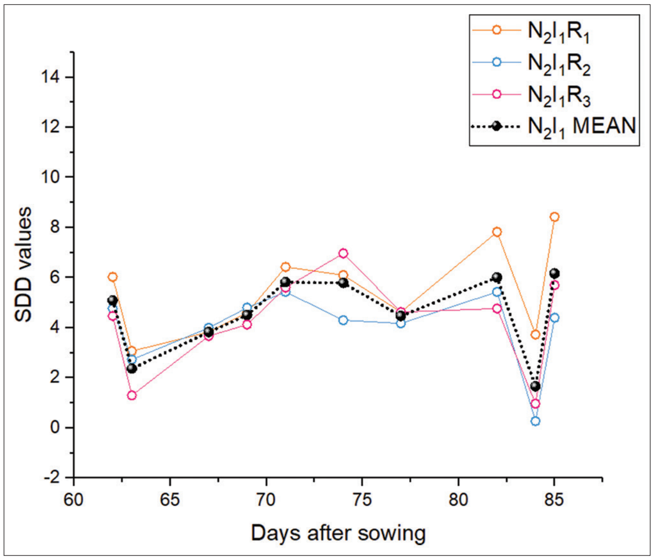

Figure 6: Days after sowing (DAS) vs SDD for treatment N_2I_1. The three replications (R_1, R_2, R_3) are shown in open circles while their average value is represented using solid circles

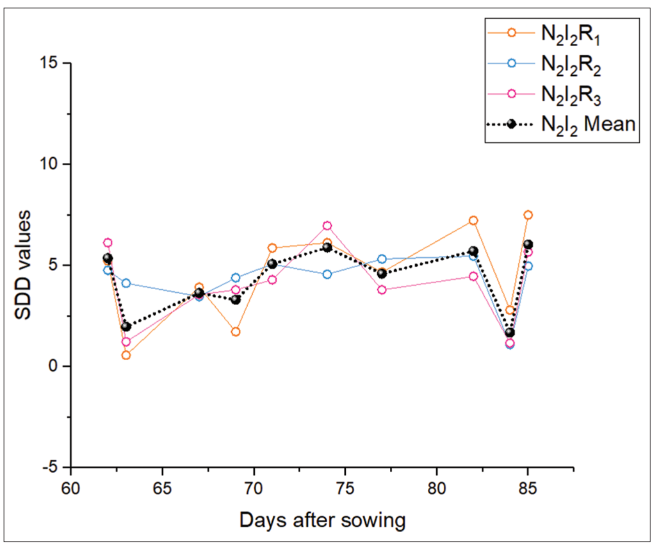

Figure 7: Days after sowing (DAS) vs SDD for treatment N_2I_2. The three replications (R_1, R_2, R_3) are shown in open circles while their average value is represented using solid circles

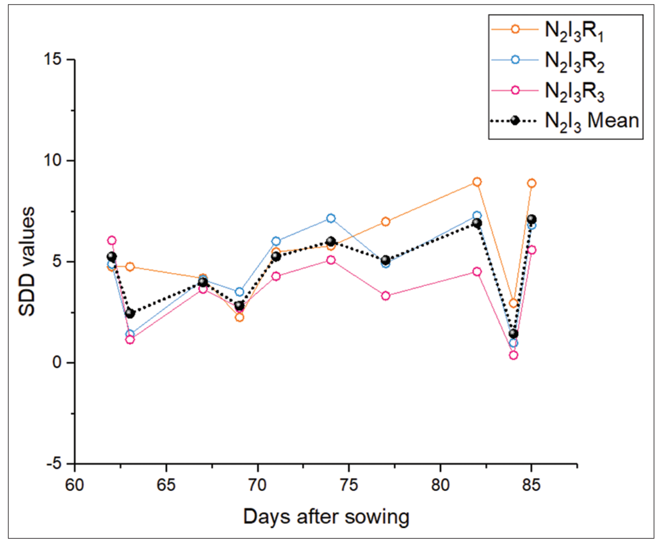

Figure 8: Days after sowing (DAS) vs SDD for treatment N_2I_3. The three replications (R_1, R_2, R_3) are shown in open circles while their average value is represented using solid circles

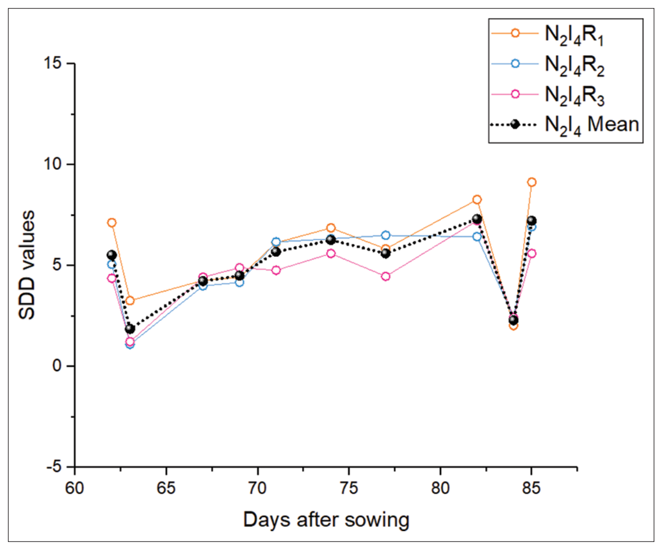

Figure 9: Days after sowing (DAS) vs SDD for treatment N_2I_4. The three replications (R_1, R_2, R_3) are shown in open circles while their average value is represented using solid circles

As discussed in this paper, use of different nitrogen and irrigation levels affect the various parameters of maize crop such as grain yield, straw yield, mean SDD values and Relative Leaf Water content (RLWC) etc. Table 2 summarizes the average value of these parameters obtained using three replications for each nitrogen and irrigation treatment. The Relative Leaf Water content (RLWC) parameter was determined by extracting leaves from the maize canopy. These leaves were washed using distilled water to eliminate any external impurities. Subsequently, gentle cleaning with filter paper was performed to remove dirt particles. The cleaned strips were then submerged in distilled water to facilitate complete water absorption, achieving a state of full turgidity. The duration of immersion, typically lasted between 10 to 12 hours and was closely monitored to ensure adequate hydration. After immersion, the fully turgid leaves were weighed and subjected to complete drying under an infrared lamp. RLWC has been calculated using the expression:

$$\text{RWLC } (\%) = \frac{\text{Fresh leaf weight} - \text{Dry leaf weight}}{\text{Fully turgid leaf weight} - \text{Dry leaf weight}} \text{x100}$$

COMMULATIVE STRESS DEGREE DAYS

Cumulative Stress Degree Days (CSDD) is the summation of canopy temperature deviations from the air temperature over a specific period. It helps in understanding how much

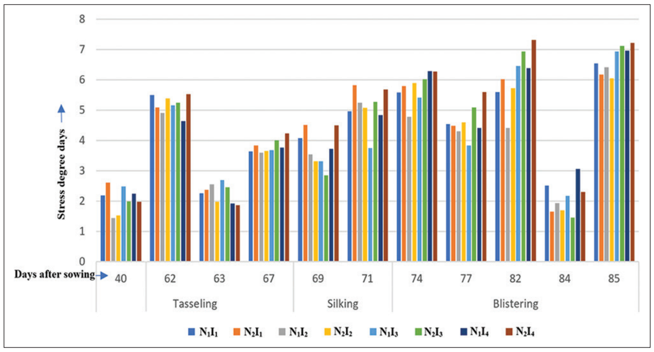

Figure 10: Different stages of maize vs SDD for all the treatments

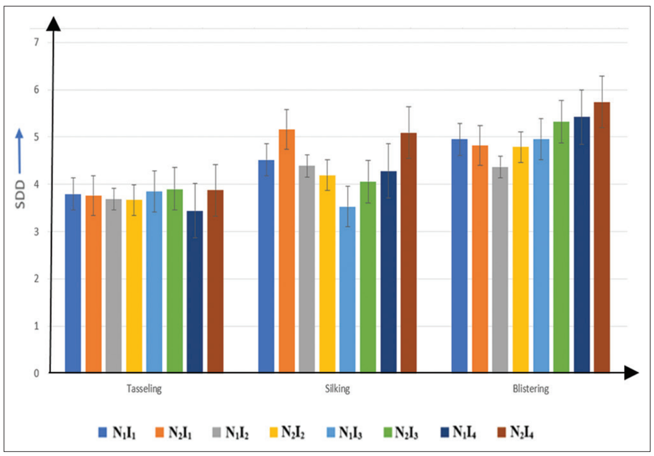

Figure 11: The mean value of SDD at different stages of maize for different treatments

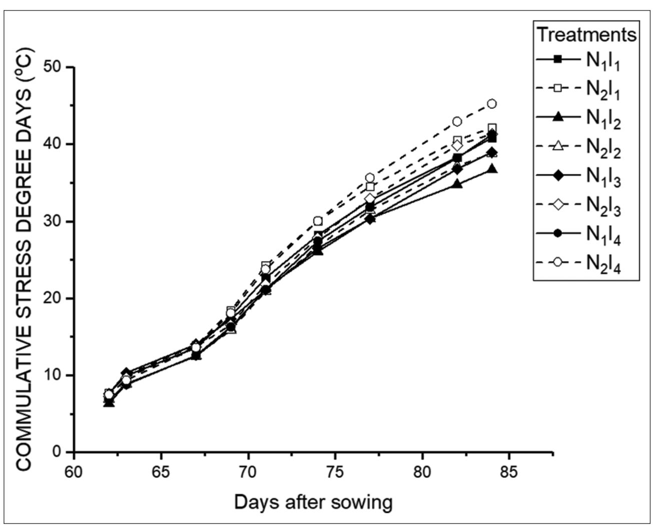

Figure 12: CSDD values for maize crop for different nitrogen and irrigation treatments vs days after sowings

temperature stress a crop has experienced during growth period.

CSDD is calculated by using following equation:

$$\text{CSDD} = \sum_{i=1}^{n}(T_c - T_a) \tag{2}$$

Table 1: Mean value of SDD for different treatment at tasseling, silking and blistering stage

Treatments	Stages		
	Tasseling	Silking	Blistering
N_1I_1	3.80	4.52	4.95
N_1I_2	3.68	4.39	4.37
N_1I_3	3.84	3.53	4.96
N_1I_4	3.44	4.28	5.52
N_2I_1	3.76	5.17	4.82
N_2I_2	3.67	4.20	4.79
N_2I_3	3.90	4.06	5.32
N_2I_4	3.87	5.08	5.74

Table 2: Grain yield, Straw yield, SDD and RLWC of maize for different nitrogen and irrigation levels

Treatment	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	∑ SDD 62-85 DAYS	RLWC (%)
N_1I_1	33.14	102.34	4.52	95.58
N_1I_2	26.63	78.40	4.16	88.93
N_1I_3	21.52	58.12	4.34	89.76
N_1I_4	26.10	70.40	4.60	90.71
N_2I_1	27.36	90.42	4.57	91.02
N_2I_2	19.37	71.29	4.33	93.87
N_2I_3	18.94	60.12	4.64	87.92
N_2I_4	20.48	66.03	5.05	92.93

T_c and T_a are canopy and air temperature respectively, summed over n number of measurements ranging from tasseling to blistering stage which is 9 in present study. In general, when a plant possesses sufficient water, T_c - T_a tends to hover around zero or dip into negative values. Conversely, if the plant experiences water stress, T_c - T_a will be greater than zero. Therefore, aggregating the positive values of T_c - T_a can function as an indicator of when irrigation is necessary. The plot of CSDD versus days after sowing in present study is shown in Figure 12 and infers that CSDD increases sharply after 70th day of sowing till 85th day as afterward there is no need for irrigation. Hence, it is important to monitor the crop in this period.

CONCLUSION

The results indicate that the I_4 irrigation treatment exhibited the highest SDD while I_2 had the lowest SDD. However, during the tasseling, silking, and blistering stages I_3 and I_4 demonstrated the highest SDD values, while I_2 had the lowest SDD value. This outcome was attributed to the less frequent irrigation in I_4, which led to a greater disparity between canopy and air temperatures. In comparison to I_1, I_4 exhibited the highest canopy temperature difference during the tasseling stage. Notably, the tasseling stage showed lower SDD values across all irrigation levels compared to the silking and blistering stages. More frequent irrigation in the I_1 and I_2 treatments contributed to maintaining higher soil moisture levels and a favourable crop microclimate, leading to a reduced difference between canopy and air temperatures. Moreover, the addition of nitrogen fertilizer increases the yield and reduces the stress due to temperature as in the case of N_1 treatments, grain yield is more than that of N_2 treatments and SDD value is lower for N_1. Although minimum stress is obtained for treatment

N_1I_2 but considering the other important parameters such as grain and straw yield, this study proposes the implementation of an irrigation strategy aligned with the IW/CPE ratio of 2.0, coupled with the application of nitrogen N_1=150 kg ha^{-1} i.e. N_1I_1 as a superior management intervention for maize hybrid PMH-13. This approach effectively mitigates crop stress while concurrently maximizing crop yield and production. Crop water stress index is a quick method to gauge crop water stress using infrared thermometers and therefore, proved as a very useful tool for monitoring the growth of crops and its yields.

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