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Infrared Thermometry Studies for Estimation of Crop Water Stress Index

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Authors' contributions

This work was carried out in collaboration among all authors. Authors PS, MVR and KK did research work on proposed study, author PS assisted in performance of statistical analysis, wrote the protocol and wrote the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

An IR thermometry enables non-contact temperature measurements of the crop canopy, capturing infrared radiation emitted by objects without physical contact, which is beneficial for accurate Crop Water Stress Index (CWSI) estimation as it minimizes interference and temperature reading alterations. In this study, handheld IRT was used to measure the canopy temperature of selected crops in 32 farms, 8 each in crop of Maize, chilly, groundnut and Black gram which were predominantly grown in Bapatla and Prakasm districts. Canopy temperature (Tc) and temperature of non-water stressed crop (Tnws) were measured 4 times during the *Rabi* season on clear sky days. The results concluded that at the initial stage, crops were grown with residual moisture of *Kharif* paddy hence at that stage CWSI values were low. The highest CWSI in the season was

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observed for the crop black gram about 0.524 and the lowest was observed for the crop chilly about 0.245. The seasonal average CWSI values for Maize, Chilly, Groundnut and Black gram were 0.382, 0.323, 0.358 and 0.399, respectively. CWSI determination helps to monitor the crop stress level, by knowing it, it is easy for irrigation scheduling by taking a threshold CWSI value to start irrigation. The average CWSI for each crop can be taken as a threshold value for irrigation scheduling.

Keywords: Canopy temperature; temperature of non-water stressed crop; infra-red thermometer; CWSI.

1. INTRODUCTION

Land and water are vital resources for agriculture and global economic development. India's diverse climates heavily rely on water for agricultural production. Water scarcity causes crop water stress, negatively impacting crops and soil. Agriculture engages over 55% of India's population, but water insufficiency affects the sector, accounting for 70% of global freshwater withdrawal. Timely farm data is crucial for effective agricultural management, promoting sustainable economic and human development. The Crop Water Stress Index (CWSI) assesses a plant's relative transpiration rate, indicating crop health. Water stress can reduce growth, yields, and increased vulnerability to diseases and pests. Monitoring CWSI identifies water stress areas, enabling timely interventions for crop health.

Since 1970, canopy temperature has been recognized as a reliable indicator of water stress in plants. When faced with water scarcity, stressed plants tend to close their stomata to conserve water, which reduces stomatal conduction, minimizes transpiration, and leads to an increase in leaf temperature [1, 2,3, 4, and 5].

The relationship between air temperature and canopy temperature has been found to be more variable during periods of water deficits [6 and 7]. Consequently, using a canopy temperature to assess plant growth and development under limited water availability has been suggested to be a more dependable approach than relying solely on air temperature [6].

Moreover, canopy temperature (Tc) can exhibit significant deviations from air temperature (Tair) [8 and 9]. For instance, following rainfall or irrigation, when the soil is wet, TC may be several degrees cooler than the surrounding air. Conversely, during dry soil conditions, canopies can be several degrees warmer than the air due to reduced transpiration rates caused by stomatal closure in response to water deficit [10].

IR thermometers allow non-contact temperature measurements, capturing infrared radiation for accurate CWSI estimation, and minimizing interference. Designed for efficiency, IR Thermometers enable rapid data collection with instant readings across multiple field locations. This ensures reliable CWSI estimations, obtaining representative crop canopy temperature samples across the study area. The irrigation effects canopy temperature and hence CWSI were dropped after irrigation compared to before irrigation reported by Mangus [11] and Alderfasi and Nielsen [12].

Based on the above-mentioned studies, this study was taken to measure CWSI of identified crops using the Idso et al, (1982) method for different crop growth stages in Rabi season.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Bapatla and Prakasm districts of Andhra Pradesh (Fig. 1). The districts are located in the tropical region of the state bearing coordinates 78º.44' to 80º.54' Eastern longitudes and 14º.57' to 16º.19' Northern Latitudes. Tropical climate conditions with extremely hot summer and cold winter prevail in these districts. April to June are the hottest months with hightemperatures in May. The mean monthly maximum temperature for Prakasm and Bapatla are 40.2ºC and 32.3ºC respectively, On the other hand, mean monthly minimum temperature of 20.3ºC and 18.5ºC respectively, the annual normal rainfall is 841.1 and 925.3mm respectively, The weather parameters measured during the crop growth period is given in Table 1. The soils in general are very fertile and they are broadly classified as Black cotton soil, red loamy and sandy loamy. The predominant crops grown in rabi season in both districts are Paddy, maize bajra, Jowar, Black gram, green gram, Bengal gram and red gram among Pulses, Cotton, Groundnut, Chillies, turmeric, tobacco and Sugarcane. Hence in this study, Maize, Chilly, Groundnut and Black grams are selected for estimation of CWSI from canopy temperature using an Infrared thermometer.

2.2 Canopy Temperature and CWSI

2.2.1 Canopy temperature (Tc)

Canopy temperature refers to the temperature of the vegetation canopy, which includes the leaves, stems, and other above-ground plant parts. It provides information about the thermal properties and physiological activity of plants. Measuring canopy temperature allows for the assessment of plant water status, stress levels, and overall health. Canopy temperature is closely linked to plant transpiration and water availability. Increasing water stress reduces transpiration and leads to higher canopy temperature.

Infrared thermometry is a noncontact method, providing surface temperature estimates without interference, integrating values over the sensor's field of view. The instrument measures the radiation emitted from the target and relates this radiation R to the surface temperature Ts by the Stefan-Boltzmann blackbody law [13].

Table 1. Mean monthly weather parameters measured during the *Rabi* season

Months	Temperature (°C)		RH (%)	Rainfal (mm)
	Min	Max		
DEC	20.6452	31.22581	65.452	1.596774
JAN	17.3548	30.48387	59.968	0.12903
FEB	18.6429	32.67857	50.893	0.14286
MAR	20.9677	33.70968	56.161	0.377419

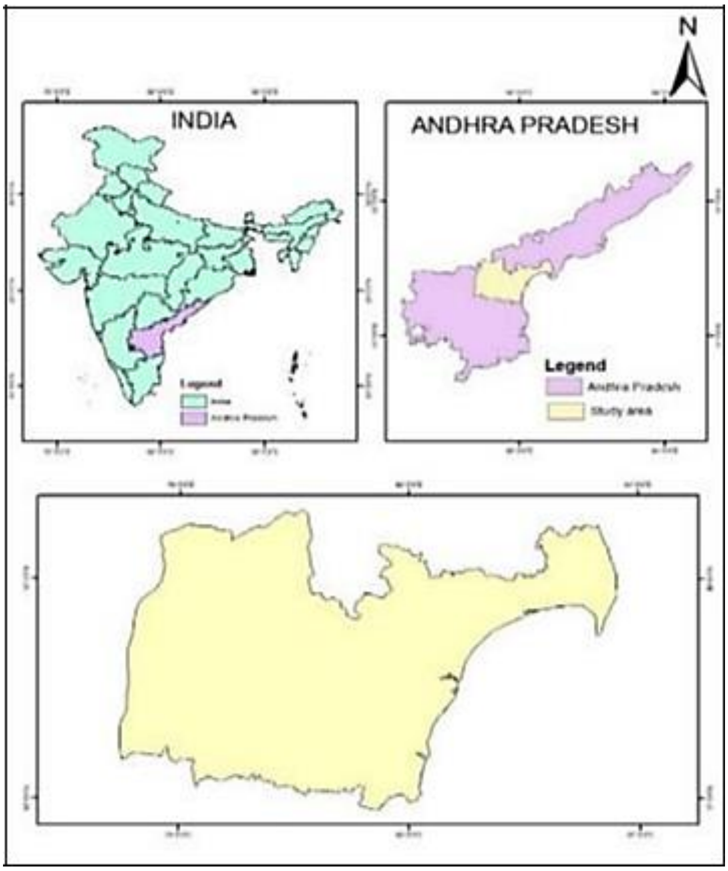

Fig. 1. Location map of study area

In this study portable handheld IR thermometer (Fig. 2.) was used to collect canopy and air temperature at 32 selected farms in the study area. The foliage temperature was measured by holding the thermometer about 30 cm above the canopy at about 45 degrees from the horizontal. Air temperature was also measured at the same time as foliage temperature. The accuracy of the instrument was calibrated and verified before purchasing from the seller. All the measurements were taken 4 times in rabi season considering four phenological crop growth stages initial stage, development stage, mid-season and harvesting stage, on clear sky days i.e., on 20-Dec 2023, 12-Jan 2023, 02-Feb 2023 and 01-Mar 2023, the view of measuring canopy temperature from IRT is shown in Fig. 2.

2.2.2 Temperature of non-water-stressed (Tnws)

The Tnws condition occurs when the vegetation is not experiencing water stress. Under In this condition the crop has sufficient water available in the soil root zone. Tnws serves as a reference point for CWSI calculation, allowing for a more accurate estimation of the plant's water stress level. By utilizing Tnws in the CWSI formula, researchers and farmers can better understand the water status of crops, enabling them to make more informed decisions regarding irrigation and crop management, thus improving water-use efficiency and optimizing crop yields. Data from a single day of measurement would not provide sufficient information to determine non-water-stressed baselines that change with crop growth stage and also the lower baseline could be different for a crop under different developmental phases as described by different researchers [14]. Hence an alternative approach was used in this study to determine a lower limit for CWSI at different crop growth stages. Temperature of non-water stressed is collected several times throughout the growing season for all the selected crops at each growth stage in *Rabi* season to overcome this argument.

Fig. 2. Canopy temperature measurement using IRT in different crops

Fig. 3. Portable Infra-red Thermometer

2.2.3 Temperature of water-stressed (Tws)

Tws is the temperature of a water-stressed crop, measured from a stressed crop. This baseline is crucial for CWSI determination, providing a reference to assess water stress, standardize and compare measurements, differentiate stress levels, and enhance accuracy. It supports research comparisons and validations. Leaf temperatures are often warmer than the surrounding air [13]. Hence in this study the value of (Tc-Ta) UL was set at Ta+5°C, based on previous studies in different crop species [15 and 16].

CWSI was calculated from the following formula (equation 1) given by [16].

$$\mathrm{CWSI} = \frac{(T_c - T_a) - (T_{nws} - T_c)_{LL}}{(T_{ws} - T_a)_{UL} - (T_{nws} - T_c)_{LL}} \qquad (1)$$

Where,

CWSI is the Crop Water Stress Index.
Tc is canopy temperature (T°C).
Ta is air temperature (T°C).
Tnws is non-water stressed temperature i.e., the temperature of a well-watered crop (T°C).
Tws is water-stressed temperature i.e., the temperature of water-stressed crop(T°C).
LL is the lower limit.
UL is the upper limit.

3. RESULTS AND DISCUSSION

3.1 Crop Water Stress Index Derived from Canopy Temperature

CWSI was calculated using measurements taken from IRT as explained in the methodology section. The results obtained from the calculation are represented in the charts. Fig. 1. shows the CWSI profile of the rabi season. From the graph, it can be observed that CWSI values are following an increasing trend up to mid-season, this can be explained by that in *Rabi* season crops were sown immediately after harvesting paddy when the field was wet, and Plants at the initial stage use more of their water in germination, root elongation etc, and maximum CWSI is in the mid-season this can be due to crops at this stage being very sensitive to water as the crop transitions into the reproductive growth stage and starts developing fruits, it becomes increasingly sensitive to water stress. Inadequate water availability can lead to reduced fruit size, decreased sugar content, and lower overall yield. Water stress during this stage can also increase the risk of fruit cracking hence full irrigation is provided at this stage to minimise losses. And again, the CWSI is decreased at the harvesting stage this is because There is generally a decreased demand for water from the above-ground plant parts. This reduced vegetative growth decreases the overall transpiration rate and, consequently, the crop's sensitivity to water stress and hence watering is not done at this stage. Analysis reveals that the seasonal average CWSI for Maize, Chilly, Ground nut and Black gram is 0.310, 0.329, 0.358 and 0.399 respectively (Table 2). Mean, SD, Variance, Range, Maximum and Minimum CWSI values are given in Table 2.

Fig. 2 shows the graphical representation of CWSI values at different crop growth stages of selected crops. Fig. 2 (a) shows maize has having highest CWSI of 0.382 where at that stage maize crop utilizes most of its water in cob development, reduced water at this stage may reduce the cob size. Fig. 2 (b) Chilly has having highest CWSI of about 0.388 at mid- season, readings at this stage were taken 2 days before irrigation, and lowest CWSI for chilly is 0.245. The average CWSI of chilly for the rabi season is 0.323. Fig. 2 (c) Groundnut has seasonal average CWSI is about 0.358 with the highest value as 0.482. Fig. 2(d) Black gram has highest CWSI is about 0.524 at midseason as it is a residual crop watering that is done twice throughout its crop period. Fig. 3 shows a combined graph of all the crops CWSI, from here it can be observed that among all the crops Black gram has having highest CWSI value of about 0.524 that is due, for black gram irrigation was given only twice throughout its crop period and lowest CWSI is 0.235 at the initial stage for the Chilly crop as it is irrigated more frequently than other crops.

Water scarcity is a pressing global issue, and its impact on agricultural productivity is a major concern. By utilizing infrared thermometry to estimate Crop Water Stress Index (CWSI), this study can provide valuable insights into the water stress levels of crops in Bapatla and Prakasam districts, as well as in Latin American agricultural territories [17,18]. Understanding how crops respond to water stress and how it affects their growth and yield can aid in developing strategies to mitigate water scarcity's impact on food production [19,20] (Hernandez and Olivares, 2019).

Table 2 Statistics of CWSI values

Crops	Mean	SD	Variance	Range	Minimum	Maximum
Maize	0.310	0.100	0.010	0.482	0.205	0.687
Chilly	0.329	0.147	0.022	0.587	0.154	0.740
Groundnut	0.358	0.138	0.019	0.529	0.133	0.662
Black gram	0.399	0.115	0.013	0.388	0.202	0.591

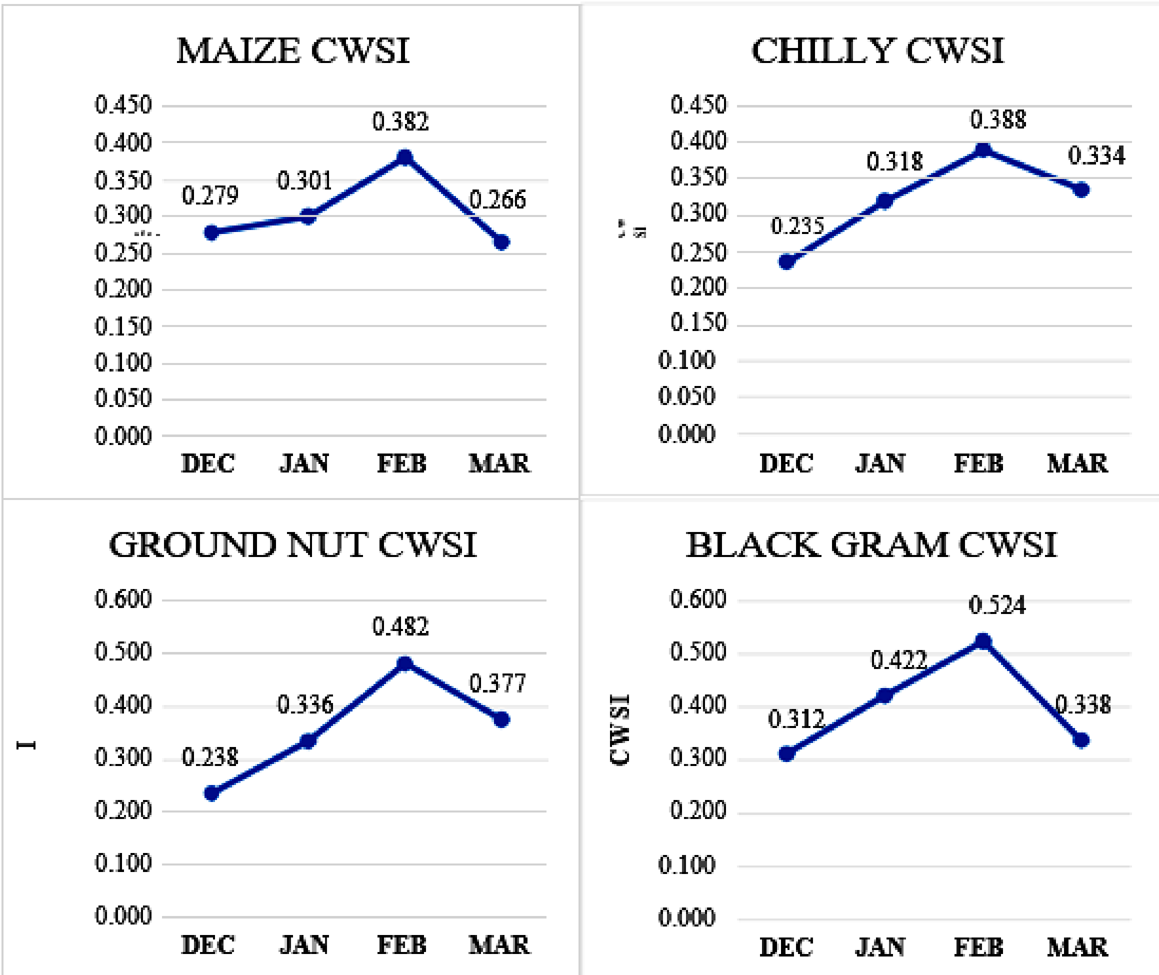

Fig. 4. CWSI at different growth stages in rabi season for
(a)Maize, (b)Chilly 179 (c)Groundnut and (d) Black gram

Infrared thermometry offers a non-invasive method for monitoring crop water stress [21] (Lopez et al. 2019). This technology can help researchers and farmers assess the physiological status of plants without physically disturbing them [22,23]. This is particularly useful for large-scale agricultural assessments, where real-time data collection on water stress can inform irrigation management decisions [24,25].

Remote Sensing and Precision Agriculture: The study's use of infrared thermometry aligns with the principles of precision agriculture. Remote sensing technologies, such as infrared imagery, can provide spatially explicit information about crop health and water stress across large agricultural areas. This can lead to more targeted and efficient irrigation practices, reducing water waste and optimizing resource use.

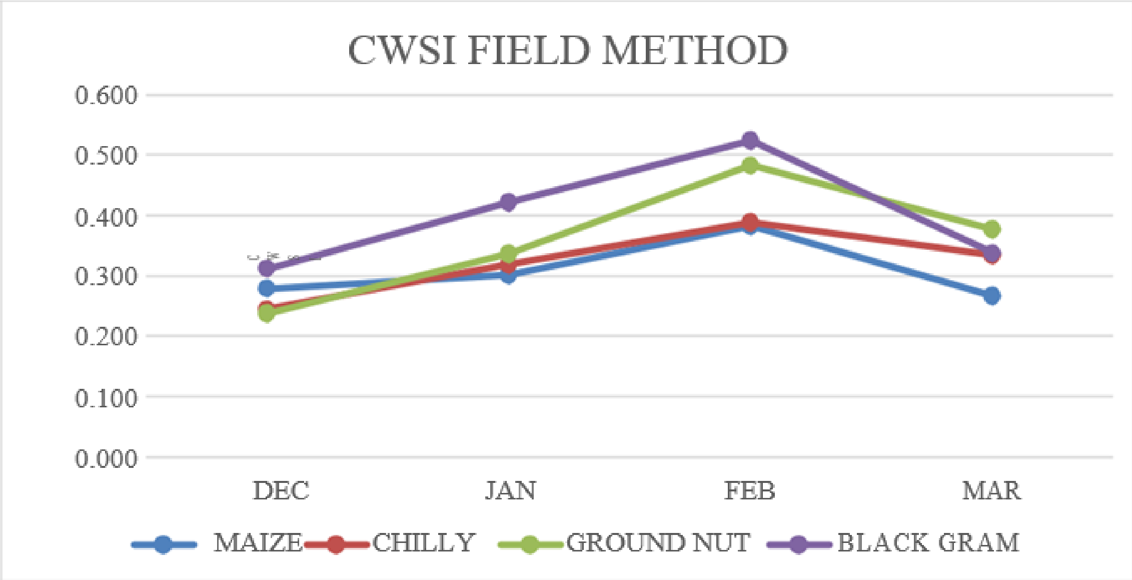

Fig. 5. Comparison of CWSI profiles for different selected crops in *Rabi* season

Comparative Analysis: By comparing the results of water stress estimation between Bapatla and Prakasam districts and agricultural territories in Latin America, the study can identify similarities and differences in crop responses to water stress under varying environmental and climatic conditions [26]. This comparative analysis can contribute to our understanding of crop-water relationships across different regions and guide the development of region-specific irrigation strategies [27,28].

With climate change affecting weather patterns and water availability, studies that assess crop responses to water stress become crucial for adapting agricultural practices to changing conditions [29] (Viloria et al. 2023). The findings of this study can offer insights into how crops in different regions respond to water stress, aiding in the formulation of adaptive strategies for sustainable agriculture [30] (Pitti et al. 2020).

Infrared thermometry data can contribute to data-driven decision making for farmers, water resource managers, and policymakers (Zingaretti and Olivares, 2018). Accurate and timely information on crop water stress can help optimize water allocation, reduce economic losses due to crop failure, and enhance overall agricultural resilience [31]. The comparison between South Asian and Latin American agricultural territories fosters international scientific collaboration and knowledge sharing. Insights gained from one region can inform practices in the other, leading to a broader understanding of agricultural water management [32].

In conclusion, the study's scientific relevance lies in its potential to advance our understanding of crop water stress estimation using infrared thermometry, its applicability to different geographical regions, and its contribution to addressing global challenges related to water scarcity, agricultural productivity, and sustainable resource management [33,34].

4. CONCLUSION

In this study, it was possible to show that canopy temperature was able to give crop water stress index. Handheld infra-red thermometer is a readily available instrument and easy to measure canopy temperature at that particular instant. Since the crops were sown with residual moisture content after the harvest of *kharif* paddy, that moisture might not be sufficient for crops' water requirement. The average highest CWSI for the season was 0.524 at mid- season for Black Gram. The result suggests that CWSI is sensitive to plant water status, however at mid-season as the plant is more Vigors at this stage and plant utilizes its water in development of fruit, proper watering at that time is important. CWSI determination helps to monitor the crop stress level, by knowing it, it is easy for irrigation scheduling by taking a threshold CWSI value to start irrigation. The average CWSI for each crop can be taken as a threshold value for irrigation scheduling.

CONSENT

As per international standard or university standard, respondents' written consent has been collected and preserved by the author(s).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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