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Infrared Thermometry Studies for Estimation of Crop Water Stress Index

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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 CWSI estimation as it minimizes interference and temperature reading alterations. In this study, handheld IRT was used to measure 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 (T_c) and temperature of non-water stressed crop (T_{nws}) were measured 4 times during *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 observed for the crop black gram about 0.524 and 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~~ 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.

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Keywords: canopy temperature, temperature of non-water stressed crop, infra-red thermometer, CWSI.

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1. INTRODUCTION

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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 fresh water 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

32 growth, yields, and increase vulnerability to diseases and pests. Monitoring CWSI identifies
33 water stress areas, enabling timely interventions for crop health.
34 Since 1970, canopy temperature has been recognized as a reliable indicator of water stress
35 in plants. When faced with water scarcity, stressed plants tend to close their stomata to
36 conserve water, which reduces stomatal conduction, minimizes transpiration, and leads to an
37 increase in leaf temperature (1, 2,3, 4, and 5)

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

42 Moreover, canopy temperature (T_c) can exhibit significant deviations from air
43 temperature (T_{air}) (8 and 9). For instance, following rainfall or irrigation, when the soil is wet,
44 T_c may be several degrees cooler than the surrounding air. Conversely, during dry soil
45 conditions, canopies can be several degrees warmer than the air due to reduced transpiration
46 rates caused by stomatal closure in response to water deficit (10).

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

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

56 57 **2. MATERIALS AND METHODS**

58 59 **2.1 Study area**

60 The study was conducted in Bapatla and Prakasm district of Andhra Pradesh (Fig
61 .1). The districts are located in the tropical region of the state bearing coordinates 78°.44' to
62 80°.54' Eastern longitudes and 14°.57' to 16°.19' Northern Latitudes. Tropical climate
63 conditions with extreme hot summer and cold winter prevails in these districts. April to June
64 are the hottest months with high temperature in May. The mean monthly maximum
65 temperature for Prakasm and Bapatla are 40.2 °C and 32.3°C respectively, On the other hand,
66 mean monthly minimum temperature 20.3 °C and 18.5°C respectively, the annual normal
67 rainfall is 841.1 and 925.3mm respectively, the weather parameters measured during the crop
68 growth period are given in Table 1. The soils in general are very fertile and they are broadly
69 classified as Black cotton soil, red loamy and sandy loamy. The predominant crops grown in
70 rabi season in both districts are Paddy, maize bajra, Jowar, Black gram, green gram, Bengal
71 gram and red gram among Pulses, Cotton, Groundnut, Chillies, turmeric, tobacco and
72 Sugarcane. Hence in this study Maize, Chilly, Groundnut and Black grams are selected for
73 estimation of CWSI from canopy temperature using Infra-red thermometer.

74 **Table 1: Mean monthly Weather parameters measured during *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

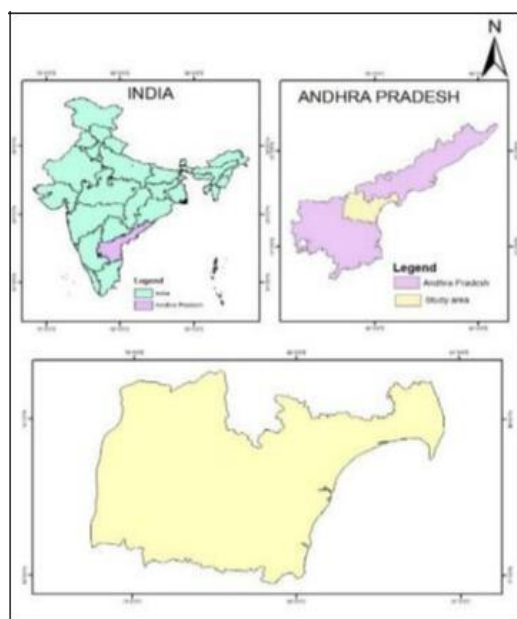
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78 **Fig 1 Location map of study area**

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80 **2.2 Canopy temperature and CWSI**

81 **2.2.1. Canopy temperature (T_c)**

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

88 Infrared thermometry is a noncontact method, providing surface temperature
89 estimates without interference, integrating values over the sensor's field of view. The
90 instrument measures the radiation emitted from the target, and relates this radiation R to the
91 surface temperature T_s by the Stefan-Boltzmann blackbody law (13).
92

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



102
 103 **Fig .2 Canopy temperature measurement using IRT in different crops**



104
 105 **Fig .3 Portable Infra-red Thermometer**

106 **2.2.2. Temperature of non-water-stressed (T_{nws})**

107 The T_{nws} condition occurs when the vegetation is not experiencing water stress. Under
 108 this condition the crop has sufficient water available in the soil root zone. T_{nws} serves as a
 109 reference point for CWSI calculation, allowing for a more accurate estimation of the plant's
 110 water stress level. By utilizing T_{nws} in the CWSI formula, researchers and farmers can better
 111 understand the water status of crops, enabling them to make more informed decisions
 112 regarding irrigation and crop management, thus improving water-use efficiency and optimizing
 113 crop yields. Data from a single day of measurement would not provide sufficient information
 114 to determine non-water-stressed baselines that change with crop growth stage and also the
 115 lower baseline could be different for a crop under different developmental phases as described
 116 by different researchers (14). Hence an alternative approach was used in this study to
 117 determine lower limit for CWSI at different crop growth stages. Temperature of non-water
 118 stressed is collected several times throughout the growing season for all the selected crops at
 119 each growth stage in *Rabi* season to overcome this argument.
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121 **2.2.3. Temperature of water-stressed (T_{ws})**

122 T_{ws} is the temperature of a water-stressed crop, measured from a stressed
 123 crop. This baseline is crucial for CWSI determination, providing a reference to assess
 124 water stress, standardize and compare measurements, differentiate stress levels, and
 125 enhance accuracy. It supports research comparisons and validations. Leaf
 126 temperatures are often warmer than the surrounding air (13). Hence in this study the
 127 value of $(T_c - T_a)_{UL}$ was set at $T_a + 5^\circ\text{C}$, based on previous studies in different crop
 128 species (15 and 16).
 129 CWSI was calculated from the following formula (equation 2.1) given by (16).

130
$$CWSI = \frac{(T_c - T_{nws}) - (T_c - T_a)_{LL}}{(T_c - T_a)_{UL} - (T_c - T_a)_{LL}} \dots\dots\dots(2.1)$$

131 Where,

132 CWSI is Crop Water Stress Index.

133 T_c is canopy temperature ($^\circ\text{C}$).

134 T_a is air temperature ($^\circ\text{C}$).

135 T_{nws} is non water stressed temperature i.e., temperature of well-watered crop ($^\circ\text{C}$).

136 T_{ws} is water stressed temperature i.e., temperature of water stressed crop ($^\circ\text{C}$).

137 LL is lower limit.

138 UL is upper limit.

139 **3. RESULTS AND DISCUSSIONS**

140 **3.1 Crop Water Stress Index derived from canopy temperature**

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142 CWSI was calculated using measurements taken from IRT as explained in the
 143 methodology section. The results obtained from the calculation is represented in the charts.
 144 Fig.1. shows the CWSI profile of rabi season. From the graph it can be observed that CWSI
 145 values are following a increasing trend up to mid-season, this can be explained by that in *rabi*
 146 season crops were sown immediately after harvesting paddy, when the field was wet, and
 147 plants at initial stage uses of more of its water in germination, root elongation etc, and
 148 maximum CWSI is in the mid-season this can be due to crops at this stage are very sensitive
 149 to water as the crop transitions into the reproductive growth stage and starts developing fruits,
 150 it becomes increasingly sensitive to water stress. Inadequate water availability can lead to
 151 reduced fruit size, decreased sugar content, and lower overall yield. Water stress during this
 152 stage can also increase the risk of fruit cracking hence full irrigation is to provide at this stage
 153 to minimise losses. And again, the CWSI is decreased at harvesting stage this is because
 154 there is generally a decreased demand for water by the above-ground plant parts. This
 155 reduced vegetative growth decreases the overall transpiration rate and, consequently, the
 156 crop's sensitivity to water stress and hence watering is not done at this stage. Analysis reveals
 157 that the seasonal average CWSI for Maize, Chilly, Ground nut and Black gram are 0.310,
 158 0.329, 0.358 and 0.399 respectively (Table 2). Mean, SD, Variance, Range, Maximum and
 159 Minimum CWSI values are given in Table 2 .

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

170 0.524 that is due, for black gram irrigation was given only twice throughout its crop period and
 171 lowest CWSI is 0.235 at initial stage for Chilly crop as it is irrigated frequently than other crops.

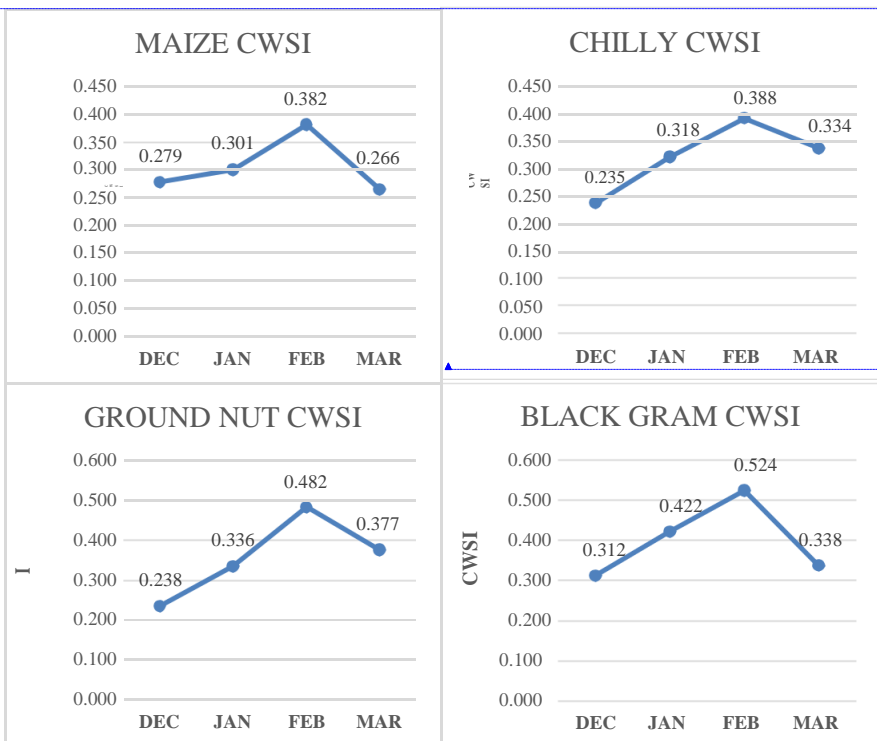
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Table 2 Statistics of CWSI values

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

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

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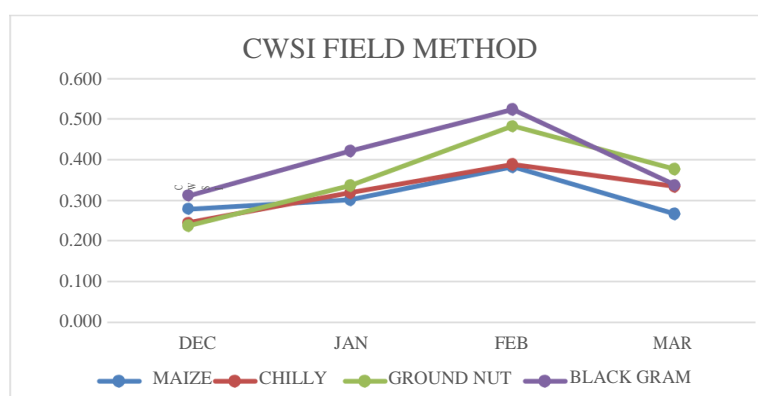
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Fig 5 Comparison of CWSI profiles for different selected crops in Rabi season

182 **4. CONCLUSION**

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

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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 (Hernandez et al. 2018; Olivares and Hernandez, 2020). 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 (Hernandez and Olivares, 2019; Hernandez et al. 2020).

Infrared thermometry offers a non-invasive method for monitoring crop water stress (Lopez et al. 2019; Olivares and Lopez, 2019). This technology can help researchers and farmers assess the physiological status of plants without physically disturbing them (Olivares and Zingaretti, 2019; Paredes et al. 2021). This is particularly useful for large-scale agricultural assessments, where real-time data collection on water stress can inform irrigation management decisions (Parra et al. 2012; Zingaretti et al. 2016).

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.

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 (Olivares et al. 2017). This comparative analysis can contribute to our understanding of crop-water relationships across different regions and guide the development of region-specific irrigation strategies (Olivares et al. 2018).

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 (Montenegro et al. 2021; Vilorio 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 (Pitti et al. 2020; Olivares Campos, 2023).

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 (Olivares et al. 2018a). 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 (Olivares et al. 2018b).

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.

205

206 **CONSENT**

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

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