

Canopy temperature as indicator of thermal and nutrient stresses in wheat crop

SUKHJEET KAUR, SOM PAL SINGH and P. K. KINGRA

*School of Climate Change and Agricultural Meteorology,
Punjab Agriculture University, Ludhiana – 141 004, India*

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e mail: sukhjeetkaur88@gmail.com

सार - गेहूँ की फसल के लिए विभिन्न तापीय कालों, नाइट्रोजन स्तरों और कैनोपी तापमान पर एनथीसिस के बाद विधियों और उनके इनडाइसिस के प्रभावों का पता लगाने के लिए 2013-14 और 2014-15 के रबी के दौरान स्कूल ऑफ क्लाइमेट चेंज और कृषि मौसम विज्ञान, पंजाब कृषि विश्वविद्यालय, लुधियाना के अनुसंधान खेतों पर क्षेत्र का अध्ययन किया गया। मुख्य प्लॉट में तापमान के तीन क्रमों में आने वाले शोधन (D₁ - अक्टूबर 30, D₂ - नवम्बर 15 और D₃ - नवम्बर 30) उप प्लॉट में तीन नाइट्रोजन लेवल (N₁ - RDF - N, N₂ - 125% RDF की संस्तुत मात्रा (संस्तुत N से 50% अधिक) N₃ - 150% RDF (संस्तुत N से 50% अधिक) और चार स्ट्रेस मैनेजमेंट एन थिसिस स्ट्रेटजी के बाद (P₀ - नियंत्रण - छिड़काव नहीं, P₁ - पानी से छिड़काव ZnSO₄.7H₂O का P₂ - पत्तों पर छिड़काव स्पिलट- स्पिलट प्लॉट के डिजाइन तैयार करने के कारण सब-सब प्लॉट में एनथीसिस के 20 दिनों के बाद तियूरिया @ 10 Mm का पत्तों पर तीन बार छिड़काव किया गया। फसल के पकने की विभिन्न अवस्था के दौरान कैनोपी तापमान रिकार्ड किया गया। फसल के पकने पर स्ट्रेस डिग्री वाले दिनों का आकलन किया गया। इस आकलन से प्राप्त हुए परिणामों से यह पता चला है कि 15 नवम्बर और 30 नवम्बर को बोई गई फसल की अपेक्षा 30 अक्टूबर को बोई गई फसल की बाद की अवस्थाओं में कैनोपी का तापमान कम पाया गया है। नाइट्रोजन एप्लीकेशन में बढ़ोतरी से 1.0 से 2.0 °C तक कैनोपी के तापमान में कमी आई जो अत्यंत गहन था और अच्छी फसल औरों की अपेक्षा 150% RDF के अन्तर्गत आती है। पूर्ण विकास के समय या उसके बाद छिड़काव नियमित अंतराल में किया जाता है। फसल पर पानी का छिड़काव ZnSO₄.7H₂O और थियूरिया भी कैनोपी के तापमान को घटाता है क्योंकि ये रसायन इस अवधि के दौरान कैनापी तापमान 0.5 से 1.0 °C को कम करते हुए फसल पर गर्मी के प्रभाव को कम करता है। 15 नवम्बर और 30 नवम्बर की अपेक्षा 30 अक्टूबर में नकारात्मक SDD मान अधिक रहे जिससे कैनोपी तापमान ठंडा रहा है अर्थात् फसल स्वस्थ है और उस पर कोई प्रतिकूल असर नहीं पड़ा है। N की मात्रा बढ़ने से SDD कम होता है जिससे N के अधिक अनुप्रयोग से कैनोपी उष्मीय पर्यावरण के अच्छे होने का पता चलता है। कैनोपी तापमान और अनाज के उत्पादन के साथ SDD और अनाज उत्पादन के साथ विशेष रूप से रेखिकीय और नकारात्मक संबंध पाए गए।

ABSTRACT. The field study was conducted at research farm, School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana during *rabi* 2013-14 and 2014-15 to find out effect of different thermal regimes, nitrogen levels and post anthesis strategies on the canopy temperature and its indices for the wheat crop. The treatments comprised of three temperature regimes in main plot (D₁ - October 30, D₂ - November 15 and D₃ - November 30), three nitrogen levels in sub-plot (N₁ - RDF- Recommended dose of N, N₂ - 125% RDF (25% more than recommended N), N₃ - 150% RDF (50% more than recommended N) and four stress management post-anthesis strategies (P₀ - Control - No Spray, P₁-Water sprayed, P₂ - Foliar spray of ZnSO₄.7H₂O @ 0.5% P₃- Foliar spray of Thiourea @ 10 mM) at anthesis and 20 days after anthesis in sub-sub plot as split-split plot design replicated thrice. Canopy temperature was recorded at different phenological stages. The stress degree days were calculated at maturity. The results showed that crop sown on October 30 experienced lower canopy temperature at later stages as compared to November 15 and November 30 sown crop. With increase in nitrogen application it also lowers down the canopy temperature by 1.0 to 2.0 °C as dense and good crop stand under 150% RDF than others. The spray of crop with water, ZnSO₄.7H₂O and Thiourea also helped to bring the canopy temperature low at anthesis or after that when sprayed at regular intervals because these chemicals helped the crop to avoid the heat stress during this period by lowering the canopy temperature 0.5 to 1.0 °C. Higher the negative SDD values under October 30 as compared to November 15 and November 30 reflect that canopy temperature is cooler which means that crop is healthy and without any stress. Increase in N dose has lowered the SDD, indicating a better canopy thermal environment under higher N application. The significantly linear and negative relationship has obtained with canopy temperature and grain yield as well as SDD and grain yield.

Key words – Wheat, Sowing dates, Nitrogen level, Post anthesis strategies, Canopy temperature, Stress degree days, Grain yield.

1. Introduction

India is the third largest producer of wheat behind the EU and China. Temperature changes from 1980 to 2008 had a bigger impact on national wheat production in India, where over 90% of wheat is irrigated (Singh and Mustard, 2012) than changes in precipitation (Lobell *et al.*, 2011). Growth and development of wheat is adversely affected by environmental stresses like high temperature, soil moisture deficit, nutrient stress, low light intensity, etc. In India, wheat is usually planted in November/ December and harvested around March/ April with higher temperatures towards the end of the growing season. Temperature affects wheat development, grain fertility, leaf senescence and immediate crop maturity if temperature exceeds a certain threshold for a given number of days. Increased crop growth due to nitrogen fertilization is attributed to increased leaf-area index (LAI) and radiation interception (Caviglia and Sadras, 2001). The nutrient content in grain and straw increased with delay in sowing of wheat whereas, uptake of these nutrients decreased as the sowing of wheat gets delayed (Kumar *et al.*, 1998). There is need to assess these different type of stresses which occurs during crop growing period so that suitable management strategies can be followed to overcome these stresses and their effect on grain yield. For that the remotely sensed infrared canopy temperatures provide an efficient tool for rapid, non-destructive monitoring of whole-plant response to any type of stress (Idso *et al.*, 1981). Canopy temperature plays an important role to sustain physiological basis of grain yield of wheat when exposed to heat or nutrient stress. Cool canopy during grain filling period in wheat is an important physiological principle for heat stress tolerance and the higher N application indicating a better canopy thermal environment. Ehdaie and Shakiba (1996) also reported that high canopy-air temperature difference due to stress conditions reduce grain yield in wheat. The degree of cooling reflects the rate of evaporation on the surface of plant canopy (Amani *et al.*, 1996). The stress degree days (SDD), a canopy temperature based index has been used in grain yield prediction. Thus, the present study aims to characterize the growth and yield of wheat based on canopy temperature whether crop experienced higher canopy temperature than air temperature if so, than which suitable strategic manipulation we can done to avoid the yield losses from these stresses to some extent.

2. Materials and method

A factorial experiment comprised of three thermal regimes in main plot (D₁ - October 30, D₂ - November 15 and D₃ - November 30) three nitrogen levels in sub-plot

(N₁- RDF (Recommended dose of N), N₂- 125% RDF (25% more than recommended N), N₃-150% RDF (50% more than recommended N) and four stress management post-anthesis strategies (P₀- Control - No Spray, P₁-Water sprayed, P₂- Foliar spray of ZnSO₄.7H₂O @ 0.5%, P₃- Foliar spray of Thiourea @ 10 mM) at anthesis and 20 days after anthesis in sub-sub plot was laid as split-split plot design at research farm, School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana during Rabi 2013-14 and 2014-15. The crop was sown on using the seed @ 100 kg/ha by 'Kera' method keeping the row spacing of 20 cm. Fertilizer were applied with the recommended dose of 150 kg N/ acre as soil texture is loamy sand in nature through urea (46% N) and P₂O₅/ acre through diammonium phosphate (18% N and 46% P₂O₅) and 20 kg K₂O/ acre through muriate of potash (60% K₂O). The entire dose of phosphorous and potassium was applied at the time of sowing and the half dose of the nitrogen was applied at sowing and half dose at first irrigation by top dressing.

The study was conducted to observe the canopy temperature of wheat crop under different treatments and relationship between the grain yield and canopy temperature based indices in winter wheat. The data was recorded at 2.30 p.m. from development of canopy till harvesting at 15 days intervals during the day with clear sky with the help of infrared thermometer (FLUKE 574) by inclining at an angle of 45° holding 1 m above the crop canopy.

2.1. Stress degree days (SDD)

The canopy air temperature difference ($T_c - T_a$) values were used to determine the accumulated stress degree days. Idso *et al.* (1977) originally developed stress degree day concept and defined as,

$$SDD = \sum_{i=1}^n (T_c - T_a)$$

where, T_c is the canopy temperature and T_a is the air temperature in °C.

3. Results and discussion

3.1. Canopy temperature

Canopy temperature is a good indicator of any type of stresses whether temperature, moisture, nutrient in crops. Canopy temperature has a direct bearing on vital physiological processes and morphological characteristics of plant which are the primary determinants of seed yield.

TABLE 1
Canopy temperature (°C) at different phenological stages of wheat under thermal regimes, nitrogen levels and post anthesis strategies

Treatments	Canopy temperature (°C)											
	Tillering		Jointing		Booting		Heading		Anthesis		Grain filling	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Thermal regimes												
October 30	20.2	18.6	17.4	15.1	14.5	15.8	19.2	18.4	23.8	22.6	26.3	24.5
November 15	17.7	16.7	16.5	14.2	13.4	14.7	20.3	19.2	24.9	23.5	29.5	26.4
November 30	17.0	15.2	15.9	13.4	12.1	14.2	22.2	20.7	26.2	25.0	31.2	28.9
CD (p = 0.05)	0.61	0.57	0.69	0.36	0.38	0.75	1.73	0.88	1.81	1.56	1.22	1.70
Nitrogen levels												
RDF	19.0	17.4	17.1	14.6	13.7	15.6	21.4	19.9	26.6	24.5	29.6	26.7
125% RDF	18.4	16.9	16.2	14.1	13.3	14.9	20.5	19.2	25.1	23.8	28.7	25.9
150% RDF	17.7	16.2	16.0	13.7	12.4	14.4	19.9	18.7	24.2	22.9	27.4	25.2
CD (p = 0.05)	0.33	0.42	0.38	0.31	0.36	0.49	0.75	0.52	1.35	1.20	1.55	1.03
Post anthesis strategies												
Control	18.4	17.0	16.9	14.4	13.6	15.2	21.6	19.6	26.3	24.7	29.3	26.8
Water sprayed	18.3	16.9	16.6	14.2	13.4	15.0	20.7	19.4	25.4	23.9	28.6	26.0
ZnSO ₄ .7H ₂ O (0.5%)	18.2	16.6	16.3	14.0	13.3	14.8	20.3	19.0	24.7	23.0	28.0	25.1
Thiourea (10mM)	18.3	16.7	16.4	14.0	13.1	14.7	20.5	19.3	25.1	23.5	28.4	25.7
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	1.08	1.11	0.65	0.86

3.1.1. Plant canopy temperature under varied temperature regime, nitrogen level and post-anthesis strategies.

The data on canopy temperature during afternoon (1430 hrs) for the different phenological stages under different thermal regimes, nitrogen levels and post-anthesis strategies are presented in Table 1.

Among the thermal regimes, under October 30 sowing, crop experienced low temperature during later stages of growth than November 15 and November 30 sowing during both years. Initially crop sown on October 30 experienced higher temperature than November 15 and November 30 sowing but this temperature favours the growth and development of the crop although the crops sown late sometimes experienced lower temperature during crop germination which ultimately affect the crop stand. Stephens and Lyons (1998) also suggested that the sowing dates in terms of changed temperatures are critical for determining appropriate crop yields. As soon as crop progress towards maturity, the October 30 sown crop did not experienced higher temperature which

otherwise effect the grain development and reduced the yield due to appearance of high temperature stress during this stage but delay sown crop suffer from high temperature stress during grain development phases which ultimately shorten the duration of grain filling. Ray and Ahmed (2015) also reported that the cool canopy during grain filling period in early sown wheat is an important physiological principle for heat stress tolerance. Singh *et al.* (2006) also found that, with the increase in temperature (maximum and minimum) during grain filling period, all the yield components of wheat were reduced in mean values ranging from 5 to 10%.

Among nitrogen levels, average canopy temperature was lower in 150% RDF followed by 125% RDF and RDF due to good crop stand which help to bring down the temperature of the canopy under 150% RDF during both the years as shown in Table 1. Garg *et al.* (2014) also reported that with the increase in N dose has lowered the canopy temperature, indicating a better canopy thermal environment under higher N application. They suggested that canopy was significantly cooler with

180 kg N ha⁻¹ application than 60 Kg N ha⁻¹ while 120 kg N ha⁻¹ made no significant impact.

Among post anthesis strategies, the data revealed that significantly lower canopy temperature was observed in ZnSO₄.7H₂O (0.5%) followed by Thiourea (10 mM), water sprayed over Control when crop was sprayed at anthesis and regular intervals after anthesis during both the years. As crop progressed towards maturity after anthesis temperature starts increasing than normal required for proper grain development this leads to temperature stress and increased the canopy temperature. During this conditions, spraying the crop with water or stress alleviating chemicals such as urea, thiourea or ZnSO₄ helps to bring the canopy temperature down than the unsprayed crop and help to reduce yield losses at this stage.

3.2. Stress degree days (SDD)

SDD concept is very useful in accounting for the yield variation due to heat and water stress conditions. SDD concept is based on the fact when the plant is fully turgid with internal moisture content, the plant leaves would have lower temperature than the air due to transpirational cooling. Therefore, the cumulative difference between leaf temperature and air temperature will be related stress period of the crop. SDD were calculated by summing the canopy-air-temperature difference over the entire growth period (Idso *et al.*, 1977).

The data pertaining to SDD under different thermal regimes, nitrogen levels and post anthesis strategies for Rabi 2013-14 and 2014-15 have been given in Table 2. The SDD differed significantly with thermal regimes, nitrogen levels and post anthesis strategies. The prevailing negative values of stress degree-days (SDD) in all the treatments indicated no stress evidenced by the crop in both growing seasons (Table 2). The canopy temperature was cooler (-322.8 °C/day) under October 30 sown crop followed by November 15 (-291.7 °C/day) and November 30 (-235.1 °C/day) sown crop at maturity during Rabi season 2013-14. During Rabi 2014-15, canopy temperature was cooler (-349.6 °C/day) under October 30 sown crop followed by November 15 (-316.8 °C/day) and November 30 (-273.7 °C/day) sown crop. Higher the negative SDD values under October 30 as compared to November 15 and November 30 reflect that canopy temperature is cooler which means that crop is healthy and without any stress.

Among the nitrogen level, canopy temperature was cooler (-325.1 °C/day) in 150% RDF treatment followed by 125% RDF (-277.9 °C/day) and RDF treatment

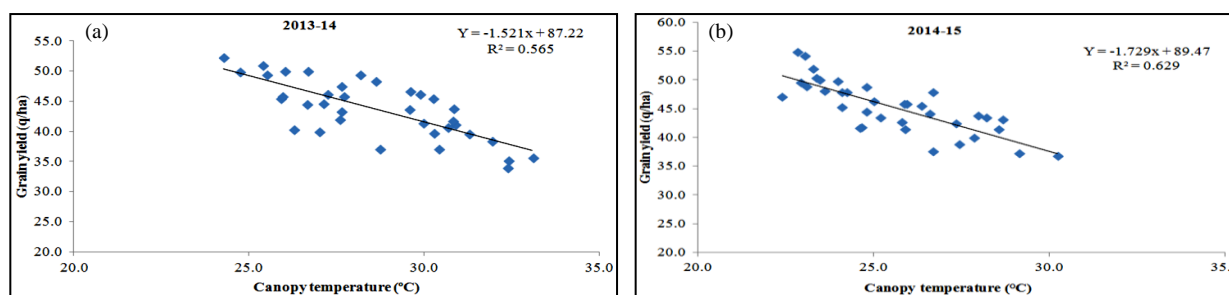
TABLE 2

Accumulated stress degree days (SDD) under different thermal regimes, nitrogen levels and post anthesis strategies in wheat

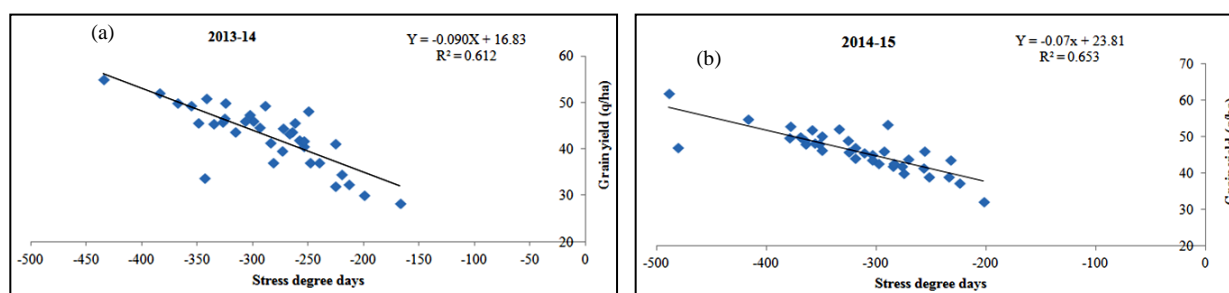
Treatment	Stress degree days (°C/day)	
	2013-14	2014-15
Temperature regimes		
October 30	-322.8	-349.6
November 15	-291.7	-316.8
November 30	-235.1	-273.7
CD (p = 0.05)	29.3	20.7
Nitrogen levels		
RDF	-246.5	-275.3
125% RDF	-277.9	-319.4
150% RDF	-325.1	-353.3
CD (p = 0.05)	17.2	17.1
Post- anthesis strategies		
Control	-233.0	-272.7
Water sprayed	-281.5	-311.1
ZnSO ₄ .7H ₂ O (0.5%)	-312.3	-347.3
Thiourea (10 mM)	-290.0	-319.5
CD (p = 0.05)	17.8	15.9

(-246.5 °C/day) during Rabi 2013-14. During Rabi 2014-15, canopy temperature was also cooler (-353.3 °C/day) were recorded under 150% RDF treatment followed by 125% RDF (-319.4 °C/day) and RDF treatment (-275.3 °C/day). Increase in N dose has lowered the SDD and provides better conditions for crop growth. Similar results were also reported by Garg *et al.* (2014).

Among the post-anthesis strategies, the significant difference in canopy temperature (-312.3 °C/day) was recorded under ZnSO₄.7H₂O (0.5%) followed by Thiourea (10 mM) (-290.0 °C/day), water sprayed (-281.5 °C/day) over control (-233.0 °C/day) during Rabi season 2013-14. During Rabi season 2014-15, the significant difference in canopy temperature (-347.3 °C/day) was recorded under ZnSO₄.7H₂O (0.5%) followed by Thiourea (10 mM) (-319.5 °C/day), water sprayed (-311.1 °C/day) over control (-272.7 °C/day) treatment. Canopy temperature gets lower by spraying the crop with water or any stress alleviating chemicals such as urea, thiourea or ZnSO₄ etc. Canopy temperature was cooler under ZnSO₄.7H₂O (0.5%) treatment followed by thiourea (10 mM), water sprayed over control treatment.



Figs. 1(a&b). Relationship between grain yield and canopy temperature of wheat during *rabi* (a) 2013-14 and (b) 2014-15 (Significant at $p < 0.05$ and $p < 0.01$)



Figs. 2(a&b). Relationship between grain yield and Stress degree days of wheat during *rabi* (a) 2013-14 and (b) 2014-15 (Significant at $p < 0.05$ and $p < 0.01$)

3.3. Relationship of canopy temperature based indices with the grain yield

3.3.1. Relationship of canopy temperature with the grain yield

A significantly negative linear regression relationship has been observed between the grain yield and canopy temperature under different thermal regimes, nitrogen levels and post anthesis strategies during Rabi 2013-14 and 2014-15 [Figs. 1(a&b)]. The regression relationship indicated 1.5 and 1.7 q/ha decrease in wheat yield with 1 °C increase in canopy temperature during 2013-14 and 2014-15 respectively. The coefficient of determination explained 56.5% variability in the grain yield due to canopy temperature during 2013-14 and 62.9% in 2014-15. The higher canopy temperature means that stress was experienced by the crop which declined the yield. Similar negative and significant relationships of grain yield with canopy temperature were also reported by Smith *et al.* 1985 and Singh *et al.* (1991) and reported that with increase in the canopy temperature, grain yield decreased.

3.3.2. Relationship of stress degree days with the grain yield

The index based on canopy temperature taken throughout the growing season of the crop, stress degree

days (SDD) were calculated which described the relationship of stress period on the grain yield. More negative the value of SDD that indicated the crop is without stress. Grain yield and SDD also have good relation which explains around 61.3% yield variability during Rabi season 2013-14 and 65.3% variability in grain yield due to SDD during Rabi season 2014-15 as shown in Figs. 2(a&b).

4. Conclusions

Canopy temperature detection can be considered as an effective tool for stress management in wheat because higher canopy temperature than air temperature was observed when crop undergoes the period of stress. Canopy temperature was lower under early sown crop as compared to late sown because crop undergoes high temperature stress during late sown conditions. Increase the dose of nitrogenous fertilizers provides the better canopy thermal environment than others. After detecting the heat stress in crop during anthesis, spraying the crop simply with water or any of the stress alleviating chemical as $ZnSO_4 \cdot 7H_2O$ or Thiourea, serve as adaptive strategy to this stress period and save the yield loss of crop to some extent. The relationship analysis also showed that grain yield was significantly, negatively and linearly related with canopy temperature as well as stress degree days (SDD).

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