

## Abstract

Canopy temperature reflects the interaction among plants, soil and atmosphere and has been recognized as an indicator of plant water status. Thermal imaging has been used to study the stomatal behavior of plants under different water conditions. This study investigates the potential use of infrared thermal imaging for calculating crop canopy temperature and determining relationship between canopy temperature and yield. Thermal images were taken from the field of different wheat genotypes in various water regimes in 2011 and 2015 at two locations. Images were processed using IR Crop Stress Image Processor Software to filter out the background soil from thermal image of the wheat plots and to calculate the mean canopy temperature of the selected area in the image. Thermal images data from these studies were analyzed. A strong negative correlation was found between canopy temperature and crop yield across the genotypes, indicating that the genotypes with relatively lower canopy temperature around mid-day during grain filling may be connected to higher yield under drought conditions. Canopy temperature of wheat genotypes measured under dryland condition was higher than in irrigated condition and significant difference in canopy temperature among the genotypes was found under dryland condition. The results indicate that canopy temperature can be a good indicator of crop water status and may be used as a selection criterion in identifying drought tolerant genotypes under water-limited conditions.

*Key words: Thermal imaging, canopy temperature, wheat yield*

## Introduction

- ❖ Every object emits infrared energy as a function of its temperature. Thermal camera collects the infrared radiation emitted by the object and creates an electromagnetic image based on the temperature differences.
- ❖ Leaf temperature is specifically determined by the rate of transpiration from the leaf. When the leaf transpires, a substantial amount of energy is required to convert liquid water into vapor, and this energy is consumed by evaporating water from the leaf which lowers the leaf temperature and thus cools it (Jones et al., 2009).
- ❖ Transpiration is positively associated with crop yield (Blum et al., 1989) and canopy temperature is negatively correlated with grain yield (Pradhan et al., 2014).

### Advantages of thermal imaging

- ❖ Cover larger area with higher precision
- ❖ Can take into account over thousand simultaneous temperature measurements



SmartField wireless IRTs



Taking thermal image using ladder

## Objectives

- ❖ To investigate the use of thermal imaging for measuring crop canopy temperature.
- ❖ To study if genotypes grown under water-limited condition show significant differences in canopy temperature.
- ❖ To study the relationship between canopy temperature and wheat yield.

## Materials and Methods

### Experimental Site

- ❖ Ten winter wheat genotypes in 2011(2010/2011) and twenty winter wheat genotypes in 2015 (2014/2015) were grown under two water regimes: Dryland and Irrigated at Etter and Bushland, Texas.
- ❖ Experimental Design: RCBD with four replications (2011) and three replications (2015)
- ❖ Planting Date: First and second week of October

### Image Acquisition

- ❖ Thermal camera used: ThermoCAM S45 HS (FLIR System, Sweden)
- ❖ Dates of image acquisition
  - In 2015
    - In dryland- From 197 DAP (between jointing and booting) to 237 DAP (late grain filling) in 7 to 12 days interval considering climate and soil moisture condition
    - In irrigated- From 188 DAP (jointing) to 226 DAP (grain filling) in 7 to 12 days interval considering climate and soil moisture condition
  - In 2011: Images were taken during grain filling stage
- ❖ Time of image acquisition
  - Dryland: 12:00 to 13:30
  - Irrigated: 14:00 to 15:30

## Image Processing

- ❖ ThermalCAM Researcher Pro 2.8 SR-1 (FLIR Systems, Inc., Boston, MA) software was used to convert the thermal JPEG format images to FLIR Public file (.fpf) format.
- ❖ IR Crop Stress Image Processor Software (Verbree, 2012) was used to process the .fpf file formats. The software filters out the background soil from the image and calculates the average canopy temperature taking into account of numerous canopy pixel points from the image.
- ❖ GLM procedure was used for mean separation and Pearson correlation coefficient was calculated using SAS® 9.4 for Windows (SAS Institute Inc., 2013).

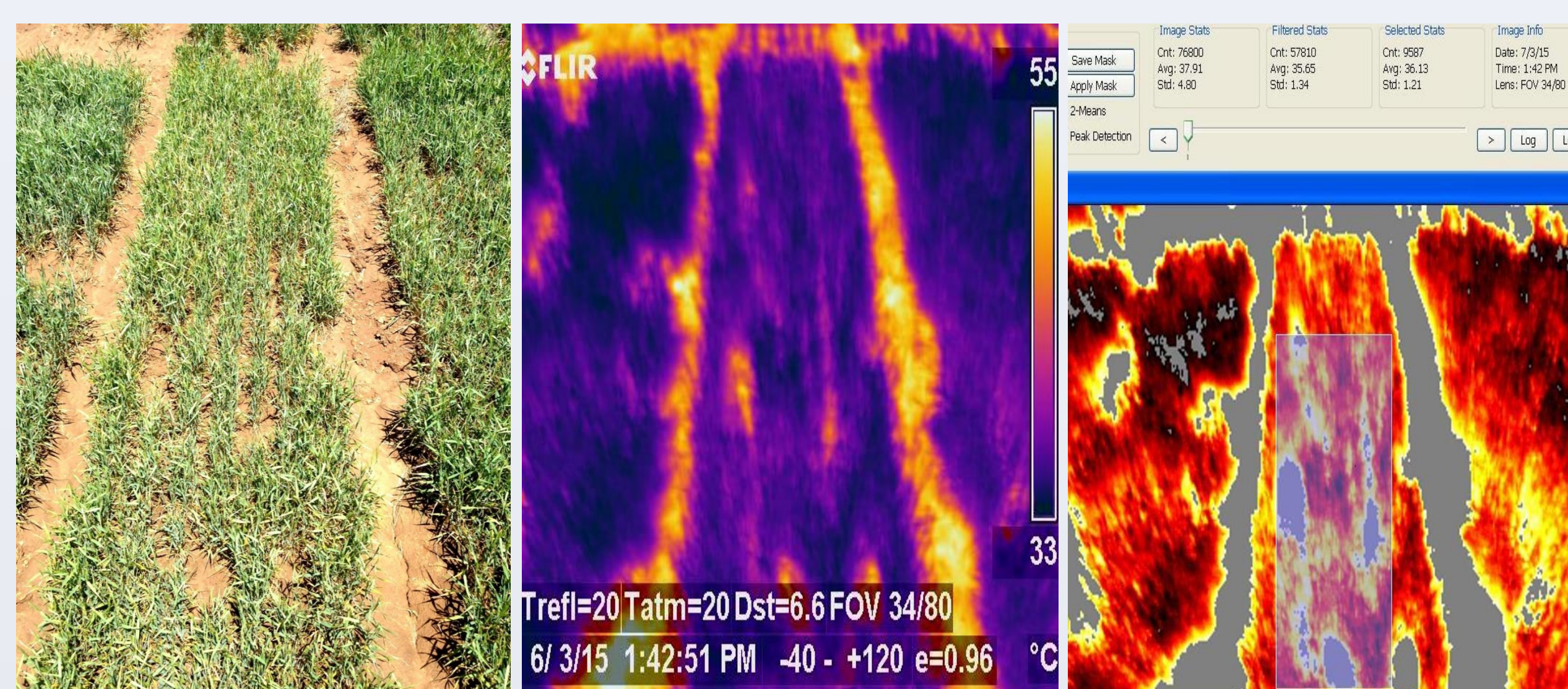


Image taken by normal camera

Image taken by thermal camera

Soil separated from the plot during image processing

## Results

Table 1. Canopy temperatures calculated from thermal images taken at different dates under dryland condition in 2015 at Bushland, Texas

Genotypes	Canopy Temperature (°C) at Days After Planting (DAP)					Supporting literatures
	197	206	218	224	232	
Billings	23.92	23.95	20.11	23.48	27.53	36.44
Dumas	22.75	23.70	20.70	24.41	28.01	37.67
Duster	23.04	23.01	19.80	23.26	27.44	36.39
Endurance	23.09	22.94	20.07	23.41	27.16	35.26
Fuller	22.74	22.67	20.51	23.58	28.50	36.53
Hatcher	23.21	24.19	20.49	23.49	27.92	37.69
Iba	21.83	22.14	20.05	23.25	26.93	36.74
Jagalene	23.03	23.05	20.20	22.89	27.01	35.90
Jagger	23.00	23.31	20.20	23.50	27.91	37.29
PlainsGo	21.29	22.62	19.86	23.03	27.08	35.57
TAM105	22.91	23.48	20.67	24.07	28.24	36.90
TAM110	21.78	23.16	20.45	24.27	28.53	37.57
TAM111	20.10	22.54	19.64	22.95	27.42	36.24
TAM112	21.80	23.55	21.04	24.29	27.67	37.03
TAM113	22.80	22.46	20.14	23.39	27.64	36.82
TAM114	20.96	22.85	20.02	23.15	27.17	34.96
TAM304	22.84	23.49	21.11	24.17	28.51	37.32
TAMW101	21.58	23.99	21.09	24.27	28.38	37.43
TX99A0153-1	21.43	23.21	20.22	23.30	27.85	37.21
Winterhawk	24.50	23.29	20.23	23.27	27.21	37.26
Mean	22.43	23.18	20.33	23.57	27.71	36.71
P-Value	0.23	0.1151	0.0427	0.0022	0.002	0.0702
Significance	NS	NS	*	**	**	NS

Table 2. Canopy temperatures calculated from thermal images taken at different dates under irrigated condition in 2015 at Bushland, Texas

Genotypes	Canopy Temperature (°C) at Days After Planting (DAP)				
	188	201	212	218	226
Billings	19.17	23.88	18.66	23.74	28.52
Dumas	17.88	23.09	18.36	23.69	29.18
Duster	17.82	23.77	18.55	23.55	26.71
Endurance	18.66	24.30	18.65	23.52	28.78
Fuller	17.82	23.52	18.23	23.98	28.77
Hatcher	17.46	24.22	18.42	23.85	28.89
Iba	18.41	23.99	18.54	23.65	28.42
Jagalene	17.44	23.76	18.08	23.39	28.35
Jagger	18.47	23.87	18.42	24.42	28.93
PlainsGo	17.86	25.04	17.94	23.14	28.48
TAM105	17.64	23.23	18.62	23.71	29.05
TAM110	17.96	23.91	18.42	23.46	29.41
TAM111	17.73	24.27	18.57	23.01	29.30
TAM112	18.48	23.94	18.45	23.91	29.52
TAM113	19.00	23.93	18.77	24.06	29.13
TAM114	18.14	24.00	17.96	23.86	29.52
TAM304	18.58	24.22	18.29	24.29	28.93
TAMW101	18.65	23.30	19.47	23.61	28.97
TX99A015	17.84	23.10	18.43	23.68	28.80
Winterhawk	18.54	23.54	18.96	23.74	29.17
Mean	18.18	23.84	18.49	23.71	28.84
P-Value	0.118	0.34	0.75	0.04	0.18
Significance	NS	NS	NS	*	NS

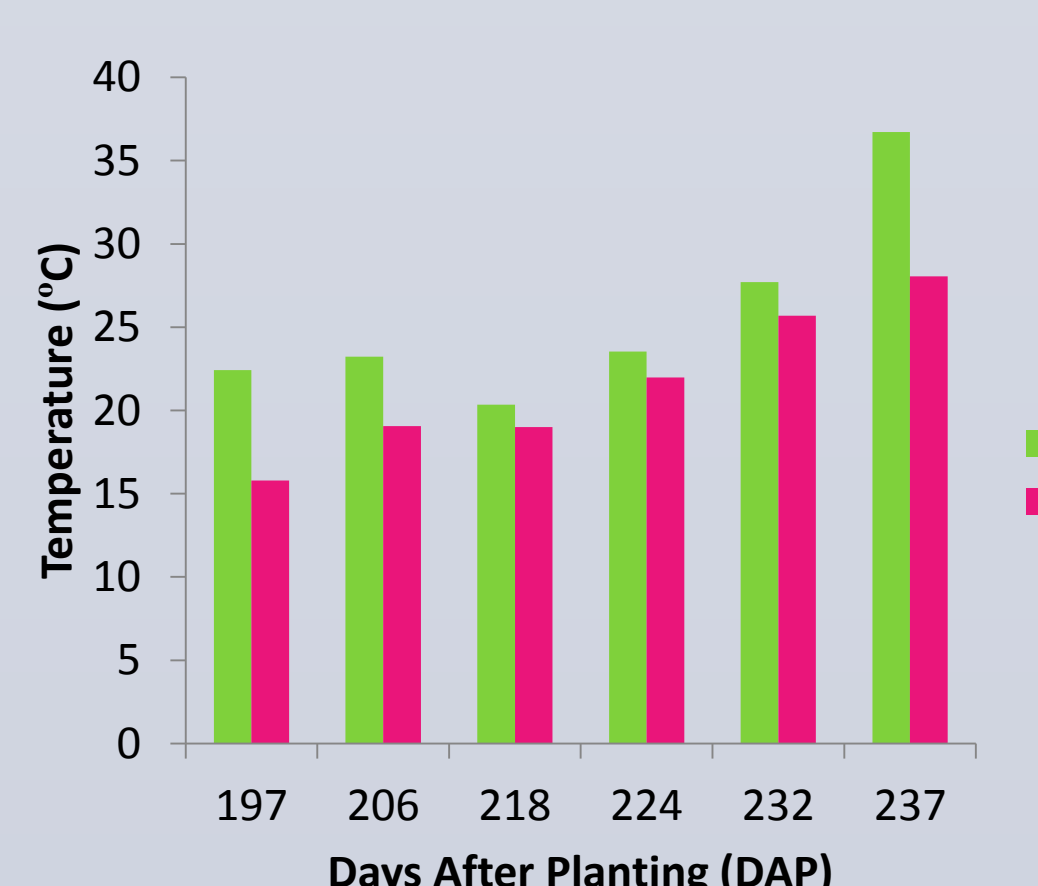


Figure 1. Air temperature and average canopy temperature of twenty genotypes at different dates after planting under dryland condition.

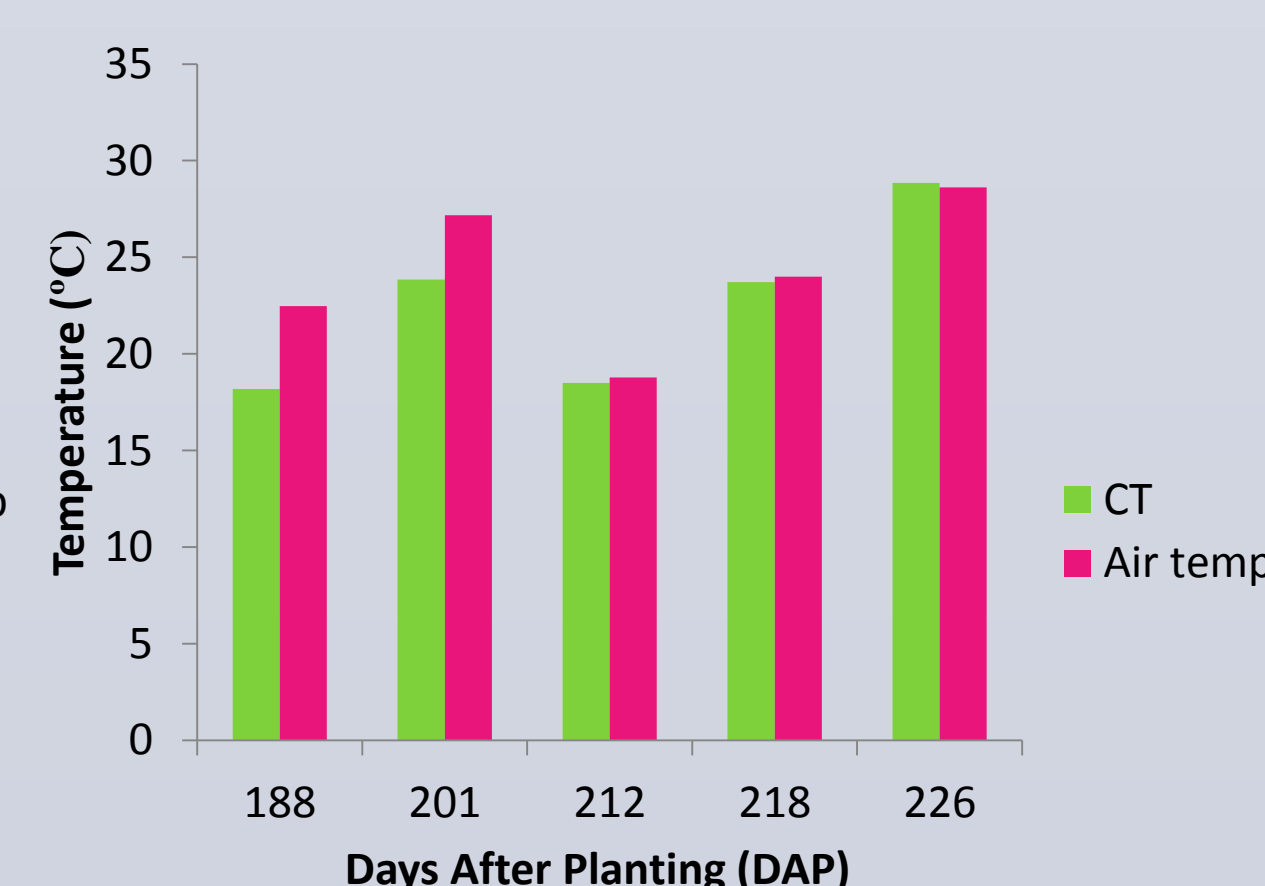


Figure 2. Air temperature and average canopy temperature of twenty genotypes at different dates after planting under irrigated condition.

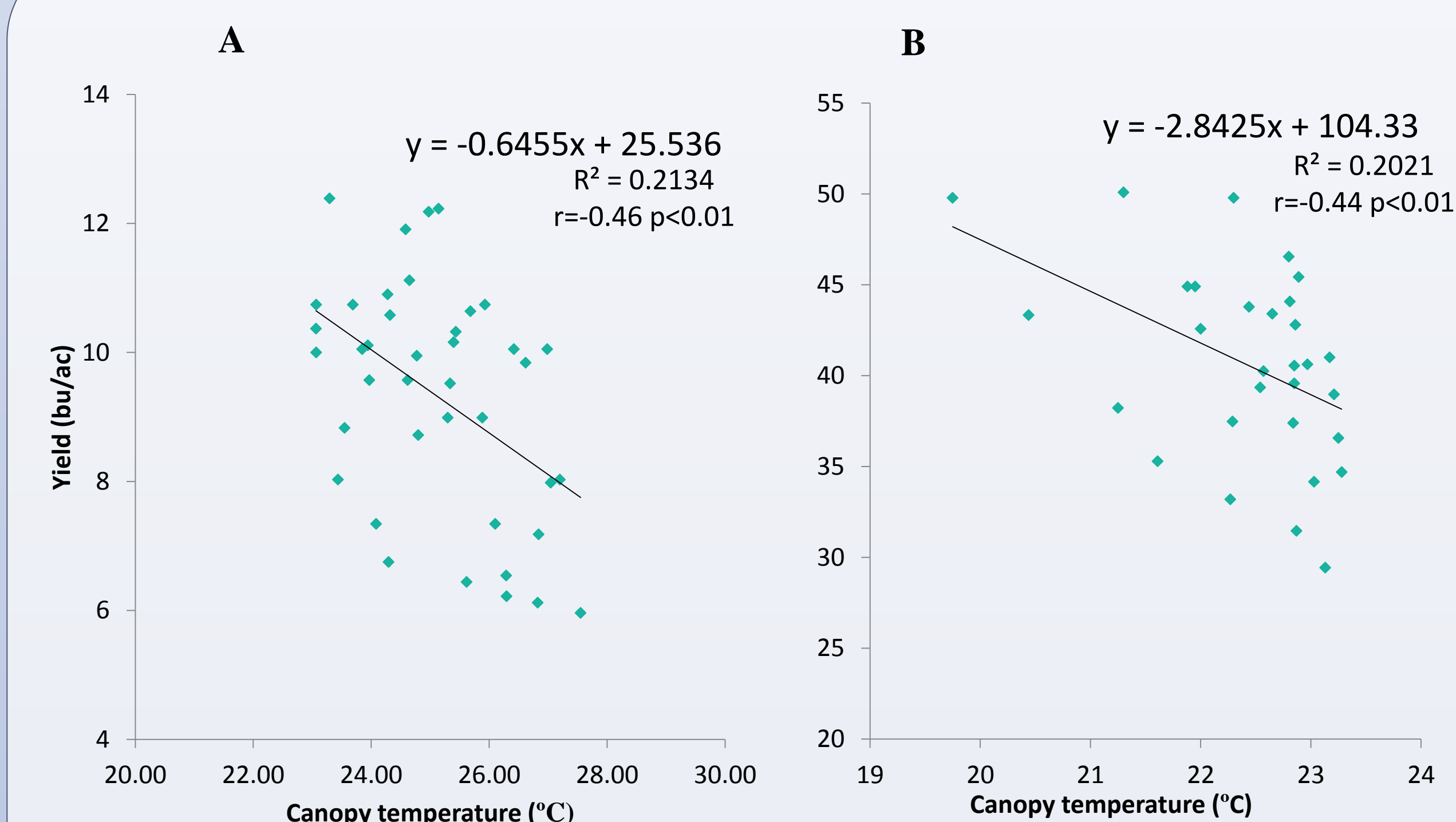


Figure 3. Relationship between canopy temperature and wheat yield grown under dryland condition (A) and irrigated condition (B) in 2011 at Bushland, Texas.

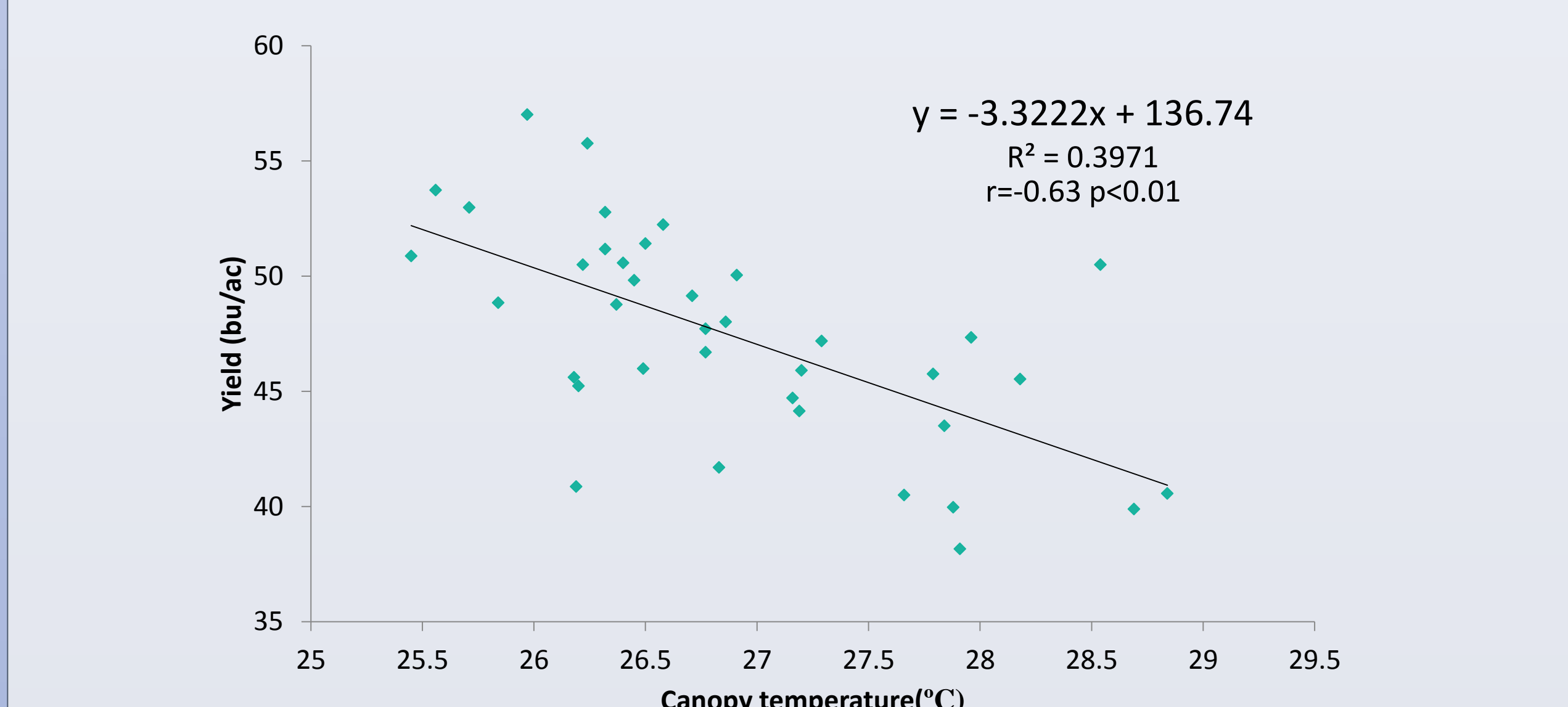


Figure 4. Relationship between canopy temperature and wheat yield grown under irrigated condition in 2011 at Etter, Texas.

## Summary

- ❖ The genotypes grown under dryland condition showed significant differences in canopy temperature at different growth stages. This indicates that infrared thermal camera can be used to calculate the canopy temperature, which may be a good methodology for evaluating wheat cultivars performance in water limited condition and phenotypic selection in breeding programs.
- ❖ Among the twenty different genotypes tested, TAM 111, TAM 114 and PlainsGold were the genotypes having lowest canopy temperature and Dumas, TAM 304, TAMW101 were the genotypes having consistent highest canopy temperature.
- ❖ A strong negative correlation between yield and canopy temperature has opened a way for further investigation of the physiological bases of canopy temperature and its relationship with other crop parameters.
- ❖ Weather conditions, growth stage, water status, time of the day and length of time in taking thermal images are some of the factors that are needed to be considered.

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