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Thermal Infrared Imaging-based Research on Winter Wheat Yield

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Abstract: Canopy temperature is an important factor of crop yield. How to test the canopy temperature for an effective prediction of crop yield is an important content of breeding research. In this study, the canopy temperature of winter wheat during their filling stage and mature stage were gained by infrared imager. Results demonstrated that the absolute canopy temperature and morning-noon temperature difference of the winter wheat are significantly negative correlated with the yield. During the filling stage, the yield (dry weight) showed a correlation coefficient (r) with the absolute canopy temperature in the morning of -0.63, -0.75 with the absolute canopy temperature at noon and -0.74 with the absolute canopy temperature in the afternoon. Meanwhile, the correlation coefficients between the yield (fresh weight) and above three absolute canopy temperatures were -0.59, -0.68 and -0.68, respectively. During the mature stage, the yield (dry weight) showed a correlation coefficient with morning-noon temperature difference of -0.76 and -0.56 with the morning-afternoon temperature difference and -0.54 with the noon-afternoon temperature difference. Meanwhile, the correlation coefficients between the yield (fresh weight) and above three temperature differences were -0.68, -0.58 and -0.40, respectively.

Key words: Thermal infrared imaging, image processing, canopy temperature, wheat yield

INTRODUCTION

The plant area of winter wheat in the world accounts for about 75% of the total wheat plant area (Wang *et al*., 2011). Parameters related with the winter wheat yield include Thousand Kernel Weight (TWK), kernels per spike, varietal characteristics, drought and fertilization (Luo *et al*., 2009). Recently, researchers discovered that canopy temperature and leaf temperature also can represent the winter wheat yield (Li *et al*., 2004). Canopy temperature not only has become an important indicator of variety breeding (Xiang *et al*., 2009) but also can be used as an important indicator of water measurement. In 1963, Tanner *et al*. proposed to test the canopy temperature by using the infrared thermometer to reflect the water status of crops for the first time (Tanner, 1963). Xu *et al*. (2007) discovered a significant negative correlation between the canopy temperature during the winter filling stage and winter wheat yield. Zhu *et al*. (2004) reported a close relationship between the canopy temperature of winter wheat during the late filling stage and yield (Leinonen and Jones, 2004).

The infrared thermometer can only provide a point measurement but can't measure the temperature distribution within a specific region.

The increasing sensitive infrared imaging system is used to detect the canopy temperature variation of crops Jones *et al*. (2009). Compared with traditional method, the infrared imaging technology is superior for quick, high-efficiency and convenient monitoring of temperature variation. Jones *et al*. (2009) carried out a remote sensing analysis on the infrared thermal imaging of crop canopy and a quantitative analysis on crops' responses to the water stress. In this experiment, the canopy temperature of winter wheat was measured by using the thermal imaging technology and the temperature variation law was analyzed which were for studying the correlation between canopy temperature and winter wheat yield.

MATERIALS AND METHODS

Test materials: A total of 20 winter wheat varieties were selected for experiment: Zhongmai175, CAU214, Zhongmai 12, CAU5225, Lunxuan 987, Jinghua 9, CAU212, Shixin 828, Lunxuan 518, CAU 5182, Zhongmai 8, XMO06, Beijing 0045, CAU211, CAU6812, XMO08, Jingdong 8, CAU5363, Jingdong 17 and CAU3432, numbered from 1~20 successively.

Experiment design: The experiment was carried out Beijing Precision Agricultural Research Demonstration

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Base from October, 2012~June, 2013. Each variety was sowed for one small zone (2.3 m (W)×100 m (L)) at a planting density of 11 kg Mu^{-1}. A total of 20 small planting zones were involved. During the early filling stage, a square area (2×2 m) with same growth was selected from each panting zone for collecting testing images. These experimental planting zones received same management (e.g., irrigation and fertilization) with general land for growing field crops.

Infrared image acquisition of canopy: In this experiment, the high-resolution portable infrared thermal imager (VarioCAM) was applied for image acquisition. Infrared images were shot at 9:00 am, 13:00 pm and 17:00 pm during the filling stage and mature stage of winter wheat.

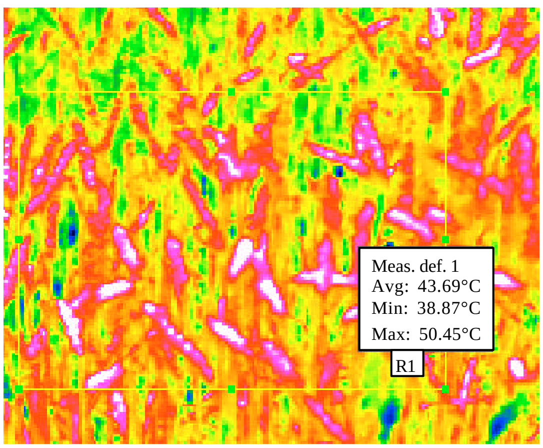

Fig. 1: Measurement of canopy temperature

Temperature measurement and data analysis: Infrared images were collected on May 20th, 2013 (filling stage) and June 19th, 2013 (mature stage), respectively. Testing winter wheat samples were harvested and threshed on June 20th, 2013. The dry weight was weighted after complete exposure to sun on July 26th, 2013.

The canopy temperature of all 20 planting zones during filling stage and mature stage was gained according to this method (Table 1). A statistical analysis on the temperature characteristics and yield was conducted by using Excel and origin75, respectively.

RESULTS AND DISCUSSION

Fresh weight and dry weight variations of different winter wheat varieties: Different winter wheat varieties achieved different yields which were related with the varietal characteristics. The difference was related with the length of filling stage and filling rate. During the filling stage, fresh weight increased firstly and then decreased. During the late filling stage, the growth of dry weight of wheat grains decelerated until becoming mature (Feng *et al*., 2009).

Canopy temperature variation law of different winter wheat varieties in one day: In Fig. 2, data were collected on July 19th, 2013. It was a sunny day with temperature ranging between 35~23°C. The average canopy temperature of winter wheat at 9:00am was 30.4°C while 13:00 pm was 44.1°C) and 17:00pm was 41.0.

The morning-noon temperature difference ranged between 11.1~15.15°C. Variety 2, 7, 9, 12, 17 and 19 showed a temperature difference larger than 14°C and

Table 1: Canopy temperature and yield statistics

Canopy tem. (°C)	2013-5-20 (filling stage)			2013-6-19 (mature stage)			Yield (g)	
Varieties No.	Morning	Noon	Afternoon	Morning	Noon	Afternoon	Fresh (g)	Dry (g)
1	25.18	25.83	25.84	30.85	43.41	41.80	1514	1498
2	24.98	26.10	26.08	30.48	45.26	42.44	1264	1236
3	24.24	24.78	24.78	31.32	43.79	40.48	1373	1340
4	24.31	25.22	25.22	30.97	42.28	40.82	1355	1306
5	24.66	24.53	24.52	30.48	45.19	41.15	1346	1264
6	25.08	25.44	25.44	30.49	43.16	39.65	1485	1454
7	24.08	24.53	24.54	30.54	43.13	39.33	1456	1364
8	25.88	25.14	25.14	30.51	44.95	40.79	1226	1136
9	26.37	26.38	26.38	30.58	45.50	41.41	1006	930
10	29.30	26.96	26.97	31.30	45.26	42.42	1057	1050
11	25.20	25.20	25.20	30.29	43.37	41.09	1380	1310
12	26.61	26.85	26.81	28.94	43.45	39.31	1454	988
13	25.15	25.01	25.01	29.37	42.51	39.73	1459	1216
14	25.43	25.65	25.65	30.23	43.43	40.33	1310	1234
15	25.66	26.65	26.65	29.81	43.69	40.99	1005	992
16	26.24	26.08	26.08	30.03	44.33	41.30	1262	1134
17	23.47	24.55	24.54	30.94	42.93	40.63	1299	1220
18	25.28	26.18	26.16	30.44	46.49	41.78	894	866
19	25.75	26.62	26.52	30.19	45.43	41.59	935	828
20	29.37	27.68	27.59	30.30	45.36	41.48	742	720

variety 1, 3, 4 and 8 showed a temperature difference smaller than 12°C. Particularly, canopy temperature in middle and late filling stage caused greater impacts on the winter wheat yield (Deng *et al*., 2009).

Relationship between absolute canopy temperature and yield: In Table 1, the absolute canopy temperature and yield during the filling stage and mature stage were analyzed on the origin software. The canopy temperature

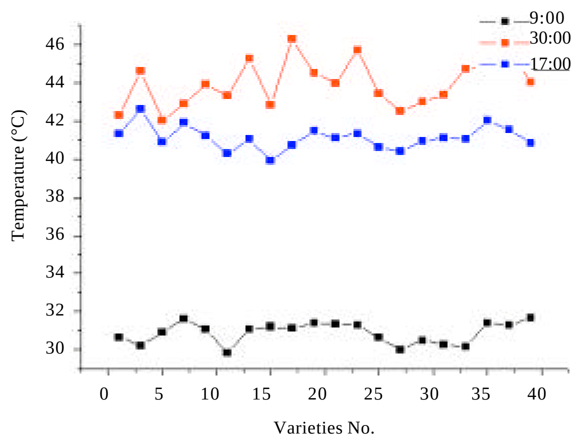

Fig. 2: Canopy temperature variation law during mature stage

(X axis) of winter wheat measured at 9:00, 13:00 and 17:00 and yield (Y axis) were used for linear fitting. The correlation coefficients were shown in Table 2.

Table 2 demonstrated a negative correlation between the absolute canopy temperature and winter wheat yield. The lower canopy temperature during the filling stage have longer functional period of leaves, higher chlorophyll content, exuberant transpiration, stronger photosynthetic capacity and slower agin (Deng *et al*., 2009). The correlation analysis results between the absolute canopy temperature and dry weight 13:00 during the fill stage were shown in Fig. 3.

Xiang Yan *et al*. found that the correlation coefficient of canopy temperature and yield of winter wheat reached -0.74 (Xiang *et al*., 2009). This agrees with our conclusion. This experiment also demonstrated a good correlation between canopy temperature at noon and afternoon and the yield. It is concluded that yield of winter wheat was negatively correlated with the canopy temperature and correlation coefficients atthree involved time periods were $r_{noon}>r_{afternoon}>r_{morning}$.

Relationship between canopy temperature difference and yield: Table 3 was the statistics of canopy temperature difference at different time periods of filling stage and mature stage. The canopy temperature difference and

Table 2: Correlation coefficients between canopy temperature at different time point and yield

Data acquisition	9:00		13:00		17:00	
Collection data	Filling	Matur	Filling	Mature	Filling	Mature
Correlation coefficient between absolute temperature and dry weight (r_1)	-0.63	0.34	-0.75	-0.65	-0.74	-0.32
Correlation coefficient between absolute temperature and fresh weight (r_2)	-0.59	-0.06	-0.68	-0.74	-0.68	-0.57

Table 3: Canopy temperature different at different time periods in different stages

	Temperature difference during filling stage			Temperature difference during mature stage		
No./temperature difference	Morning-noon	Morning-afternoon	Noon-afternoon	Morning-noon	Morning-afternoon	Noon-afternoon
1	0.65	0.66	-0.01	12.56	10.95	1.61
2	1.12	1.10	0.02	14.78	11.96	2.82
3	0.54	0.54	0.00	12.47	9.16	3.31
4	0.91	0.91	0.00	11.31	9.85	1.46
5	-0.13	-0.14	0.01	14.71	10.67	4.04
6	0.36	0.36	0.00	12.67	9.16	3.51
7	0.45	0.46	-0.01	12.59	8.79	3.80
8	-0.74	-0.74	0.00	14.44	10.28	4.16
9	0.01	0.01	0.00	14.92	10.83	4.09
10	-2.34	-2.33	-0.01	13.96	11.12	2.84
11	0.00	0.00	0.00	13.08	10.80	2.28
12	0.24	0.20	0.04	14.51	10.37	4.14
13	-0.14	-0.14	0.00	13.14	10.36	2.78
14	0.22	0.22	0.00	13.20	10.10	3.10
15	0.99	0.99	0.00	13.88	11.18	2.70
16	-0.16	-0.16	0.00	14.30	11.27	3.03
17	1.08	1.07	0.01	11.99	9.69	2.30
18	0.90	0.88	0.02	16.05	11.34	4.71
19	0.87	0.77	0.10	15.24	11.40	3.84
20	-1.69	-1.78	0.09	15.06	11.18	3.88

Table 4: Correlation coefficient between canopy temperature at different time periods and yield

Temperature difference	Morning-noon TD		Morning-afternoon TD		Noon-afternoon TD	
Stages	Filling	Mature	Filling	Mature	Filling	Mature
r_1 (fresh)	0.29	-0.76	0.32	-0.56	-0.69	-0.54
r_2 (dry)	0.29	-0.68	0.30	-0.58	-0.57	-0.40

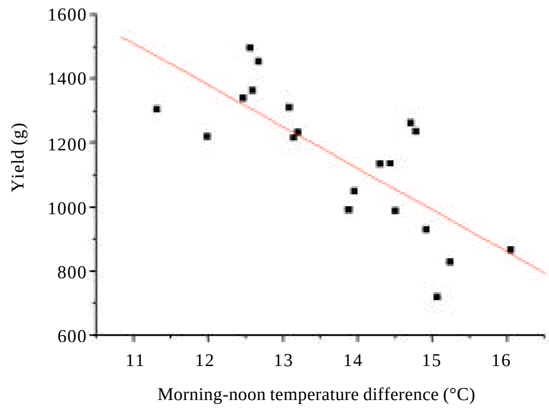

Fig. 3: Linear fitting between canopy temperature and yield of wheat

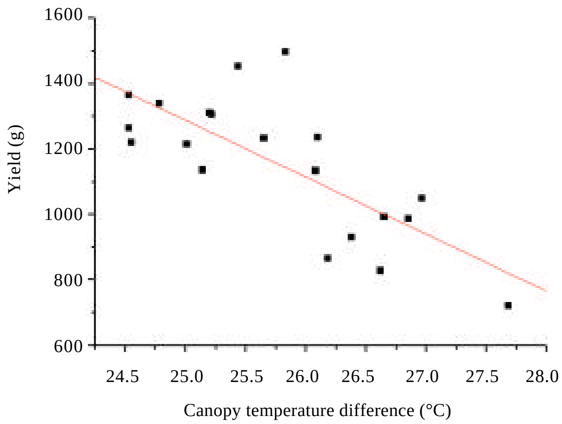

Fig. 4: Correlation between canopy temperature difference in the mature stage and winter wheat yield

yield were analyzed on the origin software. The morning-noon temperature difference, morning-afternoon temperature difference, noon-afternoon temperature difference (X axis) and yield (Y axis) were used for linear fitting. The corresponding correlation coefficients were listed in Table 4.

According to Table 4, the canopy temperature difference was negatively correlated with winter wheat yield and $r_{morning\text{-}noon} > r_{morning\text{-}afternoon} > r_{noon\text{-}afternoon}$. The correlation analysis between the canopy temperature difference during mature stage and dry weight was shown in Fig. 4.

CONCLUSION

It concludes that (1) Absolute canopy temperature during the filling stage represents a good linear negative correlation with the winter wheat yield. Higher temperature brings better correlation and (2) During the mature stage, the canopy temperature difference in one day presents a good linear negative correlation with the final winter wheat yield. Higher temperature results in better correlation.

However, this study only involves the filling stage and mature stage that are significant to the winter wheat yield. Future research will involve the whole growth stage of winter wheat and impacts of fertilization and water treatment on the canopy temperature with other physiological and biochemical parameters in order to explore the relationship with the winter wheat yield.

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