Preliminary research on model for determining crop water stress index of flowering Chinese cabbage based on canopy temperature

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Abstract: In this paper canopy temperature was measured with an infrared thermometer, air temperature, dry and wet-bulb temperature, and soil water content were measured as well to establish the model for determining the CWSI(crop water stress index) of flowering Chinese cabbage. The relationship between canopy-air temperature difference and vapor pressure deficit was determined. The preliminary model was established with regard to the influence of radiation intensity. A microcomputerized real-time data acquisition system was developed to monitor water-stress status for scheduling irrigation of vegetables.

Key words: crop water stress index; canopy temperature; vapor pressure deficit; flowering Chinese cabbage
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1 Introduction

The occurrence and extent of drought on crop growth is complex. It is affected by natural and/or man-made factors, such as weather conditions, hydrologic regime, crop variety, planting distribution, crop growing status, cultivation system and smoothness of the final land preparation prior to planting. There are several indexes used in drought research, including precipitation amount, soil water content and canopy temperature. To irrigate different crops growing in the same filed, drought indexes of the crop itself (but not soil or weather) should be directly taken for irrigation scheduling, since the objective of irrigation is crops.

Crop canopy temperature is a significant index that does not only reflect the environmental condition, such as air temperature and humidity, solar radiation, air circulation, but also indicate the relative state of physiological reaction of crop to water deficit. Detecting water deficit with canopy temperature can be employed quickly and precisely in large fields than with single leaf temperature[1]. Cai Huanjie et al. examined the relationship of water deficit and canopy temperature in cotton[2]. Wang Jihua et al. investigated the relationship of spectral reflectance and canopy water content with canopy temperature of winter wheat and pointed out that canopy temperature provided a more reliable method for determining the crop canopy water content[3]. Tanner C B first applied non-contact infrared thermometers (IRTs) to study crop temperature in 1965[4]. As the technology of measuring temperature with IRTs develop rapidly, especially when the canopy temperature can be remotely monitored in air (with aircraft or on high towers), it has been highly regarded and gained broad application. Technological advances have miniaturized IRTs and reduced power requirements so that inexpensive self-powered units are now commercially available. Sadler et al. examined spatial variation in water stress of corn with a linear array of 26 IRTs mounted on a center-pivot irrigation machine[5]. The crop water stress index (CWSI), derived from canopy-air temperature difference versus the air vapor pressure deficit, was found to be a valuable tool for monitoring and quantifying water stress as well as for irrigation scheduling. Alderfasi et al. developed a baseline equation to calculate CWSI for monitoring water status and for irrigation scheduling in wheat[6]. Wanjura et al. studied the relationship of CWSI with canopy temperature and air temperature of corn and cotton under different irrigation levels[7].

Up to now, the research on crop water deficit both in China and abroad have been mainly focused on field crops like corn, cotton, wheat etc. The main objective of this work was to establish a model for determining CWSI of flowering Chinese cabbage using canopy temperature for monitoring water deficit, which has not been reported yet. Also, a system for monitoring drought in vegetables was developed based on a microcomputer.

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2 Establishment of model for determining CWSI

2.1 Canopy-air temperature difference model

The canopy-air temperature difference t_{ca} of crop has an established relationship with air vapor pressure deficit (VPD)[6], as shown in equation (1):

$$t_{ca} = t_c - t_a = a + b \cdot VPD \qquad (1)$$

Where t_c —— canopy temperature, ℃; t_a —— air temperature, ℃; VPD —— air vapor pressure deficit, kPa; a and b are linear regression coefficients.

VPD is calculated as follows, using dry-bulb and wet-bulb temperatures:

$$e_s' = \exp\left(18.7509 - \frac{4075.16}{236.516 + t_s}\right) \times 0.13329 \qquad (2)$$

$$e = e_s' - 0.5(t_g - t_s) \times 0.13329 \qquad (3)$$

$$e_s = \exp\left(18.7509 - \frac{4075.16}{236.516 + t_g}\right) \times 0.13329 \qquad (4)$$

$$VPD = e_s - e \qquad (5)$$

Where t_g —— dry-bulb temperature of air, ℃; t_s —— wet-bulb temperature of air, ℃; e_s' —— saturated vapor pressure at t_s, kPa; e —— vapor partial pressure, kPa; e_s —— saturated vapor pressure at t_g, kPa.

As shown in Fig. 1, the crop is under severe water stress when $VPD = 0$ and the canopy temperature reaches the upper limit t_{max}, while the crop is in sufficient water status when $VPD = 6$ kPa and the canopy temperature is at the lower limit t_{min}.[8] The model for dertermining $CWSI$ is defined simply as:

$$CWSI = \frac{|t_{ca} - t_{min}|}{t_{max} - t_{min}} \qquad (6)$$

The value of $CWSI$ varies from 0 to 1. $CWSI = 0$ shows the crop in sufficient water state, while $CWSI = 1$ represents the crop under severe water stress.

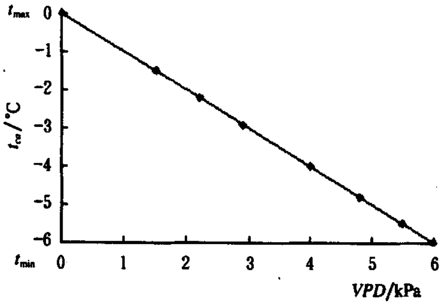

Fig. 1 The relationship between canopy-air temperature difference and vapor pressure deficit

2.2 Field tests

Field tests were conducted in the research farm at South China Agricultural University from Jan. 15 to Jan. 22, 2003. A representative field block of 3 m×8 m was selected in the research farm planting of flowering Chinese cabbage which was in the bud stage of growth for this research. The test block was divided into 8 plots in two rows. The canopy temperature was measured from different directions in the 8 plots to alleviate the influence of solar radiation. There were about 20 clear and rainless days before test and the soil was dry until Jan. 17. To change soil water content to meet the research requirements, the test field was irrigated on the afternoon of Jan. 17.

The canopy temperature of flowering Chinese cabbage was measured instantaneously using a MID02LT IRT, as shown in Fig. 2. The probe mounted on a frame which was adjustable to point diagonally across the plots. Wet and dry-bulb temperatures were recorded with a manual aspirated psychrometer. The ambient air temperature was read from a mercury thermometer.

Fig. 2 Infrared thermometer in field

Test data was recorded from 10:00 a.m. to 4:00 p.m. during the test period. An average of instantaneous readings from 8 plots was calculated. Eleven representative groups of mean data are given in table 1.

2.3 Establishment of CWSI model

VPD and canopy-air temperature difference t_{ca} were calculated based on equation (2)~(5) using data of table 1, as shown in Fig. 3. A linear regression equation was determined ($R^2 = 0.8314$):

$$t_{ca} = -1.1144 VPD - 0.5445 \qquad (7)$$

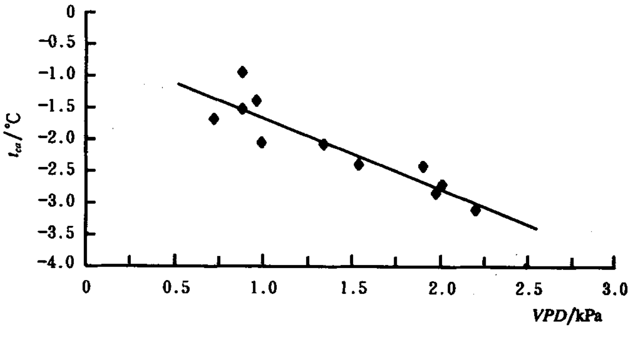

Fig. 3 Regression equation of t_{ca} vs VPD

Table 1 Test data of flowering Chinese cabbage ℃

Data acquisition time	Weather status	Canopy temperature t_c	Air temperature t_a	Dry-bulb temperature t_g	Wet-bulb temperature t_s
10:30 on Jan. 15	Heavy dew, feeble radiation	20.0	21.4	19.2	17.7
13:10 on Jan. 15	Clear, intense radiation	21.3	24.4	21.5	19.2
14:30 on Jan. 15	Clear, intense radiation	21.3	24.1	21.5	19.3
11:30 on Jan. 16	Cloudy, common radiation	20.4	22.0	19.5	18.1
14:30 on Jan. 16	Partly cloudy, common radiation	22.4	24.5	22.0	20.4
13:00 on Jan. 17	Partly cloudy, common radiation	24.0	26.4	22.5	20.8
14:00 on Jan. 17	Partly cloudy, common radiation	24.5	26.6	22.7	20.9
12:00 on Jan. 18	Partly cloudy, common radiation	22.6	25.6	22.5	21.9
14:00 on Jan. 18	Partly cloudy, common radiation	22.9	26.1	22.6	21.9
14:30 on Jan. 21	Cloudy, feeble radiation	22.6	23.6	21.0	19.9
13:35 on Jan. 22	Partly cloudy, feeble radiation	23.8	25.4	22.3	21.2

The upper and lower limits of canopy-air temperature difference were calculated using formula (7), $t_{max} = -0.5445$℃, $t_{min} = -6.1419$℃. The CWSI model of flowering Chinese cabbage was thus expressed as:

$$CWSI = \frac{|t_{ca} + 6.1419|}{5.5974} \qquad (8)$$

2.4 Improvement of CWSI model

It was found that the canopy-air temperature difference required adjustment to alleviate the influence of solar radiation. Weather status for rainless conditions were divided into 5 grades, and the corresponding correction coefficients were determined based on test results (table 2).

Table 2 Weather status vs weighted coefficients

Weather status	Grades	Correction coefficients α
Clear, intensive radiation	Grade 1	1.0
Partly cloudy, normal radiation	Grade 2	1.13
Cloudy, normal radiation	Grade 3	1.15
Partly cloudy, low radiation	Grade 4	1.17
Cloudy, low radiation	Grade 5	1.2

The improved formula (8) using table 2 results in a new model for flowering Chinese cabbage expressed as:

$$CWSI = \frac{|t_{ca} \cdot \alpha + 6.1419|}{5.5974} \qquad (9)$$

3 Development of drought monitoring system

The drought monitoring system was composed of a sensor array, a single chip microcomputer (SCM) and its interfacing circuits, communication interfacing circuits, and a PC microcomputer, as shown in Fig. 4. Sensors included a MID02LT IRT, an aspirated psychrometer, and a soil hygrometer. The SCM system included a SH-MPU89C51 Control Board which was based on an AT89C51 chip working at main frequency of 11.0592MHz and a Common Keyboard & Display Board. It can not only run in the field separately, but also communicate with a PC to make up a distribution system. The communication standard can be RS232 or RS485, selectable in term of communication distance. The drought monitoring system possessed functions of communication setup, real time surveying, data inquiry and drought analyzing.

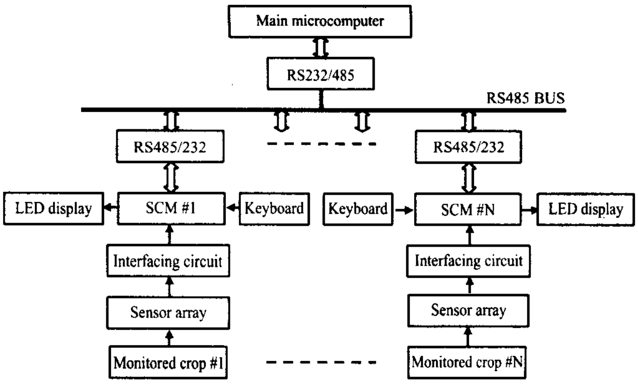

Fig. 4 Diagram of drought monitoring system

4 Conclusion and discussion

1) CWSI is a promising tool for monitoring water status and for irrigation scheduling for flowering Chinese cabbage as well as other similar vegetables and crops.

2) A preliminary model for determining CWSI based on canopy temperature was established for flowering Chinese cabbage.

3) A drought monitoring system based on a SCM was developed. It provides a test tool for similar research.

4) However, the model has its limitation in application due to factors considered in this preliminary research. Net radiation, wind speed, the rate of crop coverage and other affecting factors should be considered to modify the model in further.

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基于冠层温度的菜心缺水指数模型初步试验研究

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摘　要: 以柳叶菜心为研究对象, 测试了不同干旱条件下的土壤含水量、空气温湿度和冠层温度等参数, 确定了作物缺水指数经验模型的参数, 并针对太阳辐射强度对模型做了改进。研制了蔬菜旱情检测系统, 利用红外测温仪、土壤含水量传感器等, 可以实时测得田间作物的水分亏缺状态, 为同类研究提供了测试手段和数据分析方法。

关键词: 作物缺水指数模型; 冠层温度; 空气饱和水蒸气压差; 柳叶菜心