ANALYSIS OF WATER STRESS OF GREENHOUSE PLANTS USING THERMAL IMAGING

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ABSTRACT

Accurate quantification of plant physiological properties is often necessary for optimal control of an automated greenhouse production system. Conventional crop growth monitoring systems are usually burdensome, inaccurate, and harmful to crops. A thermal image analysis system was used to accomplish rapid and accurate measurements of physiological-property changes of water-stressed crops. Thermal images were obtained from several species of plants that were placed in a growth chamber. Analyzing the images provided the pattern of temperature changes in a leaf and the amount of differences in the temperature of stressed plants and non-stressed plants.

Key words: Thermal image processing, Crop growth monitoring, Non-destructive measurement

INTRODUCTION

A plant becomes stressed when any biological or environmental factor inhibit growth and development. Stressed plants express their symptoms in many ways. It is difficult to detect and quantify early symptoms accurately with conventional measurement methods.

Nondestructive measurement techniques such as remote sensing and digital image analysis method can be used to analyze plants many times non-invasively and without damage. The amount and quality of radiation reflected or emitted from the plant leaves and canopies are affected by the specific properties of the vegetation. Thermal image analysis is a means of detection and assessment of changes in plants and canopies. As objects change temperature, the wavelengths of energy generated vary throughout the infrared spectrum. The radiation intensity can be detected by thermal imaging system.

Measuring the temperature of a crop's leaves, relative to air temperature, has been shown to be a good way of monitoring whether plants have sufficient water or not. As the water supply runs low, the leaves warm up. Insufficient water supply or disrupted control of tissue water balance affects stomata opening and photosynthesis. Problems in plant water status close stomata and reduce photosynthesis, reduce evapotranspiration, and increase leaf surface temperature.

Hashimoto et al. (1984) reported that the thermal image processing system could monitor temperature changes occurring in leaves of sunflower undergoing water stress. The leaf temperature of the stressed plants rose 3 to 5°C above that of non-stressed plants. The thermal image processing system successfully visualized the exotherm temperatures during freezing of well-watered and drought-stressed branches of jojoba (Ceccardi et al., 1995).

The thermal image processing system can be useful in monitoring short-term temperature changes of leaves undergoing other stresses. The objective of this study was to find a technique for early detection and assessment of water stress in crops using a thermal imaging system.

MATERIAL AND METHOD

Thermal Imaging System

The thermal imaging system (IQ 812, FLIR Systems, Inc., USA) detects infrared radiation and displays real-time images that show the intensity or level of this radiation. The system comprised an infrared imager and an image processor. The infrared imager acts as a heat sensor for the system. It has infrared detector array responds to infrared radiation in the 8 to 12 μm spectrum. The thermal imaging system operates in these wavelengths because the atmosphere passes infrared radiation in these wavelengths. It detects infrared radiation and converts it into electronic signals. The signal is converted into a video signal by the image processor for observation and analysis. The video signal was digitized to an 8-bit, 320-horizontal by 240-vertical digital image. The thermal imaging system has a minimum discernable temperature of 0.08 °C and a measurement accuracy of ±2 °C.

Growth Chamber

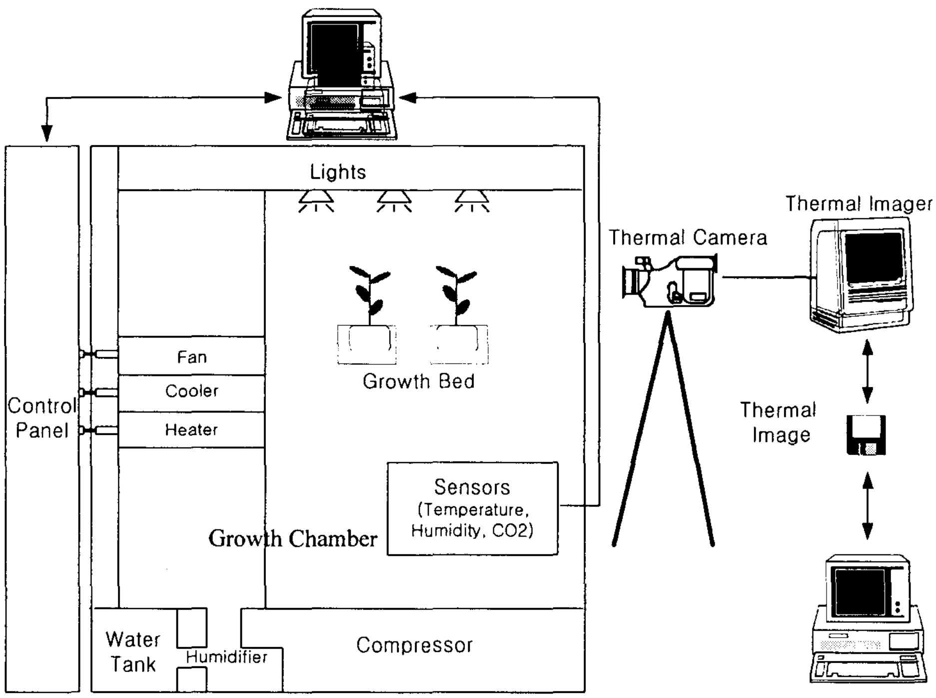
Leaf temperatures of plants are sensitive to changes in both major and minor components of the surrounding atmosphere. Fluctuations in flux and temperature of the surrounding air can affect the temperature of the plant. To maintain uniform environmental condition during the experiment, a growth chamber was used so that outdoors climate won't affect the experiment. The growth chamber has control features including temperature, humidity, light, and carbon dioxide (CO_2) and environmental monitoring. The temperature and relative humidity (RH) specifications for the growth chamber were 10 °C to 38 °C and 50 to 90%, respectively. The growth chamber could maintain the temperature and the RH within ±0.3°C and ±5 %, respectively. Photosynthetically active radiation (PAR) was provided by eight 400 W high pressure sodium (HPS) lamps which yielded an average photosynthetic photon flux (PPF) of 200 $\mu mol/s \cdot m^2$.

Water Stress

Experiments were designed to study the effects of water deficiency stress on leaf temperature of plants. To cause water stress, water supply was stopped at the beginning of the experiment. A well watered plant served as the 'control'. The control nutrient solution was a standard solution recommended by Yamazaki. The electrical conductivity (EC) of all nutrient solutions was kept the same (2 mS/cm).

Procedure

Twenty day-old lettuce, cucumber, and hot pepper plants were randomly designated as controls or treatments. The plants were placed in the growth chamber and kept at 25°C and 60% RH. The experiments began with three replicates of two plants (control and treatment) with three species. Temperature changes of the leaves were monitored in 2-min sample intervals with the thermal imaging system through the thermal window of the growth chamber. Acquired thermal images were first stored on the hard drive of the thermal image processor and then transferred to a personal computer for further analysis. Fig.1 shows the schematic diagram of the thermal image processing system.



Growth Chamber

Fig. 1. Schematic diagram of the thermal image processing system.

RESULT AND DISSCUSION

Fig. 2 shows some of the thermal images of cucumber plants. The images of water-stressed cucumber plants are in the left side, and the images of Control are in the right side. Fig. 3 shows leaf temperature changes of the cucumber plants when the light was turned on. Resulted from data lost Fig. 3 shows only the response after 16 min. The average leaf temperatures of the Control plants fluctuated to the surrounding air temperature of 25°C. However, the leaf temperature of water-stressed plants reached around 27°C. After 60 min, the difference of leaf temperature of the Control and water-stressed cucumber plants was 2°C.

For the lettuce plants (Fig. 4), till 30 min, the temperature of the Control and water-stressed plants was nearly same. After then the temperature of water-stressed plants increased slightly and reached to 26°C at 60 min. However, leaf temperatures of the Control fluctuated to 25°C.

Fig. 5 shows the responses of a Control and water-stressed hot pepper plants. The response of hot pepper plants was different from those of cucumber plants and lettuce plants. The average temperature of the water-stressed plants was lower than that of Control plants by 1°C. The temperature of the water-stressed plants decreased by 1°C at the beginning of the experiment, and maintained about 24°C. The temperatures of the Control plants were fluctuated around surrounding air temperature, 25°C.

CONCLUSIONS

The aim of this paper was the application of infrared thermography to measure temperature changes of a plant leaf coressponding to water stress. It was possible to detect the changes in leaf temperature by infrared thermography when subjected to water stress. Since the changes in leaf temperatures were different for different species, further analyses are necessary to utilize the thermography to a plant-growth monitoring system.

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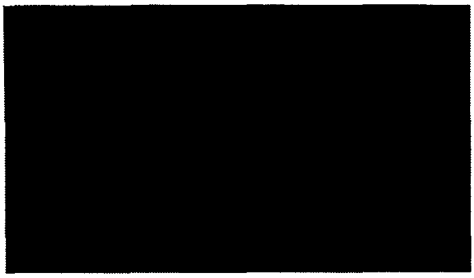

(a) Before the test

(a)' Before the test

(b) After 10 minutes

(b)' After 10 minutes

(c) After 20 minutes

(c)' After 20 minutes

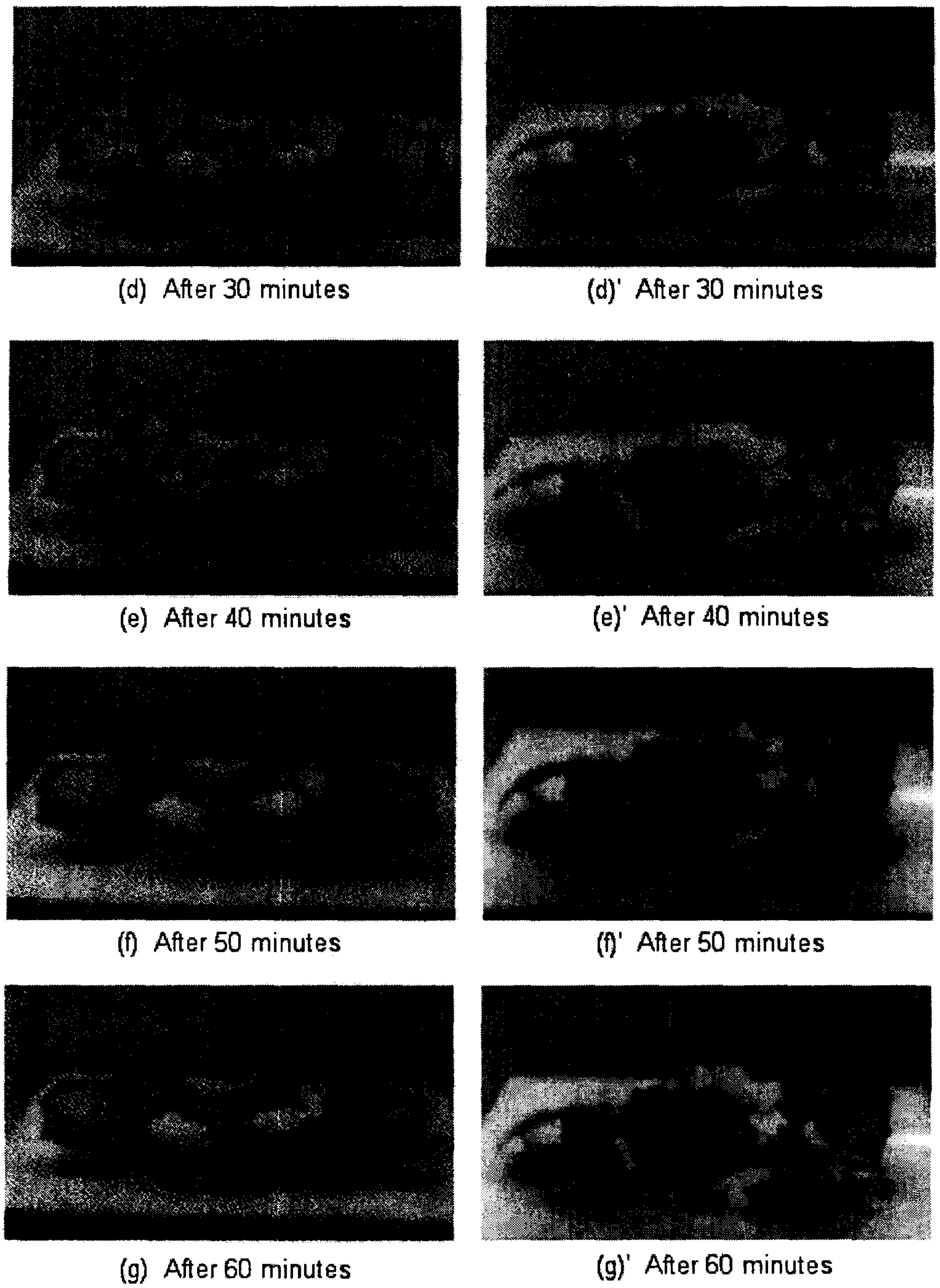

Fig. 2 Thermal images during the cucumber growing experiment
((a)~(g) : water-stressed, (a)'~(g)' : Control)

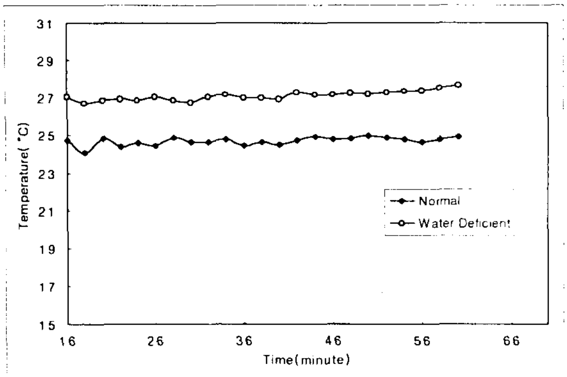

Fig. 2 Effects of water stress on leaf temperature of cucumber.

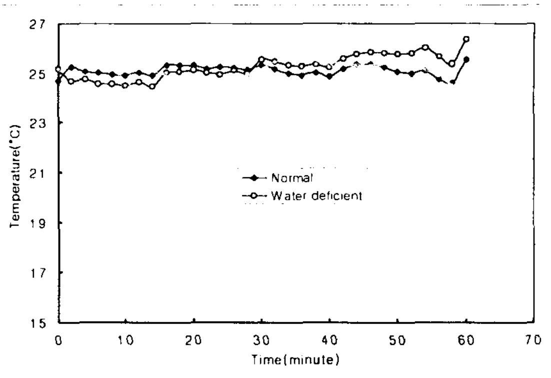

Fig. 3 Effects of water stress on leaf temperature of lettuce.

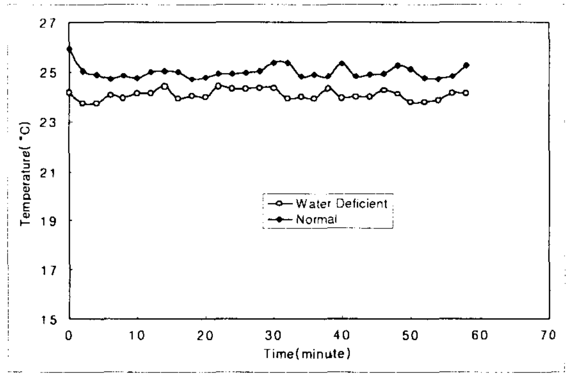

Fig. 4 Effects of water stress on leaf temperature of hot pepper

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