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Comparison of Nutrient Deficient Stress Diagnoses of Cucumber Plant Using Non-Destructive Physiological Instruments

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Abstract: This paper represents methods to diagnose nutrient deficient stresses of cucumber plants using several physiological instruments. The stresses could be detected by measuring and analyzing the difference of chlorophyll content, photochemical efficiency (Fv/Fm), temperature difference (DT) and light absorbance at wavelengths of 480nm, 560nm and 710nm between deficient and control plants. From the all over experiments, the stresses could be first diagnosed in the 3rd to 5th day in general after treatment and the overall diagnosis rate was estimated at more than 50% up to 100%.
Keywords: Nutrient stress, P, K and Ca, Stress diagnosis, Cucumber plant

Introduction

There has been much effort in developing sensors for detecting various plant stresses. Sophisticated instruments to measure chlorophyll content, leaf temperature, chlorophyll fluorescence, stomatal resistance, photosynthetic efficiency, light reflectance and sap flow have been developed and widely used (Schurer et al., 1991).

The sensors are classified as destructively and non-destructively detectable one. Destructive sensors need a lot of time and labor for detecting stresses and especially can cause stress against growing although they provide direct bio-information about plant stresses. Non-destructive (*in-vivo*) sensors, however, are not limited by these problems. Therefore, non-destructive and plant-response-based measurements for detecting plant stresses are preferred and recommended as a future sensing technology (Pearcy et al., 1989; Buschmann et al., 1994).

Among the non-destructive plant sensors Gausman and Quisenberry (1990) emphasized spectrophotometric measurement of reflectance, transmittance, and absorptance of a single leaf can often be utilized to detect plant stresses or damages caused by various nutrient deficiency, diseases, growth regulators, and soil salinity. They noted that stressed leaves usually exhibit higher reflectance (less absorbance) than non-stressed leaves. Milton et al.(1991) indicated that spectral reflectance of phosphorus deficient soybean showed higher reflectance in the green and yellow positions of the electromagnetic spectrum (about a wavelengths range from 530 nm to 570 nm). Lichtenthaler and Rinderle (1988) and Buschmann et al. (1994) noted the importance of active laser induced fluorescence measurement in stress detection in plants along with passive reflectance (sunlight reflectance). Carter (1994) and Elvidge and Chen (1995) suggested various ratios of leaf reflectance (vegetation index) which are very effective to detect plant stresses with the passive reflectance.

Sung et al. (1999) reported N deficient stress of cucumber plant could be successfully detected by a chlorophyll meter, a chlorophyll fluorescence meter and a spectrophotometer at wavelengths of 563 nm, 712 nm and 1,890 nm. Suh et al. (2000) tried to detect nutrient deficiencies of N, P and Ca of tomato plant. They noted a chlorophyll meter was useful for detecting N deficient stress, a leaf thermometer and a porometer were for P and Ca deficient stresses, a spectrophotometer (at wavelengths of 480 nm, 560 nm, 710 nm and 1,120 nm) was for N, P and Ca deficient

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stresses, and a multi-scan radiometer was for N and Ca deficient stresses.

Most of the studies on the sensors for detecting plant stresses have been mainly concerned to find sensitive physical or physiological factors to the stress. However, even though some factors for stress are found, the stress could not always be detected by the factors because of irregular response of plants due to variation of adaptation or acclimation to the stress. Hence it is very desirable to have information on possibility to detect the stresses by the factors in order to apply the diagnosis technique to practical farming.

The goals of this study are to select suitable physical instruments for non-destructively detecting nutrient deficient stresses of P, K and Ca in cucumber plant and to estimate the possibility for diagnosing the stresses using the instruments.

Materials and Methods

1. Materials

Cucumber (*Cucumis sativus L.*) seeds were sown in carbonized chaff. Three cucumber seedlings at two leafy stage were transferred into 4-L pots of nutrient solution. Solution of the pot was made of Cooper's(1975) nutrient solution and 3rd distilled water. At the appearance of the 4th true leaves, the nutrient stresses were applied to the plants after acclimatized to the circumstances.

Vigorous aeration was supplied by air pump to maintain uniform environment of nutrient solution in pots. The nutrition solution was regularly replaced at 2~3 day intervals to maintain the composition of nutrition solution with time to prevent from the unbalanced absorption of nutrients by the plants.

2. Instruments

Various physiological instruments were used to diagnose cucumber plant stresses such as a chlorophyll meter of SPAD-502 (Minolta Co. Ltd., Japan) for chlorophyll content; a chlorophyll fluorescence measurement system of CF-1000 (Morgan Scientific Inc. USA) for photochemical efficiency (Fv/Fm, Fv: variable fluorescence, Fm: maximal fluorescence) and Fm/2 increasing time ($t_{1/2}$); an infrared leaf thermometer of 510B (Everest InterScience Inc. USA) to display the difference between atmosphere and leaf temperatures (DT); and a near-infrared spectrometer of NIRS 6500 (Perstorp Analytical Inc.) to scan the spectrum data of light absorbance of plant leaves in the range of 400 nm to 2,500 nm in 2 nm intervals.

3. Methods

The experiments were performed by comparing the bio-informations of cucumber plants treated by nutrient stresses such as P, Ca and K deficiencies with those of control cucumber plants. The nutrition solution for the experiments was made by excluding each P, Ca and K from Cooper's nutrient solution for the respective stress. Each two leaves grown for 10~15 days were selected for the experiments at 3 plants per pot. Then, the bio-informations of the leaves was measured using the physiological instruments. The data were collected for 2 hours from 10:00 to 12:00 for 12~20 days.

To estimate the possibility for diagnosing, P and Ca deficient experiments were repeated 4 times and K deficient experiment twice. In each replication the four kinds physiological instruments were used to collect the bio-information of the plants except of the chlorophyll fluorescence measurement system which was used two replications only in the P and Ca deficient experiments.

All experiments above were performed in a plastic greenhouse and growth chambers at Chonnam National University, Kwangju from April 1997 to June 2000.

Results and Discussion

In order to distinguish the stressed and the control plants, a two-sample T-test was performed with the daily experimental data from the instruments. On the test, we regarded the plants maintaining the T-test result of less than 5% significant level during over continuous 3 days within the 12th day after treatment as the stressed plant. In the stressed plant, we investigated the first day to detect stresses and the diagnosis rate (value considering the ratio of the number of experiment for detecting stresses to experiment trial numbers and significant level). The diagnosis results of the instruments are as follows.

1. Chlorophyll meter

The chlorophyll meter for diagnosing P and K deficient stresses was possible but not effective because the diagnosis rate were resulted as 50%. Fig. 1 and 2 show the experimental results of P deficient stress, one for successful and the other for failed to diagnose the stress. The first day to detect P and K stresses was recorded within 9th day after the treatment.

SPAD values in Ca deficient plants tend to be lower significantly with time after treatment than that of control plant (Fig. 3). Ca deficient stress could be detected from the 2nd to the 5th day after treatment with the overall diagnosis rate of 100%.

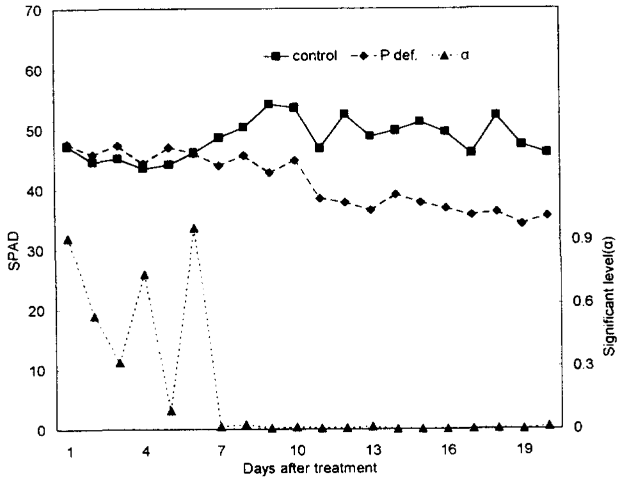

Fig. 1 Comparison of SPAD in P deficient and control cucumber plants (P deficient stress was clearly diagnosed).

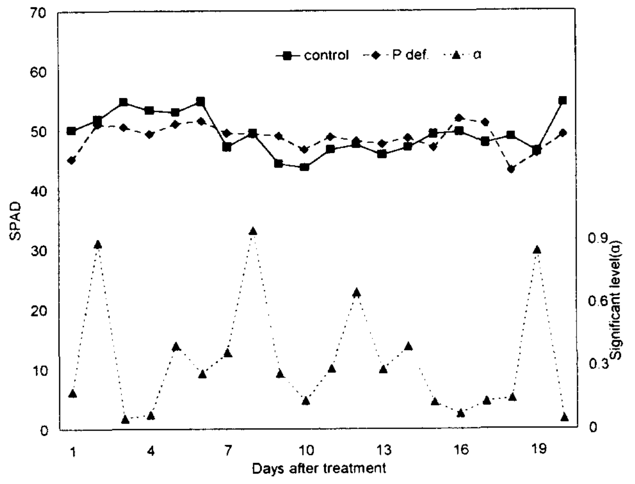

Fig. 2 Comparison of SPAD in P deficient and control cucumber plants (P deficient stress was not clearly diagnosed).

2. Chlorophyll fluorescence measurement system

In P deficient experiments using the chlorophyll fluorescence measurement system, Fv/Fm values of the deficient plants tend to be lower significantly from the 9th day than that of control plant (Fig. 4). The diagnosis rate was estimated at 50%.

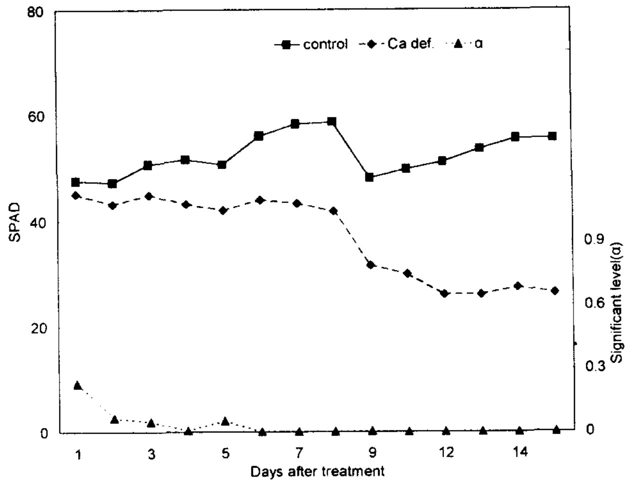

Fig. 3 Comparison of SPAD in Ca deficient and control cucumber plants (Ca deficient stress was clearly diagnosed).

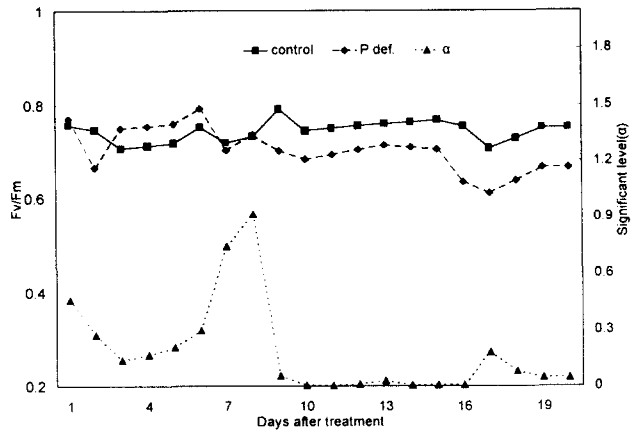

Fig. 4 Comparison of photochemical efficiency (Fv/Fm) in P deficient and control cucumber plants (P deficient stress was clearly diagnosed).

The significant difference of Fv/Fm value between K deficient and control plants from 3rd to 6th day was found (Fig. 5), although the difference of Fv/Fm was gradually reduced with time. Therefore, the K deficient stress could be detected and the overall diagnosis rate was noted as 100%.

The instrument was ineffective for diagnosing Ca deficient stress because no significant difference between the deficient and control plants, despite passing at least 12 days, was admitted.

3. Leaf thermometer

For Ca deficient and control plants, the difference of leaf and air temperatures (DT) of the deficient plant showed greater value than that of control plants from the 3rd day and the difference of the stressed plants became smaller with time after treatment (Fig. 6). From the repeated experiments, Ca deficient stress could be detected from the 6th to 10th day and the overall diagnosis rate was estimated at 75%.

Diagnosis of P deficient stress using the leaf thermometer was ineffective because the diagnosis was possible once out of 4 replications. Even in the possible case patterns of the difference of DT between deficient and control plants after treatment was not clear.

Diagnose of K deficient stress using the thermometer was possible at 50% of the diagnosis rate. Fig. 7 shows the possible case to diagnose the K deficient and control plants by DT. As shown, the first detectable day was the 6th day.

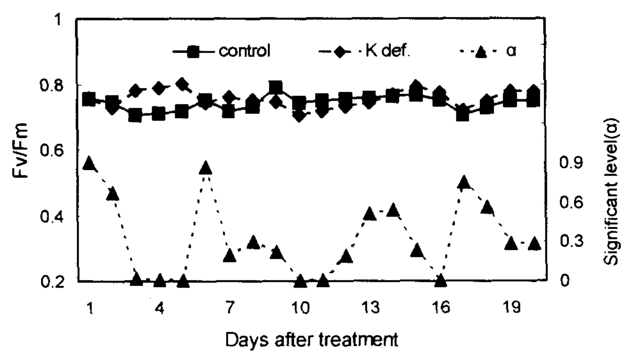

Fig. 5 Comparison of photochemical efficiency (Fv/Fm) in K deficient and control cucumber plants (K deficient stress was clearly diagnosed).

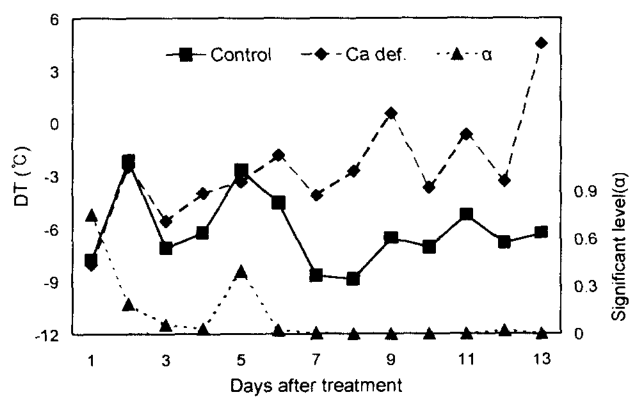

Fig. 6 Comparison of temperature difference between leaf and atmosphere (DT) in Ca deficient and control cucumber plants.

4. Near-Infrared spectrometer

This study investigated to determine the appropriate wavelengths to diagnose the stressed plants by measuring light absorbance of leaves of deficient and control plants. The appropriate wavelengths were selected in which the stressed and control plants are sensitively differentiated. Then, the diagnosis rates and the first detectable days were investigated by a series of tests. The results are as follows:

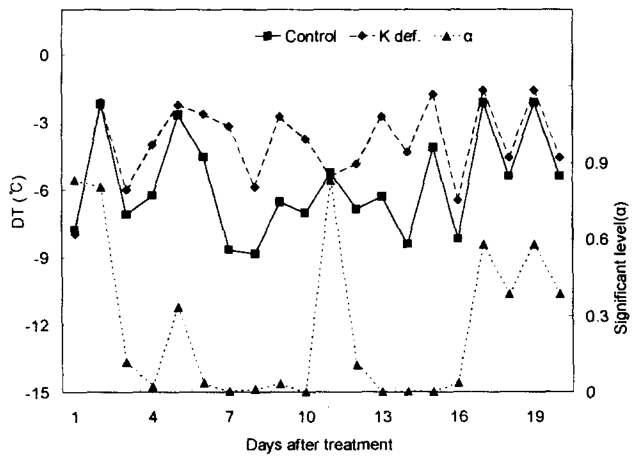

Fig. 7 Comparison of temperature difference between leaf and atmosphere (DT) in K deficient and control cucumber plants.

Sensitive wavelength ranges for P deficient diagnosis were 460~506nm, 508~658nm, 660~740nm, and 1,864~1,916nm and the appropriate wavelengths were selected about 480nm, 560nm, 710nm and 1,900nm roughly. In Ca deficient diagnosis, sensitive wavelength ranges were 450~514nm, 516~650nm, 650~740nm, and 1,912~1,950nm and the appropriate wavelengths were located at 480nm, 560nm, 710nm and 1,930nm. For K deficient plants, such appropriate wavelength was not found. As a consequence wavelengths of 480nm, 560nm and 710nm were selected as the appropriate wavelengths in this study. The selected wavelengths are almost the same as the wavelengths considered as appropriate in the previous studies (Sung et al., 1999; Suh et al., 2000).

The diagnosis of P deficiency was varied with wavelengths. The diagnosis rate estimated were 50%, 75% and 75% at the wavelengths of 480nm, 560nm and 710nm, respectively. The variation of the diagnosis rate was considered mainly due to different rate of change of pigments in cucumber leaves responded to the P deficiency. The stress could be generally detected first at the 6th to 7th day and at least in the 10th day at the appropriate wavelengths. Fig. 8 shows changes of light absorbance in P deficient and control plants at a wavelength of 560nm.

The overall diagnosis rate for Ca deficient stress was 75% at the 3 appropriate wavelengths. The stress could be generally detected first at the 4th to 5th day and at least in the 10th. Fig. 9 shows a sample of light absorbance in Ca deficient and control plants at a wavelength of 710nm. K deficient stress could not be detected by the instrument because any appropriate wavelength was not found.

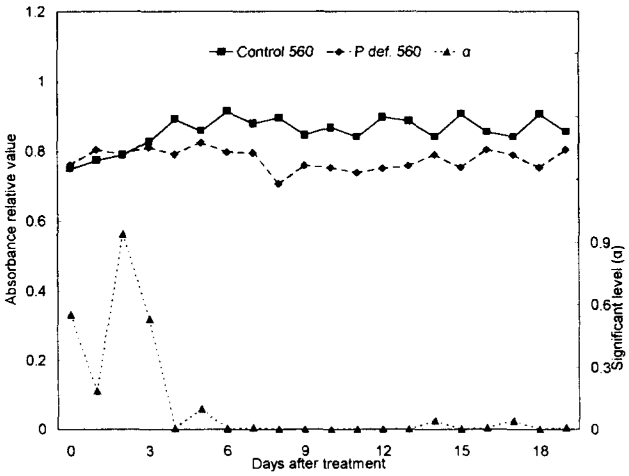

Fig. 8 Comparison of light absorbance in P deficient stress and control cucumber plants at a wavelength of 560 nm.

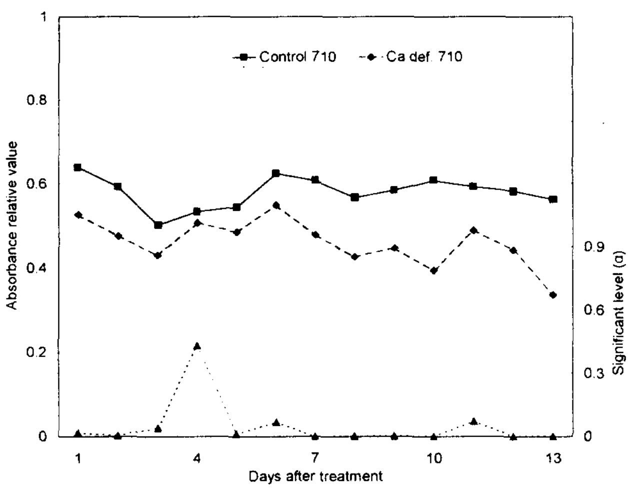

Fig. 9 Comparison of light absorbance in Ca deficient stress and controlled cucumber at a wavelength of 710 nm.

Conclusions

The results of experiments to diagnose nutrient stresses such as P, K, and Ca deficient stresses of cucumber using different measuring instruments are as follows:

The useable instruments for diagnosing P deficient stress were chlorophyll meter, chlorophyll fluorescence measurement system and near-infrared spectrometer and the diagnosis rate of the instruments were estimated at in a range of 50~75%. Near-infrared spectrometer could diagnose P deficient stress from the 4th day with the earliest detection ability.

The K deficient stress could be diagnosed by chlorophyll meter, chlorophyll fluorescence measurement system and leaf thermometer. Leaf thermometer could diagnose K deficient stress with the overall diagnosis rate of 100% from the 3rd day at the earliest. The diagnosis rate of chlorophyll meter and chlorophyll fluorescence measurement system were estimated at 50%.

The useable instruments for diagnosing Ca deficient stress were chlorophyll meter, infrared thermometer and Near-Infrared spectrometer. The diagnosis rate of the instruments were around 100%, 80% and 75%, respectively. Chlorophyll meter and near-infrared spectrometer could detect the stress from the first day, however, from 2nd to 5th day in general.

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