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# Monitoring Fresh Weight of Leaf Lettuce

## 2. Effects of light, air temperature, relative humidity and Wind velocity

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**Abstract**

Transitory changes in fresh weight of leaf lettuce. Which might be associated with the changes in ambient conditions, were analysed, thereby a suitable method for monitoring fresh weight was investigated. The fresh weight is temporarily lost by (1) illumination, (2) temperature rise at a constant relative humidity, (3) increase in vapor pressure deficit (VPD), and (4) increase in wind velocity, while it is gained under the opposite conditions. The fresh weight transitorily changed within 30 min after the state of exposure to different conditions. When the light conditions changed from dark to light, both of the transpiration rate and water saturation deficit of the leaves increased. The increase in temperature at a constant relative humidity caused loss of fresh weight, but the weight remained stable under a constant VPD. It was concluded that the transitory changes in fresh weight of leaf lettuce could be ascribed to the changes in transpiration rate. Therefore, the fresh weight as an indicator of plant growth has to be measured under the conditions that keep the transpiration rate constant.

**Discipline:** Horticulture
**Additional key words:** continuous measurement, Lactuca sativa, nondestructive measurement, transpiration

## Introduction

Data on plant status are usually taken with destructive and non-continuous methods, while the ambient conditions are determined continuously with electric sensing. It is therefore difficult to analyse short-term reactions of intact plants to the changes in environmental conditions. Sensing and computing techniques that have been developed in recent years, however, could be applicable to continuous measurements of plant status.

Instruments for continuous measurements have been developed in monitoring plant growth, such as diameter of cotton (*Gossypium indicum*)[15], stem length of tomato (*Lycopersicon esculentum*), eggplant (*Solanum melongena*), cucumber (*Cucumis sativus*) and melon (*Cucumis melo* var. *reticulatus*)[11], leaf length of winter wheat (*Triticum aestivum*)[4], fruit length of pea (*Pisum sativum*)[8], fresh weight of butterhead lettuce (*Lactuca sativa*)[18], leaf temperature of sunflower (*Helianthus annuus*)[6,7] and profile of cucumber[13]. However, the information obtained through such instruments are still very limited.

The fresh weight, among those parameters for monitoring plant growth, is an important indicator to analyse the growth of vegetables, especially leaf vegetables, the yield of which is directly associated with water contents in leaves generally exceeding 90%. Shoot and whole fresh weight of garland chrysanthemum (*Chrysanthemum coronarium*) grown under a nutrient solution culture was monitored with cantilever beam sensors[19,20]. However, detailed relationship between the fresh weight of vegetables and the environmental factors has to be studied yet.

The present study attempts to analyse responses of fresh weight of leaf lettuce to environmental changes through a nondestructive and continuous monitoring method. Toward this end, shoot fresh weight of leaf lettuce was monitored under abrupt changes in light, air temperature, humidity and wind velocity. Transpiration rate and water saturation deficit (WSD) under dark and light conditions were also measured.

## Materials and methods

*1) Instrument for monitoring shoot fresh weight*

Fig. 1 shows the instrument used for monitoring shoot fresh weight. The plants on the board were weighed by load cells, and the weight was monitored with a recorder given in the previous report[5]. The plants under study are supported by a board, and their roots below the board are submerged in a nutrient solution, which is circulated through a regulator of solution temperature. Surface level of the nutrient solution is kept constant by overflowing. The plant shoots and the board are weighed with three load cells (Kyowa Dengyo, 120 t-50 b) supporting the board. The output of the load cells is continuously transformed to shoot fresh weight and recorded by a recorder (Yokogawa Denki, YEW-3087).

*2) Materials and cultivation methods*

Seeds of leaf lettuce (*Lactuca sativa* cv. Grand rapids) were sown in charcoal-treated rice husks, and irrigated with a nutrient solution that contained: (in mmol $l^{-1}$) 7.8 $NO_3$-N, 0.8 $NH_4$-N, 0.6 P, 1.8 K, 2.1 Ca, 0.9 Mg and 0.8 $SO_4$; (in $\mu$mol $l^{-1}$) 24 Fe, 11 B, 11 Mn.

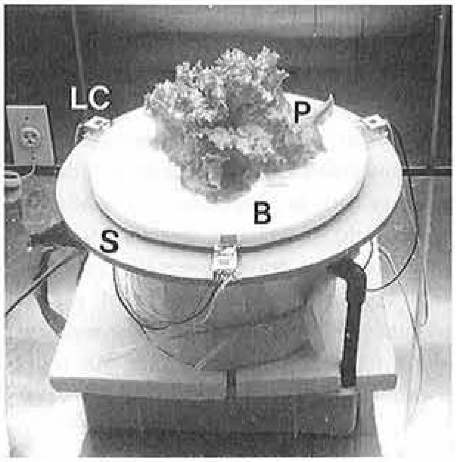
As soon as the first true leaf unfolded, the plants were transferred to the nutrient solution and grown at 20±0.5°C AT (air temperature), 75±10% RH (relative humidity) and 388 $\mu$mol $m^{-2}s^{-1}$ PPF (photosynthetic photon flux, 18-hr photoperiod). The plants were transferred to the board of the instrument described in *1)* a few days before the experiments were carried out.

*3) Effects of light changes*

**Experiment 1:** Fresh weight of three plants with 11 and 12 leaves was continuously monitored with the above-mentioned instrument under dark and light (338 $\mu$mol $m^{-2}s^{-1}$ PPF) conditions.

**Experiment 2:** Seven plants each bearing 6 leaves with a 115 $cm^2$ leaf area were transferred to the board with 6 cm spacing. The board was supported by a stand. A 1-liter container with the nutrient solution, in which the roots were submerged, was set on a balance (Shimadzu ED-2000-10) and weighed every 10 min during the dark and light treatments. Transpiration rate was calculated by the following equation:

$$TR = (\Delta Wp - \Delta Wn) / (LA \times \Delta T),$$



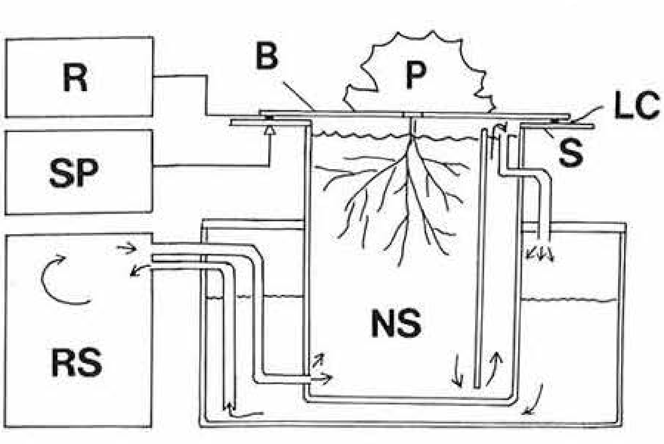




Fig. 1. External view (left) and structure (right) of the instrument used for monitoring shoot fresh weight of leaf lettuce
P: Plant, B: Board, LC: Load cell, S: Support, R: Recorder, SP: Stabilized electric power, RS: Regulator of solution temperature, NS: Nutrient solution.

where TR is transpiration rate (g $dm^{-2}$ $hr^{-1}$), $\Delta Wp$ is decrease in weight of water with plants (g), $\Delta Wn$ is decrease in weight of water without plants (g), LA is leaf area (1.15 $dm^{-2}$), and $\Delta T$ is time difference (hr).

**Experiment 3:** Four plants were subjected to the dark and light treatments (388 $\mu$mol $m^{-2}s^{-1}$ PPF). The water saturation deficit (WSD) of each leaf was measured after exposure to 4-hr darkness and 1-hr light. The WSD was given by the following equation:

$$WSD = 100 \times (SFW - FW) / (SFW - DW),$$

where WSD is water saturation deficit of a leaf expressed in percentage, SFW is saturated fresh weight (g) of the leaf after 0.5-hr soaking in water, FW is fresh weight (g) of the leaf before soaking in water, and DW is dry weight (g) of the leaf. SFW was measured after water was completely wiped out on the leaf surface. It was already confirmed that soaking in water for 0.5 hr was enough to saturate the leaves with water.

*4) Effects of temperature changes*

**Experiment 4:** Three plants were transferred to the board of the instrument as soon as 6 leaves unfolded. Air temperature was controlled at 5, 20 and 35°C every 6 hr including 1-hr transitory period shown in Fig. 4. During the treatment, the light intensity, temperature of nutrient solution and relative humidity were kept at 388 $\mu$mol $m^{-2}s^{-1}$ PPF, 25°C and 80±5%, respectively.

**Experiment 5:** Under a constant VPD of 0.6 kPa, the changes in fresh weight of three plants with the temperature changes were monitored. The air temperature was kept at 25, 35 and 25°C. The other conditions were the same as those in Exp. 4.

*5) Effects of changes in the relative humidity*

The instrument for monitoring fresh weight of lettuce plants was set in a photosynthetic chamber (125 *l*) made of transparent acryl[16]. A plant with 11 leaves and a 640 $cm^2$ leaf area was transferred to the board of the instrument. The fresh weight, transpiration rate, leaf temperature and photosynthetic rate were simultaneously monitored under the varying conditions of relative humidity ranging from 80% (0.63 kPa VPD at 25°C) through 55% (1.43 kPa) to 90% (0.32 kPa) as illustrated in Fig. 6. Air temperature and light intensity were kept at 25°C and 1300 $\mu$mol $m^{-2}s^{-1}$ PPF, respectively. Stored air at 350-ppm carbon dioxide was blown into the chamber at a rate of 20 *l* $min^{-1}$, and the carbon dioxide concentration was measured with an infrared gas analyzer (Fuji Electric ZAP-2). Leaf temperature was measured with C-C thermocouples (ø0.1 mm) attached to the leaf surface. Transpiration rate (TR, g $H_2O$ $dm^{-2}hr^{-1}$) and photosynthetic rate (PR, mg $CO_2$ $dm^{-2}hr^{-1}$) were calculated by the following equations:

$$TR = 6 \times FR \times \Delta WC / LA^{9)},$$
$$PR = (FR \times \Delta CD \times 3217.5) / (LA \times (AT + 273))^{12)},$$

where FR is flow rate of air (*l* $min^{-1}$), LA is leaf area ($cm^2$), $\Delta WC$ is differential water content in the air at the exit of the chamber and that at the entrance (g $H_2O$ $m^{-3}$, $\Delta CD$ is differential $CO_2$ concentration at the entrance of the chamber and that at the exit (ppm), and AT is air temperature (°C). In this experiment, the values of FR and LA were 20 *l* $min^{-1}$ and 640 $cm^2$, respectively.

*6) Effect of changes in wind velocity*

A plant with 20 leaves was transferred to the board of the instrument in a growth chamber controlled at 25°C, 55% RH and 136 $\mu$mol $m^{-2}s^{-1}$ PPF. The fresh weight was monitored under a wind velocity of 0 and 0.5 $ms^{-1}$ from the third day after the transfer.

## Results and discussion

*1) Effects of light changes*

Fig. 2 shows the changes in fresh weight of leaf lettuce under the dark and light conditions. The fresh weight showed a transitory decrease after the start of illumination and an increase after the onset of darkness. The transitional state ended within 30 min, and thereafter the fresh weight continued increasing in the dark and light at approximately the same rate. These phenomena are similar to the changes of the stem diameter reported in Satsuma mandarin (*Citrus unshiu*) and zelkova tree (*Zelkova serrata*)[17]. The transitional period of 30 min in leaf lettuce may be moderate, taking into consideration the duration in other plants, i.e. 60 min in rubber (*Ficus elastica*), 20 min in Satsuma mandarin and

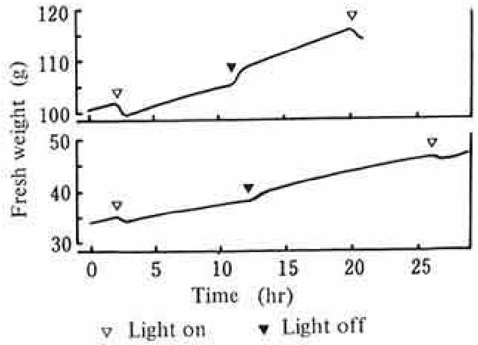



Fig. 2. Changes in shoot fresh weight of leaf lettuce
Leaf lettuce plants with 11 (bottom) and 12 (top) leaves were placed under dark and light cycles. Air and solution temperatures were controlled at 20 and 25°C, respectively. Light intensity was 388 $\mu m^{-2}s^{-1}$ PPF.

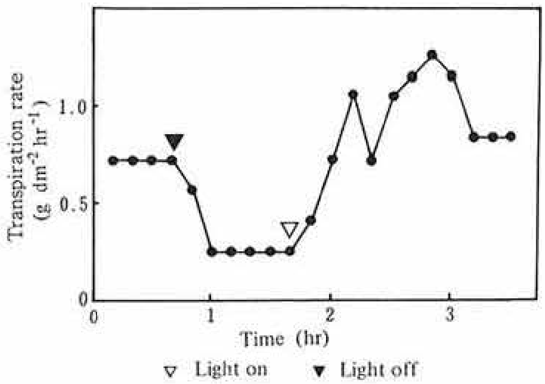



Fig. 3. Changes in transpiration rate of leaf lettuce under dark and light cycles
Air and solution temperatures were controlled at 20 and 25°C, respectively. Light intensity was 388 $\mu mol\ m^{-2}s^{-1}$PPF.

zelkova tree[17].

Fig. 3 shows the changes in transpiration rate of leaf lettuce under the dark and light cyclic conditions. The transpiration rate decreased from 0.71 g $dm^{-2}hr^{-1}$ in the light to 0.25 g $dm^{-2}hr^{-1}$ within 20 min after the onset of the dark period. Diffusive resistance of the water vapor increased in the dark followed by the decrease of the transpiration rate as shown in a figure reported by Miller et al. (1985)[14]. It was reported that the changes in transpiration rate affected the water potential of the leaf blade in wheat (*Triticum aestivum*)[3], and the values appeared to be inversely proportional to those of the leaf water potential with a lag period in maize (*Zea mays*)[1]. Therefore, the transitory change of fresh weight seems to be associated with the change in water potential in plants. The maximum transpiration rate appeared one hr after the light was switched on again, but the rate decreased and became stable at about the earlier level when the light was on.

**Table 1. Water saturation deficit (WSD) of leaf lettuce in the dark and the light**

| Position of leaf | Average fresh weight[a](g) | WSD (%)[b] | |
|---|---|---|---|
| | | Dark | Light |
| 2 | 0.27 | 1.50±0.47 | 2.48±0.37 |
| 3 | 0.48 | 1.60±0.24 | 2.55±0.59 |
| 4 | 0.81 | 1.65±0.27 | 2.50±0.40 |
| 5 | 1.41 | 1.75±0.28 | 2.10±0.27 |
| 6 | 1.28 | 1.88±0.44 | 2.13±0.35 |
| 7 | 0.46 | 4.18±0.85 | 3.98±0.55 |
| 8 | 0.08 | 7.20±1.64 | 6.93±0.83 |

a): After soaking in water for 30 min.
b): Data are expressed as the mean±SE.

Table 1 shows the values of the WSD of leaf lettuce in the dark and light. The higher the leaf position is, the larger the WSD is. The WSD in the light was larger than that in the dark except for the 7th and 8th leaf positions. The WSD around the 5th leaf, which showed the largest weight, was the major factor affecting shoot fresh weight of leaf lettuce.

The above result suggests that the light open stomata and promote transpiration, followed by the decrease in fresh weight.

*2) Effects of temperature changes*

Fig. 4 shows the changes in fresh weight of leaf lettuce with the temperature changes at a constant relative humidity. Incremental rate of the fresh weight at 20°C recovered after exposure of the plant to low (5°C) and high (35°C) temperatures, whereas the rates were lower at 5°C and at 35°C than at 20°C. The fresh weight decreased and increased, immediately after the start of the increase and the decrease in temperature, respectively. This tendency was most prominent at a high temperature.

Fig. 5 shows the changes in fresh weight of leaf lettuce with the temperature changes under a constant

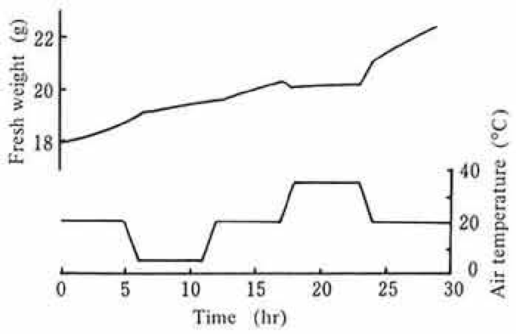



Fig. 4. Changes in shoot fresh weight of leaf lettuce with the changes in air temperature at a constant relative humidity (77±8%)
Solution temperature and light intensity were controlled at 25°C and 388 $\mu$mol $m^{-2}s^{-1}$ PPF, respectively.

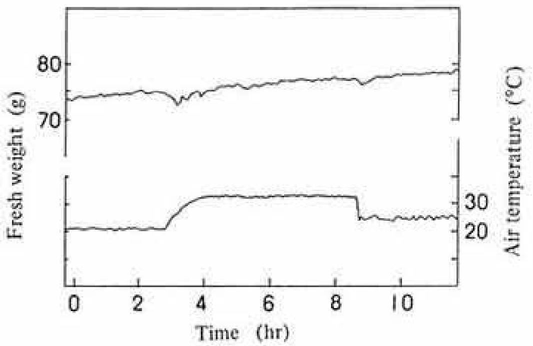



Fig. 5. Changes in shoot fresh weight of leaf lettuce with the changes in air temperature under a constant VPD (0.6 kPa)
Solution temperature and light intensity were controlled at 25°C and 388 $\mu$mol $m^{-2}s^{-1}$ PPF, respectively.

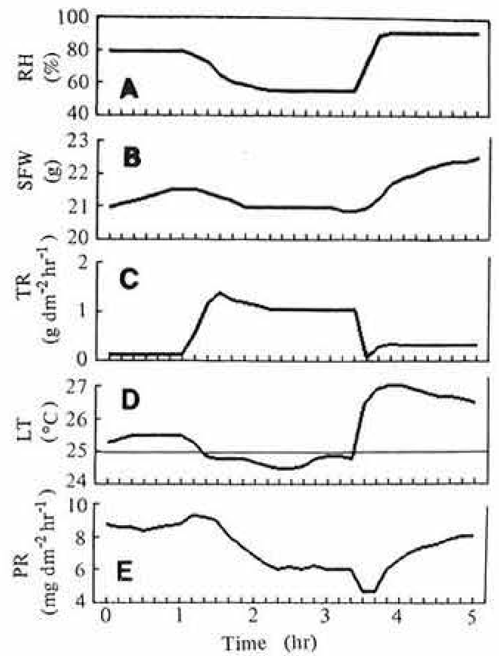



Fig. 6. Changes in shoot fresh weight (B), transpiration rate (C), leaf temperature (D) and photosynthetic rate (E) with the changes in relative humidity (A)
Air and solution temperatures were controlled at 25°C, and light intensity was 1,300 $\mu$mol $m^{-2}s^{-1}$ PPF.

VPD. The fresh weight increrased constantly in spite of the temperature change, except for the period that immediately followed the temperature change which caused a control error of the VPD.

The transpiration rate was primarily associated with the VPD. At a constant relative humidity, however, the VPD changed with the temperature changes. Since the VPD at a constant relative humidity was larger at higher temperatures, rates of the decrease and increase in fresh weight with the temperature changes were larger at a high temperature than at a low one. It was suggested that the temperature change without constant VPD cause a transitory change of the fresh weight in plants.

*3) Effects of relative humidity changes*

The changes in fresh weight, transpiration rate, leaf temperature and photosynthetic rate in leaf lettuce with the changes of relative humidity were measured simultaneously (Fig. 6). Along with the change from 80% RH through 55% RH to 90% RH, the rate of increase in fresh weight changed from 0.50 g $hr^{-1}$ through $-0.01$ g $hr^{-1}$ to 0.60 g $hr^{-1}$, and the transpiration rate did from 0.15 g $dm^{-2}hr^{-1}$ through 1.07 g $dm^{-2}hr^{-1}$ to 0.36 g $dm^{-2}hr^{-1}$. The leaf temperature was higher than the ambient temperature at 80 and 90% RH, unlike that at 55% RH. A response of photosynthesis to the humidity changes was delayed by about 30 min, and the transpiration rate was lower at 55% RH than at 80 and 90% RH.

Stomatal conductance and photosynthetic rate of soybean (*Glycine max*) were decreased with the

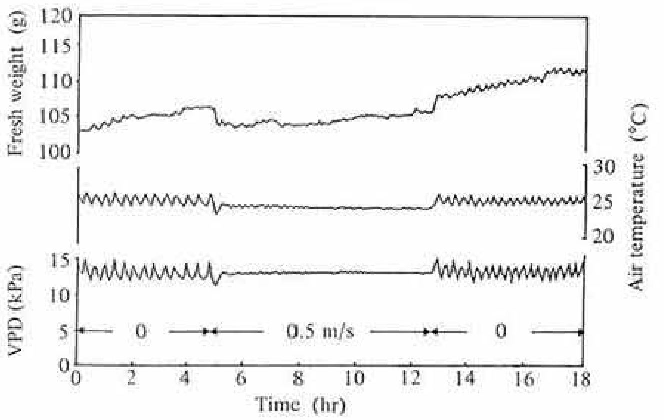



Fig. 7. Changes in shoot fresh weight of leaf lettuce with the changes in wind velocity under a constant air temperature and VPD

Solution temperature and light intensity were controlled at 25°C and 136 $\mu$mol $m^{-2}s^{-1}$ PPF, respectively.

increase in VPD from 1.0 kPa to 2.5 kPa after a 10-min lag[2]. Stomatal aperture, diffusive resistance and photosynthetic rate decreased with the increment in VPD, and the transpiration rate was proportional to VPDs less than 1.1 kPa[10]. It was clearly observed that low humidity increased the transpiration rate, as evidenced by the decrease in leaf temperature, and caused the decrease in fresh weight. Excessively low humidity, however, seems to induce water stress in plants and depress the photosynthesis.

*4) Effect of wind velocity changes*

The changes in fresh weight with the changes in wind velocity at a constant air temperature and relative humidity are depicted in Fig. 7. While the wind was blowing, the fresh weight was decreasing.

Based on this observation, it is considered that the wind breaks up the boundary layers on leaves, and accelerates the transpiration, causing the decrease in fresh weight.

## Conclusion

The current study demonstrated that fresh weight of leaf lettuce changed under the varying conditions of transpiration rate: that is, the fresh weight decreased with illumination, increased VPD and greater wind velocity. On the other hand, the changes in air temperature did not affect the fresh weight at constant VPD, whereas they affected the weight at a constant relative humidity with different values of VPD at different temperatures.

It is concluded that the transitory changes in fresh weight of leaf lettuce can be attributed to the changes in transpiration rate. Therefore, the fresh weight as an indicator of plant growth should be monitored under the conditions that have a constant transpiration rate.

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