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Monitoring Fresh Weight of Leaf Lettuce

1. Instrument for continuous measurements

Hiroshi HAMAMOTO and Masayuki ODA

Department of Applied Physiology, National Research Institute of Vegetables, Ornamental Plants and Tea (Ano, Mie, 514-23 Japan)

Abstract

Attempts were made to develop an instrument for monitoring fresh weight of leaf lettuce. First, the characteristics of a load cell, which is a component of the instrument, were investigated. Output voltage of the load cell was most stable when it was excited by a stabilized electric power source. Effects of temperature change and hysteresis after long-term loading were negligible. The readings of the weight determined by a device, equipped with a load cell, well agreed with the values of fresh weight of the plant part above the water level. This result suggests that the values of the reading be almost the same as the values of actual top fresh weight, provided that the level of water, in which the roots are submerged, is sufficiently high. Using the newly developed instrument for monitoring top fresh weight, changes of fresh weight and relative growth rate in a plant community of leaf lettuce were monitored for a 17-day period of cultivation. The fresh weight increased 23-times during the cultivation, and the relative growth rate varied in the range from 10 to 29%. These values agreed with the actual measurements taken at the same time by destructive methods. It is therefore concluded that the fresh weight of leaf lettuce plants can be accurately monitored with the instrument developed in this study.

Discipline: Experimental apparatus and methods
Additional key words: load cell, nondestructive method, nutrient solution culture

Introduction

In recent years, continuous and nondestructive methods for monitoring plant growth have increasingly received a keen interest in accordance with the development of sensing devices. In monitoring plant growth, most of those studies have dealt with elongation or expansion of part of a plant body such as stems[5], leaves[1–3], fruits[4,5] and roots[9]. However, only a few studies have pursued the growth of a whole plant[6–8].

Although fresh weight is one of the most important indexes of plant growth, it is seldom investigated, because dry matter production is generally of major interest to agronomists. In the case of vegetables, however, water is one of the major components, and the fresh weight reflects their yield and quality. Monitoring of fresh weight is therefore required for identifying effects of environmental changes on the fresh weight of plants and improving cultivation techniques of vegetables. From this viewpoint, an attempt was made to develop an instrument for continuous and nondestructive measurements of top fresh weight of leafy vegetable plants.

The following three methods are made available as sensors for measuring the fresh weight: a strain gauge, an electric balance and a load cell. Use of the strain gauge is not costly, but inaccurate and requires a temperature compensator. The electric balance gives accurate measurements but expensive. On the other hand, the load cell gives accurate measurements and is rather inexpensive.

The present paper attempts to review results of the studies on the load cell which was adopted as a sensor of the instrument for fresh weight monitoring. The study subjects include effects of the electric power source, temperature and long-term loading on the output of the load cell, and relationships of fresh weight between the measurements with the load

cell and the direct determinations. Based on the results of those tests, an instrument for fresh weight monitoring was worked out, and the leaf lettuce weight was monitored thereby for a period of 17 days.

Materials and methods

1) Device for suitability test

Fig. 1 shows a schematic device for suitability testing of the load cell (Shinkoh UT-500GR). A styrol-foam board with a wire hangs on the load cell fixed to a stand. The load cell is excited at 3-V with electric power sources. Output voltage of the load cell, which is generated in proportion to the weight on the board, is measured with a recorder (Yokogawa YEW-3087).

2) Excitation power source, temperature and long-term loading

An AC-adapter (Sharp EA-17E), dry batteries (1.5 V × 2) and a stabilized electric power source (Kikusui PAC7-10, maximum load 500 g) were used as the excitation power source and output voltage by loading a 250 g weight.

The device illustrated in Fig. 1 was set up in an incubator. The temperature in the incubator was gradually changed from 4 to 40°C and the output voltage at each temperature was measured.

The device was loaded with a 250 g weight for 20 days at 20°C, and the relationship of weight values between the start and the end was determined with a regression analysis.

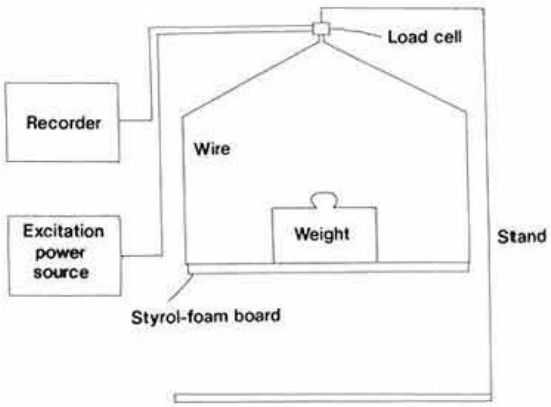

Fig. 1. Schematic device for suitability testing of the load cell

3) Measurements with the device and direct determination

A Wagner pot containing water was placed below the board as illustrated in Fig. 1. Plants with leaf lettuce (*Lactuca sativa* L. var Grand rapid) with 4, 6, 11 and 20 leaves each were put in a hole at the center of the styrol-foam board. A plant at each stage was fixed in the hole with urethane foam surrounding the stem. Roots of the plant were submerged in water, and the weight was determined by the device. Then, the actual fresh weight of partial (top and above water part) and whole plant was destructively measured with an electric balance. The relationships between the readings of weight with the device and the values of actual weight of the plant were subjected to regression analyses at several growth stages.

4) Instrument for monitoring fresh weight

The instrument for monitoring the top fresh weight of plants in a community is schematically illustrated in Fig. 2. Four load cells mounted on the upper edge of a container support a styrol-foam board (60 × 100 cm) at every corner. Plants, the stems of which were surrounded with urethane foam, were transferred to the board, and their roots were submerged in a nutrient solution. The level of the nutrient solution in the container was kept constant to minimize fluctuations of the readings. For that purpose, the level was controlled with a level sensor electrically responding. The nutrient solution in a water bucket was supplied to the container through a pump (Yamato PA-11D). Air was bubbled into the nutrient solution at some intervals by using a timer, an air pump and air stones. Output voltage from the load cells was input into a 16-bit personal computer (NEC PC-9801m) through an A/D-converter (Yokogawa YEW-3087) every 5 seconds. Signals from the load cells were transformed to the reading of the weight and averaged every hour by the computer. The relative growth rate was calculated on the basis of average weight during the last hour in the dark every day. These values were stored in a floppy disk and displayed on TV as a graph.

5) Long-term monitoring fresh weight

The instrument for fresh weight monitoring was placed in a growth chamber controlled at an air-temperature of 20 ± 0.5°C, a relative humidity of

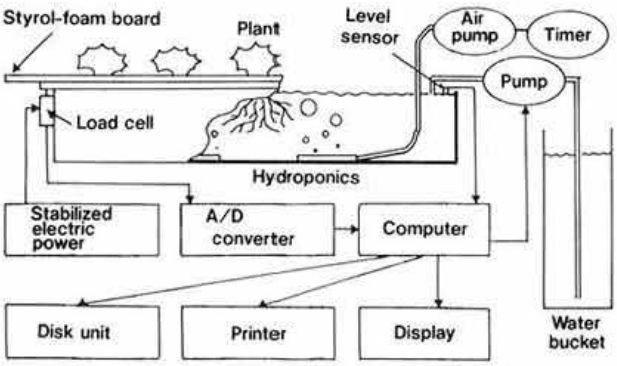

Fig. 2. Instrument for monitoring top fresh weight of leaf lettuce in a community

70–85%, a photon flux density of 342 μmol $m^{-2}s^{-1}$ with metalhalide plus mercury vapor lamps (ca. 3:2 installed wattage). The day length was 18 hr. Fifteen plants were sampled one week after seeding and transferred to the board at a 15 cm-spacing. The nutrient solution contained: (in mmol l^{-1}) 11.7 NO_3-N, 1.2 NH_4-N, 0.9 P, 2.7 K, 3.2 Ca, 1.4 Mg and 1.2 SO_4; (in μmol l^{-1}) 36 Fe, 17 B, 17 Mn. The pH of the nutrient solution was kept at 5.3–6.3 through adding NaOH. The electric conductivity of the solution ranged from 3.0 to 3.7 mS cm^{-1}. Bubbling by the air pump was discontinued during the input of signals from the load cells. The monitoring started 9 days after transfer.

Actual top fresh weight and number of leaves were measured with a destructive method for the plants cultured at the same time every 2 to 4 days.

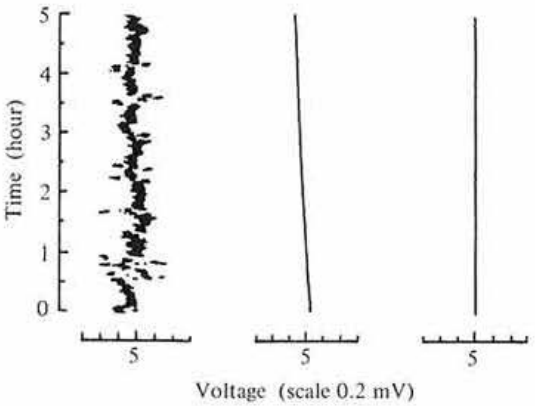

Fig. 3. Effects of power source on the output voltage of the load cell
Left: AC-adapter, Center: Dry battery, Right: Stabilized power source.

Results and discussion

1) Excitation power source, temperature and long-term loading

Output voltage of the load cell excited by the three power sources is shown in Fig. 3. The output voltage fluctuated with the AC-adapter, and gradually decreased with the weakened dry batteries, but it was constant with the stabilized electric power source. These results indicate that only the stabilized power source can be used as excitation power source for the load cell, which requires a constant excitation voltage.

Fig. 4 shows the effect of temperature on the output voltage. The load cell was not affected by temperatures ranging from 4 to 40°C. Hence, the changes of temperature may be overlooked for the

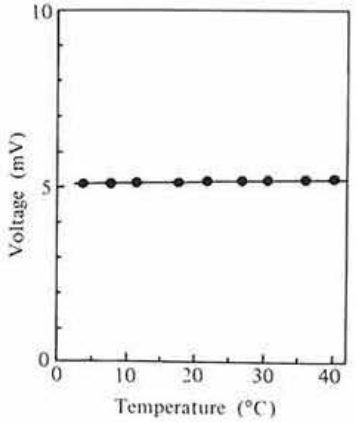

Fig. 4. Effects of temperature on the output voltage of the load cell

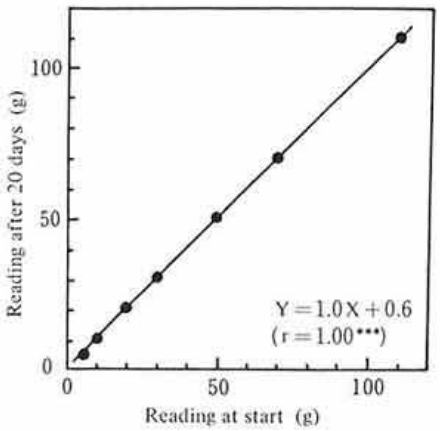

Fig. 5 Relationships of the readings of weight by the load cell between the two stages (at the start and 20 days later)

Table 1. Relationships between readings of weight by the load cell and values of actual fresh weight of leaf lettuce

No. of leaves	Reading of weight (g)	Actual fresh weight (g)*		
		Top (X_1)	Above water part (X_2)	Whole plant (X_3)
4	1.4	1.3	1.4	1.8
6	5.0	5.1	5.3	6.3
11	29.0	26.8	27.4	33.9
20	109.5	108.3	110.0	121.0

* $Y = 1.01X_1 + 0.51$, $Y = 1.00X_2 + 0.36$, and $Y = 0.91X_3 + 0.85$.

use of load cells except under extremely high or low temperature conditions.

The relationship between the reading values of weight by the test device at the start and that after 20 days (end) is shown in Fig. 5. The correlation coefficient between the values of the two readings was r = 1.00***, and the value of the reading at the end was 0.6 g higher than that at the start, suggesting that hysteresis after long-term loading be not significant.

2) Readings with the device and actual weight

Table 1 shows relationships between the readings of weight with the test device and the values of actual weight in leaf lettuce. The value of the reading (Y g) and the value of actual weight of top (X_1 g), above the water (X_2 g) and whole plant (X_3 g) were represented by the following equations:

$$Y = 1.01X_1 + 0.51 \quad (r = 1.00^{***}),$$
$$Y = 1.00X_2 + 0.36 \quad (r = 1.00^{***}), \text{ and}$$
$$Y = 0.91X_3 + 0.85 \quad (r = 1.00^{***}).$$

These functions, which are characterized by high correlation coefficients, indicate that the values of the readings were slightly higher than those of actual top fresh weight and lower than those of whole plant, but almost the same as the values of fresh weight of the plant part above the water level. Thus, the values of the readings determined with the device almost agreed with the values of top fresh weight, when the level of water contents was sufficiently high.

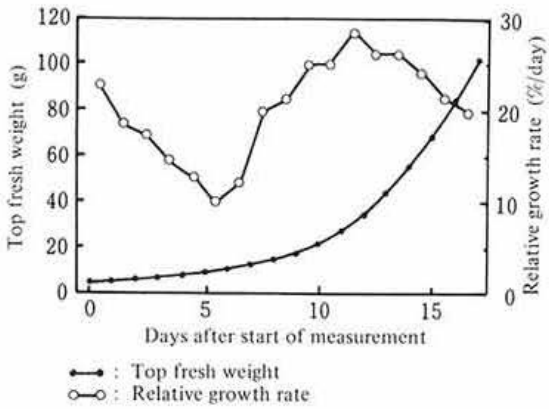

Fig. 6. Changes in top fresh weight and relative growth rate of leaf lettuce under monitoring

Table 2. Changes in top fresh weight and relative growth rate measured by destructive methods

Days	Top fresh weight (g)	No. of leaves
0	4.4	3
2	6.4	4
5	9.7	6
8	14.4	8
11	27.4	11
13	44.6	13
17	102.6	16

3) Long-term monitoring with the instrument

Average values of the fresh weight obtained by the instrument during the last hour in the dark and relative growth rates calculated for each day were

plotted in Fig. 6. The fresh weight increased 23-times during the 17-day period of cultivation. Values of the minimum and maximum relative growth rate, which were observed 5 and 11 days after the start of monitoring, were 10 and 29% for the top fresh weight of 10 and 30 g in plants with 6 and 11 leaves, respectively (Table 2). The readings of fresh weight with the instrument almost agreed with the values of actual fresh weight measured by destructive methods.

4) Use of the instrument for monitoring fresh weight

Studies of environmental effects on fresh weight have seldom been carried out. The fresh weight, however, is important for evaluating yield and quality of vegetables. In operating nutrient solution culture, fresh weight monitoring is particularly useful for managing the growth of plants based on their status. Effects of environmental changes on the fresh weight can also be investigated with the present instrument. Since the fresh weight is sensitive to environmental stress, its monitoring would provide useful information on the plant growth status. It would be expected that new methods of cultivation are developed through the accurate information which could be supplied by the above-proposed instrument for fresh weight monitoring.

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