

Continuous Automatic Measurement of Water Uptake and Water Loss of Cut Flower Stems

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Additional index words. cut flower, *Lilium hybrida*, *Rosa hybrida*, water relations, water loss, water uptake

Abstract. In studying the postharvest water relations of cut flowers, researchers aim to determine rates of water uptake and water loss along with changes in fresh weight. An automatic apparatus was devised for continuous monitoring of these indices. The novel apparatus consists of two balances automatically recording mass at a relatively high data acquisition rate (min^{-1}), a personal computer, two containers, and plastic tubing. The apparatus is accurate, labor-saving, and real-time. It enabled dynamic synchronous recording of water uptake as well as fresh weight of the cut flower stem, from which precise water uptake loss rates during vase life can be accurately determined. Rates of water uptake and water loss of individual cut rose (*Rosa hybrida* cv. Movie Star) stems were measured using the apparatus under alternating 12-h light and dark periods. Both water uptake and water loss rates fluctuated with the light to dark shift over 120 h of observation. Stem fresh weight increased rapidly over the first 40 h of vase period and decreased gradually thereafter. Cut lily (*Lilium hybrida* cv. Yellow Overlord) stems showed similar trends in water uptake and water loss rate to cut rose stems. The accuracy and sensitivity of the new apparatus was validated by comparison with manual weighing using a balance at 2-h intervals under alternating 12-h light and dark periods over 108 h. The apparatus described here constitutes a suitable method for direct measurement of water uptake and fresh weight, including capturing relatively rapid water balance responses to changes in the postharvest environment.

Termination of vase life for cut flowers is characterized by wilting associated with an imbalance developing between water uptake

through xylem conduits in stems and water loss through stomata and other structures on leaves and other organs. To better understand the onset of adverse postharvest water relations, cut flower researchers seek to acquire data on rates of water uptake and water loss. These indices are usually monitored by weighing stems and vases daily or thereabout with a single analytical balance (He et al., 2006; Liu et al., 2009; Macnish et al., 2008). This approach is appropriate to provide an accurate assessment of general trends in water uptake and water loss of cut flowers over time. However, it is costly in terms of

labor and is not appropriate for precise temporal measurement of water uptake and water loss by cut flower stems.

Thus, there is need for an apparatus that can routinely and dynamically distinguish small environment and/or treatment effects to realize precise monitoring of cut flower water uptake and water loss. To measure water uptake rates of individual cut rose stems, Carpenter and Rasmussen (1973) designed a potometer with a side arm calibrated to 0.01 mL. Although useful, it was not automatic and not highly precise. Accordingly, a continuous automatic apparatus (CAA) was devised to measure water uptake, water loss, and fresh weight of cut flowers. Its preliminary application was reported by Lü et al. (2009).

To evaluate the use of the CAA in investigating postharvest water relations of cut flowers, a series of experiments reported here were conducted. They ascertained the efficacy of the CAA to accurately measure water uptake rate and water loss rate for individual cut rose (*Rosa hybrida* cv. Movie Star) and lily (*Lilium hybrida* cv. Yellow Overlord) stems under alternating light and dark regimes during their vase period.

Materials and Methods

Plant materials

Cut rose (*Rosa hybrida* cv. Movie Star) and lily (*Lilium hybrida* cv. Yellow Overlord) flowers at the commercial stage of bud opening at petals starting to reflex were purchased from a wholesale market for cut flowers in Guangzhou, China. The cut flower stems were immediately stood upright into buckets partially filled with tap water and transported within 1 h to the postharvest laboratory of Zhongkai University of Agriculture and Engineering. The flowers were covered with plastic film during transport to minimize moisture loss. At the laboratory, stem ends were recut by 5 cm or greater under deionized (DI) water to remove air emboli. Stems of ≈ 25 cm long and free of visual defects were used in experiments.

Instrumentation

The CAA (Fig. 1) was comprised in part of a transparent lightweight plastic source container ($15 \times 15 \times 5$ cm) filled with 270 mL of DI water on a lightweight plastic pad. Its fluid level was only slightly higher (≈ 1 to 2 cm) than that in a 10 cm in height Erlenmeyer flask "vase." The slight hydrostatic pressure was a driving force for flow of water through plastic connection tubing to continuously refill the Erlenmeyer flask and compensate for water loss from the cut stem. The supply and the vase were each on separate high-precision analytical balances (± 0.001 g; FX-300i; A&D Company Limited, Tokyo, Japan) connected to a desktop personal computer (PC; Dell Computer Corporation, TX).

Before the start of data collection, all joints among the source, plastic tubing, and vase were tested to be watertight. The source and vase were then filled with DI water and an individual cut flower inserted through a hole

Received for publication 2 Sept. 2010. Accepted for publication 16 Dec. 2010.

This research was supported by the grants from Natural Science Foundation of China (No. 30771519 and 31071829) and Natural Science Foundation of Guangdong Province (No. 8251022501000002 and 10151022501000035).

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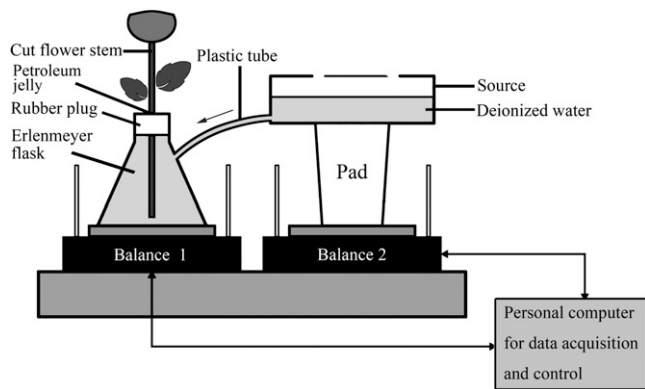


Fig. 1. Diagram of the apparatus (continuous automatic apparatus) devised to continuously and automatically measure water uptake and water loss of cut flower stems.

in a rubber plug fitting the neck of the vase. To ensure complete filling of the vase with DI water, the source was elevated until water spouted from the gap between the wall of the plug hole and the cut flower stem. This operation also assured fluid connectivity within the apparatus. Petroleum jelly was then used to fill the gap.

Water uptake was measured as the residual mass of water in the source on Balance 2. On the assumption that the mass of the vase filled with DI water was constant on Balance 1, the fresh weight (FW) of the individual cut flower stem was synchronously measured. Real-time data for residual water mass in the source representing water uptake and FW of cut flower stem were directly collected at 1-min intervals by running a specifically developed software program (A&D Company Limited, Tokyo, Japan) on the PC connected to both balances.

Experimental design and measurements

Three experiments were conducted in a vase life evaluation room at $22 \pm 2^\circ\text{C}$, $60 \pm 10\%$ relative humidity, and $12 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ light intensity (cool white fluorescent tubes) under a daily light period of 12 h. DI water used in the source in Expts. 1, 2, and 3 and also as a vase solution in Expt. 3 was not renewed in the course of individual experiments.

Expt. 1: measurement of water uptake and fresh weight of cut rose using the continuous automatic apparatus. Water uptake (residual water in the source) and FW were automatically recorded for an individual cut rose stem at intervals of 1 min. Water uptake rate was calculated as: water uptake rate ($\text{g}\cdot\text{h}^{-1}$) = $(M_{t-1} - M_t) \times 2$; where, M_t is the weight of water (g) at $t = \text{min } 30, 60, 90, \text{ etc.}$; and M_{t-1} is the weight of water (g) at the previous 30 min. Water loss rate was calculated as: water loss rate ($\text{g}\cdot\text{h}^{-1}$) = water uptake rate + FW change. The later was calculated as: FW change ($\text{g}\cdot\text{h}^{-1}$) = $(FW_{t-1} - FW_t) \times 2$; where FW_t is the weight of cut rose stem (g) at $t = \text{min } 30, 60, 90, \text{ etc.}$; and FW_{t-1} is the weight of cut rose stem (g) at the previous 30 min.

Expt. 2: measurement of water uptake and fresh weight of cut lily using the continuous automatic apparatus. Water uptake and FW were recorded for an individual cut lily stem at intervals of 1 min. Water uptake rate and water loss rate were calculated for intervals of 60 min as described for Expt. 1.

Expt. 3: validation of accuracy and sensitivity of the continuous automatic apparatus by comparison with a conventional weighing method. Water uptake rate and water loss rate were obtained for an individual cut rose stem as described for Expt. 1 and under alternate 12-h light and dark periods over 108 h of observation. In parallel for 108 h, 15 cut rose stems were placed into individual 180-mL glass vessels (vases) each containing 150 mL of DI water as the vase solution. FWs of the cut rose stems and weights of vases without the cut flowers were recorded at 2-h intervals using an analytical balance (FX-300i; AND Company, Japan). Average water uptake rate was calculated by the formula: water uptake rate ($\text{g}/\text{stem}/\text{h}$) = $(S_{t-2} - S_t)/2$; where S_t is the weight of vase solution (g) at $t = \text{hour } 2, 4, 6, \text{ etc.}$; and S_{t-2} is the weight of vase solution (g) at the previous 2 h. Average water loss rate was calculated by the formula: water loss rate ($\text{g}/\text{stem}/\text{h}$) = $(C_{t-2} - C_t)/2$; where C_t is the combined weights of the cut stem and vase (g) at $t = \text{hour } 2, 4, 6, \text{ etc.}$; and C_{t-2} is the combined weights of the cut stem and vase (g) at the previous 2 h (He et al., 2006). Vases for Expt. 3 were arranged on benches in a randomized complete block design. The resultant data were presented as mean \pm SE for 15 replicates.

Results and Discussion

Dynamics of change in water uptake and fresh weight of cut rose and lily stems. The typical time curves for water uptake and fresh weight changes of cut rose and lily stems are presented in Figures 2 and 3, respectively. Water uptake by stems of both cut flower species declined with increasing vase time (Figs. 2A and 3A). FW of the cut rose stem increased rapidly over the first 40 h of vase

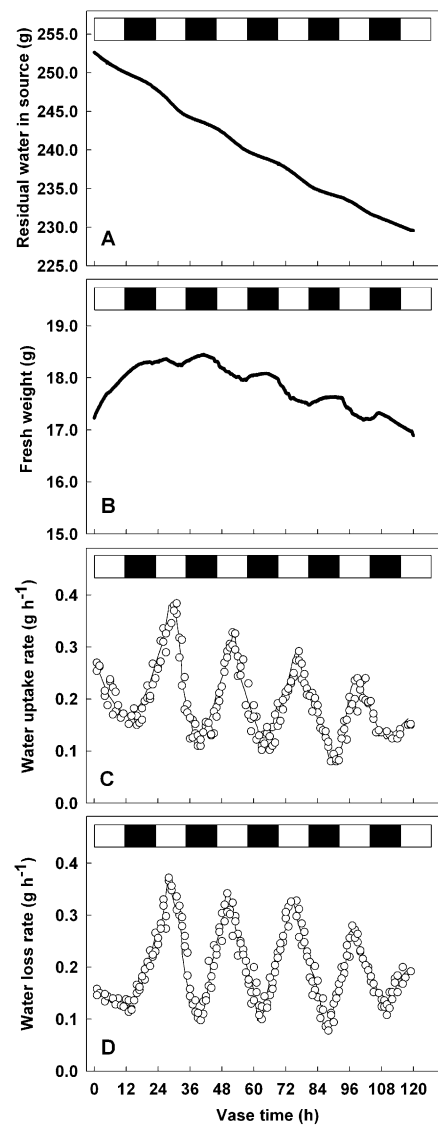


Fig. 2. Expt. 1: Water uptake and water loss of an individual cut rose cv. Movie Star stem measured by the continuous automatic apparatus under alternating 12-h light and dark regimes over 120 h. The dynamic synchronous data of residual water in source (A) and fresh weight (B) were directly recorded at intervals of 1 min over the 7200-min duration experiment. Water uptake rate (C) and water loss rate (D) were determined at intervals of 30 min. The bar in each panel indicates light (open block) and dark (solid block) periods.

life and then decreased gradually with slight diurnal fluctuations (Fig. 2B). FW of the cut lily stem remained almost constant over the first 24 h of vase life and then decreased gradually (Fig. 3B).

Water uptake rate and water loss rate change of cut rose and lily stems. Water uptake rate by the individual cut rose stem generally increased to a peak approximately midway during 12 h of light after 12 h in the dark. However, water uptake rate was much reduced during the dark periods and reached the trough roughly midway during 12 h of dark (Fig. 2C). Generally, water uptake rate was lowest during 2 to 4 h after the beginning of the dark period followed by a gradual

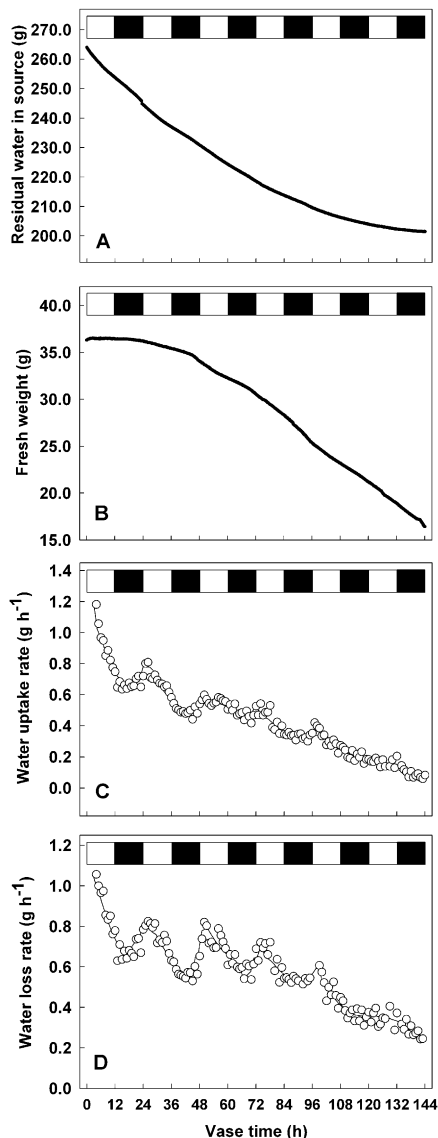


Fig. 3. Expt. 2: Water uptake and water loss of an individual cut lily cv. Yellow Overlord stem measured by the continuous automatic apparatus under alternating 12-h light and dark regimes over 144 h. The dynamic synchronous data of residual water in source (A) and fresh weight (B) were directly recorded at intervals of 1 min over the 8640-min duration experiment. Water uptake rate (C) and water loss rate (D) were determined at intervals of 60 min. The bar in each panel indicates light (open block) and dark (solid block) periods.

increase. During the first day (0 to 24 h) of the vase time, highest water uptake rate was in the light and lowest in the dark (Fig. 2C). However, water uptake rate in the light during the second day frequently exceeded rates on the first day. Thereafter, water uptake rates in the light progressively declined daily. Water uptake rates declined in the dark, trending to decrease only slightly over nights 1 through 3. Highest total water uptake rate was during the second day (24 to 48 h) as a result of higher water uptake rate on this day being highest throughout both the light and dark periods. Water uptake rate and the magnitude of alter-

nating light and dark period differences diminished over the period of study. Water loss rates by the cut individual rose showed a parallel pattern to water uptake rates (Fig. 2D). These findings are in general agreement with those of Carpenter and Rasmussen (1973), Doi et al. (1999), and Uda et al. (1995). Overall, except for transient perturbations of stomatal function presumably associated with stem recutting and placement into vase water, the data suggest a progressive dampening of a circadian rhythm in stomatal function over time in the vase.

Although dampened, trends in the rates of water uptake and water loss of the cut lily flower were generally similar to those of the cut rose. Highest water uptake rates were typically in the light and typically lowest in the dark on 24 h cycles over 6 d (Fig. 3C). Water loss rate in darkness was notably lower than that in the light (Fig. 3D). With alternating 12-h light and dark periods over vase time, water uptake rates during the light periods progressively declined toward levels in the dark.

Stomata on leaves normally react to light by opening (Kim and Lee, 2007; Seo et al., 2008; van Doorn, 1997) such that light promotes water loss (Kofranek and Halevy, 1972). Carpenter and Rasmussen (1973) reported that roses held under constant light or alternating 12 h light and 12 h dark lost five times more water than those held in complete darkness. However, de Stigter (1980) found that water uptake of cut roses held in darkness did not decline with time. In the present study, using the CAA, effects of light on water uptake and water loss through regulation of stomatal behavior on cut rose and lily flower leaves were sensitively detected.

Validation of the continuous automatic apparatus. High correspondence with rose for both water uptake rate and water loss rate curves as determined between the CAA versus the conventional weighing method was evident (compare Figs. 4A and 4B). Like in Expt. 1, the highest water uptake and water loss rates by roses were recorded in the light and lowest rates in the dark (Fig. 4A–B).

Absolute water uptake rate and water loss rate per stem will depend on each individual cut flower. The averaged water uptake of 15 cut rose stems (conventional weighing method) was consistently slightly less than that of the individual cut rose stem in the CAA. Aside from this being a difference associated with individual stems, it could conceivably have been the result of the water level difference (pressure head) between the source and the vase of the CAA system, which was 1 to 2 cm. Nonetheless, similar patterns in fluctuations for water uptake rate and water loss rate by the individual rose (CAA) and the 15 cut roses (conventional) validate the use of the CAA as a sensitive monitor of responses to external environmental variables, in this case light (Fig. 4A–B). Future work with the CAA might usefully investigate temperature and humidity influences.

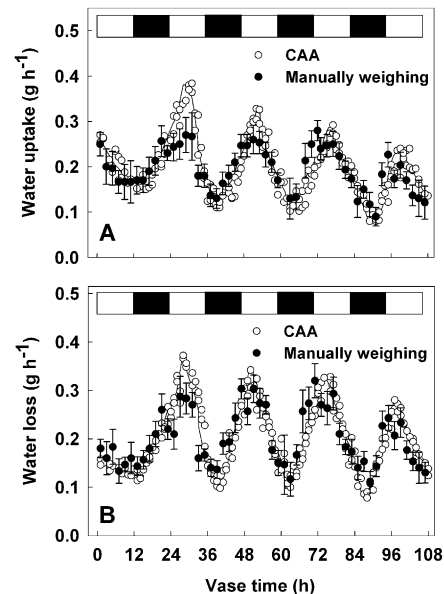


Fig. 4. Expt. 3: Validation of continuous automatic apparatus (CAA) performance by comparison with the conventional weighing method. Water uptake rate (A) and water loss rate (B) of an individual cut rose cv. Movie Star stem were measured by the CAA at intervals of 30 min (open circles). Those of 15 cut rose stems were measured by means of conventional weighing at intervals of 2 h (solid circles). The experiment was under alternating 12-h light and dark regimes over 108 h. The bar in each panel indicates light (open block) and dark (solid block) periods.

In conclusion, the CAA is a demonstrably accurate (i.e., high precision) and temporally sensitive (viz. short sampling intervals) device for measuring water uptake and water loss by individual cut flower stems. The apparatus is comprised of readily available laboratory materials and instruments and so is neither prohibitively expensive nor technically complex.

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