INTERACTIVE DYNAMICS OF FRUIT AND STEM GROWTH IN TOMATO PLANTS AS AFFECTED BY ROOT WATER CONDITION I. EXPANSION AND CONTRACTION OF FRUIT AND STEM

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INTERACTIVE DYNAMICS OF FRUIT AND STEM GROWTH IN TOMATO PLANTS AS AFFECTED BY ROOT WATER CONDITION
I. EXPANSION AND CONTRACTION OF FRUIT AND STEM

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Kitano M., Hamakoga M., Yokomakura F. and Eguchi H. *Interactive dynamics of fruit and stem growth in tomato plants as affected by root water condition. I. Expansion and contraction of fruit and stem.* BIOTRONICS **25**, 67-75, 1996. For on-line and intact measurement of fruit and stem growth, a laser displacement sensor (LDS) system was newly developed, and two sets of the LDS system were applied for dynamic analysis of fruit and stem growth in tomato plants (*Lycopersicon esculentum* Mill.) as affected by change in root water condition. The plants potted with soil were dewatered gradually for three days and then rewatered. Fruit and stem growth appeared in the dissymmetrical relationship : During dewatering, fruit growth was kept higher even under larger decrease in xylem water potential and significant stem contraction, but just after rewatering drastic fruit shrinkage was induced with rapid swelling of the stem. This demonstrates the interaction between fruit and stem growth through dynamics of water relations along the translocation path in stem. Thus, the newly developed LDS system can be reliable for dynamic analysis of fruit and stem growth.

Key words: tomato plant; *Lycopersicon esculentum* Mill.; fruit growth; stem growth; water relations; laser displacement sensor system

INTRODUCTION

Production in tomato plants is affected by expansive growth and sugar accumulation in fruits. The fruit expansive growth depends on water balannce among phloem sap flux, xylem sap flux and transpiration flux in the fruit (*1, 5*), which are estimated to be affected by root water condition such as water availability and salinity through plant water relations (*1, 2, 3, 8, 19*). For optimalizing root water condition in tomato fruit production, it is essential to understand dynamic relationship between fruit growth and water relations. In the studies on growth of plant organs (leaf, stem, fruit) in reference to water relations, on-line measurements of sizes of the organs have been performed by applying a dendrograph (*11*), a linear variable differential transformer (*7, 9, 10, 18*), a potentiometer (*6*) and a strain gauge (*17*) with direct attachment to the organs. In particular, change in stem diameter has been considered to give useful information on dynamics of plant water relations (*10, 17*).

In this study, laser displacement sensor systems newly developed were applied to on-line and intact measurements of fruit and stem growth in tomato plants, and dynamics of fruit growth and plant water relations as affected by watering and dewatering were analyzed.

MATERIALS AND METHODS

Plant materials and experimental conditions

A pair of tomato plants (*Lycopersicon esculentum* Mill. cv. Hausu-Momotaro) were potted in a 8 L pot filled with a soil of gravel/vermiculite mixture (2 : 1 in volume) and grown in a phytotron glass room at a day/night temperature of 23/ 18°C and a relative humidity of 70%, where the soil in the pot was kept moistened enough by dripping complete nutrient solution. The plants were pinched at two leaves above the first truss before anthesis of the second truss. About 3 weeks after pollination of the second fruit on the first truss, the plants potted in a pair were transported into a growth cabinet and grown with the sufficient nutrient solution at an air temperature of 20.5°C and a relative humidity of 70% under an artificial light of metal halide lamps (YOKO lamp, DR 400, TOSHIBA CORPORATION, Tokyo) through heat absorbing filters (HG, Ohara Optical Glass Mfg. Co. Ltd., Tokyo) with a PPFD of 300μmol/m^2/s in a photoperiod of 8 : 00-20 : 00. After 4 days acclimation to the growth cabinet condition, the plants were used for the experiment, where root water condition was changed by watering and dewatering : The plants were dewatered gradually for three days after the start of experiment and then rewatered sufficiently with the nutrient solution. One of the plants potted in a pair was used for on-line measurements of fruit and stem growth and leaf temperatures, and the other was used for sampling for time course evaluation of xylem water potential.

Laser displacement sensor system

The on-line and intact measurements of diameters of the plant organs (fruit and stem) were performed by applying laser displacement sensors (LDSs)(Z4M-W40, OMRON Corporation, Kyoto, Japan). Figure 1 shows a schematic diagram of the LDS system applied for measuring diameter of an intact tomato fruit, which was composed of a pair of LDSs, a stainless holder, signal converters and a computer with interface. The LDSs on the stainless holder were settled about 4 cm apart from the fruit circumference. The laser beams were emitted from the respective LDSs, and the beams reflected at the fruit surfaces were received by the LDSs. In each LDS, the distance (L_1 or L_2) to the fruit surface was detected with a high resolution of 1.5μm based on geometry of the reflected laser beam. The signals from the LDSs were converted to 0.4 V/mm in a range of L_1 and L_2 of 30 to 50 mm and transmitted to the computer. The distance (L) between the LDSs was preset in the computer, and the fruit diameter (D_F) was evaluated by subtracting L_1+L_2 from L. The LDS system was also applied to the measurement of stem diameter (D_S) in the same manner. Figure 2 shows photographs of the LDS systems applied for simultaneous measurements of
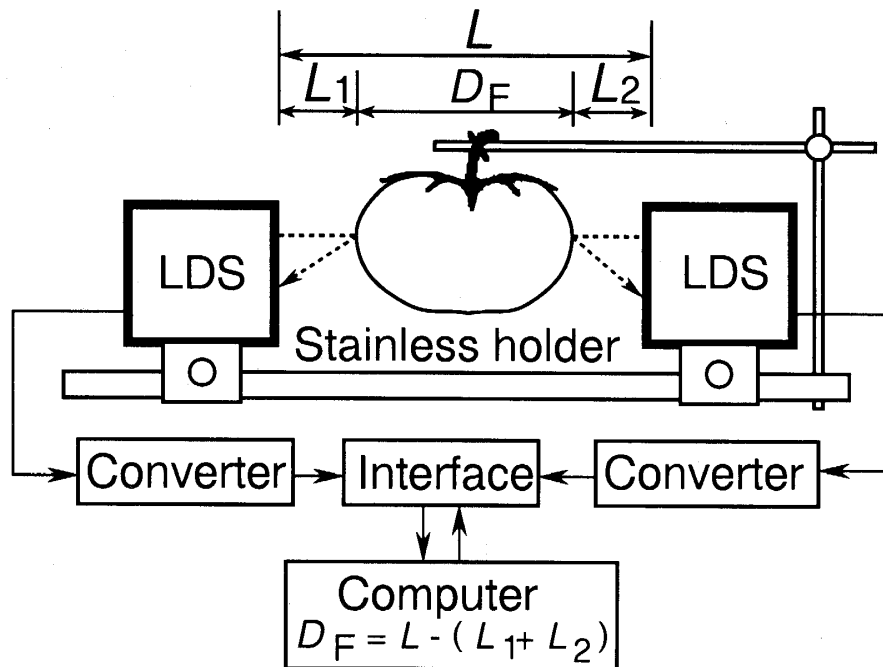
Fig. 1. Schematic diagram of the laser displancement sensor (LDS) system applied for on–line measurement of diameter (D_F) of an intact tomato fruit, where a pair of LDSs on a stainless holder were settled about 4 cm apart from the fruit circumference. The laser beams (broken lines) emitted from the LDSs are reflected at the fruit surface, and the distances $(L_1$ and $L_2)$ to the surface are detected from geometry of the reflected laser beams. The fruit diameter D_F can be evaluated by subtracting L_1+L_2 from the distance (L) between the LDSs preset in a computer.

diameters of intact fruit and stem in a tomato plant. By applying two sets of the LDS system in one of the plants potted in a pair, D_F of the second fruit on the first truss and D_S at the internode below the first truss were measured on–line.

For more accurate measurement, it was necessary to make correction for the zero drift induced by temperature changes in the LDS system (the LDSs, the converters and the holder). In the growth cabinet, radiation of the light caused temperature rise in the LDS system, and the temperature drift was induced by change in radiant flux. Figure 3 shows time course variations of the measured value (D_m) and the corrected one (D_c) for the thickness (D) of an aluminium plate under on–off action of the light. The system temperature (T_{sys}) was evaluated as the average of temperatures of the LDS, the converter and the holder measured by T–thermocouples. T_{sys} rose by 1.2°C when the LDS system was irradiated by the light, and the correction of D_m was made by a factor of 2.6 μm/°C for change in T_{sys}.
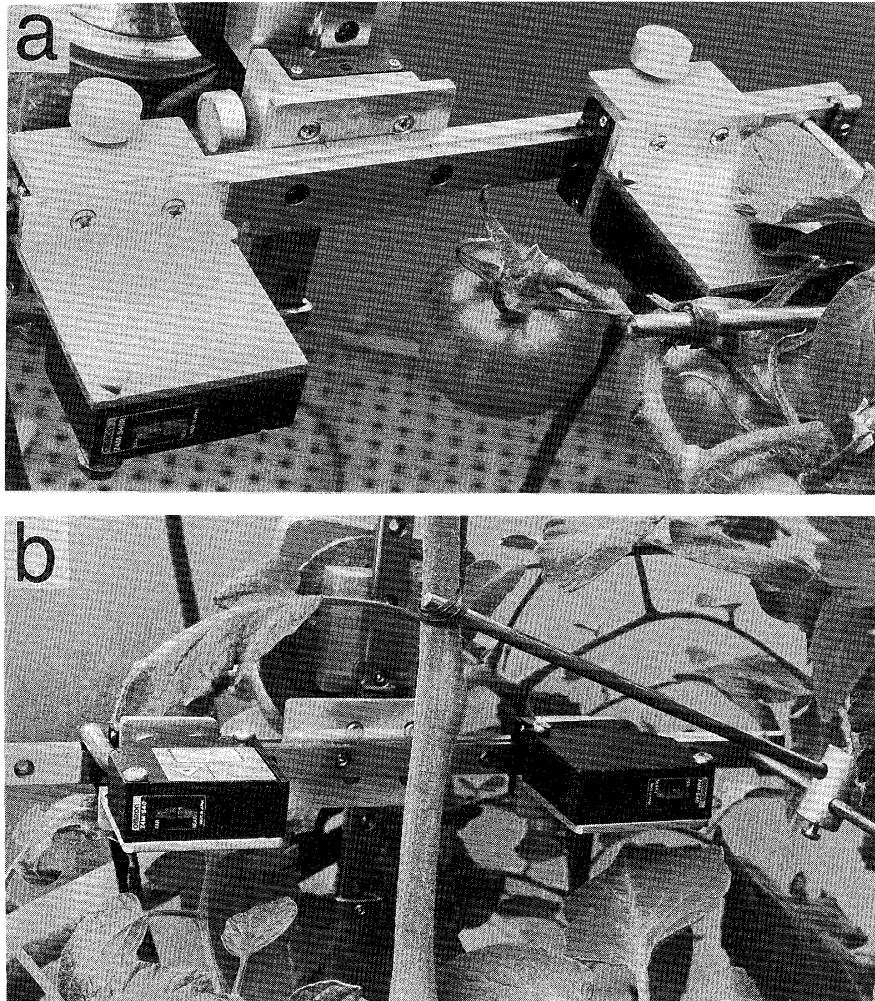
Fig. 2. Photographs of laser displacement sensor (LDS) systems
applied for on-line and intact measurements of diameters of fruit (a) and
stem (b) in a tomato plant.

On–line evaluation of fruit volume

On–line evaluation of volume (V_F) of the intact fruit was performed by
using D_F measured with the LDS system on the basis of the relationship between
V_F and D_F. The relationship between V_F and D_F was predetermined by
measuring D_F and V_F in detached fruits as follows: A detached fruit, of which
D_F was measured by a digital vernier caliper, was immersed into a cup filled up
with water, and V_F was determined by weighing the overflowing water. Figure
4 shows the relationship between V_F and D_F determined by using 16 fruits with
D_F less than 5 cm. There was a significant correlation between V_F and D_F^3 as
$V_F(\text{cm}^3) = 0.417668\ D_F^3 + 1.932\ (r^2{}^{***} = 0.98)$. On the basis of this relationship,
change in fruit diameter measured with the LDS system was converted into
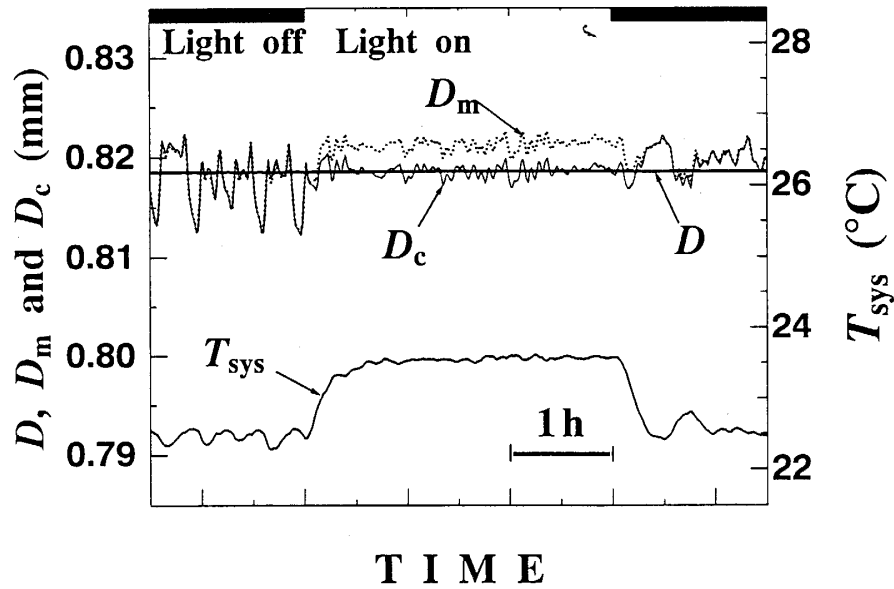change in fruit volume.

Fig. 3. Correction of the output of laser displacement sensor (LDS) system for the zero–drift caused by change in temperature (T_{sys}) of the LDS system applied for evaluating thickness (D) of an aluminum plate under on-off action of light. D_m (dotted line) is the uncorrected output of the LDS system, and D_c (fine solid line) is the output corrected for change in T_{sys} by a correction factor of $2.6\,\mu m/°C$, where T_{sys} is the average of temperatures of the aluminum plate, the LDS and the stainless holder measured with T–thermocouples.

$$V_F = 0.417668\,D_F^3 + 1.932$$
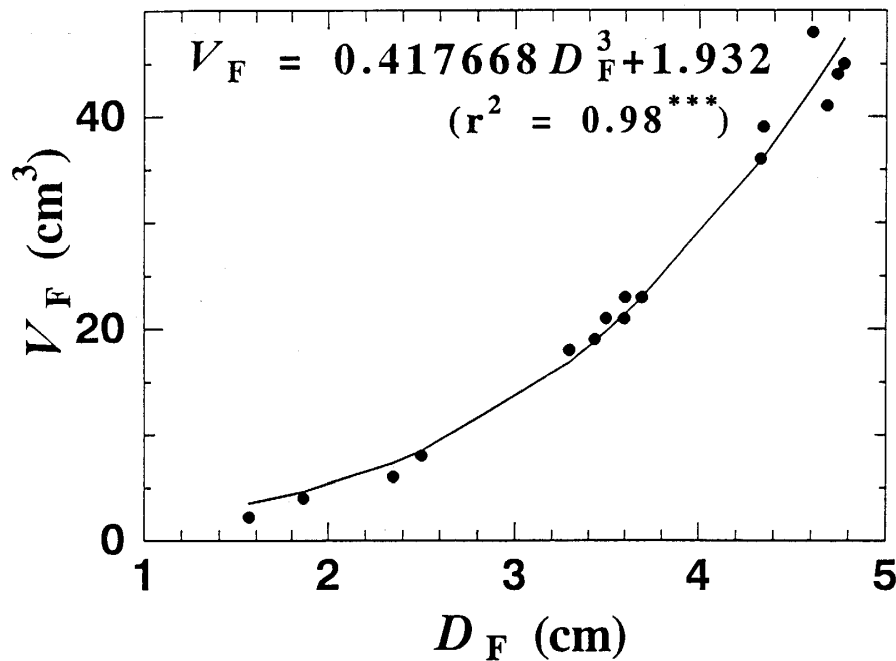$$(r^2 = 0.98^{***})$$

Fig. 4. Relationship between diameter (D_F) and volume (V_F) in tomato fruit, where a linear relationship was found between V_F and D_F^3.

Xylem water potential and leaf temperature

Xylem water potential (Ψ_X) was evaluated by measuring water potential of the matured leaflets covered with an opaque polyethylene bag, where leaf transpiration was inhibited with closed stomata and vapor saturated air in the bag, and the leaf water potential was estimated to be nearly equal to xylem water potential. In each sample, water potentials of four leaf disks of 8 mm diameter were measured by dew point psychrometry under a constant temperature, and the mean value was employed, where the standard deviation in each determination was within ± 0.06 MPa.

The time course variation of leaf temperature gives a reliable information on dynamics of stomatal conductance and leaf transpiration (*8, 9*). Temperatures of the younger leaves were measured on-line by three T-thermocouples inserted into the leaflets, and the average of the three measured temperatures was evaluated as leaf temperature (T_L).

RESULTS AND DISCUSSION

For three days after the start of the experiment, soil in the pot was not supplied with water, and the plants were dehydrated gradually by evapotranspiration. After the three days dehydration, the soil was rewatered sufficiently. Figure 5 shows time course patterns of leaf temperature (T_L), xylem water potential (Ψ_X), fruit diameter (D_F), fruit volume (V_F) and stem diameter (D_S). Effect of dewatering appeared in the respective organs in the order of stem, leaf and fruit. The first effect appeared in stem growth rate (i.e. increase rate of D_S), which began to decrese 20 h after the start of dewatering. Thereafter, T_L, which varied with the on-off action of the light, began to rise by 2°C in light and 1.5°C in dark. This T_L rise during dewatering suggested that depressions in stomatal opening and leaf transpiration were caused by water deficit after 26 h dewatering. 45 h after the start of dewatering, stem began to contract rapidly synchronizing with larger decrease in Ψ_X. During dewatering, Ψ_X dropped by 0.7 MPa and D_S decreased by more than 300 μm. On the other hand, the fruit volume continued to grow with a high rate of about 0.04 mm^3/s irrespective of stem contracting; fruit growth during 72 h dewatering was 5.9 mm in D_F and 7.5 cm^3 in V_F. This steady growth of the fruit during dewatering can be estimated to be caused by phloem translocation less sensitive to water deficit (*20*).

Just after rewatering at 72 h, the contracted stem swelled immediately by about 400 μm in D_S, but in contrast the growing fruit shrank drastically by 500 μm in D_F even under no change in the evaporative demand around the fruit. This fruit shrinkage of 500 μm resulted in volume loss of 0.6 cm^3, which was equivalent to the growth during half of a day. These changes of several hundred micrometers in fruit and stem diameters were significant changes detected with the LDS system with a high resolution of 1.5 μm. These drastic changes in fruit and stem diameters resulted in dissymmetrical patterns of their growth rates. Figure 6 shows a typical time couese patterns of fruit growth rate
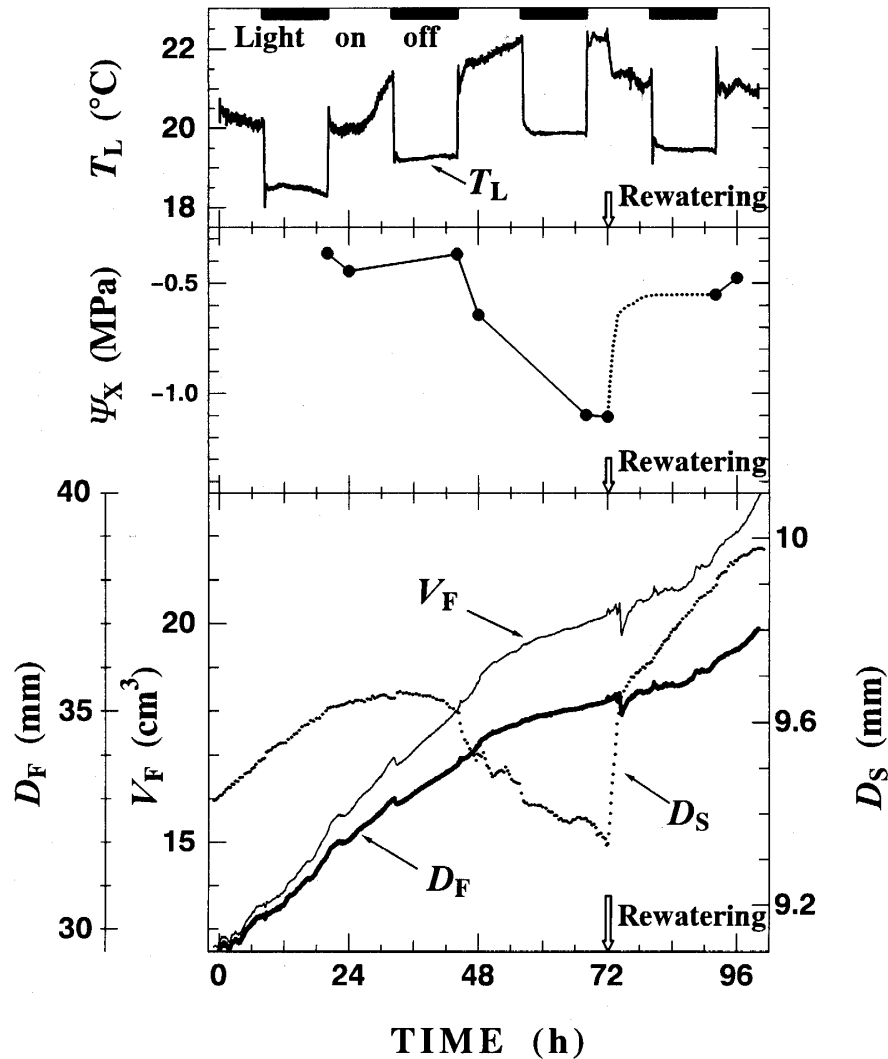
Fig. 5. Time course patterns of leaf temperature (T_L), xylem water potential (Ψ_X), fruit diameter (D_F), fruit volume (V_F) and stem diameter (D_S), where the plant was dewatered gradually for 72 h and then rewatered.

(GRF) and stem growth rate (GRS), where the plants were rewatered after 72 h dewatering. The patterns of fruit growth rate and stem growth rate appeared dissymmetric: Just after watering, the stem swelled rapidly, and GRS rose to the peak higher than $0.05 \mu m/s$. On the other hand, the fruit shrank at an extremely high rate, and GRF decreased to $-0.2 mm^3/s$.

Tomato fruits have been estimated to have a mechanism preventing sap backflow from the fruit $(5, 7, 14, 15)$, and the fruit shrinkage without any change in the evaporative demand around the fruit has not been reported. The drastic fruit shrinkage observed coincident with rapid stem swelling just after rewatering (Figs. 5 and 6) suggests that rapid backflow of sap from the fruit can be induced through phloem or xylem. In tomato fruits, the major component of water imported into the fruit for the expansive growth is known to enter via
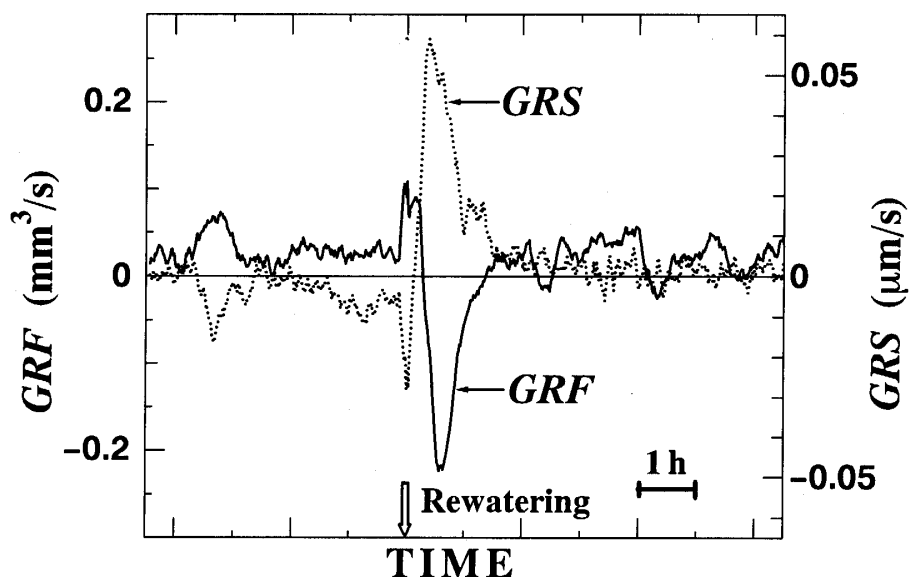
Fig. 6. Time course patterns of fruit growth rate (*GRF*) and stem growth rate (*GRS*), where the plant was rewatered after 72 h dewatering.

phloem translocation (*1, 5*), which is driven by pressure potential gradient along the long distance of phloem translocation path from leaves to fruits (*7, 13, 16*). This pressure potential gradient along the phloem translocation path has been estimated to need a relay mechanism (*12*) and to be broken by killing only 15 mm length of the pedicel phloem with a heat–ring (*3, 4*). The dissymmetrical relationship between fruit and stem growth shown in Fig. 6 clearly indicates that there is a dynamic interaction between fruit and stem growth through water balance along the translocation path in the stem, which affects the pressure potential gradient (i.e. driving force of phloem translocation). Thus, the newly developed LDS system was useful for understanding dynamic relationships between fruit growth and plant water relations as affected by change in root water condition.

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