Pattern of Seasonal Water Use of Asian Pears Determined by Lysimeters and the Heat-pulse Technique

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Abstract. Seasonal water use data are presented for 4-year-old *Pyrus serotina* Rehder cv. Hosui growing in drainage lysimeters and trained onto a Tatura trellis. Weekly water use (WU) was calculated using the mass balance approach. For 8 consecutive weeks during late summer, instantaneous WU was also measured by the compensation heat-pulse technique for measuring sap flow. Although good agreement was found between the two methods for 4 weeks after probe installation, discrepancies increased after this time. Water use was highest in early to mid-January in New Zealand, averaging ≈ 8 liters/tree per day, or 2 liters·m² canopy surface area/day. Total water use over the growing season was 1070 liters/tree, or 245 liters·m² canopy surface area. The correlation coefficient between weekly WU and evaporation from a nearby Class A pan was 0.81 for the season. Weekly crop coefficients thus calculated for the well-watered trees ranged from 0.15 to 0.55 and 0.20 to 0.83 when calculated using canopy surface area and projected ground area, respectively. Low values were due to low values of canopy leaf area early in the season. Withholding irrigation during three periods resulted in a gradual decline in water use. Water-stressed trees had a lower predawn water potential than fully irrigated trees. This pattern was followed by a more-rapid decline during the morning, and a slower recovery during late afternoon and early evening. Midday leaf water potential never fell below -2.5 MPa.

Asian pears, known as Nashi in Australia and New Zealand, are a relatively new crop in the New Zealand fruit industry. The first experimental plantings were made in 1981, and commercial plantings started in 1984. Export volumes rose almost 6-fold from 51,000 trays (4 kg net weight of fruit/tray) in 1987 to 290,000 trays in 1990. Based on plantings in New Zealand up to 1986, an export crop potential approaching 1 million trays could be expected by 1992-93 (Drewitt, 1990). As these plantings reach maturity, information relating to proper irrigation management becomes increasingly important.

Crop coefficients (k_c) are important in irrigation scheduling to match the evapotranspiration (ET) estimated from weather data, to crop ET. The former is often based on easy-to-use measurements of potential water use, such as the Class A pan. Irrigation volumes applied to replace water used by a crop will thus be too high if crop coefficients are overestimated.

Consequences of over-irrigation include leaching of nutrients out of the root zone, increased drainage to water table, and reduced water-use efficiency. However, plants may experience water stress when water replacement is based on k_c values that are too low. This stress can lead to suboptimal yields, depending on the degree and duration of stress, the susceptibility of the plant species to water stress, and the developmental stage of the plant.

A wide range of crop coefficients for a given species can be found in the literature. These differences are partly due to plant age, planting density, training system, and environment, but may also be affected by differences in the method used for relating actual ET to some measure of evaporation. For example, different estimates of the size of the evaporating plant canopy have been developed, such as planting square area, area covered or shaded by canopy, area actually wetted by emitters, trunk cross-sectional area, and canopy surface area (Elfving, 1982; Mitchell et al., 1991). Further, the term "crop coefficient" has been used to relate crop ET not only to reference evapotranspiration (E_{tr}), also known as potential ET, but also to unadjusted E_{pan} values. Clearly, it would simplify comparison of data among sites or species, or both, if researchers agreed on a standard approach.

A drainage lysimeter was built at Massey Univ. in 1987 to study the water relations of Asian pears. Preliminary results obtained during the noncropping period indicated the drainage lysimeter was a reliable alternative to weighing lysimeters for monitoring ET of trees in a windy climate (Chalmers et al., 1992), when operated for ≈ 1 week.

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Abbreviations: DAFB, days after full bloom; DC, drying cycle; E_{pan} , potential water use measured from a Class A pan; ET, evapotranspiration; k_c , crop coefficient; WU, water use; Ψ_l , leaf water potential.

The aims of the research presented here were to test further and improve the performance of the lysimeter installation; to determine the seasonal trend in crop water use for Asian pears in relation to the ambient weather conditions; and to obtain data on the effects of short-term water stress conditions on the water balance, tree water relations, and fruit growth and yield.

Extended periods of water deficit were not applied during the above experiments to avoid effects on tree growth and size that might confound the statistical design of later experiments.

Materials and Methods

Experimental conditions. The lysimeter facility of Massey Univ., Palmerston North, New Zealand (lat. 40.2° S, long. 175.4°E), is situated within a 1.1-ha block of Asian pears that was planted at the same time as the trees in the lysimeters in 1986-87. The whole block is within a bird canopy that reduces light levels by 15%.

The facility consists of 12 drainage lysimeters, each a steel cylinder 1.2 m deep $\times$ 1 m in diameter. Each cylinder is surrounded by a concrete sleeve that gives a 1.2-m/tree spacing within rows. The rows are 5 m apart and the ground cover is grass, with a 2-m-wide herbicide-treated strip. The tops of the inner cylinders are $\approx$ 0.1 m above ground level.

The bottom 0.15 m of each steel container is filled with sand, while the bottom 0.05 m of the cylinder is conical in shape to provide drainage to a central discharge pond. A polyethylene pipe is connected to the outlet to transport drainage water. The resulting lysimeters allowed a total soil depth of 1 m. Eight lysimeters were selected at random and carefully packed in 0.1-m layers with Manawatu fine sandy loam excavated from the B horizon. To investigate the effect of soil layering on tree performance, the lower 0.4 m of the remaining lysimeters were similarly packed with the coarse, gravelly sand from the C horizon, with the B horizon above. This textural interface impedes unsaturated water transport, but water drains freely during saturated flow when the soil-water potential at the interface approaches zero. This arrangement mimics the natural layering and flow conditions of the surrounding orchard.

The Asian pear tree cultivar Hosui, grafted onto seedling rootstock, was planted in each of the lysimeters in Sept. 1987 and trained onto a Tatura trellis (Chalmers et al., 1978). Irrigation and fertilizer were applied to each tree via a closed nutrient-irrigation system fed from two 9100-liter tanks. Nutrient concentration of the solution was (in mg-liter⁻¹) 105 N, 31 P, 68.4 K, 125 Ca, 48.6 Mg, 98 S, 3.0 Fe, 26.6 Cl, 0.5 B, 0.5 Mn, 0.05 Zn, 0.02 Cu, and 0.05 Mo. The pH of the solution was adjusted to 6.5 by adding sulfuric acid. The solution was pumped, filtered, and divided into three lines controlled by a solenoid, followed by a pressure regulator. Flow was metered using a Picoflux EV Superjet flow meter (Andrae Leonberg, Leonberg, Germany). Each solenoid was independently activated and supplied nutrient solution to a group of four lysimeters. Solution was applied to the surface of the soil in each lysimeter via eight pressure-compensated trickle emitters (Netafim, Israel). Each emitter was rated for 2 liters-h⁻¹. Emitters were located in a circle some 0.3 m from the tree trunk to provide uniform water distribution. Individual lysimeters were covered with reflective, opaque plastic covers to minimize rainfall entry and soil evaporation.

The drainage from each lysimeter was routed through a polyethylene pipe to a tipping-bucket gauge (Pronamic, Them, Denmark) located within a subterranean control room. Automatic operation of the lysimeter facility was managed by a multitasking controller/datalogger (Wormald 1830, Christchurch, New Zealand).

Digital pulses from flow meters and drainage gauges were stored, and pump and solenoids controlled by the controller/datalogger. Irrigation and drainage volumes accumulated hourly were stored in arrays. Data from the arrays were automatically transferred to disk each day on an MS-DOS personal computer.

Additional details on design and performance of the lysimeter facility are given in Chalmers et al. (1992). Pesticides were applied according to standard cultural practice during maintenance of the surrounding orchard.

Soil moisture measurements. Access tubes for a neutron moisture meter were placed 0.2 m from the trunks of the trees in each lysimeter. A neutron hydroprobe (Model 503DR, CPN Corp., Martinez, Calif.) was used to take measurements twice weekly at 0.2-m depth intervals, from 0.2 to 1.0 m beneath the soil surface. Soil water storage (in mm) was obtained by multiplying the volumetric soil-water content (m³-m⁻³) by soil layer depth in mm (300, 200, 200, 200, and 100 for the 0.2, 0.4, 0.6, 0.8, and 1.0 m measurement depths, respectively). This arrangement allowed conversion to liters of water storage per lysimeter by multiplying total soil-water storage by 0.785 m³/lysimeter (since 1 mm = 1 liter-m⁻²). "Pot capacity" was defined as the soil-moisture content when drainage from the lysimeters had ceased. There was no significant difference in pot capacity between the B- and B/C-horizon lysimeters.

Meteorological measurements. The E_{pan} evaporation data were obtained from a Class A evaporation pan located $\approx$ 1 km from the lysimeter facility. Rainfall, sunshine hours, total daily wind run, and maximum and minimum temperatures were also recorded at that location.

Plant measurements. Water use (WU) was measured using an appropriate form of the conservation of water equation (Sharma, 1985): $WU = I - \Delta W - D$, where I is irrigation, ΔW is change in the soil-water storage, and D is drainage. Irrigation volumes for individual lysimeters were determined by dividing recorded flow meter volumes by four. The storage change (ΔW) was calculated from neutron probe readings, while D was that accumulated over the period.

Crop coefficients for Asian pears were determined by dividing mean weekly water use by weekly E_{pan} data.

Between 18 Jan. and 13 Mar. 1991, transpiration of two neighboring trees in the lysimeters was also measured from the rate of sap movement upwards through the stem using the compensation heat-pulse technique (Swanson and Whitfield, 1981). Two thermistors, connected in a Wheatstone bridge configuration, were accurately placed 10 mm above and 5 mm below a 2-mm-diameter stainless steel heater. These heat-pulse probes were installed at depths of 5 and 15 mm below the cambium in both trees. The probe sets were placed at $\approx$ 20 cm above the graft union on the west side of the trees. Trunk diameters for the trees were 59.5 and 62.5 mm, and canopy surface areas were 3.5 and 4.4 m², respectively.

The interval between heat-pulse measurements was 20 min, and the duration of the pulse was 1 sec. The heat-pulse data were recorded by a Custom Heat Pulse Logger (HortResearch, Palmerston North, New Zealand). Sap flux was derived from the corrected sap velocities according to Edwards and Warwick (1984). From 6 Feb. to 4 Mar., total sap flux for the larger tree was based on one probe only, due to malfunction of the second probe.

Leaf water potential (Ψ_l) was measured once a week, using a Scholander pressure bomb (Soilmoisture Equipment Corp., Santa Barbara, Calif.), before sunrise (predawn Ψ_l) and at solar noon (midday Ψ_l) throughout the season. In addition, diurnal Ψ_l measurements were made on several occasions.

The first flowers opened in mid-Sept. 1990, but full bloom,

when >95% of flowers had opened, was not until 7 Oct. The fruit were thinned 46 days after full bloom (DAFB) to ≈ 20 fruit/m² canopy surface area. The change in fruit volume was calculated from weekly measurements of fruit diameter, using digital calipers, of at least 10 fruit/tree. Nashi fruit were assumed to be spherical. Measurements started 28 Nov. 1990 (i.e., 52 DAFB). A regression analysis between estimated fruit volumes and fruit volumes measured by water displacement indicated that using the above assumption, actual fruit volume was slightly overestimated ($Y = 0.15 + 0.92 \cdot X$, $r^2 = 0.99$, $n = 97$) using the maximum diameter, but slightly underestimated using the minimum diameter ($Y = -1.8 + 1.09 \cdot X$, $r^2 = 0.99$, $n = 52$). The fruit density was ≈ 1.01 g·cm⁻³.

Growth of 67 shoots was measured weekly, starting 54 DAFB. Leaf stomatal conductance (g.) was measured on fully expanded, sunlit leaves with a transit-time porometer (Delta-T Devices, Model Mk3, Cambridge, United Kingdom).

Canopy surface area of each tree was calculated by summing the area of four inclined rectangles, two on either side of the Tatura trellis, which best represented the canopy outline in the plane of the trellis. Mean canopy surface area was 4.36 m². Projected ground cover, (i.e., the area estimated to be covered by evaporating plant canopy) was 2.9 m².

Irrigation regime. Between Oct. 1990 and Apr. 1991, trees were irrigated daily to keep the soil moisture at pot capacity, except for the periods 21 to 30 Dec. 1990 [75 to 84 DAFB, drying cycle 1 (DC-1)], 14 to 23 Jan. 1991 [99 to 108 DAFB, (DC-2)], and 28 Feb. to 13 Mar. 1991 [144 to 157 DAFB, (DC-3)]. During these periods, no irrigation was applied. At the end of DC-1, the lysimeters had dried down to an average of $\approx 60\%$ of pot capacity when they were rewatered. Four trees were rewatered on 23 Jan., whereas the remaining trees were rewatered on the morning of 24 Jan., following a predawn Ψ_s measurement. Three regimes of rewatering were applied during DC-3: four trees were returned to full irrigation on each of 11, 12, and 13 Mar., respectively, following the last Ψ_s measurement for each day.

Data analysis. As in a previous study (Chalmers et al., 1992), no significant differences were observed between trees growing in B- or B/C-horizon lysimeters for any of the characteristics measured. The data presented here are the means of 12 trees, unless stated otherwise in the text.

Results and Discussion

Withholding irrigation resulted in a rapid decline in soil moisture in the lysimeters (Fig. 1). For the larger trees, the lysimeters could be dried down to $\approx 50\%$ of pot capacity within 10 days. The decline was faster during DC-1 and DC-2 than DC-3, because of higher evaporative demands during those periods.

Mean daily E_{pan} and WU varied considerably during the season (Fig. 2A). Substantial daily fluctuations in E_{pan} with occasionally low daily E_{pan} values, are typical of this region of New Zealand. Such variation is, however, masked when weekly averages are used (Fig. 2B). Mean daily water use increased steadily for the first 3 months following bloom and peaked at ≈ 8 liters/tree (≈ 2 liters·m⁻² canopy surface area) in early-mid January (≈ 90 DAFB). This increase was due to the concurrent development of leaf area and evaporative demand. Leaf area was slightly reduced by summer pruning in early January (88 DAFB). 'Hosui' has three to four periods of intensive vegetative growth during one season. Generally, two or three growth flushes occur before the onset of rapid fruit growth, and one or two following harvest. Shoot growth slowed down (Fig. 3) by late December (≈ 80 DAFB), and only shoots growing towards the inside of the V-shaped canopy were

Fig. 1. Mean soil water content per lysimeter during the 1990–91 season. Horizontal lines represent drying cycles (DC).

Fig. 2. Mean daily water use (●) of 'Hosui' Asian pear trees growing in lysimeter and E_{pan} values (○) for 18 Oct. 1990 to 9 May 1991 (11 to 214 days after full bloom) presented as (upper) 3- and 4-day averages and (lower) weekly averages. Horizontal lines represent drying cycles (DC).

removed by summer pruning.

During periods when soil moisture was not limiting, daily WU averaged ≈ 7.0 liters/tree (1.8 liters·m⁻² canopy surface area) from mid-January to harvest (109 to 130 DAFB), and ≈ 4.5 liters/tree (1.1 liters·m⁻² canopy surface area) following harvest until the first signs of leaf senescence in mid-April (186 DAFB) (Fig. 2B). Similar values were found for noncropping Asian pears in late Summer and Autumn 1990 (Chalmers et al., 1992). Seasonal water use (Oct. 1990 to May 1991) averaged 1070 liters/tree (245 liters·m⁻² canopy surface area), and E_{pan} was 780 mm.

There was a good linear correlation between weekly E and water use over the season ($r = 0.81$, $n = 30$). This correlation was lower ($r = 0.69$) when 3- and 4-day averages were used. Similarly, Worthington et al. (1984) reported a daily correlation coefficient of 0.61 for peaches [*Prunus persica* (L.) Batsch] growing in weighing lysimeters. The correlation was improved ($r = 0.88$, $n = 18$) when weekly averages were used. They also concluded that

whereas estimation of evapotranspiration of peaches using the Class A pan is suitable over longer periods, it may not be as meaningful on a daily basis.

Crop coefficients were derived from weekly E_{pan} and water-use data, so that $k_c = WU/E_{pan}$. When calculated on the basis of the canopy surface area or the projected ground area of the trees, these coefficients ranged from 0.15 to 0.55 and 0.20 to 0.83, respectively. Their averages for the season were 0.34 and 0.51, respectively. Similar values were obtained for the 1991-92 season (unpublished data). The crop coefficients increased with time through the season, but with increasing variability close to leaf fall. Withholding irrigation reduced crop coefficients (Fig. 4). During summer and autumn, Chalmers et al. (1992) found weekly k_c values for well-watered Asian pears averaged 0.52 (canopy surface area basis), but these declined to 0.38 when irrigation was withheld.

Water use declined when irrigation was withheld (Fig. 5). In these experiments the decline was more pronounced for the first two drying cycles due to higher evaporative demands and, possibly, the effect of fruit load. The presence of fruit has been shown to increase transpiration or stomatal conductance, or both, in peaches [*Prunus persica* (L.) Batsch] (Chalmers et al., 1983), grapes (*Vitis vinifera* L.) (Downton et al., 1987), and apples (*Malus domestica* Borkh.) (Hansen, 1971; Lenz, 1986). Transpiration of peach trees was higher in fruiting than in defruited trees during rapid fruit growth (DW III), but decreased when fruit were removed at harvest (Chalmers et al., 1983).

At the start of the drying cycles, trees transpired at a rate similar to trees under full irrigation (Fig. 5). With decreasing soil moisture levels, water use gradually declined. Correlation coefficients between WU and E_{pan} for the drying cycles were low (0.16), showing the diminishing effect of weather on water use as the available soil moisture decreased.

Heat-pulse data during DC-2 not only confirmed this gradual decline in WU, but also showed differences in the degree to which the water use declined. Trees with a larger canopy surface area depleted the available soil water faster at the start of a drying cycle than smaller trees. Toward the end of the drying cycle, the larger trees were more severely stressed than smaller trees, which resulted in a substantial reduction in daily water use. At the beginning of DC-2 [14-23 Jan. for large trees; 14-22 Jan. for small trees (Fig. 6)], the larger tree transpired at a rate 35% higher than the smaller tree. Soil moisture for the large and small tree then fell to 58% and 71% of pot capacity, respectively. Close to the end of DC-2, under conditions of decreased water availability, both trees used a similar amount of water on an instantaneous basis. Irrigating one tree while continuing to withhold water from the other resulted in a higher instantaneous water use by the irrigated tree (Fig. 6). Because of differences in tree size (i.e., trunk cross-sectional areas), the effect of rewatering is more obvious when sap velocities instead of total sap fluxes are compared. Sap velocities in both stems dropped during the drying cycle. As a result of irrigation, the sap velocity in the irrigated tree increased, while the sap velocity in the nonirrigated tree continued to decline (Fig. 7).

Stomatal conductance decreased in both trees compared to well-watered conditions, yet were two to three times higher in the rewatered tree than the nonirrigated one (A.R. Renquist, unpublished data). After both trees were returned to full irrigation, it took 4 to 5 days for the initial ratio of water use between the two trees to be re-established (Fig. 8).

Water-stressed trees had a lower predawn leaf water potential (Ψ_i) than fully irrigated trees, and Ψ_i followed a more rapid decline during the morning, and a slower recovery during late afternoon

Fig. 3. Shoot (●) and fruit (○) growth of 'Hosui' Asian pear trees growing in lysimeter during 1990-91 season. Only one shoot growth flush is shown.

Fig. 4. Seasonal change of crop coefficient (water use/m² canopy surface area per E_{pan}) of 'Hosui' Asian pears. Horizontal lines represent drying cycles (DC).

Fig. 5. Mean daily water use of a 'Hosui' Asian pear tree with 4.4 m² canopy surface area (○) and one with 3.5 m² canopy surface area (●) before, during, and following drying cycles (DC) 1 and 2. Horizontal lines represent DC.

(Fig. 9). Predawn Ψ_i dropped during the drying cycles, yet returned to prestress values once irrigation was restored (Table 1). The midday Ψ_i of stressed trees never fell below -2.5 MPa, although well-watered trees also had leaf water potentials of this value at midday on days when evaporative demand was high. Accordingly, predawn and late afternoon proved to be better than the midday to discriminate between water-stressed and irrigated trees using leaf

Fig. 6. Trunk sap flow measured by heat-pulse technique in a relatively small and a large 'Hosui' Asian pear trees (●, 3.5 m² canopy surface area; ○, 4.4 m² canopy surface area) for day 5 to day 10 of a 10-day drying cycle. Irrigation for the larger tree was withheld from 14 to 23 Jan. 1991 [99 to 108 days after full bloom (DAFB)], and for the smaller tree from 14 to 22 Jan. 1991 (99 to 107 DAFB).

water potential measurements. In contrast, Behboudian (unpublished data), in a greenhouse study on 'Nijisseiki' Asian pears, found differences in midday Ψ_i between well-watered and water-stressed trees to be more pronounced than predawn values. In our experiment, differences in Ψ_i between rewatered and dry treatments became significant (Fig. 10 and Fig. 11) during the late afternoon. Leaf water potentials of trees rewatered on 23 Jan. 1991 (108 DAFB) were not significantly different to Ψ_i of nonirrigated trees for most of the day (Fig. 10), but showed a faster recovery during late afternoon. In addition, rewatered trees had a significantly higher predawn Ψ_i on the morning of 24 Jan. 1991 (data not shown). Similarly, during DC-3, significant differences were observed for the last measurements on 12 and 13 Mar. 1991 (156 and 157 DAFB) (Fig. 11). After all trees were returned to full

irrigation, predawn Ψ_i on 14 Mar. 1991 (158 DAFB) was similar for all treatments (Fig. 11). For 14 Mar. 1991 completion of diurnal measurements was prevented by rainfall.

Although a strong reduction in WU was observed in DC-1, there was no effect on the rate of fruit growth (Fig. 3). In contrast, during DC-2, the strong reduction in WU appeared to inhibit fruit growth. Without a well-irrigated control for comparison, however, no conclusion can be drawn about how the water deficits affected fruit growth during the two drying cycles. Mild water stress during early or late stages of fruit growth had no deleterious effects on fruit growth of 'Nijisseiki' Asian pears (Behboudian, unpublished data) and apples (Durand, 1990; Irving and Drost, 1987). Thus, it appears that fruit were more efficient sinks for reduced photosynthates and water than leaves, which could account for the capacity

Fig. 7. Differences in trunk sap velocities measured by heat-pulse technique in a relatively small and a large 'Hosui' Asian pear trees caused by rewatering (23 Jan., 108 days after full bloom). Filled symbols represent rewatered tree (3.5 m² canopy surface area), open symbols represent nonirrigated tree (4.4 m² canopy surface area). Circles and squares represent sensors at depths of 5 mm and 15 mm below cambium, respectively.

Fig. 8. Stem sap flow measured by heat-pulse technique in a relatively small and a large 'Hosui' Asian pear trees (●, 3.5 m² canopy surface area; ○, 4.4 m² canopy surface area) following the return to full irrigation.

of fruit to grow at low water potentials (Chalmers et al., 1986). This hypothesis is supported by Behboudian (unpublished data), who found that fruit had higher water potentials than leaves before dawn and at midday, and that osmotic adjustment occurred in fruit of the early stress treatment, but not in fruit when trees were deficit-irrigated close to harvest.

For the entire period, the heat-pulse data indicated a 0.5% higher and 17% lower total WU than the lysimeter for the bigger and smaller tree, respectively (Table 2). There was a good agreement between the two methods in measuring WU for the first 4 weeks, but WU values based on the heat-pulse technique became more variable after this initial period. Consequently, the regression coefficients between heat-pulse and lysimetry declined from 0.97 and 0.95 for the first 4 weeks to 0.87 and 0.83 for the smaller and bigger tree, respectively, over the entire period. These results are consistent with other work, which has found sensors became between 2% and 25% less sensitive after 30 days (Swanson, 1983).

The degree to which sensors lost sensitivity was seasonal. Sensors installed in August (northern hemisphere) registered ≈98% of actual stem flow after being installed for 50 days, whereas sensors installed in May recorded just 70%. It appeared that the wound response of the tree was related to the phenological period during which the wounding occurred (Swanson, 1983).

The crop coefficients for Asian pears reported here and by Chalmers et al. (1992) are lower than k_c values of 0.4 to 1.0 (Worthington et al., 1984) and 0.69 to 1.25 (Natali et al., 1985), on a projected ground area basis, for peaches, or 0.95 to 1.0 and 1.05 to 1.1 for European pears (*Pyrus communis* L.) and apples, respectively (Doorenbos and Pruitt, 1977). Since individual pots of the lysimeter were covered and evaporation from the soil surface is directly related to net radiation, it can be assumed that this contribution to total WU was minimal, particularly under the humid conditions in New Zealand (Jensen et al., 1989). Contribution of evaporation from the surface of the soil to total WU is

Fig. 9. Diurnal changes in leaf water potential of well-watered (○) and water-stressed (●) 'Hosui' Asian pear trees. Bars represent twice SE.

Table 1. Predawn leaf water potentials (Ψ_l) of 'Hosui' Asian pears before, during, and following drying cycles (DC; Nov. 1990 to Mar. 1991, 36 to 158 days after full bloom).

Observation period	Days of test	Predawn Ψ_l (MPa)
Prestressed		-0.19 to -0.27
DC-1	9	-0.33
	11	-0.58
Well-watered		-0.20 to -0.22
DC-2	10	-0.39
	11	-0.45
Well-watered		-0.14 to -0.25
DC-3	12	-0.26
	13	-0.31
	14	-0.32
Well-watered		-0.17

largest early in the growing season, and at low planting densities (Loreti et al., 1988). Stevenson (1989), comparing total water use of 'Macspur McIntosh' apple trees growing in lysimeter with and without a grass cover crop, found WU to be lower in the bare soil treatment. The differences were small, averaging 8% for nine growing seasons. Low evaporation from the soil surface, however, could only partly explain the substantially lower k_c found in this study. Similar values found for the 1991-92 season (unpublished data) suggest a lower crop coefficient for Asian pears than for European pears and apples.

The lysimeter facility described here proved to be a valuable system for studying water relations of Asian pears. The system enabled a good control of the soil water level, and thereby good control of the plant water status, and accurate measurement of water use. These results confirm observations by Chalmers et al. (1992) that Asian pears grown on a Tatura trellis have a rather low maximum water use under the humid New Zealand climate. Predawn and late-afternoon leaf water potentials were good indicators of the plant water status, whereas midday leaf water potential was more strongly influenced by climatic conditions. Since the main portion of vegetative growth of 'Hosui' occurred before the

Fig. 10. Diurnal changes (23 Jan. 1991) in leaf water potential for dry (●) and rewatered (○) 'Hosui' Asian pear trees. Bars represent twice SE. Mean separation by Duncan's multiple range test. ***Significant at $P=0.05$ or 0.01 , respectively.

Fig. 11. Effect of rewatering on diurnal leaf water potential of 'Hosui' Asian pears (11 to 14 Mar. 1991). Trees were returned to full irrigation following the last measurement on 11 Mar. (●), 12 Mar. (Δ), and 13 Mar. 1991 (○). Bars represent twice SE.

Table 2. Comparison of water use [liters/tree] of 'Hosui' Asian pear trees, calculated from lysimetry and heat-pulse measurements.

Observation period	Days after full bloom	Tree size (relative)			
		Small		Large	
		Heat-pulse	Lysimetry	Heat-pulse	Lysimetry
17-20 Jan. ²	102 to 105	18.8	24.0	28.2	27.0
21-23 Jan.	106 to 108	17.4	17.9	20.9	17.6
24-27 Jan.	109 to 112	22.0	26.4	22.6	24.2
28-30 Jan.	113 to 115	14.9	19.4	18.4	21.4
31 Jan. to 3 Feb.	116 to 119	25.8	28.8	36.1	40.2
4-6 Feb.	120 to 122	13.8	16.5	19.7	21.3
7-10 Feb.	123 to 126	29.5	38.2	39.2	38.2
11-13 Feb.	127 to 129	15.6	18.3	21.7	18.6
21-24 Feb.	137 to 140	21.2	26.1	29.4	28.0
25-27 Feb.	141 to 143	15.1	21.7	22.8	22.7
28 Feb.-3 Mar.	144 to 147	15.6	13.5	24.7	13.4
7-10 Mar.	151 to 154	17.9	16.9	19.6	24.2
11-13 Mar.	155 to 157	12.6	21.2	12.7	17.7

²Heat-pulse values for 18-20 Jan. 1991.

start of rapid fruit enlargement, when about two-thirds of final fruit weight was accumulated, Asian pears may also respond favorably to regulated deficit irrigation (RDI) (Chalmers et al., 1986).

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