sities compared to the untreated check in 2000. We assume that the DPT weed control activity was a combination of postemergence and preemergence activity, since weeds were present at the time of application, and additional weed emergence occurred between time of application and the time of the weed density counts.

Conclusions and recommendations

Herbicides applied IPT that were considered to be safe, irrespective of strawberry cultivar, included carfentrazone at 0.075 and 0.15 lb/acre, sulfentrazone at 0.175 and 0.25 lb/acre, flumioxazin at 0.063 lb/acre, and the industry standard, napropamide, at 4.0 lb/acre. Strawberry was less tolerant of herbicide applications made DPT than of applications made IPT; triflusulfuron at 0.016 lb/acre was the only DPT treatment that both cultivars tolerated. We assume that because the strawberry plants were dormant at the IPT timing, they were more tolerant of herbicides than when actively growing at the DPT timing. The differences in selectivity between 'Selva' and 'Camarosa' to many of the treatments tested here indicates that the crop safety of any herbicide should be verified by testing on many strawberry cultivars. Triflusulfuron demonstrated relatively weak activity on bur clover and shepherd's purse compared to many of the other herbicides (Table 7). Care must be taken in future evaluations to determine if triflusulfuron can provide a useful level of weed control for strawberry. Sulfentrazone at 0.25 lb/acre applied immediate posttransplant appeared to provide the best combination of crop safety and weed control in strawberry and should be evaluated further.

Literature cited

Agamalian, H.S., C.L. Elmore, and B.B. Fischer. 1994. Weeds, p. 99–113. In: M.L. Flint (ed.). Integrated pest management for strawberries. Univ. Calif., Oakland, IPM Publ. 3351.

Ahrens, W.H. (ed.). 1994. Herbicide handbook. 7th ed. Weed Sci. Soc. Amer., Champaign, Ill.

Ajwa, H. and T. Trout. 2000. Strawberry growth and yield with three years of drip fumigation. Annual International Research Conference of Methyl Bromide Alternatives and Emissions Reductions, Orlando, Fla., p. 25.1–25.4

California Dept. of Pesticide Regulation. 2000. 1999 annual pesticide use report. Calif. Dept. of Pesticide Regulation. Sacramento.

California Strawberry Commission. 1999. Crop profile of strawberries in California. Natl. Pesticide Assessment Prog. 7 Aug. 2001. <http://pestdata.ncsu.edu/cropprofiles/docs/castrawberries.html>.

Duniway, J.M., C.L. Xiao, H. Ajwa, and W.D. Gubler. 1999. Chemical and cultural alternatives to methyl bromide fumigation of soil for strawberry. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, Calif., p. 2.1–2.2.

Economic Research Service. 2000. Economic implications of the methyl bromide phase out. USDA Agr. Info. Bul. 756.

Fennimore, S.A., M.J. Haar, and H. Ajwa. 2000. Weed control options in California strawberry without methyl bromide. Annu. Intl. Res. Conf. Methyl Bromide Alternatives and Emissions Reductions, Orlando, Fla. p. 65.1–65.5.

Hokanson, S.C. and C.E. Finn. 2000. Strawberry cultivar use in North America. HortTechnology 10:94–106.

Lange, A.H. 1985. Soft fruits, p. 352–355. In: E.A. Kurtz (ed.). Principals of weed control in California. Thompson Publ., Fresno, Calif.

Locascio, S.J., J.P. Gilreath, D.W. Dickson, T.A. Kucharek, J.P. Jones, and J.W. Noling. 1997. Fumigant alternatives to methyl bromide for polyethylene mulched tomato. HortScience 32:1208–1211.

National Agricultural Statistics Service. 2000. Vegetables 1999 summary. USDA, Wash., D.C.

United Phosphorous. 1999. Devrinol 50-DF sample label. United Phosphorous Inc., Wilmington, Del.

Wilhelm, S. and A.O. Paulus. 1980. How soil fumigation benefits the California strawberry industry. Plant Dis. 64:265–270.

Rapid Equilibration of Leaf and Stem Water Potential under Field Conditions in Almonds, Walnuts, and Prunes

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Summary. Covering a plant leaf with a reflective, water impervious bag ensures that equilibrium is reached between the nontranspiring leaf and the stem, and appears to improve the accuracy of determining plant water status under field conditions. However, the inconvenience of covering the leaf for 1 to 2 hours before measuring stem water potential (SWP) has constrained on-farm adoption of this irrigation management technique. A second constraint has been that the requirement of midafternoon determinations limits the area that can be monitored by one person with a pressure chamber. This paper reports findings from field studies in almonds (*Prunus dulcis*),

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prunes (*P. domestica*), and walnuts (*Juglans regia*) demonstrating modified procedures to measure midday SWP, making it a more convenient and practical tool for irrigation management. For routine monitoring and irrigation scheduling, an equilibration period of 10 min or longer appears to be suitable to provide accurate SWP measurements. Based on the large sample sizes in this study, we estimate that measurement error related to equilibration time for SWP can be reduced to an acceptable level [0.05 MPa (0.5 bar)] with a sample size of about 10 leaves when using a 10-min equilibration period. Under orchard conditions where tree growth and health appears uniform, a sample of one leaf per tree and 10 trees per irrigation management unit should give an accurate mean indicator of orchard water status. Under more variable orchard conditions a larger sample size may be needed. Midmorning and midday SWP both exhibited similar seasonal patterns and responded alike to irrigation events. On some occasions, midday SWP was accurately predicted from midmorning SWP and the change in air vapor pressure deficit (VPD) from midmorning to midday, but both over- and underestimate errors [to 0.3 MPa (3.0 bar)] appeared to be associated with unusually low or high diurnal changes in VPD, respectively. Hence, direct measurement of SWP under midday conditions (about 1300 to 1500 HR) is still recommended.

Many soil, plant, and climate-based techniques exist for irrigation scheduling. Since the primary objective of irrigation is to influence plant water status and hence plant productivity, one technique is to base irrigation on some measure of plant water status, such as leaf water potential (Boyer, 1995). A number of studies, however, have shown that leaf water potential was not clearly related to symptoms of plant water stress, and its value for quantifying plant water status have been questioned (Sinclair and Ludlow, 1985; Bates and Hall, 1981; and Jones 1985).

Dynamic environmental conditions (Meyer and Green, 1980); a within leaf water potential gradient during transpiration (Shackel and Brinckman, 1985); and desiccation of transpiring leaves after excision from the plant (Turner and Long, 1980) may all obscure the relationship between leaf water potential and commonly observed symptoms of plant water stress such as stomatal closure and reductions in photosynthesis and plant growth (Bradford and Hsiao, 1982). The relationship between leaf water potential and plant water status is improved by using predawn measurements (Meyer and Green, 1980), when the water potential throughout the plant should be relatively uniform. However, predawn determinations indicate the overnight recovery in plant water potential, and under heterogeneous soil-water distribution, such as with drip or low volume irrigation, predawn water potential may show a very limited response to progressive soil drying (Ameglio et al., 1999). Predawn measurements of leaf water potential also pose obstacles to on-farm adoption due to the unusual hour of field measurement and potential labor problems. A measure of water potential experienced by the plant under midday conditions, when photosynthetic rates and plant transpiration are typically highest and when it is most practical to collect field data is preferable.

It is possible to eliminate both excision artifacts and within leaf water potential gradients by stopping leaf transpiration prior to excising the leaf from the plant (Garnier and Berger, 1985; Olien and Lakso, 1986). A methodology of placing light and moisture impervious bags on leaves located near the main stem or trunk and leaving them attached to the tree on the order of 2 h or more allows the leaf water potential to equilibrate with the water potential of the stem (Begg and Turner, 1970; McCutchan and Shackel, 1992). This measure of SWP is less influenced by short-term environmental changes than is transpiring leaf water potential (Meyer and Green, 1980). Overcoming these factors that compromise the relationship between plant water potential and plant water stress further justifies the use of SWP as a more appropriate measure of plant water status (McCutchan and Shackel, 1992).

Using SWP for irrigation scheduling has been under investigation in northern California prune orchards since 1998 as part of the Prune Pest Management Alliance (PMA), an environmentally sensitive approach to prune management. Leaves bagged in the morning and SWP measured at midday have resulted in a reduction of applied irrigation water, increased sugar content in the fruit, and decreased fruit dehydration requirements while maintaining fruit yield (Lampinen et al, 2001; Olson et al, 2001). Each of these responses is a measure of an effective irrigation scheduling method. Values are reliable, repeatable and well adapted to multiple monitoring sites within an orchard with spatially variable soils and rootzones. Equipment costs are affordable and many irrigation managers are enthusiastic about using a plant-based method to determine when irrigation is needed.

One constraint to gaining adoption of SWP measurements for routine irrigation scheduling is the time required for bagged leaves to reach equilibrium with the stem. Bagging times on the order of 2 h require two trips to the field, one to bag the leaf in the morning and a second to measure SWP at midday. This requirement may not be acceptable to managers of large almond, prune, and walnut orchards. Due to limited time and personnel resources, one trip to the field to bag the leaf and collect SWP data is desirable. A second constraint to gaining adoption of this technique is the emphasis on midday (1300 to 1500 HR) measurements. Limiting the hours when midday SWP can be determined restricts the acres that can be monitored by one person with a pressure chamber.

This paper reports findings from two related experiments. One investigates the minimum bag duration time needed to assure that leaf water potential has equilibrated with SWP. If the bag duration times could be shortened without significant accuracy loss, collection of midday SWP data will be more acceptable to irrigation managers. In the second experiment, field experimentation with three alternative bag durations seeks to confirm the findings from the first experiment as well as compare the seasonal patterns in midafternoon and midmorning SWP. The second experiment is also used to illustrate a typical application of SWP as an irrigation guide during the growing season in prunes.

Materials and methods

Expt. 1—Bag time duration

STUDY SITE SELECTION. Equilibration time required to measure SWP was evaluated for three deciduous crop species: 'French' prune; 'Nonpareil,' 'Butte,' and 'Carmel' almond, and 'Vina' walnut on paradox (*Juglans regia* x *J. hindsii*) rootstock during the 2000 season.

One prune orchard, two almond orchards, and one walnut orchard were selected for this study. All of the sites were established, fully bearing orchards. The prune orchard was located near Red Bluff, Calif., and the walnut orchard was located in Vina, Calif., on Tehama loam and Vina loam soils, respectively. Both orchards were flood-irrigated. One almond orchard was located near Gerber, Calif., on a Zamora silty clay loam and was irrigated with solid set sprinklers. The second almond orchard was located near Arbuckle, Calif., on an Arbuckle gravelly sandy loam. A portion of this orchard was irrigated with microsprinkler and a portion of the orchard was irrigated with two lines of surface drip irrigation.

Experimental materials. Materials used in the study included: a plant stress monitoring console [model PG 2000; 4.0 MPa (40 bar) range, Soilmoisture Equipment Corporation, Goleta, Calif.] to measure water potential; mylar bags (PMS Instrument Company, Corvallis, Ore.) for bagging the leaves before measuring SWP; a sharp razor blade to remove leaves from the tree for measurement and to provide a smoothly cut stem surface for determining the end point of the measurement; and a 6× or 10× magnifying glass to enlarge the view of the cut stem once it was placed in the pressure chamber.

Data collection. Healthy test trees were selected within the interior rows of each orchard. The northeast and northwest quadrants of a single tree were used to collect duplicate sets of data for the same day of measurement. The same tree was used for successive days of data collection until the number of healthy, accessible leaves for measuring midday SWP became limiting. Fully expanded, healthy leaves located on the interior of the tree canopy were selected at a 1.5 to 2.5-m (60 to 100-inch) height. When suitable leaves for midday SWP were insufficient, an adjacent, healthy tree of the same variety was selected for measurement. In walnut, fully expanded terminal leaflets were selected from the compound leaves.

After selecting the tree, 4 or 10 leaves (usually 10) were bagged at least 2 h before midday measurements were collected. These leaves were used to determine midday SWP using the standard method of measurement (McCutchan and Shackel, 1992).

After solar noon, usually between 1230 and 1330 HR, two people returned to complete SWP measurements and the data collection. Each person had eleven, sequentially numbered bags. One person placed bags on the leaves located in the northwest quadrant of the tree and the other person duplicated the bagging procedure in the northeast quadrant, simultaneously. Bags were placed on a pair of leaves at times 0, 5, 10, 15, 20, 25, 26, 27, 28, 29, and 30 min. The leaf-bagging process required 30 min. The bagged leaves remained attached to the tree for later SWP determination. In initial studies, leaves were incrementally covered over a 2-h period but clearly the findings showed that bag times in excess of 1 h were unnecessary.

Midday water potential measurements began 1 min after the eleventh pair of bags (time 30 min) was placed on the tree. The bagged leaves were cut from the tree and water potential was measured one leaf at a time in the reverse order of which they were bagged. Hence the eleventh pair of leaves, bagged at 30 min after the first pair of leaves at time 0, were then cut and measured at about 1 and 2 min after they were initially covered, respectively. Then the tenth pair of leaves, bagged at 29 min after the first pair of leaves, were cut and measured at about 3 and 4 min after they were initially covered, respectively. This sampling process was repeated for all 11 pairs of bagged leaves over a period of about 50 min. During this sampling period, water potential was intermittently measured every 5 to 10 min on the leaves that were bagged for more than 2 h. With the exception of the Arbuckle almond site, water potential was also determined on 4 or 10 nonbagged leaves (no bag used before or during the measurement) for comparison. For these leaves, incidental, partial shading from the sampler's hand on the order of 20 to 30 s occurred when the nonbagged leaves were manually excised from the tree and inserted into the pressure chamber for measurement of water potential. The total time to excise a leaf from the tree, insert it in the pressure chamber, and reach the end point of the water potential measurement was about 1 min. All water potential measurements were made midafternoon between 1300 and 1530 HR.

Frequency and conditions of data collection. Data were collected on 10 different days in the prune and almond orchards, respectively, and 9 different days in the walnut orchard, representing a wide range of plant water status conditions. Measurements were taken in conditions ranging from 3 d to 3 weeks after irrigation in the flood irrigated prune orchard. Measurements were taken 3 d to 6 weeks after irrigation in the flood irrigated walnut orchard. Measurements were taken 3 d to 2 weeks after irrigation in the sprinkler irrigated almonds, and under irrigation conditions ranging from near 50% to over 100% of estimated crop evapotranspiration in the high frequency, drip and microsprinkler irrigated almond orchard. Measurements were taken in mid and late summer prior to crop harvest.

Pressure chamber operation. Two pressure chambers were used in this study and the same two individuals operated their respective pressure chambers during all of the water potential measurements. One console and pressure chamber operator was dedicated to collecting all water potential measurements in the walnuts. A second console and pressure chamber operator was dedicated to all water potential measurements in the prunes. Both consoles were used and both operators collected water potential data in almonds. One console and operator was assigned all data collection in the almonds at the Gerber site. The second pressure chamber and operator collected all of the data at the Arbuckle almond site.

Care was taken to gradually increase the pressure in the chamber around the leaf (Naor and Peres, 2001). In prune and almond, SWP ranging from –1.0 to –2.0 MPa (–10 to –20 bar) were measured over 45 to 60 s [0.03 to 0.05 MPa·s^{-1} (0.3 to 0.5 bar/s)]. In walnut, SWP between –0.4 and –0.8 MPa (–4.0 and –8.0 bar) were measured over about 30 to 40 s [0.01 to 0.03 MPa·s^{-1} (0.1 to 0.3 bar/s)].

Statistical methods. For each sampling day , all of the SWP values obtained from both quadrants of the tree using the standard method (2 h)

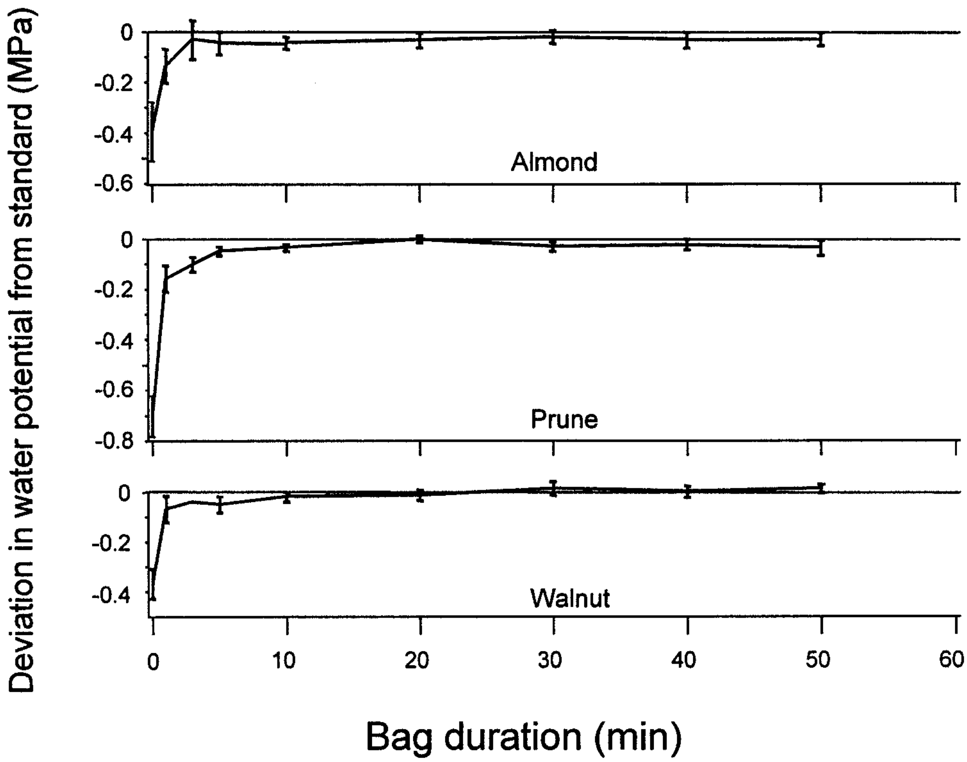


Fig. 1. Response of measured leaf water potential, expressed as a difference from the standard value, to the duration of time that the leaf was covered with a reflective plastic bag to prevent leaf transpiration in almond, prune, and walnut. Vertical bars represent ±2 SE; 1.0 MPa = 10 bar.

were averaged into one mean to represent one set of data ($SWP_{standard}$). Each measurement obtained using the test bagging duration (SWP_{test}) was expressed as a difference from this average value collected with the standard (2 h) method ($SWP_{test} - SWP_{standard}$). For each species, all of the differences were pooled into eight rounded bagging duration intervals (1, 3, 5, 10, 20, 30, 40, and 50 min) with nonbagged values arbitrarily assigned a 0 min interval. All the values for each species and interval were pooled for the purposes of data presentation.

Expt. 2—Bag duration and midmorning SWP measurements

Five different methods, one standard and four experimental, of measuring SWP were compared in a Butte County orchard. The orchard was drip irrigated, on a Gridley clay loam soil. The trees used were French Prune, which were about 17 years of age in 2000. Trees were planted at a 6.1 × 6.1 m (20 × 20 ft) spacing on Myrobalan (*Prunus cerasifera*) seedling rootstock. Trees were selected by starting at the third tree in from the west edge of the orchard and selecting every third tree in that row until 10 trees were chosen. These same trees were used for all five methods of measuring SWP throughout the 2000 season. All leaves selected for these methods were located in the interior, shaded canopy along the trunk or a main scaffold.

The first method is referred to as the standard method, the same method described in the Materials and Methods section for Expt. 1 of this paper. The leaves were covered at about 0900 HR and SWP was measured about 3 to 4 h later (1200 to 1300 HR). This method of measurement was practiced weekly from 26 Apr. to 6 Sept. (23 occasions).

The method referred to as morning readings involved placing a bag over an additional interior leaf on each of the same 10 trees at about 0900 HR. At 1030 HR, about 1.5 h later, SWP was measured using the pressure chamber as described in Expt. 1. This method was practiced weekly from 6 June to 6 Sept. (14 occasions).

The 2 to 3 min method involved covering the leaf with a bag for 2 to 3 min before measuring SWP. A leaf was covered for 2 to 3 min between 1200 and 1300 HR. The covered leaf was excised from the tree and SWP was then measured. SWP using this 2 to 3 min experimental method was measured on every other tree monitored with the standard method for a total of five trees each day. This experimental method was practiced on four occasions from 6 June to 17 July.

The immediate method involved measuring SWP within 1 min after the leaf was bagged between 1300 and 1400 HR. Five trees (every other tree) were used for this third experimental method, which was practiced on six occasions from 21 June to 6 Sept.

The 7 to 10 min method involved measuring SWP after the leaves had been covered for about 7 to 10 min. A bag was placed over a leaf between 1200 noon and 1300 HR. After bags were placed on all 10 trees, SWP was measured for each of the trees starting with the first tree that had a bag placed on it. This method was completed on 1 and 17 Aug. (two occasions).

PRESSURE CHAMBER OPERATION. A pump-up pressure chamber [PMS Instrument Company, Corvallis, Ore.; 2.0 MPa (20 bar) range] was used in this experiment. The same person operated the pressure chamber each day that water potential measurements were completed. Since a pump-up pressure chamber was used in the experiment, the pressure in the chamber around the leaf was increased gradually. Ranges in water potential from –0.5 to –1.6 MPa (–5.0 to –16 bar) were determined in about 45 to 60 s, similar to the rates of measurement described for the prunes in the first experiment.

WEATHER DATA. For each sampling date, midday conditions of vapor pressure deficit (VPD) were calculated from relative humidity and water vapor pressure data obtained from a weather station located about 37 km (23 miles) from the orchard (California Irrigation Management and Information System, CIMIS, station 12, Durham, Calif.). The orchard in this study was irrigated to achieve the moderate water stress target values proposed for prune by Shackel et al. (2000).

STATISTICAL METHODS. For the immediate, 2 to 3 min, and the 7 to 10 min experimental methods, SWP determinations from individual trees were used in the statistical analysis. SWP values from these experimental methods

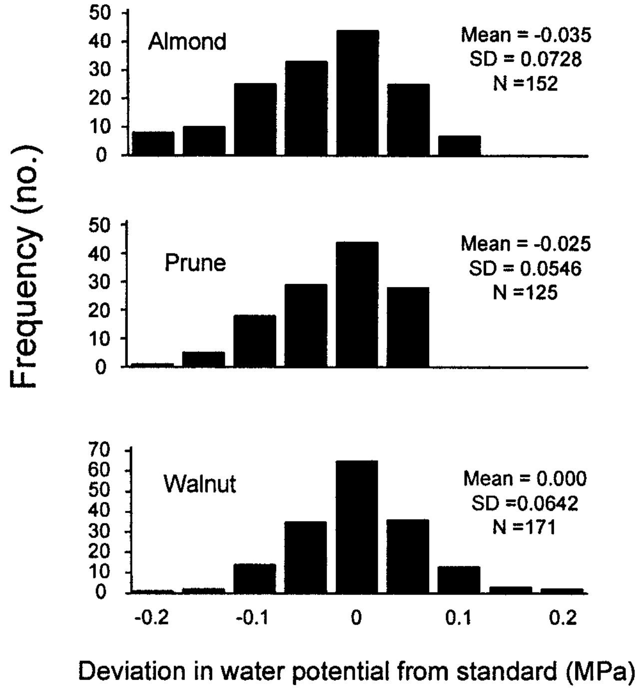


Fig. 2. Pooled deviations of the measured values of water potential from the standard value for bagging durations of 10 min or greater in almond, prune, and walnut. Also shown are summary statistics for each species; 1.0 MPa = 10 bar.

were used as the dependant variable (Y) and regressed against the SWP values determined for the same trees on the respective days using the standard method as the independent variable (X). The slope and intercept of the regression lines for each experimental method were tested for a significant difference from 1 and 0, respectively.

Results and discussion

Expt. 1. In all species tested, there was a very rapid increase in measured water potential during the first few minutes after bagging, and measured values closely approximating the standard value occurred for bagging durations of about 10 min or longer (Fig. 1). The particularly low values of water potential measured on nonbagged leaves (Fig. 1, bagging duration = 0 min), were probably the result of both leaf transpiration effects on water potential, and desiccation of the leaf following excision (Turner and Long, 1980). This is noteworthy for our study, because only interior canopy, shaded leaves were chosen for measurement. These leaves would be expected to have much lower levels of stomatal conductance compared to outer canopy, exposed leaves, and hence might be expected to have both lower transpiration and experience less postexcision desiccation than outer canopy leaves. Hence the initial rapid change in apparent water potential with bagging duration that we observed in all species (Fig. 1) would have probably be even more dramatic for outer canopy leaves. For all species, the distribution of values obtained after 10 or more minutes of bagging had a mode of 0.0 MPa (0.0 bar), and a reasonably symmetrical distribution around this value (Fig. 2).

Since the sample size was large for each species, we believe that the standard deviation calculated from these distributions can be used as a reliable estimate of the measurement error for SWP values obtained under field conditions. Based on this assumption, the critical values for a two-tailed students *t* test ($t = 1.96$, df > 120) were used to determine the 95% confidence interval for various sample sizes (Table 1).

These values indicate that a moderate level of sampling (10 leaves) should be sufficient to reduce measurement error related to SWP equilibration to an acceptable level (<0.05 MPa) in the species that we have examined. Under field conditions however, there may be additional sources of variability, such as soil texture and depth, irrigation system nonuniformity, and tree health that may lead to real differences in tree water stress across an orchard. These sources of variability are also important and may increase the sample size that will be required for experimental monitoring or irrigation scheduling purposes using midday SWP.

Expt. 2. In addition to measurement error, the range over which midday SWP is expected to vary is also an important practical consideration in evaluating the usefulness of midday SWP for routine water stress monitoring or irrigation scheduling. The data in figure 1 indicate that even relatively short periods of bagging gave a close approximation to the standard method of determining SWP. In Expt. 2, there was a clear correlation with the standard method for each of three alternatives tested [immediate, 2 to 3 min, and 7 to 10 min bagging duration (Fig. 3)]. Both the intercept and slope of the regression equation for immediate bagging duration were significantly different from 0 and 1, respectively. In contrast, the intercepts and slopes for the two other alternatives were not significantly different from 0 and 1, respectively, indicating that even a few minutes of bagging duration may allow for a reasonable approximation of midday SWP. However, 7 to 10 min of bagging did result in the highest regression coefficient ($R^2 = 0.83$). These results agree with the findings in Expt. 1 that 10 min or more of bagging should provide a suitable equilibration period to make an accurate determination of SWP. The pattern of deviation from the 1:1 relation for immediate bagging is interesting in that the agreement with the standard method appears to improve as water potential declines. This pattern is consistent with the results of Turner and Long (1980), who found that desiccation artifacts were reduced at low water potentials, presumably due to the reduction in stomatal conductance and leaf transpiration with increasing plant water stress.

For irrigation management in prune orchards, we have proposed that a progressive, moderate stress may have horticultural benefits such as improving (lowering) fruit hydration ratio (fresh weight/dry weight) at harvest. We have established target values of midday SWP for this purpose (Shackel et al., 2000). The irrigation management

Table 1. Confidence intervals (95%) in stem water potential for different sample sizes, assuming only measurement error related to equilibration time.

Species	Sample size (N)	95% Confidence interval (MPa)[z]
Almond	3	±0.08
Almond	5	±0.06
Almond	10	±0.04
Almond	20	±0.03
Prune	3	±0.06
Prune	5	±0.05
Prune	10	±0.03
Prune	20	±0.02
Walnut	3	±0.07
Walnut	5	±0.06
Walnut	10	±0.04
Walnut	20	±0.03

[z]1.0 MPa = 10 bar.

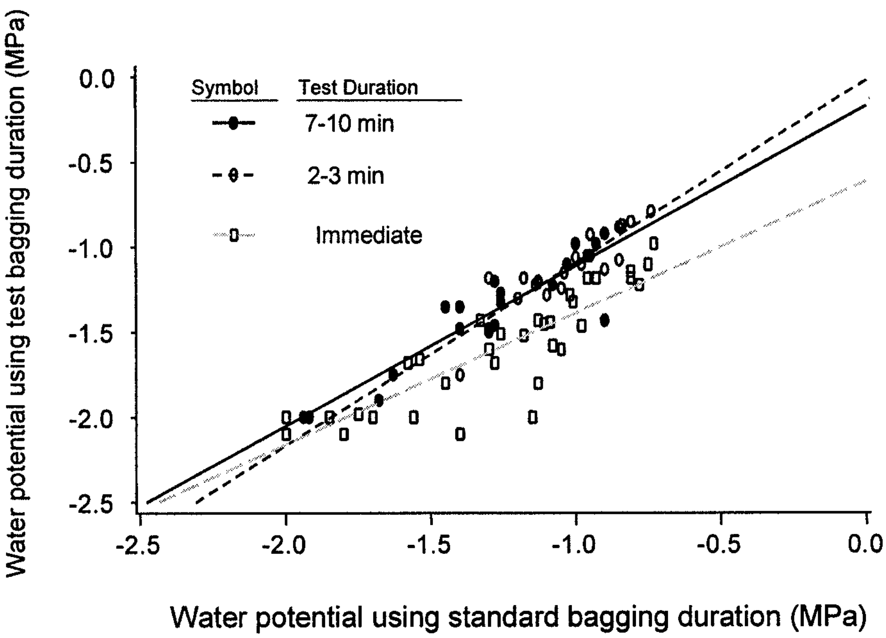


Fig. 3. Relation of midday stem water potential measured using three alternative bagging durations (immediate, 2 to 3 min, and 7 to 10 min) to water potential measured on the same tree using the standard duration (minimum 2 h), over a range of irrigation and weather conditions; 1.0 MPa = 10.0 bar. The regression results were, for the immediate method: Y = –0.78 × X – 0.61 (R^2 = 0.76, N = 33), for the 2 to 3 min method: Y = 1.08 × X –0.02 (R^2 = 0.77, N = 19) and for the 7 to 10 min: Y = 0.94 × X – 0.17 (R^2 = 0.83, N = 19).

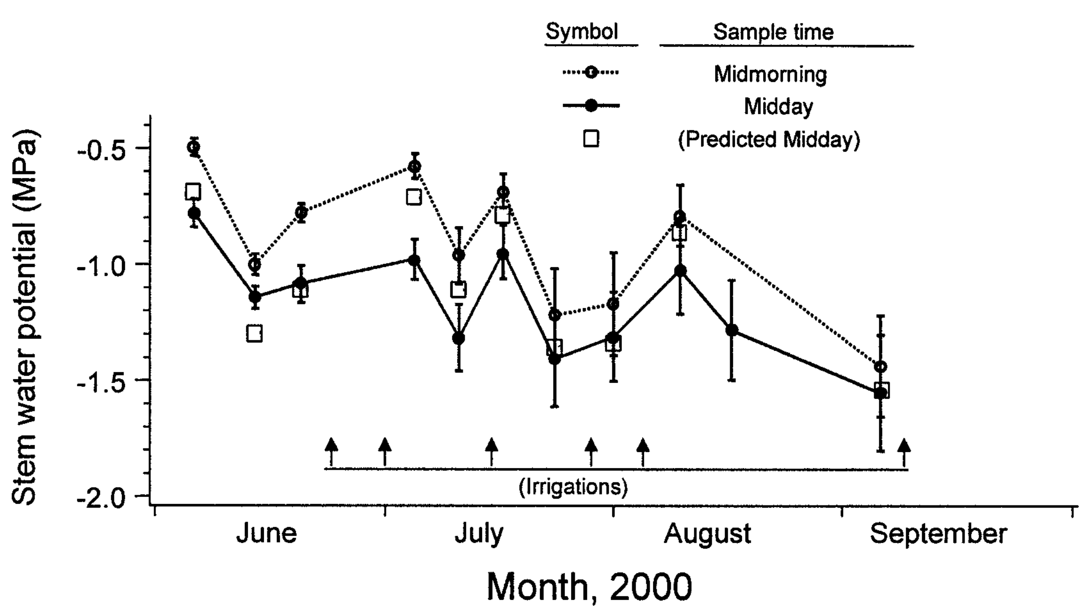
used in Expt. 2 demonstrated this strategy by calling for irrigation when the measured midday SWP was at or below the target value (Fig. 4).

The midmorning SWP values that were collected in Expt. 2 paralleled the changes exhibited by midday SWP as it responded to the combined influence of irrigation and day-to-day variation in midday weather conditions (Fig. 4). The current target values recommended for prune trees are based on SWP measurements made at midday, however, when VPD is maximum. Under fully irrigated conditions, prune trees exhibit a decline of 0.12 MPa·kPa^{-1} (0.12 bar/mbar) air VPD (McCutchan and Shackel, 1992), and, assuming the same sensitivity of SWP to VPD under irrigation deficit conditions, we attempted to predict midday from midmorning SWP using the midmorning to midday change in air VPD (Fig. 4). On 5 of the 10 sampling dates (6 and 20 June, 24 July, 1 Aug., and 6 Sept.) the agreement between predicted and observed values was reasonably good, but on one date (14 June) midday SWP was substantially underestimated, and for the remaining dates SWP was substantially overestimated. The average diurnal patterns of VPD for these groups of dates (Fig. 5) suggest that over- and underestimates of midday SWP were associated with days of relatively small or large fluctuations in VPD, respectively, but a regression analysis for the entire data set (not shown) did not indicate any significant relation between the midmorning to midday changes in VPD and SWP. Hence, additional research is needed to determine to what extent diurnal patterns in SWP are related to diurnal patterns in VPD or other environmental conditions.

Conclusions

In almonds, prunes and walnuts, the water potential of shaded leaves in the interior canopy appears to equilibrate rapidly with SWP once transpiration is stopped by covering the leaf with a reflective, water impermeable bag. For routine monitoring and irrigation scheduling, 10 min or longer appears to be a suitable equilibration period. Under the conditions of this experiment, measurement error of SWP can be reduced to about 0.05 MPa with sample sizes of 10 leaves, although accounting for spatial variation within the orchard may require a larger sample than this. These results demonstrate that midday SWP

Fig. 4. Example data collected from a prune orchard over the 2000 growing season, in which irrigations were scheduled to achieve the target values of midday stem water potential recommended by Shackel et al. (2000). Dates of irrigation are indicated by upward pointing arrows. Also shown are midmorning measurements of stem water potential, and values of midday stem water potential that were predicted based on the midmorning measurements and the change in air vapor pressure deficit from midmorning to midday. Lines connect the daily means of midmorning and midday stem water potential and vertical bars represent ± 2 SE; 1.0 MPa = 10.0 bar.



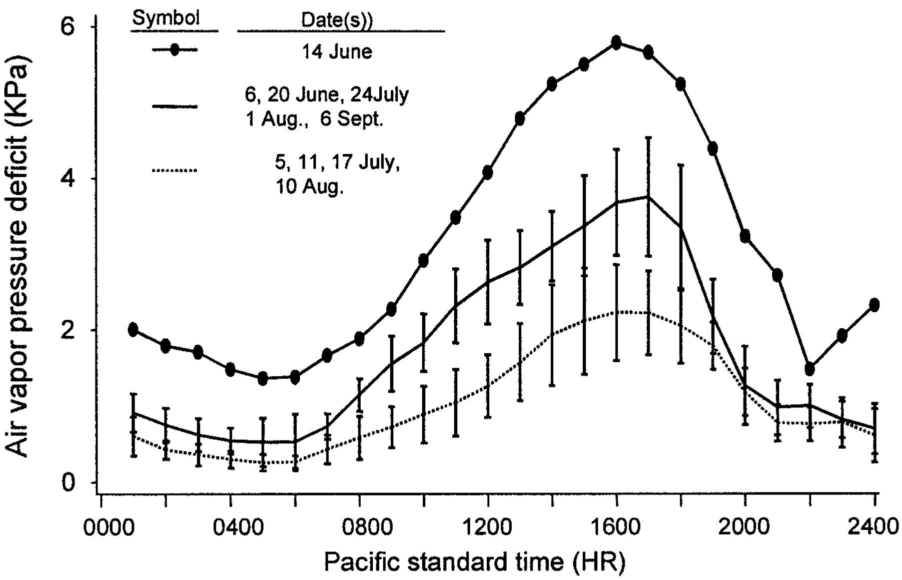


Fig. 5. Diurnal patterns in hourly average air vapor pressure deficit corresponding with midmorning and midday stem water potential measurements. Vertical bars represent ± 2 SE where multiple dates are pooled; 1.0 MPa = 10.0 bar.

can be a convenient and practical tool for irrigation management. There may also be opportunity to further adapt SWP measurement for on-farm irrigation management, if mid morning measurements can be accurately related to mid afternoon measurements of SWP but this will require additional experimentation.

Literature cited

Ameglio, T., P. Archer, M. Cohen, C. Valancogne, F. Daudet, and P. Cruiziat. 1999. Significance and limits in the use of predawn leaf water potential for tree irrigation. Plant Soil 207:155–167.

Bates, L.M. and A.E. Hall. 1981. Stomatal closure with soil water depletion not associated with changes in bulk leaf water status. Oecologia 50:62–65.

Begg, J.E. and N.C. Turner. 1970. Water potential gradients in field tobacco. Plant Physiol. 46:343–346.

Bradford, K.J. and T.C. Hsiao. 1982. Physiological responses to moderate water stress. Encyclopedia Plant Physiol. 12B:263–324.

Boyer, J.S. 1995. Measuring the water status of plants and soils. Academic Press, San Diego, Calif.

Garnier, E. and A. Berger. 1985. Testing water potential in peach trees as an indicator of water stress. J. Hort. Sci. 60(1):47–56.

Jones, H.G. 1985. Physiological mechanisms involved in the control of leaf water status: Implications for the estimation of tree water status: Acta Hort. 171:291–296.

Lampinen, B.D., K.A. Shackel, S.M. Southwick, and W.H. Olson. 2001. Deficit irrigation strategies using midday stem water potential in prune. Irr. Sci. 20:47–54.

McCutchan, H. and K.A. Shackel. 1992. SWP as a sensitive indicator of water stress in prune trees (*Prunus domestica* L. cv. French). J. Amer. Soc. Hort. Sci. 117:607–611.

Meyer, W.S. and G.C. Green. 1980. Water use by wheat and plant indicators of average soil water. Agron. J. 72:253.

Naor, A. and M. Peres. 2001. Pressure increase rate effects the accuracy of stem water potential measurements in deciduous trees using the pressure chamber technique. J. Hort. Sci. Biotechnol. (in press).

Olien, W.C. and A.N. Lakso. 1986. Effect of rootstock on apple (*Malus domestica*) tree water relations. Physiol. Plant. 67:421–430.

Olson, W. et al. 2001. Environmentally sound prune systems (E.S.P.S). Prune Res. Rpt. California Prune Board, Pleasanton.

Shackel K.A. and E. Brinckman. 1985. In situ measurements of epidermal cell turgor, leaf water potential, and gas exchange in *Tradescantia virginiana* L. Plant Physiol. 78:66–70.

Shackel, K.A., B. Lampinen, S. Southwick, W. Olson, S. Sibbett, W. Krueger, J. Yeager, and D. Goldhamer. 2000. Deficit irrigation in prunes: maintaining productivity with less water. HortScience 35:30–33.

Sinclair, T.R and M.M. Ludlow. 1985. Who taught plant thermodynamics? The unfulfilled potential of plant water potential. Austral. J. Plant Physiol. 12:213–217.

Turner, N.C. and M.J. Long. 1980. Errors arising from rapid water loss in the measurements of leaf water potential by the pressure chamber technique. Austral. J. Plant Physiol. 7:527–537.

Effects of Microbial, Botanical, and Synthetic Insecticides on 'Red Delicious' Apple Arthropods in Arkansas

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ADDITIONAL INDEX WORDS. ***Cydia pomonella*, *Grapholita molesta*, spider mite, virus, predator, *Bacillus thuringiensis*, pest control**

SUMMARY. Insecticides were compared for control of codling moth (*Cydia pomonella*) and oriental fruit moth (*Grapholita molesta*), and effects on european red mites (*Panonychus ulmi*) and predatory mites (*Neoseiulus fallacis*) in 'Red Delicious' apple trees (*Malus* ×*domestica*). Ten days after treatment with azinphosmethyl, celery

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