# Improving Irrigation Scheduling Protocols for Nursery Trees by Relating Cumulative Water Potential to Concurrent Vapour Pressure Deficit©

Newton Tran, Polina Bam, Katie Black, Thomas Graham, Ping Zhang and Mike Dixon
Controlled Environment Systems Research Facility, School of Environmental Sciences,
University of Guelph, Ontario, Canada
Email: ntran@uoguelph.ca

Bob Reeves
Root Rescue Environmental Ltd., Waterdown, Ontario, Canada

Alec Downey
ICT International Pty. Ltd., Armidale, NSW, Australia

**Conventional irrigation practices are based on physical factors and observations, however this fails to include plant water status measurements. This study examined the relationship between cumulative water potential with concurrent cumulative vapour pressure deficit (VPD) for the common nursery species *Thuja occidentalis* 'Smaragd' (emerald pyramidal cedar). Establishing the relationship for these plant-environment interactions will provide nursery growers with a rational irrigation scheduling tool that indicates a more effective and efficient use of scarce water resources. Plant water status and environmental conditions were monitored throughout a growing season taking measurements every 15 min between irrigation events. The overall relationship between cumulative water potential and cumulative VPD exhibited a slope response of -2.2 MPa·h/kPa·h. This coefficient provides growers with an objective tool for irrigation management for this species and leads the way to exploit this approach across the spectrum of nursery commodities.**

## INTRODUCTION

Irrigation scheduling is the balance between frequency and amount of water applied to a crop and is a fundamental concept in irrigation management (Linacre and Till, 1969). Nursery growers tend to base their scheduling on factors such as observed leaf wilt, soil dryness, and general weather forecasts. These decisions are largely subjective and can lead to inefficient or ineffective use of water resources, namely over-irrigation or under-irrigation. Ultimately, poor irrigation scheduling can reduce plant growth and directly affect product quality (Wilson et al., 1998).

Several techniques have been developed to assist nursery growers in determining the most appropriate time to irrigate; these techniques are described by Howell et al. (2007) and Jones (2004). A common procedure used for irrigation scheduling is the pan evaporation method. This technique measures the evaporation rate of an open water surface as a surrogate measure of evapotranspiration or the total water lost by the plant system. The method is a baseline attempt to integrate conventional environmental variables such as solar radiation, vapour pressure, and precipitation that influence the overall water status of the crop. It is due to the simplicity and economy of the pan evaporation technique and the robust relationship with plant water use (Eliades et al., 1988) that it is widely used. Eliades et al. (1988) and Ertek et al. (2006) have both demonstrated effective irrigation scheduling for cucumber production based on pan evaporation measurements. Although quality in irrigation scheduling is improved by using pan evaporation measurements in comparison to irrigation by observation (Howell et al., 2007), the method does not quantify the *actual* plant water status responses between irrigation events. To assess plant water status under any water management strategy, measurements of plant water potential (status) are required.

The study of water relations has developed numerous techniques to measure plant water potential, which is essentially an integrated response to all environmental variables influencing the plant. The temperature corrected stem psychrometer (Dixon and Tyree, 1984) has emerged as the most field applicable and temporally responsive method for monitoring plant water status. Further, the method is non-destructive and, with current advancements (ICT International Pty. Ltd., Armidale, NSW, Australia), plant water status of representative plants in the field can be remotely monitored. Studies conducted by Edwards and Dixon (1995), Offenthaler et al. (2001), and Stöhr and Lösch (2004) have demonstrated the effectiveness of the stem psychrometer as a plant water status monitoring tool.

Water stress is a cumulative process that impacts a plant's overall performance between irrigation events. Quantifying the cumulative plant water status between irrigation events can lead to a deeper understanding of plant-water requirements. Smart and Barrs (1973) established that between 74-96% of diurnal variation of water potential can be explained by temperature, radiation, and vapour pressure deficit (VPD). Combining modern instrumentation to collect water potential data and concurrent measurement of standard environmental variables (e.g., temperature, relative humidity, light, etc.) can lead to improved irrigation practices, particularly if the relationship between vapour pressure deficit and plant water potential can be resolved at the whole plant level.

The relationship between cumulative water potential and environmental demand (i.e., VPD) for a common nursery species was used to develop a modified (relative to current nursery irrigation scheduling) irrigation schedule. A detailed assessment of the modified schedule was conducted to analyze and correlate cumulative water status with environmental demand (i.e., VPD) with the objective of predicting plant water status from VPD, an easily calculated environmental variable.

## MATERIALS AND METHODS

The presented study was conducted over two consecutive growing seasons (summers 2013 and 2014) and consisted of two distinct phases: (1) assessment of nursery tree water status under conventional irrigation management (season one), and (2) assessment of nursery tree water status under modified irrigation schedules designed to reduce water use (season two). Although the overall study involved two phases, only the modified irrigation scheduling results from season two are presented herein. However to summarize the first phase, baseline water status responses were collected, analyzed, and fully characterized to develop a modified irrigation strategy which was applied the following year. In the second phase, water status responses were monitored under the modified irrigation strategy and was correlated with concurrent environmental measurements of VPD to determine the relationship between these variables.

### Site Description

The study was conducted at a tree nursery located in Waterdown, Ontario, Canada (N 43° 21'24.231", W 79°54'34.568"). *Thuja occidentalis* 'Smaragd' (emerald pyramidal cedar) was selected as a representative ornamental evergreen. Each tree was grown in a pot-in-pot production system with manually scheduled/triggered drip irrigation. The trees were evaluated on the basis of the modified irrigation protocols developed from data collected in phase one (data not shown). The trees were grown in 38 L (10 gal.) pots using a potting media comprised of: peat moss (PM), composted pine bark (CPB), and leaf and yard waste compost (WC) Gro-Bark (Milton, Ontario, Canada).

### Irrigation Management

Trees were irrigated using a drip irrigation system. Drippers were calibrated gravimetrically to ensure homogeneous distribution of water during irrigation events. The average output of a dripper head was 0.19±0.01 L/min. Irrigation events were 30 min in duration, which provided a sufficient volume of water to generate a small amount of run-off, ensuring near field capacity in the pots.

Watering events were defined as either a rain event or irrigation. The modified irrigation scheduling (described below) was imposed as part of the experimental protocol, a threshold of 10 mm or more of rain was deemed equivalent to a normal irrigation event.

**Assessing Modified Irrigation Protocols — 2014 Field Season**
Trees were arranged linearly with 30 trees, however only 21 trees were randomly selected for experimentation due to limited instrumentation. Edge effects were controlled by two additional buffer rows surrounding the row of trees. There were three irrigation treatments with seven randomly selected trees ($n$=7) in each treatment level. Previous field trials with this species (Dixon et al., 2015) had identified the range of water potentials expected under conditions designed to induce severe water stress. The first phase of the present study found that the trees never approached the levels of water stress they had exhibited (and tolerated) in that study. Therefore the routine practice of the nursery was subjectively labeled as the mild stress treatment (control). Treatments were determined as multiples of the average cumulative water potential integrals previously measured under conventional nursery practices. These were identified as: mild (1$x$), moderate (2$x$), and high (3$x$) levels of water stress. For the purposes of this report only mild and moderate stress levels will be examined.

**Water Potential Measurements**
Water potential responses were measured every 15 min using a PSY1 Stem Psychrometer sensor package from ICT International Pty. Ltd. (Armidale, NSW, Australia). The assembly and installation process is demonstrated in detail at: <http://www.ces.uoguelph.ca/psychrometer_media.shtml>.

**Cumulative Water Potential Threshold Determination**
Cumulative water potential integrals were the sums of average water potential measurements (MPa) by time (hours) accumulated during daylight hours between watering events. Each stress threshold treatment was derived as a multiple of the water stress values from the conventional irrigation protocol study in phase one. Accumulated water potential integral between irrigation events was approximately -50 MPa·h in the first phase. Based on these stress ranges, three different thresholds were selected between the lowest and highest cumulative water potential integral to cover: mild (-50 MPa·h) and moderate (-100 MPa·h) levels of water stress conditions. For each threshold, after a watering event, the cumulative threshold was reset to zero to indicate adequate soil moisture and the process was repeated throughout the season.

**Meteorological Measurements**
Meteorological data was collected using a Vantage Pro 2 wireless weather station (Davis Instruments Corp., California, USA). Measurements were collected every 15 min. which provided the same measurement frequency as stem water potentials. The main environmental variables that were monitored consisted of: solar radiation (W/m$^2$), air temperature (°C), wind speed (km/h), precipitation (mm), and relative humidity (%). Using these variables, VPD was calculated by vapour pressure equations found in Allen et al. (1998). Cumulative VPD integrals were then accumulated during daylight hours between watering events when solar radiation values (W/m$^2$) were greater than zero. These were correlated and analyzed with the cumulative water potential integrals.

**Statistical Analysis**
Statistical analyses were conducted with SAS 9.4 (SAS Institute Inc., Cary, North Carolina, USA) on water potential measurements. All treatments were compared using a repeated measures test following the mixed model procedure (PROCMIXED) to indicate significant differences between water stress treatments.

## RESULTS

### *Thuja occidentalis* Water Status

Figure 1 illustrates a sample of stem water potential data exhibiting mild and moderate stress treatments. Throughout this period, water stress levels for each treatment exhibited a distinct separation that persisted until a significant watering event occurred to rehydrate the trees in both treatments. Separation of treatment levels was based on stress thresholds that were assigned to each treatment. Under the moderate stress treatment, the trees temporarily exceeded the approximate threshold for stomatal closure of -2.0 MPa reported by Dixon et al. (1984). At that threshold, stomata begin to close in response to the experienced water stress in an attempt to decrease transpiration rates. This isohydric response is a mechanism used by plants to conserve internal water supplies and prevent water stress.

### *Thuja occidentalis* Cumulative Water Stress and VPD

In Figure 2, the relationship between VPD and water potential integrals exhibited a slope response of -2.2 MPa·h/kPa·h with a strong coefficient of correlation ($r^2$=0.83). A relationship with this degree of reliability implies that growers can simply accumulate environmental vapour pressure measurements and trigger irrigation at an appropriate corresponding level of plant water status as predicted by this relationship. Additional field trials will be used to confirm this relationship that will include multiple nursery species, which will allow for the development of a catalogue of water status responses based on environmental conditions.

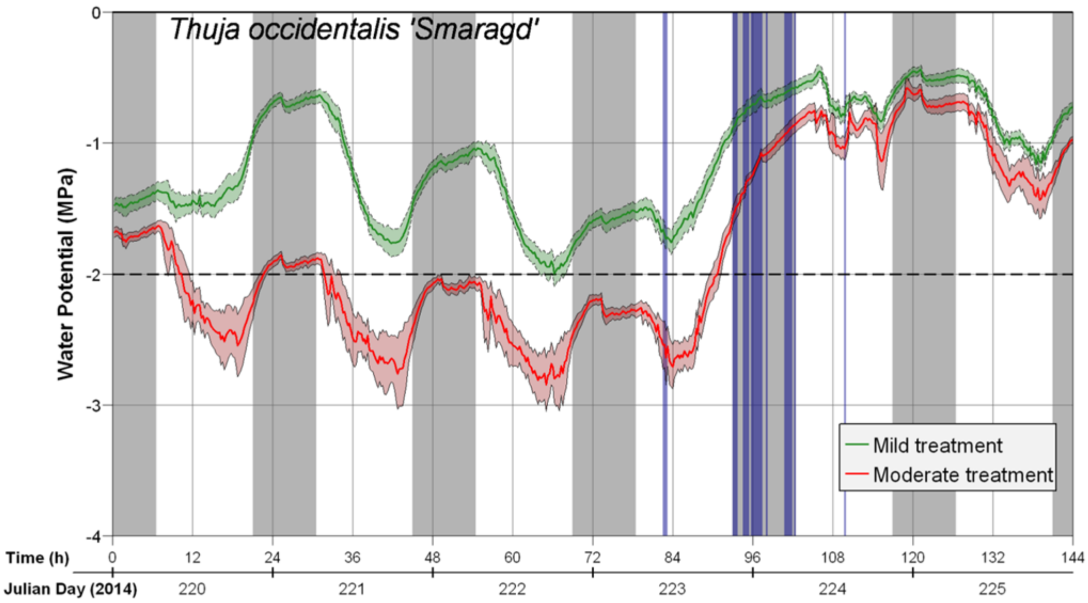


Fig. 1. A 6-day diurnal time course of water potential (MPa) measurements for *Thuja occidentalis* ‘Smaragd’ that illustrates water stress treatments: mild (upper line) and moderate (lower line). Lines follow a local regression smoothing algorithm (loess) for the data collected at 15 min intervals for each stress treatment. Transparent bands surrounding the water potential measurements are error bars of ± SEM. Grey shaded vertical bars indicate sunset to sunrise periods and blue vertical bars indicate a watering event. The dashed lines at -2 MPa represents the threshold of stomatal closure observed by Dixon and Tyree (1984). Using repeated measures integrated analysis, mild treatment and moderate treatments were significantly different with a P<0.01.

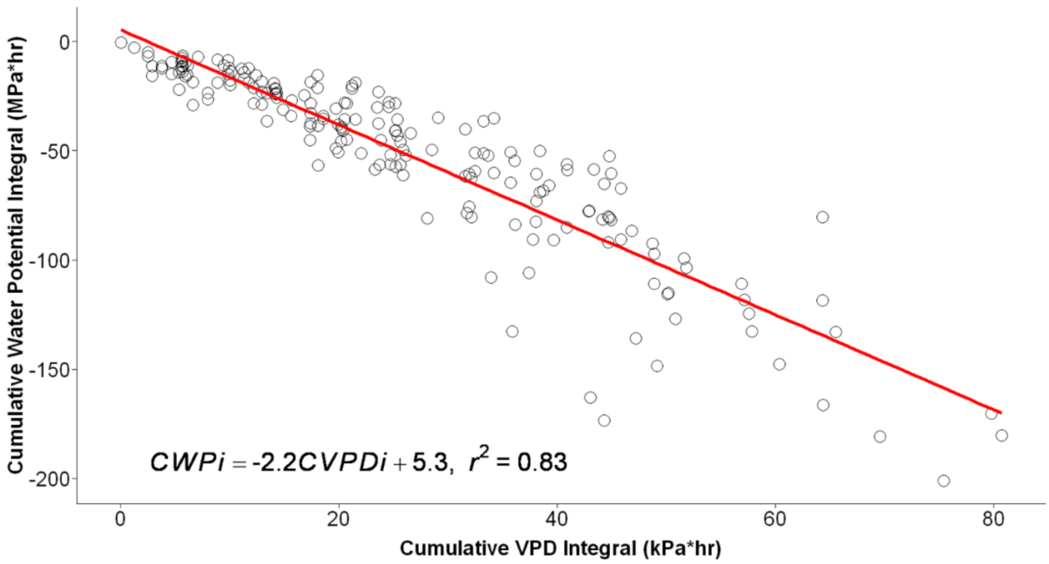


Fig. 2. Relationship between cumulative vapour pressure deficit integrals (CVPDi) vs cumulative water potential integrals (CWPi) between watering events from sunrise to sunset for *Thuja occidentalis* 'Smaragd'. Data shown contains mild and moderate treatments during the experimental period. The red line represents a fitted regression line that illustrates a slope response of -2.2 MPa·h/kPa·h with a strong $r^2$ of 0.83.

## CONCLUSION

The ultimate goal of this study was to develop and demonstrate a rational approach to irrigation management that is less subjective and more efficient than conventional methods. An irrigation management strategy that requires nothing more than a conventional weather station will provide nursery growers with a tool to indicate the exact time to initiate an irrigation event based on predicted plant water requirements.

This research represents the penultimate step towards developing an irrigation-scheduling tool that will use standard meteorological measurements to accurately predict plant water status in the field. This in turn can be used to trigger irrigation events based on actual plant needs rather than making often subjective assumptions of plant needs. The presented data clearly established the reliability of the relationship between plant water potential and VPD for this species. This relationship will now be used to form irrigation schedules based solely on calculated VPDs, with plant water potential measurements used to validate the efficacy of the scheduling in ongoing research in this field.


## ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank ICT International Pty. Ltd for their kind contributions of instrumentation and technical support. Connon Nurseries C.B. Vanderkruk Holdings Ltd. for providing all plant material, irrigation supplies, and personnel support in the field. As well as Root Rescue Environmental Ltd. for contributing and supporting all of our field operations.


## Literature Cited


Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. 1998. Crop evapotranspiration — guidelines for computing crop water requirements. Food and Agriculture Organization of the United Nations Irrigation and Drainage Paper No. 56, Rome.

DaCosta, M. and Huang, B. 2006. Deficit irrigation effects on water use characteristics of bentgrass species. Crop Sci. 46:1779-1786.

Deroo, H.C. 1969. Leaf water potentials of sorghum and corn, estimated with pressure

bomb. Agron. J. 61(6):969-970.
Dixon, M.A. and Tyree, M.T. 1984. A new stem hygrometer, corrected for temperature gradients and calibrated against the pressure bomb. Plant, Cell and Environ. 7:693-697.
Dixon, M.A., Grace, J. and Tyree, M.T. 1984. Concurrent measurements of stem density, leaf and stem water potential, stomatal conductance and cavitation on a sapling of *Thuja occidentalis* L. Plant, Cell and Environ. 7:615-518.
Edwards, D.R. and Dixon, M.A. 1995. Mechanisms of drought response in *Thuja occidentalis* L. I. Water stress conditioning and osmotic adjustment. Tree Physiol. 15:121-127.
Eliades, G. 1988. Irrigation of greenhouse-grown cucumbers. J. Hort. Sci. 63(2):235-239.
Ertek, A., Sensoy, S., Gedik, I. and Kucukyumuk, C. 2006. Irrigation Scheduling based on pan evaporation values for cucumber (*Cucumis sativus* L.) grown under field conditions. Agric. Water Manage. 81:159-172.
Howell, T.A. and Meron, M. 2007. 3. Irrigation scheduling. Developments Agric. Engineer. 13:61-130.
Jones, H.G. 2004. Irrigation scheduling: advantages and pitfalls of plant-based methods. J. Exp. Bot. 55(407):2427-2436.
Kramer, P.J. and Boyer, J.S. 1995. Water relations of plants and soils. Academic Press, California, San Diego.
Linacre, E.T. and Till, M.R. 1969. Irrigation Timing and Amounts. The Australian Institute of Agricultural Science, Australia p.175-196.
Meron M., Grimes D., Phene C., Davis K. 1987. Pressure chamber procedures for leaf water potential measurements of cotton. Irrigation Sci. 8(3):215-222.
Offenthaler, I., Hietz, P. and Richter, H. 2001. Wood diameter indicates diurnal and long-term patterns of xylem water potential in norway spruce. Trees 15(4):215-221.
Oktem, A., Simsek, M. and Oktem, A.G. 2003. Deficit irrigation effects on sweet corn (*Zea mays saccharata* Sturt) with drip irrigation system in a semi-arid region I. Water-yield relationship. Agric. Water Manage. 61:63-74.
Scholander, P.F., Hammel, H.T., Bradstreet, E.D. and Hemmingsen, E.A. 1965. Sap pressure in vascular plants – Negative hydrostatic pressure can be measured in plants. Science 148(3668):339-346.
Simonne, E., Ouakrim, N. and Caylor, A. 2002. Evaluation of an irrigation scheduling model for drip-irrigated potato in southeastern United States. Hortsci. 37(1):104-104.
Smart, R.E. and Barrs, H.D. 1973. The effect of environment and irrigation interval on leaf water potential of four horticultural species. Agric. Meteorol. 12:337-346.
Stöhr, A. and Lösch, R. 2004. Xylem sap flow and drought stress of *Fraxinus excelsior* saplings. Tree Physiolo. 24:169-180.
Wilson, D.R., Stone, P.J. and Gillespie, R.N. 1998. Drought effects on water use, growth and yield of sweet corn. Proceedings of the 9th Australian Agronomy Conference, 20-23, Australia: 1-7.