

## Recent developments and strategies in the use of plant indicators for irrigation scheduling

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### Summary

Plants experience water stress when the internal deficit in plant tissues reaches a critical level affecting various physiological processes including growth. Plant indicators of water stress and allied measurements have traditionally been developed and used to detect water stress, diagnose water availability and interpret plant growth. Systems used for physiological measurements of water stress in plants are generally less flexible than soil and /or atmospheric measurement systems for the diagnosis of water availability and irrigation scheduling. This paper compares various direct and indirect measurements of water stress in plants and identifies the technological opportunities for improving irrigation scheduling using indicators of plant stress. Key features of the commonly used plant indicators are discussed along with strategies for integration with existing scheduling tools to improve irrigation effectiveness.

### Background

Irrigation scheduling involves determining both the timing of irrigation and the quantity (volume) of water to apply. Plant stress responses provide the most direct measure of identifying the plant demand for water. However, it should be noted that while plant stress indicators provide a direct measure of when water is required, they do not provide a direct volumetric measure of the volume of water required to be applied.

Terrestrial plants have evolved with the mechanisms to absorb water and nutrients from soil and capture energy and carbon via atmosphere to synthesize organic compounds which helps plant to grow, develop and produce. Loss of plant water by transpiration is required for photosynthesis and a minimum requirement of irrigation should be to replenish this internal plant water deficit. However, irrigation is applied to the root zone of plants and an additional irrigation application volume is normally necessary to replace evaporation loss and flush salts from the root zone. Hence, for plants growing in soil, irrigation scheduling involves replenishing both the evapo-transpiration losses and the root zone salt leaching requirement. As plants grow, their transpiration capacity and size of root zone expands along with the demand for water.

When internal demand for water in plants is high and supply is limited, water uptake by roots is reduced causing plants to experience water stress. An indication of water stress in plants is the closure of stomata in most leaves and close to zero transpiration rate. Many plants experience temporary water stress during summer and in the early afternoon without serious adverse impact on growth or productivity as they rehydrate during night. However, prolonged

and/or recurring water stress is the main cause of decline in growth and productivity of plants.

### Plant indicators of water stress

A selected list of direct and indirect plant indicators of water stress is shown in Table 1. How well an indicator responds to accumulated water deficit in soil and/or atmosphere is shown as sensitivity in Table 1. The classical physiological measurements of leaf water potential (with a pressure chamber on detached leaves) and stomatal conductance (with a diffusive porometer or chamber methods for intact leaves) are only moderately sensitive even if these are based on theoretically sound approaches and have good precision. This is because plants can control leaf water potential of a single leaf or even the entire canopy at a wide range of atmospheric evaporativity (Jones, 2004). Similarly, stomatal conductance can become stable when the plants are able to adapt to water deficits (Morigana and Fereres, 2002). It would appear that leaf water potential measured for fully rehydrated (pre-dawn measurement) or fully dehydrated (solar noon) leaves might be a better indicator of the seasonal water stress. However, lack of sensitivity of some of these measures with soil moisture and high labour costs have restricted their widespread use for commercial irrigation scheduling. Stem water potential measured on detached, bagged and equilibrated leaves has emerged as a more robust indicator of plant water status (Chone *et al.*, 2001) because it is an integrator of the whole plant transpiration, soil water availability, soil hydraulic conductivity and plant capacity to transport water from the soil to the atmosphere (Chone *et al.*, 2000; Chone *et al.*, 2001). However, it suffers from the same limitation as leaf water potential in its applicability to commercial irrigation scheduling.

**Table 1. Relative sensitivity, cost and commercial application potential of selected plant indicators of water stress for irrigation scheduling.**

Indicators	Sensitivity	Capital cost	Commercial application
<b>Direct indicators</b>			
Leaf water potential	Moderate	Low	Poor
Stomatal conductance	Moderate	High	Poor
Stem water potential	High	Low	Poor
Sap flow	High	Moderate	Good
<b>Indirect indicators</b>			
Canopy temperature	Moderate	Low	Good
Thermal imaging	High	High	Good
Fruit/stem diameter	High	Low	Good

Continuous measurement of sap flow rates in plant stems can be a good indicator of water deficit in plants as sap flow can be quite sensitive to stomatal conductance, transpiration and atmospheric demand (Misra and Sands, 1992). It is also feasible to design irrigation scheduling schemes using controlled threshold values of sap flow rates to detect onset of water stress for specific crops, such as grapevines (Ginestar *et al.*, 1998a,1998b; Lu *et al.*, 2003; Patakas *et al.*, 2004; Fuentes *et al.*, 2004), olives ( Giorio and Giorio, 2003).

Over decades of irrigation research, a number of stress indices have been proposed for irrigation scheduling based on indirect measures of water stress, such as canopy temperature (Table 1). Infrared thermometry and thermography are based on the fact that variations in temperature within a typical canopy, as conductance changes, would be expected to increase approaching stomatal closure (Fuchs, 1990). Canopy temperature can be measured quite rapidly with non-contact, infrared sensors which allow calculation of an index (e.g. crop

water stress index, Idso *et al.*, 1981) using reference temperature of a non water stressed and a non-transpiring leaf. Such indices appear to perform better in arid and semiarid areas than humid areas. In order to expand its potential application, Jones *et al.* (2002) recommends substitution of the reference temperatures with more suitable reference leaf temperatures and using infrared thermography rather than thermometry because the latter is limited to an average temperature of a single target area that could inadvertently include soil, trunk or sky in the sensed area, with consequent errors in the estimated canopy temperature (Moran *et al.*, 1994). Such subtle, yet important changes have shown that thermal imaging of crop canopies with infrared cameras is a promising and practical tool (Jones *et al.*, 2002; Fuentes *et al.*, 2004).

Growth rate measurements of either the whole or part of the plant are considered to be very sensitive indicators of water stress, although measurements can be difficult and interpretation needs experience. With the recent advance in linear variable displacement transducers, it is possible to measure growth rates of stems and fruits from diameter measurements (Moriana and Fereres, 2002). Such measurements is expected to help develop control systems for irrigation using critical values of growth rates for well irrigated and water stressed plants.

### Discussion and conclusions

Most of the plant indicators of water stress reviewed here have reasonable ability to indicate timing of irrigation provided these are calibrated for the site, crop, climate and irrigation system. It is possible to achieve high measurement precision for each of the indicators, but sensitivity to water stress is highly dependent on the crop and operating conditions. Similarly, the potential application of the various indicators for commercial irrigation is a function of sensor portability, potential for automation and the skills required for operation and interpretation. Relative advantages and disadvantages of these indicators are not explicitly addressed as such comparisons must include the ease of use as well as cost (time and labour) and training requirement.

Indirect plant indicators appear to be the most promising tools due to their potential for integration with existing soil-water and atmospheric measurement systems used for irrigation scheduling. Non-contact sensing systems developed recently by integrating machine vision of growth, infrared thermometry and soil-water measurements (Kacira and Ling, 2001) and arrays of infrared thermometers with centre pivot irrigation systems appear to hold great promise for future developments of automated irrigation scheduling (Sadler *et al.*, 2002).

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