Scheduling Considerations for Automated Irrigation in the 1990s

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Summary. This work focuses on recent developments and examples of irrigation scheduling that concern *where* in the root system and *when* in the plant's phenology water should be applied. Information is provided on using and measuring soil variability to help schedule irrigation. An irrigation model is described that emphasizes the soil water-holding capacity and root distribution in designing irrigation systems and scheduling water application. Recent research is reviewed on the subject of fruit crops that can tolerate severe water stress during specific growth periods of the fruit. Finally, a method of using infrared thermometers and canopy temperature data in cloudy, humid regions is presented that has the potential to extend the use of this technology.

The amount of information gathered and used to decide when, where, and how much water to apply to an irrigated field or a nursery container can be enormous with our current sensor and data-logging technology. In automated irrigation systems, a high level of data processing will be necessary to optimize water application and cost efficiency. The determination of how much water to apply (peak water use) is the subject of intense research (Hoffman et al., 1990) and is critical to the design of irrigation systems and optimization of plant performance. In this overview, however, water requirements will not be addressed. This paper focuses on recent developments and examples in irrigation scheduling that relate to where and when water should be applied.

Soil variability has long been a confounding problem in the uniform application of water to plants. Variability in soil physical characteristics and topography alters the water-holding and infiltration capacity of the soil. These factors determine the amount of plant available water and the depletion time before the next irrigation. Aston and van Bavel (1972) suggested that the inherent variability in soil properties, rainfall, and/or irrigation distribution lead to variability in available water content. As the available water was depleted, increased variability in the crop temperature within an irrigation unit indicated the onset of water stress. Clawson and Blad (1982) incorporated this idea into a study of irrigation scheduling criteria using infrared thermometry as an indicator of water stress in maize. They developed a canopy temperature variability index (CTV) in which the range of canopy temperature (maximum minus minimum) within a plot was compared to a predetermined threshold value of 0.8C. When the threshold value was exceeded, water was applied to the CTV treatments at a rate equal to the weekly amount applied to their adequately watered reference plots. This scheduling criteria reduced water application 45%, with no significant reduction in grain yield (7202 vs. 7575 $kg\cdot ha^{-1}$) relative to the adequatelywatered control. Their work demonstrated the feasibility of using plant response variability to schedule irrigation. This irrigation scheduling approach deserves further consideration for horticultural crops for three reasons: 1) Many horticultural crops are grown in small fields (5 to 10 ha), where CTV measurements can be collected and evaluated rapidly using portable infrared thermometers and data loggers, with a measure ofcertainty that the entire field has been sampled. 2) Non-water stress baselines of canopy minus air temperature vs. air vapor pressure deficit have not been developed for most fruit and vegetable crops. This lack of information precludes the use of the crop water stress index (CWSI) commonly used to schedule irrigation in large-acreage agronomic crops. 3) It is a scheduling criteria requiring minimum capital costs (infrared thermometer only) and the user could alter the threshold value for irrigation based on experience.

Soil variability can be visualized by changes in topography, soil mapping, and plant performance. Plant performance variability, when expressed in large homogeneous units, suggests that the irrigation system itself can be redesigned to accommodate variation in soil water-holding and infiltration capacity. Glenn and Takeda (1989) demonstrated that guttation in strawberry was related to the available water level in the plant. Plants expressing predawn guttation had higher stomatal conductance and a greater transpirational cooling effect at midday than plants not expressing predawn guttation. They scheduled irrigation of individual rows of strawberry based on a) the presence of guttation, or b) an evaporation pan water budget, and compared berry weight and water applied. They found no significant difference in total yield or mean berry weight of June-bearing strawberries, but water application was reduced 20% using the guttation criteria. When the spatial variability and plant available water are accommodated in the design of the irrigation system and subsequent scheduling of irrigation, water application will be reduced, because the potential for overirrigation is minimized.

Irrigation system design must meet the daily maximum water use demand to prevent water stress. To do so, water must be supplied to the root and transpiring leaf system at a rate equal to the environmental demand. The water uptake capacity of a root system is driven by the water potential gradient between the root surface and the substomatal cavity, but limited by the soil and plant hydraulic conductivity and total length of roots in contact with the water films (Taylor and Klepper, 1975). Methods of estimating plant water use are available, and there are a variety of irrigation designs to deliver water to plants. However, there are situations in which the root system x irrigation system interaction limits water-use efficiency. A recent example is a study by Myburgh and Piaget (1990) in which full surface wetting of a mature apple orchard was not supplying sufficient water to the root system, even though the applica-

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tion rate met the environmental demand. In this case study, the microsprinkler system was designed to wet the entire orchard floor. When water was applied for the irrigation interval, insufficient wetting depth of the root zone occurred. Soil sampling also indicated that there were no roots in the inter-row area, even though water was applied there. In light of the lack of roots in the inter-row area and insufficient depth of root-zone wetting, Myburgh and Piaget recommended a strip-wetting microsprinkler design that concentrated the application area beneath the tree and resulted in wetting the complete root zone. Myburgh and Piaget listed many recommendations based on the study; notably, to consider the depth and distribution of the root system and the soil water-holding capacity in designing an irrigation system.

Worthington et al. (1991) developed an irrigation management model that addresses the problems encountered by Myburgh and Piaget (1990). This model requires data on the soil water-holding capacity and the volume of soil wetted by the emitter (surface area x root-zone depth). It calculates the volume of wetted soil needed (number of emitters) to supply the peak water requirement for the irrigation interval without exceeding 50% of available water depletion. In their model, the design emphasis is placed on the ability of the soil to hold and supply the peak water requirement.

Many crops require full-season, nonstressed irrigation to maximize yield (i.e., leafy vegetables, forage crops). Chalmers et al. (1981, 1986) and Mitchell et al. (1982, 1986, 1989) demonstrated that peach and pear can tolerate periods of stress during specific stages of fruit growth with no reduction in yield or size. Water stress during fruit growth stages tolerant to stress reduces shoot growth and potentially can improve the canopy light interception. Such "windows" provide an opportunity to reduce water application with no yield reduction, resulting in greater net return.

Infrared technology is seldom used in humid and subhumid regions due to the variable nature of incoming solar radiation. Canopy temperature or leaf minus air temperature, and the air vapor deficit and net radiation level are interrelated physically (Jackson, 1981). Feldhake and Edwards (1990) proposed a stress-monitoring system that integrates the interaction of canopy temperature (expressed in units of energy), net radiation, and air vapor pressure deficit. This approach is similar to the CWSI of Idso et al. (1981) in that a nontranspiring and a nonstress baseline are empirically determined and the plant stress level is at or between these two baselines. It differs in complexity, requiring a three-dimensional solution (multiple regression) vs. the two-dimensional solution in the CWSI (linear regression) and the simultaneous measurement of net radiation, canopy temperature, and air vapor pressure deficit. The field portable data logging devices currently available can monitor instrumentation easily for these three measurements. Additional research will be required on this technique, but if proven reliable, it will be incorporated easily into automated irrigation scheduling systems since the CWSI already is used in such automated systems in the western United States.

In summary, automated irrigation systems hold the promise of not only reduced labor costs but increased water-use efficiency. The use of automated soil and crop water status sensors, together with accurate water use and water need estimates, will lead to improved water use efficiency. Refining irrigation system design to minimize soil variability will require a reduction in the scheduling unit of each system, but "scaling down" the size of each scheduled unit will minimize overirrigation and the subsequent waste of water and increased potential for nutrient leaching.

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