Water Conserving Irrigation Systems

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Many factors (sprinkler spacing, sprinkler performance, water pressure, wind, and others) combine to determine how efficiently and uniformly water is applied to plants growing in the greenhouse, nursery, or landscape. The myriad factors can be organized into the following categories: Pre-Design Considerations, Design Considerations, Irrigation System Modifiers, and Irrigation System Control. General guidelines have been used in the past to analyze irrigation systems and optimize the distribution of water. However, as energy and water conservation issues begin to play larger roles in the production and maintenance of ornamental plants, irrigation system analyses must become more precise to improve the uniformity of water application and increase the efficient use of available water.

PRE-DESIGN CONSIDERATIONS

Site Dimensions and Water Availability. Whether you are planning to irrigate a defined turf area or a number of plants growing in containers, you need to know the area and the area's shape where water is to be applied. This information will help determine your choices for the type of water emitter (sprinkler, drip). The water supply is also important in terms of quantity (volume) that is available and its pressure. Water quality is very important in that there is little that can be done to improve water once it arrives at your site. Water quality characteristics can be described in terms of electrical conductivity (EC), ion concentrations (Na^{+2}; HCO_3^-, Ca^{+2}, Cl^-), pH, and/or insoluble particulates.

Water Emitter Selection. Overhead sprinklers or some type of drip system may be used to irrigate plants in the greenhouse, nursery, or landscape. Drip (i.e. Chapin spaghetti) systems are used extensively to irrigate greenhouse crops, while in the outdoor nursery overhead sprinklers are used for can-tight crops and drip systems are reserved for larger spaced crops. Manufacturers of irrigation equipment can help growers decide on the type and placement of emitters for a particular area. Irrigation system design recommendations (spacing arrangement and distances) based on tests of sprinkler heads (emitters) placed at ground level to determine distribution patterns are generally available. In a nursery, sprinkler heads will typically be placed some height above the ground to avoid interference from the developing crop canopy. Raising the sprinkler head 40 in. above the ground can lead to interesting and significant changes in its distribution pattern. The difference in the distribution patterns of the same sprinkler at the same pressure at two heights, ground level and 40 in. above the ground, are shown in Figure 1. While it is interesting to note that the distribution patterns are different at the two heights, the important point is that the optimum spacing for the sprinkler head at the two heights is different.

Crop Requirements. Work at Davis and around California has shown that container-grown crops have differing requirements for water. Plants can be grouped into heavy, moderate, or light water user groups (Burger et al., 1987).

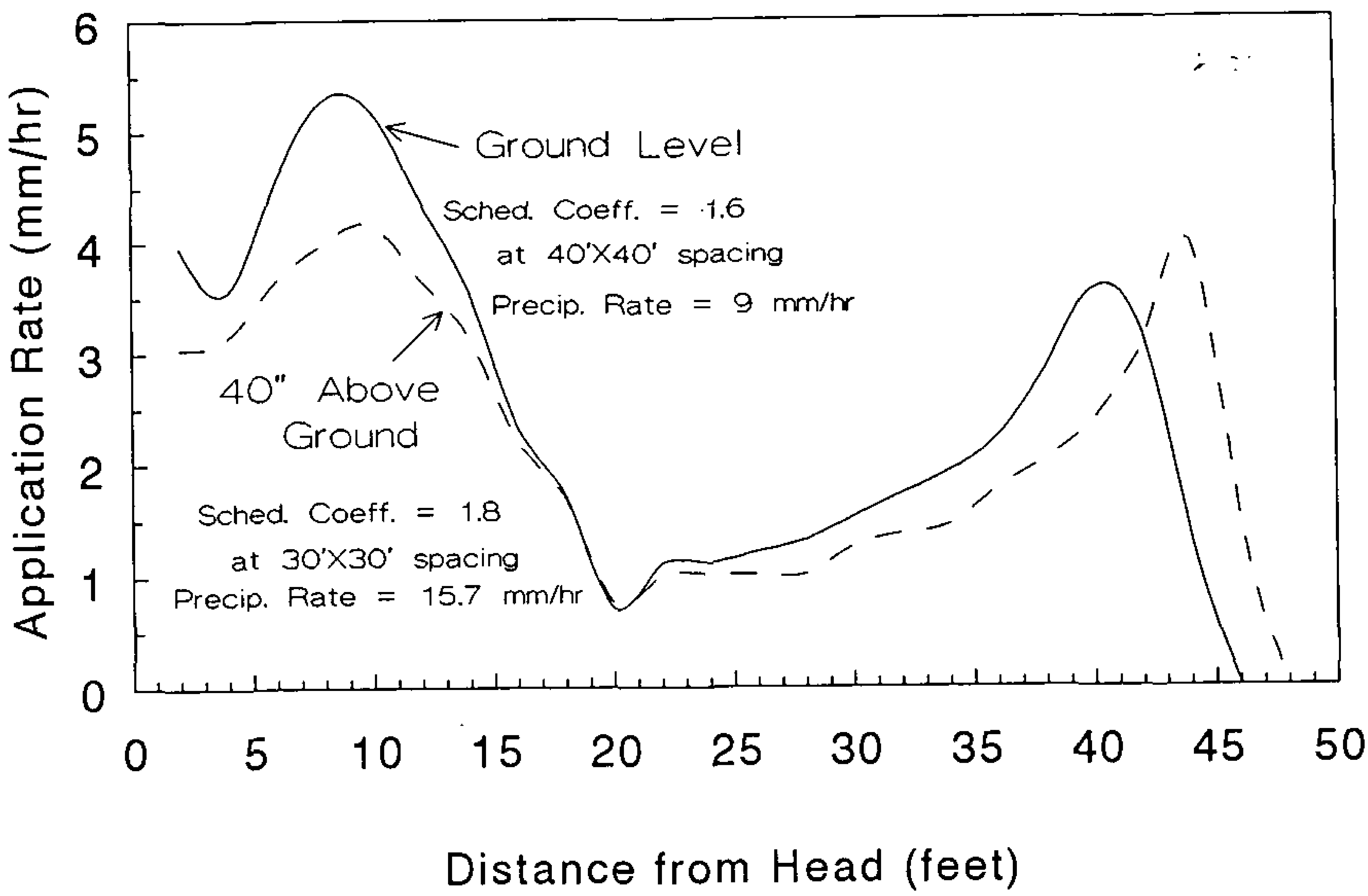

Figure 1. Distribution patterns of a sprinkler at two different heights (ground level and 40 in. above the ground).

Because the differences among species is relatively great in their respective requirements for water, it makes sense to locate those species having similar water requirements together and irrigate them similarly if not simultaneously.

The same plants growing in different climates will have different water requirements (Burger et al., 1987). Research done at Davis, Watsonville, the South Coast Field Station (Irvine), and San Bernardino, California indicates that by using ET_0 (reference evapotranspiration) as a basis, crop coefficients can be calculated that remain relatively constant among different environments.

A particular water requirement for a given plant can change as the plant develops. As the leaf surface area and root length density increases, the amount of water required to maintain the highest growth rate and quality also increases. Therefore, one needs to routinely monitor the water requirement of a developing crop.

Container Spacing. As container-grown plants grow, they are spaced farther apart to provide room for canopy development. The spacing of containers leads to increased solar radiation and increased temperature loads on the containers, thus increasing water use (transpiration) and loss (evaporation) (see Fig. 2). Even when containers are arranged "can-tight", all of the ground is not covered by the containers. One-gallon containers arranged "can-tight" cover only 79% of the surface, meaning 21% is left uncovered. Because the plants are arranged in beds, there are differences in the exposure of plants to sunlight and temperature between those plants in the interior and those on the borders.

DESIGN CONSIDERATIONS

Pressure Loss. The most important factor contributing to the uniform application of water is pressure. The quantity of water delivered by a sprinkler head (gallons

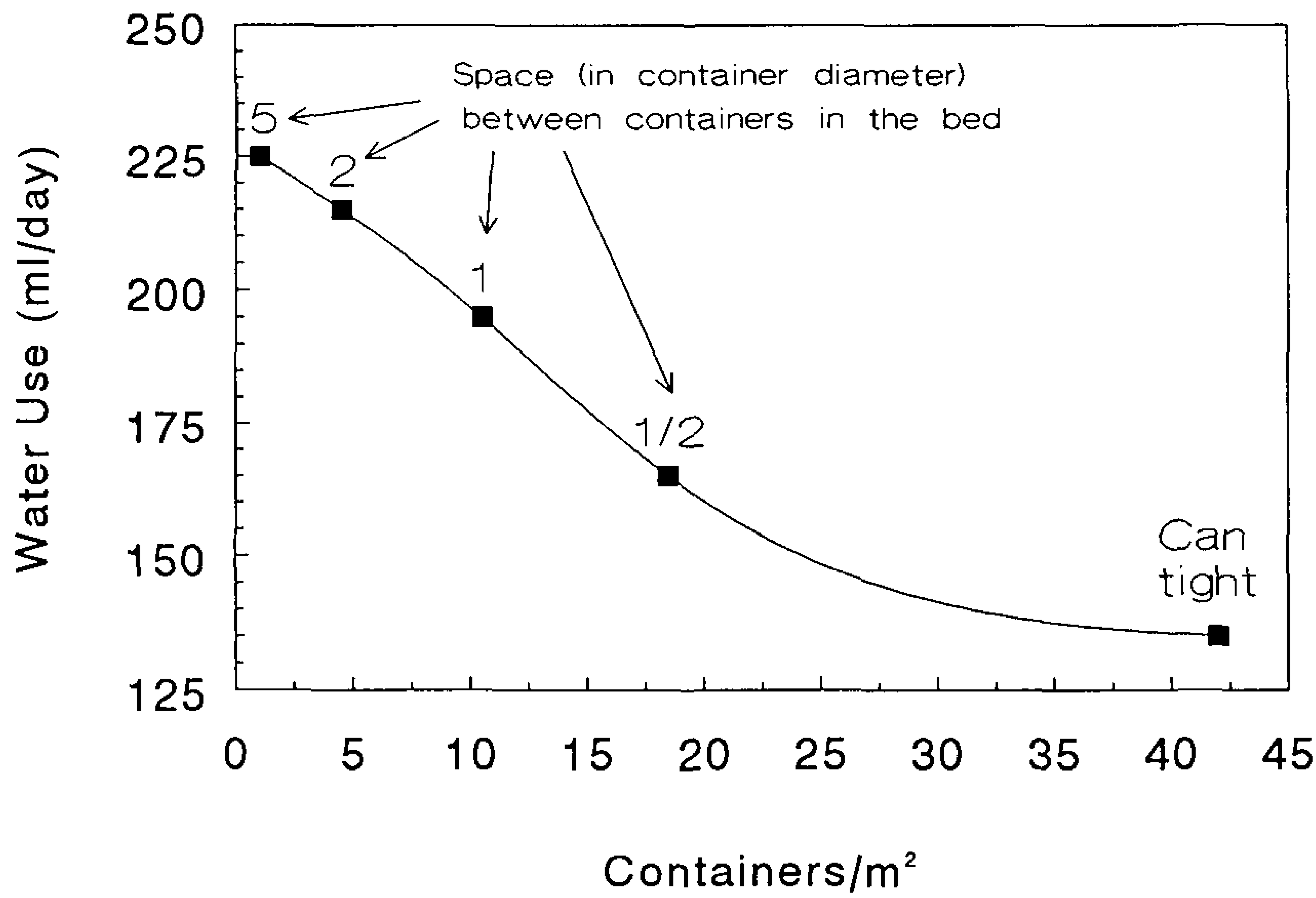

Figure 2. Water use (loss) characteristics of plants growing at different spacings.

per minute, GPM) is calculated using the following equation:

$$GPM = \sqrt{P \times D^2 \times C \times 29.82}$$

where P = pressure in pounds per square inch, D = orifice diameter of the sprinkler, in inches, C = coefficient of discharge for that sprinkler, and 29.82 is a constant. Variables D and C and the quantity 29.82 are all constant for any given sprinkler head; therefore, GPM is proportional to the square root of pressure. So, while the design of irrigation systems seems to be focused on the movement and control of water, a more important consideration is the control of pressure.

Uniformity of Water Application. The goal of any irrigation system is to apply exactly the same amount of water to every square inch or to every container. The degree of uniformity that is achieved by an irrigation system is usually expressed as the Coefficient of Uniformity (CU). The CU is determined by laying out a grid of cans (for example, every 5 ft in a square pattern) on the area being irrigated by a single system. The irrigation system is operated for a known period of time after which the accumulated water in each can (catchment data) is measured (volume in ml or cc). If the top surface area of the can is known, the application rate (in./h, mm/h) can be determined. The catchment data is used to calculate the average quantity of water per can. The CU is then calculated by the following equation:

$$CU = 100 \left(1.0 - \frac{\Sigma |\bar{x} - x_i|}{\bar{x} n} \right)$$

where $|x - x_i|$ = sum of the deviations of each observation (x_i) from the mean ($\bar{x}$-) of the observations and n = the number of observations. The CU has a maximum possible value of 100 which would indicate a perfectly uniform application of water. A CU less than 80 indicates a poorly designed irrigation system.

Application Rate. Catchment data can be used to determine application (precipitation) rates. The application rate is the average rate at which water is being applied to the area covered by the sprinkler layout. The application rate should be known for all irrigation systems. For drip or spaghetti systems the application rate can be measured by catching water from the system over a known period of time.

Scheduling Coefficient. The scheduling coefficient is another measure of uniformity. It is the ratio between the average precipitation rate (application rate) and the lowest precipitation rate in the sprinkler layout. Catchment data from can tests are used to calculate this value. The scheduling coefficient has a value equal to or greater than 1.0 and can be thought of as a multiplier to determine sprinkler system timing. For example, if the average application rate for a system was 12 mm/hr and the driest area had an application rate of 7 mm/hr, the scheduling coefficient would equal 12/7≈ 1.7. This means that if a group of plants required 9 mm of water per day, this irrigation system would have to be operated for 1.3 hours per day (1 h/12 mm x 9 mm/day x 1.7) to insure that all plants received an adequate supply of water. A scheduling coefficient closer to 1.0 indicates a more uniform irrigation system.

IRRIGATION SYSTEM MODIFIERS

Wind. The direction and velocity of wind in the area under sprinkler irrigation can drastically affect the uniformity of water distribution. To date, there is no one satisfactory answer to this problem; however, the problem can be minimized by operating sprinkler systems at recommended pressures and sprinkler head spacings.

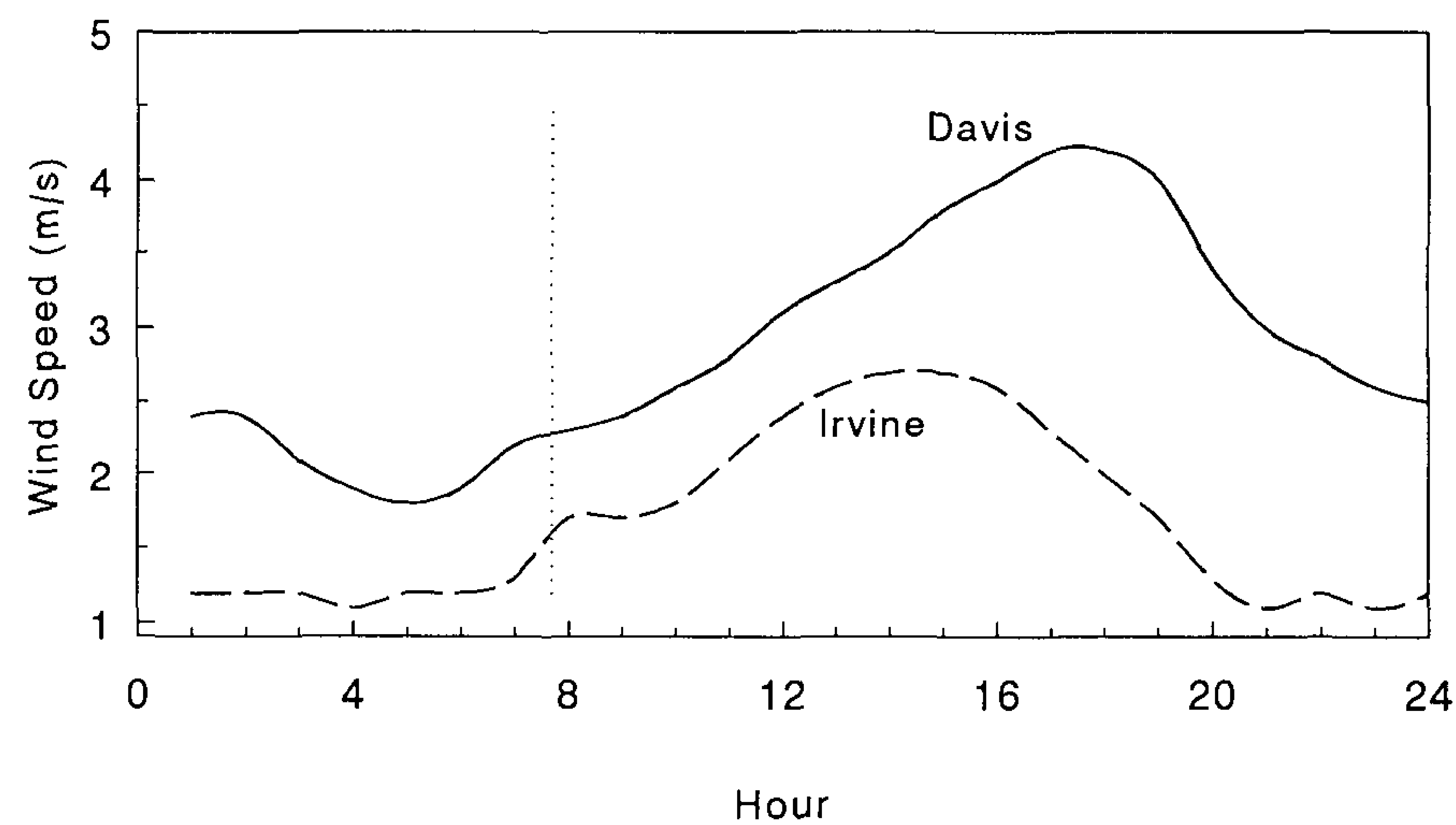

Figure 3. Average hourly wind speed from June 1-30, 1992 for Davis and Irvine, CA.

The best an irrigation manager can do to minimize the effect of wind on the irrigation system is to schedule irrigations during the time of the day when the wind speed is lowest. At Davis and Irvine, CA, the wind speed is lowest before 8:00 A.M.. (Fig. 3).

Crop Canopy. The morphological characteristics of the crop(s) under sprinkler irrigation can lead to the funneling of water toward the container (funnel effect) or deflection of water away from the container (umbrella effect). These two modifiers can have beneficial or adverse consequences depending upon the crop in question and the uniformity characteristics of the irrigation system.

Shade Cloth. Plants growing under shade cloth present problems for sprinkler irrigation. If the sprinklers are placed under the shade, the supporting structure interferes with the application of water. If the sprinklers are placed above the shade to avoid the supports, water distribution patterns will likely be changed.

IRRIGATION SYSTEM CONTROL

"Look and Feel". With experience, one can determine when to irrigate based on how the crop looks and how the soil feels (dry or not). This is probably the best way of determining when to irrigate; however, it is extremely time consuming and labor intensive and certainly not the choice for large-scale production.

Time. Most irrigation is done based on time regardless of the particular crop's need for water. This is easily done with the use of timers controlling irrigation valves. Observant irrigation managers periodically change irrigation timing to reflect

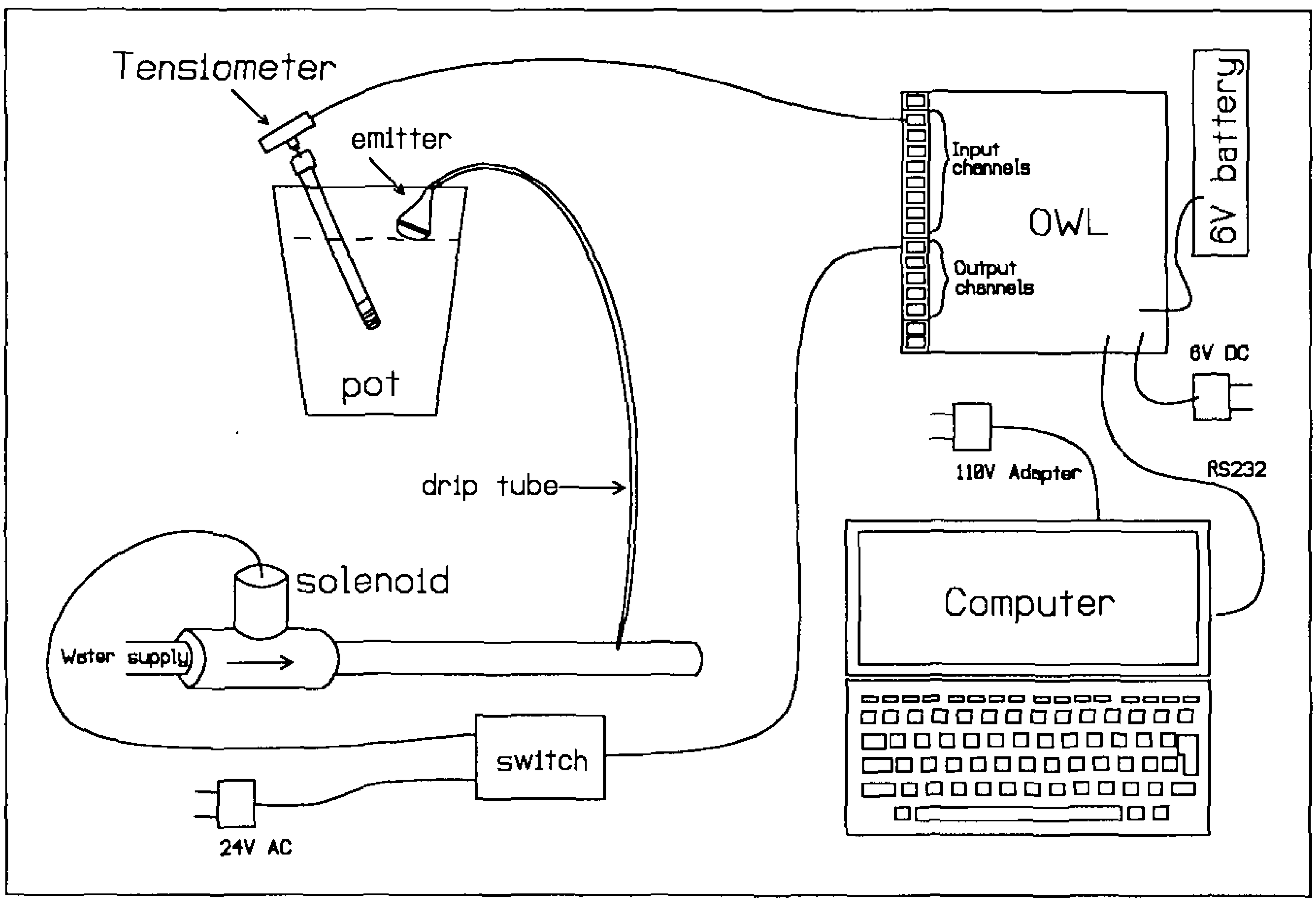

Figure 4. Schematic diagram of UCD-EH, computer-controlled irrigation system driven by a soil moisture sensor (tensiometer).

changes in climate or season. Success with this technique can be largely attributed to the fact that container media are porous allowing overwatering without adverse accumulation of water in the container.

Soil Moisture Sensors. Tensiometers and gypsum blocks that monitor soil moisture characteristics have been used to determine irrigation scheduling. Problems including lack of precision and high maintenance have plagued these devices. The recent development of solid-state tensiometers (Burger and Paul, 1986) for the computer control of irrigation systems in greenhouses (Lieth and Burger, 1988; Fig. 4) may provide solutions to some of the problems while leading to increased water use efficiencies and decreased off-site pollution from run-off.

Solar Radiation Sensors. Solar radiation sensors can be used to control the application of water. An example of this is the solar controllers used to control the flow of water to mist nozzles on propagation benches. These sensors can collect solar radiation, convert it into electricity, determine when to activate the valve, and supply the necessary voltage to the valve. One sensor (Jeffery Electronic Control, Australia) that has been studied at UCD has proven to be successful in controlling the mist benches. During the day, as the incident solar radiation increases, the frequency of water application increases while at night the valve is not activated (Fig. 5). Plants have rooted as well or better under this control system and the water usage has been reduced by one-half.

Stem Water Flow Gauges. A device designed to directly measure the flow of water through stems 1-15 cm in diameter has recently been developed (Bake. and

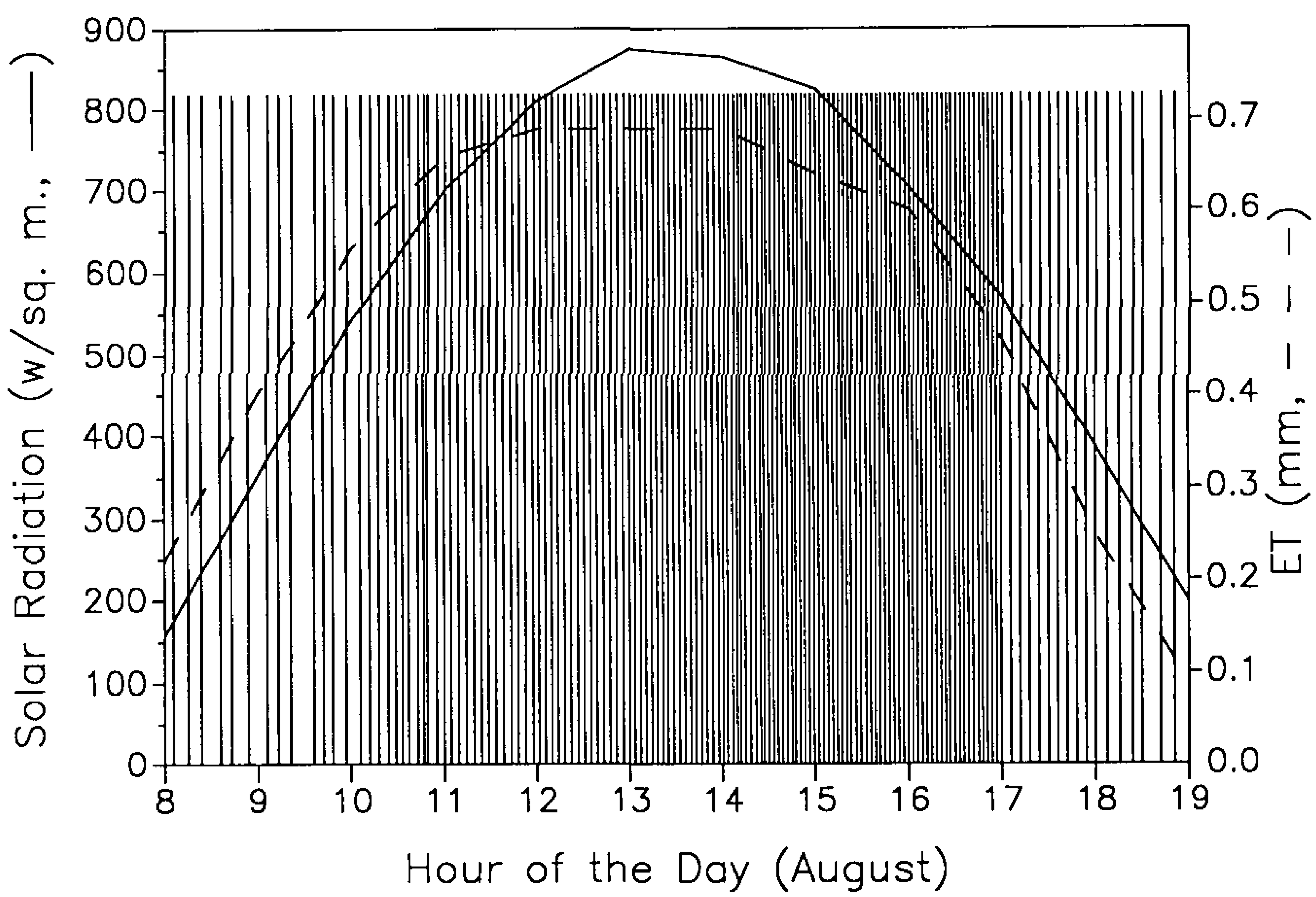

Figure 5. Response of an overhead mist valve (vertical lines) controlled by a solar radiation sensor.

Van Bavel, 1987). The Dynamax Dynagage Stem Flow Gauge (Dynamax Inc., Houston, TX; Fig. 6) may prove to be useful in the measurement of water use for container-grown as well as for landscape plants. At present, it is costly and requires the use of computer interfaces to operate effectively.

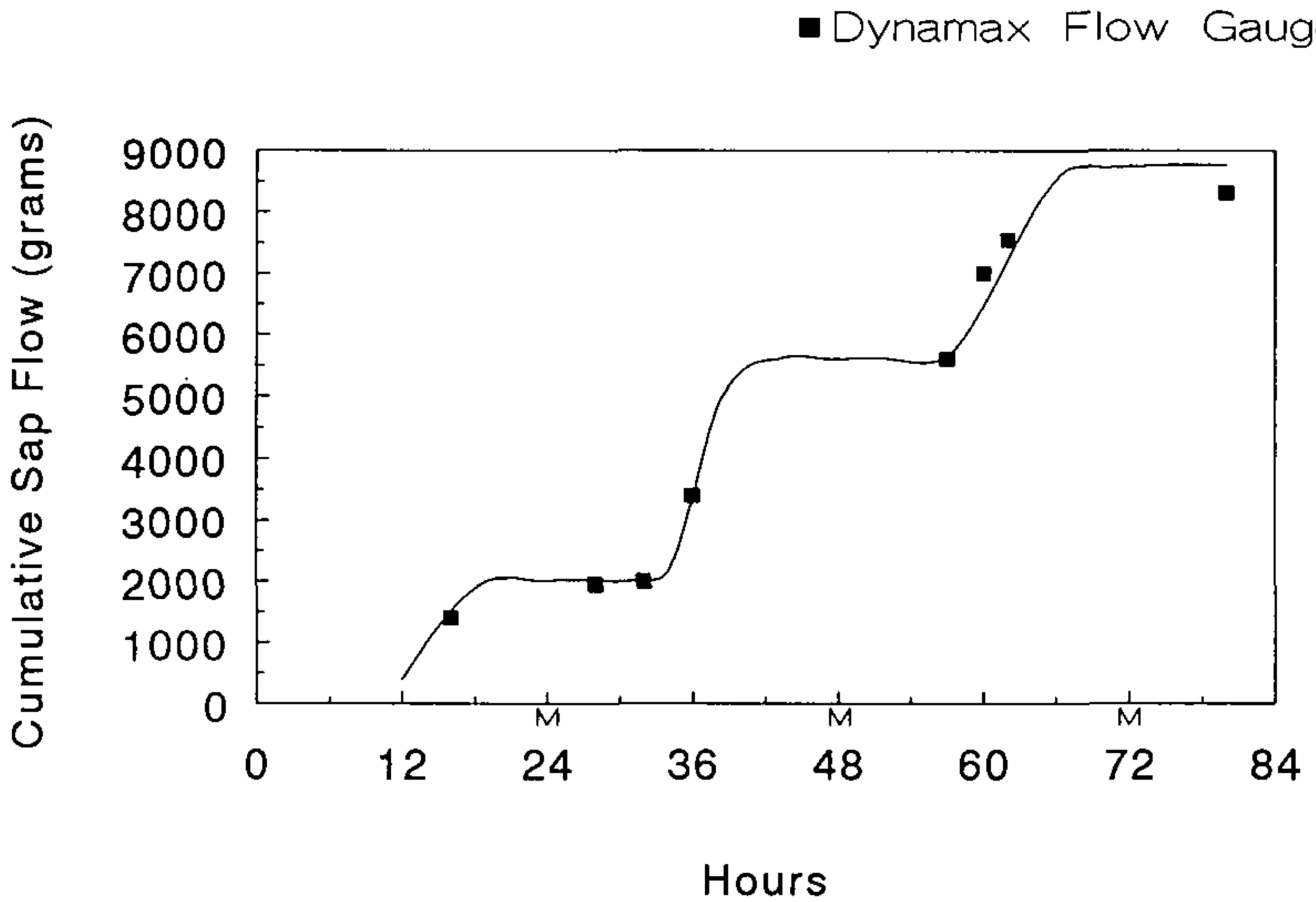

Figure 6. Measurement of water (sap) flow through a plant stem with the use of a Dynamax Flow Gauge. "M" along the X-axis denotes midnight.

Weighing Lysimeters. Research is underway at Davis to determine whether weighing lysimeters can function as irrigation control devices. The advantage of using a weighing lysimeter is that it can weigh several containers and therefore obtain a representative estimation of the water needs of the crop. In practice, the weighing lysimeter would be placed in the nursery bed in the area receiving the least amount of water from the irrigation system and/or in the area with the highest evapotranspiration potential (the south-west corner of the bed). The lysimeter would then dictate when water was applied to the plants it represented.

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