TIME DOMAIN REFLECTOMETRY AND IRRIGATION MODELING

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Supplemental irrigation has become a standard practice on home lawns, athletic fields, golf courses and cemeteries, as home owners and turf managers strive to maintain high quality turf. Even in the humid regions of the U.S. where cumulative rainfall exceeds evapotranspiration, soil moisture levels fail to meet the daily evaporative demand at all times. The result is the use of a large percentage of the city water supply for irrigation purposes. The competing demands for water mandates more efficient use of our water resources. The challenge for turf growers is to maintain a delicate balance between turf quality and environmental concerns.

Ideally, just enough water should be applied to meet plant evaporative demand. The driving force for evapotranspiration is the weather. Unfortunately, we have no control over the weather and our ability to accurately predict rainfall, particularly rainfall amounts still needs improvement. Irrigation modeling using Time Domain Reflectometry, (TDR) can simplify the decision on when to turn on the water and when to turn it off.

Models mimic experimental observations using measured system properties. The success of a model is based on how well the predictions agree with experimental observations. Good models have the ability to predict the response of yield or quality to changes in soil management under various climatic conditions. In irrigation modeling, the system consists of the atmosphere, the soil and the plant often described as the soil-plant-atmosphere-continuum. Rainfall and irrigation are inputs while evapotranspiration, drainage and runoff are outputs. Water infiltrating into the soil is stored in the soil at least temporarily and eventually lost as output. The purpose of an irrigation model is to predict current and future soil water contents under different management and environmental conditions. Such a model must have the capacity to indicate when the desired soil moisture content is reached during irrigation and to specify when irrigation should begin during a dry cycle.

The irrigation needs of plants are often determined using evapotranspiration (ET) estimates, plant stress indicators and to a limited extent soil moisture depletion with time or some combination of these. The gravimetric method is the standard to which other methods are compared. This method is time consuming and labor intensive. The information is seldom available in time to determine how much water should be applied.

Methods of soil moisture measurements are tensiometers, gypsum blocks, the neutron probe and TDR. Tensiometers respond to water potentials in the soil as do plants. However, the tensiometer response is reliable only over a limited range of potentials experienced by plants. Also, the tensiometers require frequent servicing. Gypsum blocks are the least expensive but require frequent calibration. The evolution of the neutron probe has improved its adaptability in irrigation scheduling. However, the radiation hazard, the need for calibration, operator controlled depth selection, and the interpretation of neutron probe data are limitations to its use. In turf management, the shallow rooting depth is another major limitation to the use of the neutron probe.

Over the last decade, TDR has been extensively employed in the measurement of soil water content in the field and in laboratories. TDR measures the electrical properties of a given volume of soil. The volumetric soil moisture content (VMC) of the soil is proportional to its dielectric constant as measured by TDR. The TDR method does not have the limitations stated above for the other soil moisture sensors. TDR is thus a viable option for controlling the turn-on and turn-off decision in irrigation scheduling. The major problem with TDR is the prohibitive initial cost. The development of TDR instrumentation that directly reads volumetric soil moisture content at an affordable cost will greatly enhance its use in real-time irrigation programming.

The TDR probes can be permanently installed in the soil or hand held probes may be used to measure VMC. Permanently installed probes reduce the effect of spatial variability. Site selection and probe placement are important factors that must be considered before installing the TDR probes. Site selection should be based on convenience of access and how well the site represents turfgrass conditions. Probes should be installed away from field edges. The site where the probes are installed should typify the area to be irrigated. Finally, the irrigation rate and application uniformity must be taken into consideration.

A hand held TDR Is manually used to sample VMC on the area to be irrigated. The locations with the average or the lowest water content are logical sites for permanent probe installation. The site with the lowest water content shows stress sooner than that of the median water content. Using this site may mean over watering other sites. Probes placed at a 45° angle to the surface minimize preferential paths for water movement during irrigation and drying. It also ensures a more representative soil volume than the vertical or horizontal placement, but it is more difficult to install and may be disturbed by the turf equipment. Horizontal probes are preferred in layered soils in which the moisture holding capacity varies with depth.

The development of a model depends on the objectives, the nature of the problem being addressed, and the level of basic and applied knowledge related to the problem. A model is thus based on a mix of data, knowledge and conjecture. Model development begins with the establishment of objectives and the hypothesis to be tested. A conceptual diagram or flow chart or pictorial representation of the different components is then made. This usually includes the inputs, the outputs and the links or pathways between the different components of the model.

Once the essential components of the model have been established, they are linked by established mathematical relationships that best describe the behavior of the sub-systems or transformations between components. A model that contains a time variable is known as a dynamic model and usually describes a time course event such as soil moisture depletion with time or rainfall with time.

Real time irrigation models use weather inputs to estimate ET. The most widely used model is the Penman model or some modification of it. The inputs for this model are temperature, solar radiation, wind speed, and relative humidity. The use of weather data arose from the difficulties and delays associated with repetitive gravimetric soil moisture determination. Innovations in technology continue to provide alternative methods of estimating the evapotranspiration. TDR technology has shown much promise as a usable tool in turf irrigation modeling. It has been used to measure VMC on a repetitive basis. This provides information on the soil moisture storage or soil moisture depletion with time, which is an essential parameter in the water balance model.

The water balance model is based on the law of mass conservation. This means water input into the soil is equal to the amount stored in the soil plus the losses or output. The main water inputs to the soil includes rainfall and irrigation. Evapotranspiration, drainage and runoff are the outputs. The above relationship can be written as:

$$I + P = D + R + VMC + ET$$

where I is the irrigation amount, P the amount of precipitation or rainfall, D the drainage and R the runoff. During dry periods and when irrigation is not being applied, irrigation, precipitation, drainage and runoff are effectively zero. The above equation reduces to

$$ET = VMC_1 - VMC_2$$

where (VMC_2, VMC_1) is the soil moisture depletion over a given time interval. Under these conditions, the soil moisture depletion is equivalent to the ET. The water balance model thus depends essentially on the measurement of irrigation amounts, rainfall, and soil moisture content. Efficient irrigation scheduling can be achieved under continuous or daily monitoring of VMC by establishing two critical VMC values, the set full and the refill point.

The set-full point is a predetermined VMC at which irrigation is turned on. This value should be a fraction of the field capacity. Field capacity is the soil moisture content two days after saturation of a bare soil covered with plastic so that no losses to evaporation or transpiration occur. This point is selected to minimize leaching yet guarantee adequate redistribution of water to the depth of interest. In automated systems, the TDR monitors when the full point is being approached and the irrigation system shuts off at the set-full point.

The refill point is selected to minimize moisture stress to the plant. It is usually based on about 50% of the plant available water left in the soil or the management allowable depletion (MAD). Normally, an average refill value is assumed for the entire soil profile. In layered soils or systems with TDR probes installed at different depths, the refill point can be based on root density distribution by layers or the weighted average of the soil moisture content by layer.

Repeated measurements of water content provide the soil moisture depletion rate with time. From this information, it is possible to estimate the date when the plant available moisture will be depleted to the refill point. In automated systems, the irrigation is programmed to apply water once the refill point is reached. This refill point may have a built-in safety factor to minimize the occurrence of stress. Also, a rain override should be incorporated into the model to prevent irrigation scheduling that coincides with rainfall.

Models serve as a tool that could be used to make strategic planning and management decisions. Modeling leads to less adhoc experimentation. The variation of one component or parameter while holding the others constant describes a sensitivity analysis. A sensitivity analysis provides a better understanding of how various parameters affect ET, determines which inputs cause the greatest error (the weakest point in the model) and helps us redirect our efforts to model components that can be improved upon. Model requirements pinpoint areas where knowledge is lacking and stimulate new ideas or experimental approaches. Finally, simulations help us speculate inexpensively. Once the model is developed, simulations are not as expensive to run as field experiments.

Although modeling is principally done by researchers and consultants, improvements in computer languages and literacy will result in more widespread use of models in the future. Soil based irrigation programming is a relatively simple and reliable method of irrigation modeling. However, the lack of adequate techniques for repetitive soil moisture monitoring has delayed its use in most irrigation models. It is expected that by the turn of the decade the markets will be flooded with affordable and accurate soil moisture sensors that will increase the use of soil based models in irrigation scheduling.