Determining Irrigation Wetting Patterns Using Time Domain Reflectometry

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Abstract. A time domain reflectometry (TDR) technique was used to measure water in the soil profile to derive wetting patterns of drip and microjet irrigation systems in a peach [*Prunus persica* (L.) Batsch] orchard. A distinct cone shape of >50% available soil water (ASW) extending from the emitter down to a depth of >45 cm was observed in the drip system. The 50% ASW zone in the microjet system was an elongated semicircle from the soil's surface down to a depth of 35 cm. TDR can be used successfully to determine wetting patterns of various irrigation systems to develop better irrigation scheduling.

Irrigation scheduling is a difficult management task that can be improved using time domain reflectometry (TDR). The goal of irrigation scheduling is to provide an adequate amount of water to plants in a timely fashion to meet their consumptive use while minimizing the potential for leaching caused by applying excess water. Irrigation schedules can be evaluated by monitoring irrigation efficiency, which, in turn, depends on water application uniformity and efficiency of water infiltration into soils. These two factors have been studied extensively in relation to drip and sprinkler irrigation.

Water infiltration strongly depends on soil characteristics such as texture, structure, and hydraulic properties. It also depends on irrigation design criteria, such as application rate, total volume applied, and irrigation frequency (Jury and Earl, 1977; Risse and Chesness, 1989). Many researchers have attempted to analyze and model the infiltration process to locate wetting fronts (Ben-Asher et al., 1978; Healy and Warrick, 1988; Raats, 1971; Wooding, 1968). These irrigation boundaries are important because they are a measure of irrigation efficiency. Experimental data for soil moisture have been collected with tensiometers and gravimetric sampling to test infiltration models, and sequential photographs have been used to evaluate ponding areas on the soil's surface (Bresler et al., 1971; Clothier and Heiler, 1983; Clothier et al., 1985; Jury and Earl, 1977; Lafolie et al., 1989; Levin et al., 1979). Risse and Chesness (1979) used bromide as a tracer to locate the wetting front. All these procedures are tedious and disturb the environment in which they are used. TDR is being used increasingly to determine soil water content rapidly in situ (Brisco et al., 1992; Nadler et al., 1991; Topp and Davis,

1985; Topp et al., 1984). TDR determines the dielectric constant of a soil by measuring the transit time of a high-frequency electromagnetic pulse launched along a pair of parallel wave guides embedded in the soil. The dielectric constant is a function only of volumetric soil water content, not other physical properties of the soil. The dielectric constant is calibrated and converted to percent volumetric soil water content. This technique is a rapid, nondestructive method of measuring soil water content in field experiments.

The objective of this study was to show that TDR can be used to evaluate wetting patterns of various irrigation methods. As a result, discrepancies due to the combined effect of nonuniform water application and infiltration in the field could be corrected.

Irrigation treatments consisted of drip, microjet, and no supplemental irrigation. All treatments were replicated three times in a peach orchard at Ridge Farm, Harrow Research Station, Ontario. The drip irrigation treatment included two pressure-compensated emitters (NETAFIM Irrigation, N.Y.) with a flow rate of 4.5 liters·h⁻¹ at 138 kPa. The emitters were inserted into 13-mm (internal diameter) polyethylene pipe, 60 cm from the tree base on the north and south of each tree. The microjet treatment included one microjet (SOLCOOR, Los Angeles) located 5 cm from the base of each tree, with a 360° spray pattern and a flow rate of 28.9 liters·h⁻¹ at 138 kPa. The irrigation amount and frequency for drip and microjet treatments were determined using corrected long-term evaporation derived from a class A pan at a nearby weather station, tree age and density, number of emitters or microjets per tree, flow rate of emitter or microjet, and soil moisture retention characteristics (Tan and Layne, 1991). Irrigation through the drip system was applied 3.5 h every day and irrigation through the microjet system was applied 2.3 h every 2 days. Irrigation began in mid-May and continued to early September.

TDR (Model 6050X1 Trase System; Soilmoisture Equipment Corp., Santa Barbara, Calif.) was used to measure volumetric soil water content. The relationship of the

dielectric constant value to the volumetric water percentage in the TDR system was established by the company using various types of soils carefully prepared to accurately known volumes of water in soil. This relationship then was used to convert field measurement of dielectric constant automatically to the volumetric soil water content. The calibration curve showed only a minor difference (±2%) in the evaluation of the volumetric water content for all soil types. Field measurements of volumetric soil water content were taken on the south and north sides of each tree at 0, 15, 45, 75, and 105 cm away from the emitter, microjet, or tree (depending on the treatment). At each location, volumetric soil water content was measured using stainless steel wave guides inserted vertically from the soil's surface to 5-, 15-, 30-, and 45-cm depths. All readings were taken after 2 months of irrigation treatments.

The experiment was conducted on Fox sand (Hapludalf) that contained 83% sand, 12% silt, and 5% clay from 0 to 20 cm deep and 86% sand, 8% silt, and 6% clay from 20 cm downward. Field capacities were 0.207 m³·m⁻³ from 0 to 20 cm and 0.172 m³·m⁻³ from 20 cm downward. Permanent wilting points (PWP) were 0.067 m³·m⁻³ from 0 to 20 cm and 0.057 m³·m⁻³ from 20 cm downward. Therefore, 50% available soil water (ASW) corresponded to 0.137 m³·m⁻³ from 0 to 20 cm deep and 0.115 m³·m⁻³ from 20 cm downward (Tan and Fulton, 1981).

A profile of the volumetric soil water content near the drip emitters and microjets, as

Fig. 1. Volumetric soil water content vs. lateral distance from emitter, microjet, or tree from soil surface to 5, 15, 30, and 45 cm soil depths for drip (○), microjet (●) and nonirrigation (▽) plots. Error bars are ses of means, n = 3.

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measured by TDR, showed an increase in soil water content 105 cm north of the drip emitter. Soil water content increased here because this position was ≈ 15 cm south of the second emitter that irrigated the tree (Fig. 1). For the top 5 cm, volumetric soil water content was $>50\%$ ASW within a distance of ≈ 20 cm from drip emitters but extended to 50 cm from microjets. For the 15-cm soil profile, ASW was $>50\%$ within a distance of ≈ 30 cm from drip emitters but extended to 50 cm from microjets. As expected, microjets covered a larger surface area at shallower depths. For the 30-cm soil profile, volumetric soil water content was $>50\%$ ASW within a distance of ≈ 50 cm from drip emitters but only within 20 cm from microjets. For the 45-cm soil profile, all readings were $>50\%$ ASW for drip emitters (even $>100\%$ within 50 cm from drip emitters) and none were $>50\%$ ASW for microjets. Again, as expected, drip emitters provided a larger volume of water at greater depths. This pattern could have profound implications for the irrigation frequency chosen when watering a tree using different irrigation methods. All readings for the nonirrigated treatment were near or below PWP.

In a contour plot (Cohort's Coplot Software, Berkeley, Calif.) of the drip emitter wetting pattern, as determined by TDR measurements, a distinct cone shape $>50\%$ ASW ($0.137 \text{ m}^3 \cdot \text{m}^{-3}$) extending from the emitter downward existed (Fig. 2). Jury and Earl (1977) have generated such contour plots from gravimetric sampling moisture data and obtained a semicircular shape on a Buren sandy loam. They also plotted tensiometer readings 15 and 60 cm from the emitter with time and noticed a considerable difference in soil water matric potential. Risse and Chesness (1989) plotted soil water matric potential and bromide concentration contours to locate the wetting front on a sandy loam soil and obtained a semicircular shape. In the present study, we observed that, with the drip emitter positioned 60 cm south of the tree, the first 10 cm of soil under the tree had volumetric soil water content close to PWP. It was only at a depth of 35 cm that the moisture level directly beneath the tree reached 50% ASW. Therefore, the duration of water applications should be minimized to reduce this loss when drip emitters are used.

In a contour plot of microjet wetting pattern from TDR measurements, the 50% ASW ($0.137 \text{ m}^3 \cdot \text{m}^{-3}$) zone was an elongated semicircle from the soil's surface down to a depth of 35 cm just beside the tree (Fig. 3). Clothier and Heiler (1983) obtained tracings of the wetting front for various discharge rates on a Chertsey silt loam (Udic Ustochrept), and a large shallow band (≈ 30 cm deep) was observed. When microjets are used, the duration of water applications should be lengthened, depending on the desired depth, to replenish the root zone to adequate water content.

Quantified wetting patterns can be used to develop more efficient irrigation schedules that help reduce chances of deep percolation or water deficit and help maintain suitable moisture for root growth and nutrient uptake.

Fig. 2. Volumetric soil water content contours for drip irrigation (two emitters per tree) plot receiving $31.5 \text{ liters} \cdot \text{day}^{-1}$. Dotted line represents 50% available soil water (ASW) and shaded area represents soil water content $>50\%$ ASW.

Fig. 3. Volumetric soil water content contours for microjet irrigation (one microjet per tree) plot receiving 66.5 liters every 2 days. Dotted line represents 50% available soil water (ASW) and shaded area represents soil water content $>50\%$ ASW.

From the drip emitter wetting pattern, we can expect the roots to penetrate deeper into the soil as a result of the deep, cone-shaped wetting pattern. This can be a disadvantage for the tree, since nutrients are concentrated at the shallower depths. Drip irrigation also can lead to anaerobic conditions in the root zone, denitrification, and rapid nutrient leaching because hydraulic conductivity is maximized. However, it may be an advantage during periods of drought, when irrigation is not provided. Under these conditions, the tree can exploit moisture available at greater depths. The microjet wetting pattern shows a definite advantage for nutrient uptake, but more water is required because of its high flow rate (which still resulted in a water deficit in the root zone), which resulted in a lower irrigation efficiency. TDR can be used successfully to determine

wetting patterns to improve irrigation scheduling and adapt the schedule to the system in use. In this study, TDR clearly compared the wetting patterns generated by two irrigation methods.

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