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# EFFECTS OF MICROSPRINKLER PRECIPITATION RATE, SOIL TYPE, AND WATER DEPLETION ON DEPTH OF SOIL WETTING

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*Abstract.* **Deep percolation loss of water and soil-applied fertilizers and pesticides due to improper irrigation is an increasing concern in Florida. Microsprinkler irrigation systems operated for long durations can potentially contribute to a waste of water and groundwater contamination. The role of microsprinkler precipitation rates and spray diameters on depth of wetting in the soil is emphasized. Commonly used microsprinkler precipitation rates were used to estimate the effect of irrigation duration, soil type, and soil water depletion on depth of water movement in the soil. To reduce percolation or runoff, irrigation durations to bring soil to field capacity in the normal citrus rooting zone are calculated. With small diameter spray patterns and low soil water depletions, irrigation durations of one hour or more may drive water below the main root zone. The depth of the newly applied water after irrigation is compared to the depth soil is brought to field capacity. Examples from soils of different citrus growing regions including Florida, Texas, and California are discussed.**

Microsprinkler irrigation was introduced into Florida citrus groves in the early 1970s. Microsprinklers, or spray jets, are small emitters that generally deliver 5 to 25 gallons $hr^{-1}$. Microsprinklers normally wet only a localized area under the tree. If they are run for long durations, water can be lost by deep percolation below the main root zone. In recent years, manufacturers have developed microsprinklers which produce a variety of spray patterns and precipitation rates. Microsprinklers with small spray patterns are frequently used for irrigation and cold protection of young trees (Parsons and Wheaton, 1987). Deflector or "top hat" attachments give a small pattern of 3 to 5 feet in diameter suitable for young trees, while other caps can produce spray diameters of more than 20 feet.

Water movement through the soil is a complex process. The objective of this paper is to demonstrate a simple and reasonably accurate procedure to estimate to what depth soil will be brought to field capacity when microsprinklers are operated. Hence, this paper presents simplified formulas and tables that show approximate depths of penetration of water from microsprinklers with different precipitation rates and times of operation. These tables should aid in management of applied irrigation water.

Specific goals are to 1) show the precipitation rates of microsprinklers with different flow rates and spray diameters, 2) calculate the effects of soil type and water depletion on depth of soil water movement, 3) illustrate the time required to bring the root zone to field capacity, and 4) distinguish between the depth of wetting to field capacity and depth of the newly applied water. Emphasis is placed on how long spray jets with certain precipitation rates can be operated without wetting the soil to field capacity below the main root zone.

*Precipitation Rate.* Precipitation rates for microsprinklers of given flow rates and wetted diameters can be calculated by the following formula:

Equation 1

$$PR = \frac{FR\,(43560\ ft^2\ acre^{-1})}{\pi\frac{(d)^2}{4}\,(27154\ gal\ acre^{-1}\ inch^{-1})} = \frac{2.04\ FR}{d^2}$$

where PR = Precipitation rate (inches $hr^{-1}$)
FR = Flow rate of emitter (gallons $hr^{-1}$)
d = Diameter of spray pattern (ft)

This formula assumes a uniform application rate over the wetted area. Boman (1989) has shown that uniformity varies among microsprinklers. Precipitation rates for microsprinklers with nonuniform wetting shapes such as spoke or doughnut patterns should be estimated using the area of its particular wetted zone.

Precipitation rates of jets with different flow rates and spray diameters vary over a wide range (Table 1). For example, a 16 gal $hr^{-1}$ jet with an 18 ft spray diameter has a precipitation rate of 0.10 inch $hr^{-1}$. The same 16 gal $hr^{-1}$ jet with a 6 ft diameter would have a precipitation rate of 0.91 inch $hr^{-1}$, 9 times greater than the jet with the 18 ft spray pattern. Because the precipitation rate is inversely related to the square of the jet diameter, the precipitation rate increases 9-fold when the diameter is decreased 3-fold.

*Depth of Wetting.* The depth to which an irrigation event affects soil water content is determined by the amount of water applied, the water holding capacity of the soil, and the amount of water depleted from the soil by evaporation and transpiration prior to irrigation. Field capacity (FC) is usually defined as the water content 1 to 2 days after rainfall or irrigation when downward movement of water has become negligible. Hence, FC is the amount of water a soil can hold against gravity. Field capacity varies greatly with soil type and depth. Field capacity can be expressed as inches of water per inch or foot of soil.

Depending on soil type, precipitation rate, and soil water depletion, a rainfall or irrigation event in excess of that which will bring the soil to FC in the root zone will either run off or drain to depths below the root zone. Water will wet sandy soils with deep water tables well below the root zone if high irrigation amounts are applied (e.g., Florida ridge sands). Only the amount of water needed to bring the soil in the root zone to FC should be applied. Precipitation at rates higher than the infiltration capacity of the soil will produce runoff or ponding on the surface.

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Table 1. Effect of flow rate and wetted diameter on microsprinkler emitter precipitation rate.

| Flow rate (gal $hr^{-1}$) | Wetted diameter (ft) 3 | 5 | 6 | 8 | 9 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Precipitation rate (inch $hr^{-1}$) | | | | | | | | | | | |
| 4 | 0.91 | 0.33 | 0.23 | 0.13 | 0.10 | 0.08 | 0.06 | 0.04 | 0.03 | 0.03 | 0.02 | 0.02 |
| 6 | 1.36 | 0.49 | 0.34 | 0.19 | 0.15 | 0.12 | 0.09 | 0.06 | 0.05 | 0.04 | 0.03 | 0.03 |
| 8 | 1.81 | 0.65 | 0.45 | 0.26 | 0.20 | 0.16 | 0.11 | 0.08 | 0.06 | 0.05 | 0.04 | 0.03 |
| 10 | 2.27 | 0.82 | 0.57 | 0.32 | 0.25 | 0.20 | 0.14 | 0.10 | 0.08 | 0.06 | 0.05 | 0.04 |
| 12 | 2.72 | 0.98 | 0.68 | 0.38 | 0.30 | 0.24 | 0.17 | 0.12 | 0.10 | 0.08 | 0.06 | 0.05 |
| 14 | 3.17 | 1.14 | 0.79 | 0.45 | 0.35 | 0.29 | 0.20 | 0.15 | 0.11 | 0.09 | 0.07 | 0.06 |
| 16 | 3.63 | 1.31 | 0.91 | 0.51 | 0.40 | 0.33 | 0.23 | 0.17 | 0.13 | 0.10 | 0.08 | 0.07 |
| 18 | 4.08 | 1.47 | 1.02 | 0.57 | 0.45 | 0.37 | 0.26 | 0.19 | 0.14 | 0.11 | 0.09 | 0.08 |
| 20 | 4.53 | 1.63 | 1.13 | 0.64 | 0.50 | 0.41 | 0.28 | 0.21 | 0.16 | 0.13 | 0.10 | 0.08 |
| 22 | 4.99 | 1.80 | 1.25 | 0.70 | 0.55 | 0.45 | 0.31 | 0.23 | 0.18 | 0.14 | 0.11 | 0.09 |
| 24 | 5.44 | 1.96 | 1.36 | 0.77 | 0.60 | 0.49 | 0.34 | 0.25 | 0.19 | 0.15 | 0.12 | 0.10 |

Not all water retained in the soil can be used by the plant. As the soil dries, the remaining water is held more tightly. The permanent wilting point (PWP) is the soil water content at which plants can no longer extract water from the soil rapidly enough to avoid wilting. The available water (AW) for plant growth is the difference between FC and PWP. Permanent wilting point and AW also may be expressed as inches of water per inch or foot of soil.

Field capacity, PWP, and AW vary considerably among soils. Soils in Florida are predominantly sandy soils with low FC and PWP values. Texas and California soils usually contain larger amounts of clay and organic matter and thus generally have higher FC and PWP values. Available water for representative citrus soils from Florida, Texas, and California (Table 2) range from 0.6 inches $ft^{-1}$ in some Florida soils to 1.8 inches $ft^{-1}$ in California (Carlisle et al., 1978; Jacobs, 1981; Bowers et al., 1989).

The depth of the root zone also varies with soil type and rootstock. The total amount of AW stored in the root zone is determined by multiplying AW by the depth of the main root zone. For Florida Ridge soils such as Astatula and Candler, the main root zone for citrus can be considered to be approximately 4 feet deep. While some citrus roots penetrate well below this depth in sandy soils, up to 80% of the roots are in the top 4 feet (Castle et al., 1989). Flatwood soil types such as Myakka, Riviera, and Wabasso are limited to a 1 or 2 foot rooting depth due to impervious layers and high water tables.

The depth to which irrigation brings soil to FC also depends on the amount of water in the soil prior to irrigation. Koo (1969), using overhead irrigation, determined that near optimum citrus yields could be obtained when a maximum depletion level of 33% was allowed from January to June and a maximum 67% depletion level was allowed for the rest of the year. More irrigation was needed in the spring to promote fruit set and retention. These depletion levels can be used as starting points. No experimental data are available indicating an appropriate depletion level for microsprinkler irrigation under Florida conditions. With microsprinkler systems covering less than 100% of the land area, smaller allowable depletions than 33 or 67% may be preferred. The range of possible allowable depletion levels would be approximately 0.5 to 0.75 of the 33% depletion recommended for overhead irrigation. This would result in the need for irrigation at 16 to 25% depletion. In this paper, 16% depletion is used as a possible alternative to partially compensate for microsprinkler's lack of complete soil area coverage.

Application amount, soil type, and percent depletion affect the depth of wetting (Table 2). The depth of wetting, or the depth to which the soil is brought to FC, can be calculated by the following equation:

Equation 2

$$D_w = \frac{I}{(AW)\,(\%\ \text{Depletion})}$$

where $D_w$ = Depth to which soil is brought to FC (ft)

I = Inches of water applied

AW = Average available soil water content (inches $ft^{-1}$)

% Depletion = % depletion of AW in the root zone prior to irrigation

Irrigation amounts of 0.5 and 1.0 inches and depletions of 16, 33, and 67% are used to illustrate a range of depths to which typical irrigation practices would bring the soil to FC (Table 2). The depth calculated by Equation 2 is equivalent to the depth of wetting front ($d_{wf}$) described by Rao et al. (1976).

Equation 2 assumes that the water already in the profile is pushed ahead of the new water entering at the soil surface. This would be similar to a piston pushing a fluid ahead of it.

Equation 2 also assumes a constant % depletion throughout the entire soil profile. Soil in Florida is often wetter below the root zone than is the soil in the main root zone. Because of this wetter subzone, irrigation would move FC to an even greater depth than that calculated by equation 2 resulting in over-irrigation and the wasting of water. Hence, some of the values calculated in Table 2 may underestimate the depth to which FC would extend.

Available water and percent depletion markedly influence the depth to which various soils are brought to FC. Over-irrigation is a real possibility even with 0.5 or 1.0 inch applications on some soils. Application of 1 inch of water for most Florida soils at 16% depletion would result in wetting below the root zone. For a flatwood soil such as Myakka with restrictive zones and a high water table, a 1 inch application at 33% depletion would wet the soil well below the root zone, resulting in runoff and/or raising of

Table 2. Effect of irrigation amount and percent soil water depletion on depth of wetting for several citrus soils.

| State and soil series | Root depth (ft) | Available water[z] (inch ft$^{-1}$) | Irrigation amount and soil water depletion | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 0.50 inch | | | 1.00 inch | | |
| | | | 16% | 33% | 67% | 16% | 33% | 67% |
| | | | Depth of wetting[y] (ft) | | | | | |
| Florida | | | | | | | | |
| Astatula | 4 | 0.64 | 4.88 | 2.37 | 1.17 | 9.77 | 4.73 | 2.33 |
| Candler | 4 | 0.59 | 5.30 | 2.57 | 1.26 | 10.59 | 5.14 | 2.53 |
| Myakka | 2 | 0.77 | 4.06 | 1.97 | 0.97 | 8.12 | 3.94 | 1.94 |
| Riviera | 1 | 1.79 | 1.75 | 0.85 | 0.42 | 3.49 | 1.69 | 0.83 |
| Wabasso | 2 | 1.56 | 2.00 | 0.97 | 0.48 | 4.01 | 1.94 | 0.96 |
| Texas | | | | | | | | |
| Brennan | 4 | 1.75 | 1.79 | 0.87 | 0.43 | 3.57 | 1.73 | 0.85 |
| Hidalgo | 4 | 1.44 | 2.17 | 1.05 | 0.52 | 4.34 | 2.10 | 1.04 |
| California | | | | | | | | |
| Exeter | 2 | 1.80 | 1.74 | 0.84 | 0.41 | 3.47 | 1.68 | 0.83 |
| Porterville | 4 | 1.68 | 1.86 | 0.90 | 0.44 | 3.72 | 1.80 | 0.89 |
| San Joaquin | 2 | 1.80 | 1.74 | 0.84 | 0.41 | 3.47 | 1.68 | 0.83 |

[z] Average in the root zone.

[y] Depth of wetting = depth of soil brought to FC by surface application of water.

the water table. In contrast, because of their greater water holding capacities, a one-inch application on Texas and California soils at 33% depletion remains well within the root zone. Only when irrigation occurs at a 16% depletion does a one-inch application move FC below the root zone in some Texas and California soils.

*Irrigation Time to Bring Root Zone to Field Capacity.* Precipitation rate, soil type, and percent depletion all affect the irrigation time required to bring the root zone to FC (Table 3). The irrigation time required to bring the root zone to FC can be calculated as follows:

Equation 3

$$\text{Hours Required} = \frac{(AW)\ (\%\text{Depletion})\ (\text{Root Depth})}{PR} = \frac{I}{PR}$$

where AW = Available soil water content (inches ft$^{-1}$)
% Depletion = % depletion of AW prior to irrigation
Root Depth = Depth of root zone (ft)
PR = Precipitation rate (inches hr$^{-1}$)
I = Inches of water applied

Precipitation rates of 0.1 and 1.0 inch hr$^{-1}$ shown in Table 3 reflect the wide range of application rates found in commercial plantings. Microsprinklers with precipitation rates of 0.10 to 0.30 inches hr$^{-1}$ are most commonly used in citrus plantings. Depending on soil type, irrigation times at these precipitation rates range from 1.7 hours in Florida to more than 23 hours in Texas at 33% depletion of available soil water. Irrigation durations of more than 10 hours may be required on some Florida flatwoods soils (e.g., Wabasso) at application rates of less than 0.1 inch hr$^{-1}$ which is characteristic of some of the large pattern microsprinklers. The use of deflectors to reduce the wetted area can provide application rates of 1.0 inch hr$^{-1}$ or more. Thus, if applying water at this high rate, irrigation durations for Florida soils should be reduced to one hour or less at 33% depletion to prevent over-irrigation.

*Depth of Newly Applied Water.* It is important to distinguish between the depth to which the soil is brought to FC and the depth of the newly applied water. Equation 2 describes the depth to which irrigation will increase soil water content to FC. Because water is not completely depleted from the soil near the surface, some water still remains. This water present in the soil is displaced downward by

Table 3. Effect of application rate and soil water depletion on time (hours) required to bring the root zone of several citrus soils to field capacity.

| State and soil series | Depth (ft) | Available water[z] (inch ft$^{-1}$) | Precipitation rate and soil water depletion | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 0.10 inch hr$^{-1}$ | | | 1.00 inch hr$^{-1}$ | | |
| | | | 16% | 33% | 67% | 16% | 33% | 67% |
| | | | Irrigation time (hrs) | | | | | |
| Florida | | | | | | | | |
| Astatula | 4 | 0.64 | 4.10 | 8.45 | 17.15 | 0.41 | 0.84 | 1.72 |
| Candler | 4 | 0.59 | 3.78 | 7.79 | 15.81 | 0.38 | 0.78 | 1.58 |
| Myakka | 2 | 0.77 | 2.46 | 5.08 | 10.32 | 0.25 | 0.51 | 1.03 |
| Riviera | 1 | 1.79 | 2.86 | 5.91 | 11.99 | 0.29 | 0.59 | 1.20 |
| Wabasso | 2 | 1.56 | 4.99 | 10.30 | 20.90 | 0.50 | 1.03 | 2.09 |
| Texas | | | | | | | | |
| Brennan | 4 | 1.75 | 11.20 | 23.10 | 46.90 | 1.12 | 2.31 | 4.69 |
| *Hidalgo* | 4 | 1.44 | 9.22 | 19.01 | 38.59 | 0.92 | 1.90 | 3.86 |
| California | | | | | | | | |
| Exeter | 2 | 1.80 | 5.76 | 11.88 | 24.12 | 0.58 | 1.19 | 2.41 |
| Porterville | 4 | 1.68 | 10.75 | 22.18 | 45.02 | 1.08 | 2.22 | 4.50 |
| San Joaquin | 2 | 1.80 | 5.76 | 11.88 | 24.12 | 0.58 | 1.19 | 2.41 |

[z] Average in the root zone.

Table 4. Comparison of new water front depth and field capacity depth from application of 0.5, 1.0 and 2.0 inches of water. Field capacity depth is calculated at 33% depletion of AW.

| State and soil series | Field capacity (inch inch$^{-1}$) | Water application (inches) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0.5 | | 1.0 | | 2.0 | |
| | | FC[z] | NW[y] | FC[z] | NW[y] | FC[z] | NW[y] |
| | | Depth (inches) | | | | | |
| Florida | | | | | | | |
| Astatula | 0.061 | 28.59 | 8.20 | 57.18 | 16.39 | 114.35 | 32.79 |
| Candler | 0.055 | 30.92 | 9.09 | 61.84 | 18.15 | 123.68 | 36.36 |
| Myakka | 0.099 | 23.67 | 5.05 | 47.35 | 10.10 | 94.97 | 20.20 |
| Riviera | 0.170 | 10.17 | 2.94 | 20.34 | 5.88 | 40.68 | 11.76 |
| Wabasso | 0.154 | 11.65 | 3.25 | 23.31 | 6.49 | 46.62 | 12.99 |
| Texas | | | | | | | |
| Brennan | 0.210 | 10.38 | 2.38 | 20.76 | 4.71 | 41.51 | 9.52 |
| Hidalgo | 0.180 | 12.63 | 2.78 | 25.25 | 5.56 | 50.51 | 11.11 |
| California | | | | | | | |
| Exeter | 0.280 | 10.10 | 1.79 | 20.20 | 3.57 | 40.40 | 7.14 |
| Porterville | 0.390 | 10.82 | 1.28 | 21.65 | 2.56 | 43.29 | 5.12 |
| San Joaquin | 0.280 | 10.10 | 1.79 | 20.20 | 3.57 | 40.40 | 7.14 |

[z] FC = depth of soil brought to field capacity in inches.
[y] NW = depth of new water front in inches.

any new water applied to the soil surface. Thus, the depth of the soil profile that is brought to FC will be greater than the depth to which the new water has migrated. The depth of new water is the depth to which the first drops of newly applied water go. This distinction is important when the movement of chemicals applied to the soil surface is considered. Any highly soluble, readily leachable compound such as nitrate applied to the surface can be driven to approximately the same depth as the new water front (Hornsby, 1990). Depth of the new water can be calculated from the following equation:

Equation 4

$$D_{nw} = \frac{\text{I (inches)}}{\text{FC (inch inch}^{-1}\text{)}}$$

where $D_{nw}$ = Depth of new water (inches)
I = Water applied (inches)

Table 4 illustrates the effect of irrigation amount on the depth in inches of the new water for representative soils. Note that FC values in Table 4 are in inches inch$^{-1}$ or percent. Depths of new water for Florida soils, having comparatively low FC values, range from 5.9 to 18.2 inches inch$^{-1}$ of water applied. New water depths for Texas and California soils range from 2.6 to 5.6 inches inch$^{-1}$ of applied water. The depth of new water discussed here is similar to the nonreactive solute front or solute front location after redistribution described by Rao et al. (1976). This front cannot be easily seen unless one begins with a dry soil or uses tracers applied at the soil surface.

Table 4 compares the depth of the new water to the depth to which FC extends. With these soil types and depletion levels, the new water front ranges from 12 to 29% of the depth of field capacity. Note that the depths indicated in Tables 2 and 4 refer to depths under the wetted area, not the area outside the microsprinkler spray pattern.

## Conclusions

The proper use of water is becoming a greater concern in Florida. Proper irrigation management involves accurate knowledge of application rate, soil type (water holding characteristics), and percent soil water depletion. Application rate, effective irrigation depth, and irrigation time required to bring the root zone to FC for a variety of conditions can be easily calculated from the equations provided. This provides the basis for avoiding potential over-irrigation.

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