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Irrigation Scheduling with Evaporation Pans [1]

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Introduction

To schedule irrigations using the water budget method, the irrigation system manager must be able to measure or estimate the rate at which water is being used by a crop. Evaporation pans can be used to indicate the rate of crop water use. An evaporation pan is an open pan of water that is subject to the same climatic conditions as a growing crop, and from which water is evaporated as a result of the climatic conditions experienced.

The climatic factors that are most important in causing pan evaporation and evapotranspiration (ET) are illustrated in Figure 1 . When soil-water is readily available to a crop, the rate of water evaporation from an evaporation pan has been demonstrated by many researchers and irrigation schedulers to be proportional to the rate of crop water use (James, 1988; Jensen, 1980; Pair et al., 1983).

A living plant is a very complex organism with respect to water use. It possesses mechanisms for limiting transpiration rates during water stress periods. The evaporation pan does not possess such mechanisms. However, this is not a serious limitation for irrigation scheduling, because irrigations are

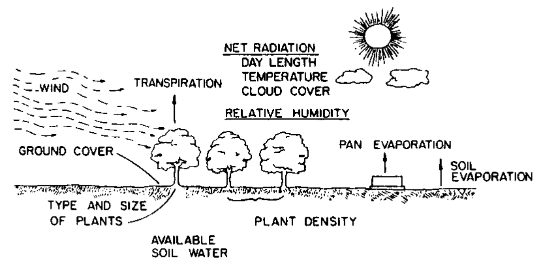

Figure 1 .

normally scheduled to maintain favorable soil-water contents and to avoid crop water stresses.

The ET rate varies for different crop species. That is, some crops use water at greater rates than others when subject to similar climatic conditions and similar soil-water conditions. This occurs because of differences in resistance to water transport from different soils and through different types of plants. Soil characteristics, root characteristics, leaf area, crop height, plant density, and the number of stomata on leaves are among the factors which affect this resistance to water transport and ET rates (Figure 1).

Since the rate of evaporation from an evaporation pan is primarily dependent upon climatic factors, an evaporation pan cannot directly predict differences in water use due to differences in crop species or cultural

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practices. This requires that a pan must be calibrated for the specific conditions of the crop to be irrigated.

Besides climatic factors, the rate of evaporation from an evaporation pan depends upon the type of pan used, the amount of water in the pan, and the location of the pan. The physical properties of the area surrounding an evaporation pan (such as whether it is surrounded by bare soil, pavement, or a well-watered crop) will affect the microclimate in the area and, thus will also affect the rate of evaporation from the pan. Therefore, evaporation pans must be constructed, maintained and located according to standard specifications if they are to be an accurate reference for crop water use.

NWS Standard Evaporation Pan

The National Weather Service (NWS) adopted the evaporation pan as one of the instruments in a standard weather station. In the standard NWS weather station, the evaporation pan is arranged with other instruments as shown in Figure 2 . The other instruments include a wind anemometer with the center line of the cups mounted 6 to 8 inches above the top of the pan for wind speed measurements, a stilling well with a hook gauge for precise water level measurements, and thermometers located in the evaporation pan for maximum and minimum water temperature measurements.

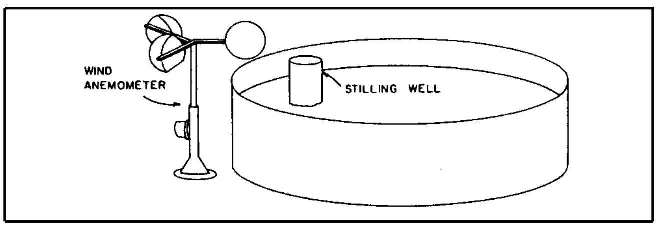

Figure 2 .

To standardize the measurement of evaporation, the NWS also adopted standard dimensions. materials of construction, and instructions for use of evaporation pans. Figure 3 (SCS Technical Staff, 1964) shows the NWS standard evaporation pan dimensions. The standard pan inside diameter is 47.5 inches, and its depth (inside the pan) is 10 inches.

Evaporation pans are commonly constructed of galvanized steel (# 22 guage). They are also available in stainless steel and monel (plated) metals, but these

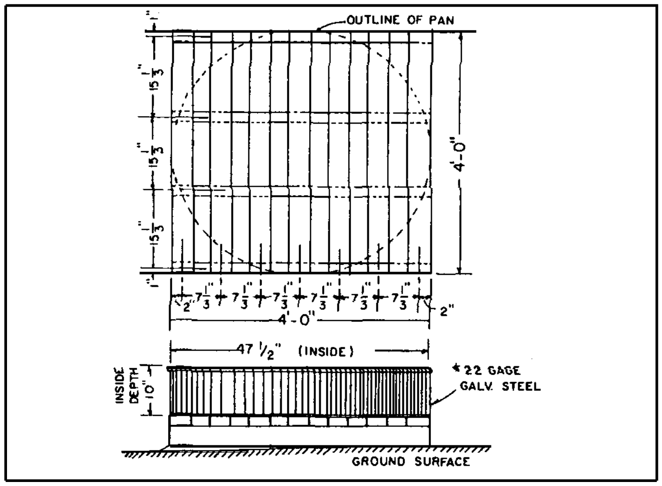

Figure 3 .

materials are more expensive. The greater expense may be required if the water used is corrosive to the galvanized steel pan. Figure 3 also shows the wooden stand for the standard evaporation pan. The stand should be 4 feet square and constructed of 2 x 4 inch treated lumber in the slatted arrangement illustrated. Soil should be placed around the wooden stand, but air circulation between the slats should be permitted to prevent the bottom of the pan from rusting. Because heat conduction affects the rate of evaporation, evaporation pans should never be placed directly on a concrete, paved, gravel, or other non-wooden surface. The pan should be level for data collection.

Evaporation Pan Management

Evaporation pans should be kept free of algae or other organic growths because such growths will affect evaporation rates. Small concentrations (5-10 ppm) of copper sulfate (Caution, large concentrations may cause the pan to rust) or chlorine can be used to prevent organic growths.

Rust spots should be repaired when they occur, and repaired spots must be painted the same color as the pan. A darker color will tend to heat up faster and increase evaporation rates. Oil or grease of any type must not be used in pans because such products will tend to float and prevent evaporation.

Evaporation pans must be kept fenced to prevent animals from drinking from them. Their use by birds as water sources should also be discouraged.

The amount of water in an evaporation pan will affect how fast it gains or loses heat. Thus, water levels in evaporation pans must always be maintained between 2 and 3 inches from the top of the pan. This provides a 7 to 8 inch depth of water in the standard 10-inch deep pan. To facilitate measurements, make marks inside the pan at 2 and 3 inches below the top of the pan. Manage pan water depths by filling the pan to the top mark (2 inches from the top of the pan) to initiate readings, then allow evaporation to deplete water from the pan over several days. Refill the pan when the water level drops to near the 3-inch mark. Following this procedure, the pan might be refilled every 3 or 4 days during high ET months, but only weekly or less frequently during low ET months.

Because rainfall is collected in an evaporation pan, rainfall depth will be measured by changes in pan water levels. After large rainfall events, the pan water level may need to be reduced to near the 2-inch mark.

Measuring Pan Water Levels

Water levels in an evaporation pan can be most accurately measured using a stilling well (as illustrated in Figure 2) with a hook gauge and micrometer. The stilling well provides a fixed reference point for accurate measurements even if the pan is not perfectly level. The hook gauge and micrometer permit depths to be measured to the nearest 0.001 inches, which is much greater accuracy than required for irrigation scheduling.

Accuracies sufficient for irrigation scheduling can be obtained using a finely-graduated ruler or meter stick. However, the water depth measurement must always be made at the same location, and care must be taken to assure that the ruler is held vertically when measurements are made.

Because evaporation pans are not refilled daily, errors made in daily depth measurements will compensate over several days. Measurement errors will be most serious for crops which are irrigated very frequently (daily or more often), but even so, sufficient accuracies can often be obtained using rulers if care is taken in their use.

For ease of interpretation, evaporation measurements should be made at about the same time each day. Normally, early morning or late evening measurements are most convenient. Early morning measurements permit yesterday's ET to be estimated and today's irrigations to be scheduled. Late evening measurements can be used to estimate today's ET for irrigations to be scheduled tonight or early tomorrow morning.

Estimating Crop ET

The NWS standard evaporation pan has been studied extensively for irrigation scheduling. In general, evaporation rates from NWS standard evaporation pans are greater than crop ET rates under field conditions. The rate of water use by a crop under field conditions can be estimated by the following two-step process:

1. First, calculate potential evapotranspiration (ETp) by multiplying the rate of evaporation from the NWS standard evaporation pan by a correction factor (from Table 1) called a pan coefficient (Kpan). ETp is a reference ET rate, specifically the ET rate from a short, well-watered, actively growing crop with a canopy that completely covers the sail surface, such as a grass crop.

2. Second, calculate crop ET by multiplying ETp (from Step 1) by a crop water use coefficient (Kc) for the specific crop, stage of growth, and cultural conditions.

Pan Coefficients

Table 1 lists pan coefficients (Kpan) required to calculate ETp from pan evaporation. These coefficients are specific for NWS Class A evaporation pans.

Kpan values to be used from Table 1 depend upon the location of the evaporation pan, the average daily relative humidity, and the average daily wind speed. It is not necessary to make detailed measurements of relative humidity or wind speed. Rather, general categories of dry or humid for average daily relative humidity, and light, moderate and strong for average daily wind speed are adequate. These may be obtained by visual observation of daily weather conditions.

Values to be used for Kpan also depend upon the type of area surrounding the pan. The pan evaporation rate (and thus the value of Kpan) is different if the pan is surrounded by bare soil as opposed to a vegetated surface. The extent of the bare soil or vegetated surface surrounding the pan is also important. However, as with the weather parameters, the extent of the areas surrounding the evaporation pan can be visually estimated rather than being precisely measured.

As an example of the use of Table 1, if the daily pan evaporation measured was 0.27 inches, the pan was located in a grassed area with about 300 ft of grass surrounding the pan, daily wind speed was light (estimated to be less than 5 mph), and humid conditions prevailed (daily minimum relative humidity was greater than 40%, as typical of most days in Florida), Kpan would be read as 0.85. ETp would then be calculated as the multiple of 0.85 times 0.27 inches, which equals 0.23 inches.

As another example, if daily pan evaporation was 0.40 inches, the pan was located in a field surrounded by 30 ft of bare soil, daily wind speed was moderate (5-10 mph), and high humidity conditions again prevailed, Kpan would be read as 0.7. ETp would be calculated as the multiple of 0.7 times 0.40 inches, which equals 0.28 inches.Notice that Kpan ranges from 0.45 to 0.85 in Table 1. Because of this wide range, it is important to use Table 1 to properly select a value of Kpan for the prevailing climate conditions. For rough estimates, Kpan = 0.8 can be used for humid (Florida) conditions, and Kpan = 0.7 for dry (arid and semi-arid areas) conditions.

Crop Water Use Coefficients

To estimate ET for a specific crop, ETp must be multiplied by a correction factor, called a crop water use coefficient (Kc). Kc values are assumed to be constants for a specific crop, stage of growth, and cultural conditions. Kc values are typically given as average monthly values for perennial crops and as a function of stage of growth (or days since planting or transplanting) for annual crops.

Lists of Kc values that are applicable to Florida crops and conditions have been published by Jones et al. (1984), Smajstrla and Zazueta (1988), and Doorenbos and Pruitt (1977). Kc values for specific crops are also found in many individual publications. Those publications or crop production guides for the specific crops being grown should be consulted to obtain Kc values for specific applications.

Irrigation Scheduling with NWS Evaporation Pans

The NWS Standard Evaporation Pan can be used to schedule irrigations by following an accounting (bookkeeping) procedure. In brief, the evaporation pan can be used to estimate daily rates of water use, and thus the amount of water required to replenish the soil water content by irrigation. If Kc values and the amount of water stored in the effective root zone of the crop are known, daily crop ET rates can be calculated and subtracted from the soil water storage until a critical soil-water depletion level is obtained. At that point, an irrigation would be scheduled to replenish the soil-water content. Thus, the evaporation pan would be used to determine both the timing of irrigation events and the amount of water that has been depleted. Also, if rainfall occurs, amounts must be measured and entered into the bookkeeping procedure to account for all water inputs to the soil.

Irrigation Scheduling Work Sheet

Table 2 demonstrates the use of a work sheet to make the computations required in the accounting procedure for irrigation scheduling based on the NWS Class A Evaporation Pan. The example is for citrus grown on Lakewood fine sand. This soil has a waterholding capacity of 0.4 inches/ft.

If the root zone depth where soil water is to be managed is the upper 3 ft of the soil profile (where most of the roots actively involved in water uptake are located) then the soil-water capacity in this zone is 1.2 inches (0.4 inches/ft x 3 ft). If irrigations will be scheduled when 2/3 of the available water has been depleted, then 0.8 inches (1.2 inches x 2/3) is available for ET between irrigations. This is the assumed usable soil-water that will be retained in the soil profile following irrigation or rainfall.

In this example, for convenience the bookkeeping procedure boons when the usable soil-water content is 0.80 inches (field capacity). This condition would occur after an irrigation or sufficiently large rainfall.

In actual applications, if field capacity conditions did not exist the soil-water content would need to be measured or estimated to obtain a starting point

Column I shows day of the month for reference. Column 2 shows elapsed time in days since the sell was restored to field capacity by irrigation or rainfall (or days since last irrigation or large rainfall). This column is re-initiated at 1 whenever the usable soil-water content is restored to 0.80 inches by either irrigation or rainfall.

Column 3 is used to tabulate daily values of usable soil-water in inches. Beginning at 0.80 inches for this example, this value is increased by rainfall and reduced by ET until it is nearly or entirely depleted. At that time, an irrigation is scheduled.

Column 4 is used to record daily measured values of pan evaporation in inches. Pan coefficients, Kpan, are read from Table 1 and recorded in Column 5 for the specific pan site, wind, and humidity conditions. Column 6 is the estimated ETp, calculated by multiplying Column 4 times Column 5.

Column 7 is used to record daily values of crop water use coefficients, Kc. For citrus in this example, a value of 0.9 is used as a constant for this month. This value would change from month to month throughout the year. The value of 0.9 is from Rogers et al. (1984) from data measured on a flatwoods citrus research site, Ft. Pierce Agric. Research and Education Center. Column 8 is the estimated daily crop ET, calculated by multiplying ETp (Column 6) times Kc (Column 7).

Column 9 is used to record rainfall (inches), and Column 10 for irrigation (inches). Rainfall is obtained from a rain guage at the field site, and irrigation is scheduled whenever the usable soil-water storage is depleted.

For the example shown in Table 2, it is assumed that the evaporation pan is read in the late evening. The daily ET (Column 8) is subtracted from the usable soil-water to obtain the now value of usable soil-water for the next day. If this value is critically low, then an irrigation can be scheduled tonight or early tomorrow morning.

On rainy days, the rainfall amount (Column 9) is added to the usable soil-water, after subtracting ET. If the usable soil-water calculated exceeds 0.80 inches, It is reduced to 0.80 inches, because this is the maximum amount that this soil can hold at field capacity. The excess water would be lost to drainage or runoff. The rainfall stored in the crop root zone is called effective rainfall.

The irrigation amounts shown in Table 2 are the amounts required to be stored in the crop root zone to restore the soil-water content to field capacity. The amount of water to be pumped would need to be larger than this amount because of losses due to inefficiencies in water application. If, for example, an overhead sprinkler irrigation system is used, and its efficiency is 0.75 (efficiency values for Florida irrigation systems were given by Smajstrla et al., 1988), then the amount to be pumped would need to be 1.07 inches (0.8 inches ÷ 0.75) in order to store 0.8 inches in the soil profile.

In Table 2, the first rainfall (0.30 inches) on August 8 is all assumed to be effective since it can be stored within the soil profile without exceeding the usable soil-water storage at field capacity (0.80 inches). However, on August 9, only 0.39 inches of the 0.76 inch rainfall was effective, because that was the amount required to restore the usable soil-water storage to 0.80 inches. The remaining 0.37 inches was lost to drainage or runoff because it could not be stored in the soil profile.

The two irrigations shown in Table 2 were scheduled when the usable soil-water storage dropped to (or below) 0.00. On August 7, the usable soil-water storage dropped exactly to 0.00, so exactly 0.80 inches were applied. On August 14, the ET caused the usable soil-water storage to drop below 0.00, thus 0.85 inches of irrigation was required to restore the soil to field capacity. This would be accomplished by running the irrigation system longer to apply the larger amount of water. Further detailed discussion of the accounting procedure is given in IFAS Circular 431 (Choate and Harrison, 1977).

Summary

Many researchers and irrigation schedulers have shown that evaporation pans can be used to accurately schedule irrigations. An accounting (bookkeeping) procedure for the management of soil-water content is required to make effective use of evaporation pans. Pans must be properly constructed, located, and managed for accurate use in ET estimation and irrigation scheduling. All evaporation pans must be calibrated for their specific application. This is done by using pan coefficients and crop water use coefficients. Refinement of calibration is obtained by field experience.

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Table 1.

Table 1. NWS Class A pan coefficients for different groundcover and levels of mean relative humidity and average daily wind speeds. (adapted from Doorenbos and Pruitt, 1977).

					Pan surrounded by bare soil	
Daily minimum relative humidity (%)			> 40% (Humid Day)		< 40% (Dry Day)	
Average Daily Wind	Upwind distance of green crop (ft)			Upwind distance of bare soil (ft)		
Light: less than 5 mi/hr	3	.65	.75	3	.8	.85
	30	.75	.85	30	.7	.8
	300	.8	.85	300	.65	.75
	3,000	.85	.85	3,000	.6	.7
Moderate: 5-10 mi/hr	3	.6	.65	3	.75	.8
	30	.7	.75	30	.65	.7
	300	.75	.8	300	.6	.65
	3,000	.8	.8	3,000	.55	.6
Strong: greater than 10 mi/hr	3	.5	.60	3	.65	.7
	30	.6	.65	30	.55	.65
	300	.65	.7	300	.5	.6
	3,000	.7	.75	3,000	.45	.55

Table 2.

Table 2. Example of accounting method for irrigation scheduling of citrus grown on Lakewood fine sand[z].

1 Day Aug.	2 Elapsed Time (days)	3 Usable Soil-Water (inches)	4 Pan Evap. (Inches)	5 Kpan[y]	6 Calc. Etp (inches)	7 Calc. Kc	8 ET (inches)	9 Rain (inches)	10 Irrigation (inches)
1	1	0.80[x]	0.17	0.75	0.13	0.90	0.12		
2	2	0.68	0.21	0.75	0.16	0.90	0.14		
3	3	0.54	0.11	0.85	0.09	0.90	0.08	0.30	
4	4	0.76	0.25	0.85	0.21	0.90	0.19		
5	5	0.57	0.32	0.85	0.27	0.90	0.24		
6	6	0.33	0.26	0.80	0.21	0.90	0.19		
7	7	0.14	0.21	0.75	0.16	0.90	0.14		0.80
8	1	0.80	0.24	0.80	0.19	0.90	0.17		
9	2	0.63	0.26	0.85	0.22	0.90	0.20	0.76	
10	1	0.80	0.18	0.85	0.15	0.90	0.14		
11	2	0.66	0.22	0.80	0.18	0.90	0.16		
12	3	0.50	0.33	0.80	0.26	0.90	0.24		
13	4	0.26	0.27	0.75	0.20	0.90	0.18		
14	5	0.08	0.23	0.75	0.17	0.90	0.15		0.87
15	1	0.80	0.25	0.80	0.20	0.90	0.18		
16	2	0.62	0.22	0.85	0.19	0.90	0.17		
17	3	0.45							

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1 Day Aug.	2 Elapsed Time (days)	3 Usable Soil-Water (inches)	4 Pan Evap. (Inches)	5 Kpan[y]	6 Calc. Etp (inches)	7 Calc. Kc	8 ET (inches)	9 Rain (inches)	10 Irrigation (inches)

[z]Assumed usable soil-water for citrus with a 3.0 ft effective root zone, a soil water-holding capacity of 0.4 inches/ft, and an allowable water depletion of 2/3 between irrigations = 0.80 inches.

[y]Pan coefficients are read from Table 1 for a pan surrounded by grass and with various assumed conditions of wind speed and relative humidity.

[x]Assumed starting with soil profile at field capacity, such as after a large rainfall.