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IFAS EXTENSION

Atmospheric Parameters Which Affect Evapotranspiration[1]

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INTRODUCTION

The primary reason for irrigation is to provide water to a crop when the frequency and amount of rainfall is not sufficient to replenish water used by a crop system. Water requirements of the crop system depend on growth and development needs as well as environmental demands. The levels of water used by the plant in growth and development are usually small compared to the atmospheric demands. Therefore a knowledge of the parameters involved with the water use process will help the irrigation scheduler understand the driving forces associated with the water requirements of the crop.

An exchange process between incoming energy and outgoing water occurs at the crop surface, which can be evaluated by an energy balance. Water is transferred out of the plant system as a result of satisfying this balance. This transfer process is called evapotranspiration (**ET**), which refers to the evaporation (**E**) of water from plant and soil surfaces and the transpiration (**T**) of water through the plant to the atmosphere. This publication will describe the parameters involved in this process, their relation to each other, and their ranges.

EVAPOTRANSPIRATION

Water evaporates from soil and plant surfaces and transpires through the plant to satisfy an atmospheric demand. The combination of these processes is termed evapotranspiration (**ET**). A detailed discussion of **ET** concepts, estimation methods, and levels for Florida conditions is presented in IFAS Bulletin 840, "Estimated and Measured Evapotranspiration for Florida Climate, Crops, and Soils" (Jones, et al., 1984). Evapotranspiration is simply a component of an energy budget of activities occurring at the crop surface. An energy budget is used to identify the individual components. These components are net radiation, sensible heat flux , soil heat flux, **ET** and solar radiation stored as photochemical energy.

The primary energy input to the system is solar radiation **Rs**. However, some of **Rs** is reflected while the remainder is absorbed and converted to other energy forms. The amount of **Rs** reflected depends

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on the albedo (**a**, solar radiation reflectivity) of the surface. Additional radiant energy transfers occur in the form of thermal radiation generated by the temperature of the surface (upward long-wave radiation, **Ru**) and of the atmosphere (downward long-wave radiation, **Rd**). All of these terms are combined to define the net radiation (**Rn**) received at the crop or soil surface.

Sensible heat flux (**H**) is the transfer of heat energy due to the temperature difference between two surfaces, such as the plant surface and the atmospheric environment. If the plant surface is warmer than the environment, heat energy flux will be from the plant surface to the environment, and vice-versa. Similarly, soil heat flux (**G**) occurs due to a difference in temperature between two regions in the soil, such as the surface and a position below the surface.

Evapotranspiration is also known as latent heat flux. The previous three components, **Rn**, **H**, and **G** are used to define and evaluate **ET**. The last component, associated with photochemical energy storage, is very small when compared to the other components and can be neglected. Additional detail on the process of **ET** can be obtained from Burman et al. (1980), Brutsaert (1982) and Campbell (1977).

POTENTIAL AND REFERENCE CROP EVAPOTRANSPIRATION

When the water supply available to a crop system is limited, the **ET** component of the energy budget is reduced and the heat flux terms are increased. However, for most crop systems it is desirable to maintain adequate water supplies to the crop such that **ET** levels are at their maximum. This avoids water stress to help achieve high levels of production. The term potential evapotranspiration (**ETp**) is used to describe the maximum or potential level of **ET** resulting from non-limiting water conditions and satisfaction of the energy budget. Interpretation of **ETp** depends upon the surface conditions of the crop system and can be ambiguous. Therefore the term "reference crop evapotranspiration" is becoming more common in use.

Reference crop evapotranspiration (Burman et al., 1980; and Doorenbos and Pruitt, 1977) refers to **ET** from a uniform green crop surface, actively growing, of uniform height, completely shading the ground, and under well-watered conditions. Two standards have been accepted for use as a reference crop. These are grass maintained at a 3 to 6 inch height and alfalfa with 12 to 18 inches of vegetative growth. Reference crop **ET** based on grass is generally denoted as **ETo** while alfalfa based reference crop **ET** is denoted as **ETr** (Burman et al., 1980). Actual **ET** for a crop is then determined by using a crop coefficient (**Kc**) which relates the water use properties of that crop to the reference level of **ET**. Equation Box 1 shows this relationship.

$$ET = Kc \times ETo \text{ (grass based reference)}$$
$$ET = Kc \times Etr \text{ (alfalfa based reference)}$$

Equation 1.

For proper application, it is important to know which reference base was used in determining the crop coefficient.

The Penman (1948) equation for calculating **ETp** is probably the most widely accepted energy based method. This approach combines two components to estimate **ETp**. These are a radiative component and an advective component. This method is presented in IFAS Bulletin 840 (Jones et al., 1984) as shown in Equation 2.

$$ETp = \frac{D \times Rn/L}{D + G} \text{ (radiative term)} + \frac{G \times Ea}{D + G} \text{ (advective term)}$$

Equation 2.

Where:

ETp = Potential evapotranspiration

D = Slope of the saturated vapor pressure temperature curve of air,

Rn = Net radiation at the crop surface,

L = Latent heat of vaporization of water,

G = Psychrometric constant,

Ea = A vapor pressure deficit/wind function term;

= 0.263(ea - ed)(0.5 + 0.0062 U2),

ea = Saturation vapor pressure of air at the ambient temperature,

ed = Saturation vapor pressure of air at the dewpoint temperature, and

U2 = Wind speed at a height of 2 meters.

The driving forces of solar radiation and wind are both dependent upon the temperature and vapor pressure conditions of the air. Each of these parameters are discussed in greater detail in a later section of this bulletin.

EVAPOTRANSPIRATION PARAMETERS

Net radiation, **Rn**, is the net level of solar and thermal radiation energy at the crop surface. It can be broken down into the components of short-wave and long-wave radiation. Net radiation is measurable and instruments are available for this purpose. If direct measurement is not possible, **Rn** can be estimated from the short-wave and long-wave radiation components (Brutsaert, 1982; Burman et al., 1980; Jones et al., 1984).

The units associated with radiation parameters are energy related. Energy units are generally expressed in terms of calories (**cal**) or as joules (**J**). Instantaneous radiation levels on a surface are received as an energy flux or rate per unit area such as calories per square centimeter per minute (1 **cal/cm^2/min** equals 1 **langley/min**) or watts per square meter (**W/m^2**) [an energy flux of 1 watt is equal to 1 joule per second]. Daily accumulated levels of radiation such as cal/cm^2/day or MJ/m^2/day (M denotes mega or million) are generally used in ET prediction equations.

Short-Wave Radiation

Short-wave radiation is the radiation flux resulting directly from solar radiation and has wavelengths of 0.3 to 4 micrometers (Campbell, 1977). Short-wave radiation received by an object may be the result of direct, diffuse, or reflected solar radiation. Direct radiation is highly directional and depends on the angle between the surface and the sun. Radiation scattered and reflected by clouds has no specific direction and is called diffuse radiation. Additional reflection of short-wave radiation can occur from the ground surface or other objects. As with diffuse radiation, this "terrestrial" reflected radiation has no specific direction and is diffuse as well.

Rates of direct short-wave radiation may range from 150 W/m^2 (0.215 cal/cm^2/min) during very hazy or overcast periods to 900 or 1000 W/m^2 (1.29 to 1.43 cal/cm^2/min) during bright sunny periods. However, daily accumulated levels in Florida may range from 12 to 34 MJ/m^2 (300 to 800 cal/cm^2).

The reflectivity of a surface to short-wave solar radiation is known as the **albedo** of the surface. The higher the reflectivity of the surface, the higher the albedo. Typical values of albedo are: open water, 0.05; dry soil (light color), 0.32; woodland, 0.16-0.18; and crop surfaces, 0.15-0.26 (0.23 is often used for complete canopy, green crops). The level of reflected radiation is the product of the albedo and the incoming short-wave radiation.

Long-Wave Radiation

Long-wave (infrared) radiation is also called terrestrial radiation and has wavelengths in the range of 4 to 80 micrometers (Campbell, 1977). Long-wave radiation is emitted and absorbed by both the atmosphere and terrestrial objects. Atmospheric long-wave radiation is emitted and absorbed by water vapor and carbon dioxide contained in the atmosphere. Similarly, terrestrial long-wave radiation is emitted by objects on the earth's surface.

Basically, long-wave radiation depends on the temperature and **emissivity** of the emitting surface. As temperature increases, so does the emitted level of long-wave radiation. Emissivity is a value which characterizes the efficiency of emittance of the surface. A black body has the highest efficiency of emittance and has an emissivity of 1. Clear sky emissivity will depend on the levels of water vapor and carbon dioxide in the atmosphere and will range from 0.7 to 0.9 for Florida conditions. The higher levels occur at higher temperatures. Natural surfaces will generally have emissivities between 0.90 and 0.98.

Upward (**Ru**) and downward (**Rd**) long-wave radiation rates will generally range from 300 to 500 W/m^2 (0.43 to 0.72 cal/cm^2/min). Of particular importance is the net long-wave radiation. This value is the difference between **Ru** and **Rd** and daily accumulated levels may range from 8 MJ/m^2 (200 cal/cm^2) net outgoing thermal radiation during clear cool weather to 2 MJ/m^2/day (50 cal/cm^2/day) net incoming thermal radiation during warmer weather.

Latent Heat of Vaporization

The latent heat of vaporization (**L**) represents the amount of energy required for water to change from a liquid to a gas (water vapor). Water is in a liquid state in the plant and is changed to a vapor during **ET**. The value of **L** varies with temperature and is about 2425 joules per gram (580 cal/g) at 86 degrees F (30°F). This is equivalent to 2.425 MJ/m^2/mm (58 cal/cm^2/mm) for conversion to mm of water evaporating.

Vapor Pressure

Air contains water vapor and can be either saturated or partially saturated. Saturation conditions exist when the air contains the maximum possible level or density of water vapor for the existing temperature conditions. Generally, the air is partially saturated where the density of water vapor in the air is less than the maximum possible level. The amount of water vapor that can be held in the air is temperature dependent. As temperature increases, the amount of water vapor that it can hold also increases.

Vapor pressure (**e**), the partial pressure exerted by the water vapor, is more commonly referred to and is related to vapor density and temperature (**T**) by the perfect gas law. Tables and equations of **e** with respect to **T** are available (Burman et al., 1980; Campbell, 1977; Doorenbos and Pruitt, 1977; and Jones et al., 1984). Units of **e** are generally expressed in millibars (mb) or kilopascals (kPa), although inches of water or inches of mercury are sometimes also used. Saturation vapor pressure varies from 12 mb (1.2 kPa) at 50°F (10°C to 57 mb (5.7 kPa) at 95°F(35°C).

The term (**ea - ed**) in **Ea** of Equation 2 represents the vapor pressure deficit of the air, basically quantifying the amount of additional water vapor that the air can hold. The saturation vapor pressure at the ambient air temperature is designated by **ea**, while the saturation vapor pressure at the dewpoint temperature is designated by **ed**. These two values are related by the relative humidity. The relative humidity (**RH**) of the air is the ratio of **ed** to **ea**. A well irrigated plant will generally have a "moist" surface with a vapor pressure greater than the surrounding air. Water vapor will move from the plant surface to the surrounding atmosphere as long as these conditions exist.

Two additional terms related to vapor pressure and temperature are the slope of the saturation vapor pressure-temperature curve (**D**), and the psychrometric constant (**G**). Basically **D** is the slope of the curve defining the relationship between air temperature and saturation vapor pressure at the ambient air temperature. The psychrometric constant is the ratio of the heat capacity of the air to the latent heat of vaporization (Campbell, 1977). Therefore, **G** varies with temperature and pressure, but very little such that it is considered to be a constant. The value of **G** for Florida conditions is 0.66 millibars per degree C (mb/C).

Temperature

Air temperatures are classed as dry bulb or ambient (**Ta**), wet bulb (**Tw**), and dewpoint (**Td**). Units can be either degrees Fahrenheit (F) or degrees Celsius (C). Ambient air temperature is the most common temperature reported, and it is measured using a standard thermometer. Wet bulb and dewpoint temperatures characterize the moisture properties of the air.

As air moves over a wet surface, such as a wet leaf, the temperature of the surface decreases until the air surrounding the surface is saturated, resulting in a temperature lower than ambient and is called the wet bulb temperature. Measurement of wet bulb temperature is not very difficult. A small sock or wick of material is placed over the end of a thermometer, the material is wetted with water, and air is blown over the wet material. The material cools to the wet bulb temperature and remains there until all of the water has evaporated.

The wet bulb temperature is the minimum temperature to which air can be cooled by evaporative cooling such as the fan and wet pad systems used in greenhouses. Because Florida's humidity levels are relatively high, the air does not have much additional capacity for water resulting in relatively high wet bulb temperatures. Therefore evaporative cooling systems do not perform as well as in drier climates.

Dew point temperature is the temperature to which an air sample must be cooled for that air sample to become saturated without adding water. For example, as ice is added to a glass of water the glass cools, and if the glass is cool enough, water condenses on the outside of the glass. This condensed water comes from the surrounding air and the dew point temperature is the temperature of the glass at which water first condenses on the outside. The surface of the glass cooled the air next to it to the temperature necessary for the existing vapor density conditions to be at a saturated level.

A saturated air sample is at its maximum level of vapor density or pressure. Therefore, at saturation the relative humidity is 100%, and the dry bulb, wet bulb, and dew point temperatures are in equilibrium, and are all the same. This situation can be an advantage in humid climates where early, predawn atmospheric conditions are generally at or very near saturation, 100% relative humidity. This is also the time of mimimum daily temperature allowing the use of this value for the daily dew point temperature and to determine **ed**.

Conditions of partial saturation will have dry bulb, wet bulb, and dew point temperatures of different values. For example, air at a dry bulb temperature of 50°F(10°C) and a **RH** of 50% will have a wet bulb temperature of 42°F (5.5°C) and a dew point of 32 degrees F (0°C). As temperature and humidity increase, the differences between these different temperature parameters decrease. Air at 95°F (35°C) and 70% **RH** has wet bulb and dew point temperatures of 86 and 83°F (30 and 28.5°C), respectively. As stated earlier, this signifies the lower cooling capacities of these type of environments.

Wind

The previously discussed parameters of temperature, vapor pressure, and humidity indicate how moisture can move from the plant surface into the atmosphere. The air surrounding the plant can approach saturation with water vapor from the plant. When air movement is zero, this saturated air mass moves very slowly away from the plant, and the vapor pressure deficit is minimized. Therefore, air movement plays a major role in transporting the water vapor transpired from the plant into the atmosphere. Wind can help to maintain a significant vapor pressure deficit around the plant surface.

Wind speed varies with height above a crop surface. Wind will be at a minimum near the crop surface, and it increases with height above the crop. The wind speed term in Equation 2 uses wind speed measured at a height of 2 meters (**U2**) and is generally measured in miles per day or kilometers per day. At Belle Glade, Florida, average wind speed or wind run at 2 meters may range from 46 to 54 miles per day (75 to 85 km/day) during the summer months and from 65 to 81 miles per day (105 to 131 km/day) during the late winter and early spring months (Jones et al., 1984). Wind speed measured at other heights can be adjusted to that which would occur at a height of 2 meters (Burman et al., 1980; Jones et al., 1984).

SUMMARY

The process of evapotranspiration was discussed as a combination of two processes, a radiative energy process and an advective transfer process. Both of these processes create an atmospheric demand for water movement from the crop. If this demand is not satisfied, the crop will heat up and dry out. To better understand these processes, each of the factors affecting them and their interrelationships were discussed. Units and expected levels associated with the various parameters were also presented for Florida conditions. Familiarization with this information can help the irrigation manager understand the effects of varying atmospheric conditions on the water demands of a crop.

REFERENCES

Brutsaert, W. 1982. *Evaporation into the Atmosphere*. D. Reidel Publishing Company, Boston. 299 pp.

Burman, R. D., P. R. Nixon, J. L. Wright, and W. O. Pruitt. 1980. *Water Requirements. In: Design and Operation of Farm Irrigation Systems*, M. E. Jensen (ed.) ASAE Monograph No. 3. American Society of Agricultural Engineers. St. Joseph, MI. Pp. 189-234.

Campbell, G. S. 1977. *An Introduction to Environmental*

Biophysics. Springer-Verlag, New York. 159 pp.

Doorenbos, J., and W. O. Pruitt. 1977. *Guidelines for Predicting Crop Water Requirements*. Food and Agriculture Organization of the United Nations. Irrigation and Drainage Paper No. 24. 144 pp.

Jones, J. W., L. H. Allen, S. F. Shih, J. S. Rogers, L.C. Hammond, A. G. Smajstrla, and J. D. Martsolf. 1984. *Estimated and Measured Evapotranspiration for Florida Climate, Crops, and Soils*. Bulletin 840 (Tech.). Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL. 65 pp.

Penman, H. L. 1948. *Natural Evaporation from Open Water, Bare Soil, and Grass*. Royal Soc. of London Proc. 193:122-145.