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CENTER PIVOT SPRINKLER APPLICATION DEPTH AND SOIL WATER HOLDING CAPACITY

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SUMMARY

Advanced irrigation technologies, including center pivot irrigation, are excellent tools that make it possible to meet crop water requirements with a high level of water and energy efficiency and distribution uniformity. Within constraints of available water capacity and other site-specific limitations, a well designed, maintained and managed irrigation system provides for a high level of flexibility and precision to meet crop water requirements with minimal losses. The key to optimizing center pivot irrigation is management, which takes into account changing crop water requirements and the soil's permeability and water holding capacities.

LOW PRESSURE CENTER PIVOT IRRIGATION SYSTEMS

Center Pivot irrigation systems are used widely throughout the Central High Plains, including the Texas High Plains where most of the systems are low pressure systems, including Low Energy Precision Application (LEPA); Low Elevation Spray Application (LESA); Mid-Elevation Spray Application (MESA) and Low Pressure In-Canopy (LPIC).

Low pressure systems offer cost savings due to reduced energy requirements as compared with high pressure systems. They also facilitate increased irrigation application efficiency, due to decreased evaporation losses during application. Considering high energy costs and in many areas limited water capacities, high irrigation efficiency can help to lower overall pumping costs, or at least optimize crop yield/quality return relative to water and energy inputs.

LEPA irrigation applies water directly to the soil surface through drag hoses (primarily) or through "bubbler" type applicators, (such as the LEPA mode of Senninger Irrigation Inc. Quad-Spray™ products[1].) Notably LEPA involves more than just the hardware through which water is applied. It involves farming in a circular pattern (for center pivot irrigation systems) or straight rows (for linear irrigation systems). It also includes use of furrow dikes and/or residue management to hold water in place until it can infiltrate into the soil.

LEPA irrigation generally is applied to alternate furrows; reducing overall wetted surface area, and hence reducing evaporation losses immediately following an irrigation application. Because a relatively large amount of water is applied to a relatively small surface area, there is the potential of runoff losses from LEPA, especially on clay soils and/or sloping ground. Furrow dikes and circular planting patterns help reduce the runoff risk. Still, LEPA is not universally applicable as some slopes are just too steep for effective application of LEPA irrigation.

Low pressure spray systems – LESA, MESA and LPIC - offer more flexibility in row orientation, and they may be easier for some growers to manage, especially on clay soils or sloping fields. Objectives with these systems include applying water at low elevation (generally 1-2 feet from the soil surface for LESA; often 5 - 10 feet for MESA) to reduce evaporation losses from water droplets (especially important in windy conditions); applying water at a rate not exceeding the soil's infiltration capacity (preventing runoff); and selecting a nozzle package that provides good distribution uniformity and appropriate droplet size and wetting pattern.

A well designed, maintained and managed center pivot irrigation system can provide a high level of irrigation application efficiency and distribution uniformity. It offers the ability to apply a range of application rates to meet changing crop water requirements, and it can be re-nozzled if needed to adapt to changing irrigation capacities. A key to efficient irrigation management through center pivot application is optimizing irrigation scheduling (depth and timing) to meet the crop water demand with an application rate (precipitation rate) to match soil permeability.

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[1] The mention of trade names of commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the Texas AgriLife Extension Service or Texas AgriLife Research.

IRRIGATION SCHEDULING: WHEN AND HOW MUCH?

Good irrigation management provides sufficient water to the crop to avoid drought stress, while avoiding over-irrigation which can lead to runoff and/or deep percolation losses as well as poorly aerated (anoxic) conditions. In meeting crop water demands, it is helpful to keep in mind how plants use water. Without addressing the specifics of plant physiology, plants draw water and dissolved nutrients from the root zone through their roots, xylem, plant tissues and eventually through stomata. Generally speaking, roots grow best in moist soil, since dry or saturated conditions limit root growth. Contrary to popular belief, roots do not grow in dry soil. Managing soil moisture conditions that encourage an expansive root system can in effect maximize the plant's ability to extract water and dissolved nutrients from a greater volume of soil, therefore potentially increasing nutrient use efficiency as well as water use efficiency (from rainfall, irrigation and stored soil moisture sources).

Irrigation planning should take into account crop water needs (seasonal and peak water use), soil permeability, soil moisture storage capacity, irrigation water availability (well capacity or water allocations) and equipment capabilities. Particularly in water-limited crop production systems, water use efficiency and relative economic return can be key factors in irrigation management decisions. To aid producers in irrigation resource allocation and planning, Klocke, et al. (2005) developed the Crop Water Allocator, (available at www.oznet.ksu.edu/mil) that is a user-oriented computer program for cropping system decisions based on economically optimum allocation of limited irrigation resources.

Pre-season and Early Season Irrigation Management

Where water resources and/or irrigation system capabilities are insufficient to meet full irrigation demand, and where soil moisture at planting is insufficient to ensure crop germination, it is common practice to apply a pre-season or "pre-plant" irrigation. The decision of when to apply a pre-season irrigation and how much to apply can be challenging. Research conducted at Halfway, Texas (Bordovsky and Porter, 2003) indicated that in this area known for its dry windy spring conditions, pre-season irrigation losses can be very high, with total water losses from irrigation and rainfall exceeding 47% in the 30-45 days preceding planting. In the same study, however, yield reductions were observed in fields where pre-plant irrigation was limited. Hence although starting irrigation applications too early can result in excessive losses of applied water, insufficient stored soil moisture limits crop productivity, particularly where irrigation capacities are insufficient to meet crop water requirements.

Pre-season irrigation considerations include:

- What is the soil moisture? Consider the seedbed as well as the crop's potential root zone. Soil moisture is field-specific and can be greatly affected by the crop previously grown in that field as well as off-season precipitation and atmospheric conditions.
- What is the capacity of the irrigation system and water resource? Low (gallons per minute per acre) capacity systems require more time to apply a given amount of water to the field. Table 1 relates approximate irrigation application rates according to irrigation system capacity.
- What is the target pre-season soil moisture? Consider the soil's water holding capacity, and whether the soil is to be wetted to field capacity, or if allowance should be made for the storage of anticipated rainfall before planting.
- Keep in mind that through the early part of the crop season (planting through early vegetative stages) crop water requirements may be relatively low; hence there may be opportunity to continue to build soil moisture reserve after planting.

Table 1. Approximate depths of application (inches per day or inches per week) as related to irrigation system capacity (gallons per minute per acre).

Relating irrigation system capacity to depth of application (Gallons per minute per acre to inches per day or inches per week)		
GPM/Acre	**Inches/Day**	**Inches/Week**
1	0.053	0.37
2	0.11	0.74
3	0.16	1.11
4	0.21	1.48
5	0.27	1.86
6	0.32	2.23
7	0.37	2.60
8	0.42	2.97
9	0.48	3.34
10	0.53	3.71
Note: these values do not take into account irrigation efficiency.		

In-season Irrigation Scheduling

In-season irrigation scheduling generally involves meeting crop water demand, including peak water demand, if possible. Long-term averages and research-based water use curves can be very useful in irrigation planning, and many of these are available through local or state Cooperative Extension Services. Optimal day-to-day in-season management, however, takes into account current soil moisture, crop and atmospheric demand conditions. Evapotranspiration (ET) networks provide in-season crop water demand estimates as determined by atmospheric conditions, crop(s) and growth stages. ET data sources include the Kansas State University Weather Data Library (http://www.oznet.ksu.edu/wdl/); the High Plains Regional Climate Center Automated Weather Data Network (AWDN, serving Colorado, Iowa, Kansas, Minnesota, Missouri, Montana, North Dakota, Nebraska, South Dakota and Wyoming http://www.hprcc.unl.edu/awdn/); the North Dakota Agricultural Weather Network (NDAWN, serving North Dakota, Montana and Minnesota, http://ndawn.ndsu.nodak.edu/); Oklahoma Agweather (http://agweather.mesonet.org/); the Texas High Plains Evapotranspiration Network (TXHPET, http://txhighplainset.tamu.edu); and others.

Crop water demand varies with crop and growth stage. Also the relative effect of drought stress on crop yield can vary with growth stage. For instance, the most critical period during which water stress will have the greatest effect on corn yield potential corresponds with the maximum water demand period, approximately two weeks before and after silking. Cotton yield potential is largely determined before square initiation; yet peak water demand occurs during flowering. Excess water and nitrogen late in the season can encourage excessive (undesirable) late season vegetative growth in cotton. Crop production manuals published by state Cooperative Extension services provide detailed information on crop water requirements. Examples of these materials and how they may be accessed include Kansas State University crop production handbooks for alfalfa, corn, grain sorghum, soybeans, sunflowers and wheat which are available from the KSU Mobile Irrigation Lab Tool Kit and Resources (http://www.oznet.ksu.edu/mil/ToolKit.htm).

Late Season Irrigation Management

Irrigation termination decisions involve predicting how much water will be needed by the crop from the last irrigation until physiological maturity or harvest. Long-term “average” crop water use curves from local experience or published literature; estimates of stored soil moisture; anticipated rainfall and other climate considerations; economic considerations (yield return vs. irrigation costs); and irrigation system capabilities are all factors that should be considered. Irrigation termination recommendations are often based upon local applied research programs.

MANAGING SOIL MOISTURE

Especially where irrigation capacities are insufficient to meet crop water demand, stored soil moisture is relied upon to help make up the difference. Soil moisture monitoring is a very useful complement to evapotranspiration (ET)-based information.

In many semi-arid areas, including the Texas Southern High Plains, pre-season irrigation or excess early season irrigation is used to provide moisture for crop establishment and to fill soil moisture storage capacity to augment often deficit irrigation during peak crop water use periods. Pre-season irrigation water losses through evaporation and deep percolation can be quite high. Hence it is important for growers to understand how much water their soil root zone will hold, taking into account the effective root zone depth and soil moisture storage capacity per foot of soil. Applying more water than the soil can hold can result in deep percolation losses or runoff; starting irrigation too early increases opportunity for evaporation losses. These risks need to be balanced with irrigation system capacity.

The Root Zone and Soil Water Holding Capacity

The potential root zone depth is determined by the crop; however effective root zone depth is often limited by soil conditions. Soil compaction, caliche layers, perched water tables, and other impeding conditions will limit the effective rooting depth. Roots are generally developed early in the season, and will grow in moist (not saturated or extremely dry) soil. Most crops will extract most (70% - 85%) of their water requirement from the top one to two feet of soil, and almost all of their water from the top 3 feet of soil, if water is available. Deep soil moisture is beneficial primarily when the shallow moisture is depleted to a water stress level. Commonly reported effective root zone depths by crop are listed in Table 2.

Table 2. Effective root zone depths reported for selected crops. These values represent the majority of feeder root as reported by various sources.

Crop	**Approximate Effective Rooting Depth (feet)**
Alfalfa	3.3 – 6.6+
Corn	2.6 – 5.6
Cotton	2.6 – 5.6
Sorghum	3.3 – 6.6
Vegetables	1 - 3

Deep percolation losses are often overlooked, but they can be significant. Water applied in excess of the soil's moisture storage capacity can drain below the crop's effective root zone. In some cases, periodic deep leaching is desirable to remove accumulated salts from the root zone. But in most cases, deep percolation losses can have a significant negative impact on overall water use efficiency - even under otherwise efficient irrigation practices such as low energy precision application (LEPA) and subsurface drip irrigation (SDI) irrigation. Leaching of nutrients and agricultural chemicals through deep percolation can reduce efficiency and efficacy of these inputs and present groundwater contamination risks. Coarse soils are particularly vulnerable to deep percolation losses due to their low water holding capacity. Other soils may exhibit preferential flow deep percolation along cracks and in other channels formed under various soil structural and wetting pattern scenarios.

Runoff losses occur when water application rate (from irrigation or rainfall) exceeds soil permeability. Sloping fields with low permeability soils are at greatest risk for runoff losses. Vegetative cover, surface conditioning (including furrow dikes), and grade management (land leveling, contouring, terracing, etc.) can reduce runoff losses. Irrigation equipment selection (nozzle packages) and management can also help to minimize runoff losses.

A soil’s capacity for storing moisture is affected by soil structure and organic matter content, but it is determined primarily by soil texture. **Field capacity** is the soil water content after soil has been thoroughly wetted when the drainage rate changes from rapid to slow. This point is reached when all the *gravitational water* has drained. Field capacity is normally attained 2-3 days after irrigation and reached when the soil water tension is approximately 0.3 bars (30 kPa or 4.35 PSI) in clay or loam soils, or 0.1 bar in sandy soils. **Permanent wilting point** is the soil moisture level at which plants cannot recover overnight from excessive drying during the day. This parameter may vary with plant species and soil type and is attained at a soil water tension of 10-20 bars. *Hygroscopic water* is held tightly on the soil particles (below permanent wilting point) and cannot be extracted by plant roots. **Plant available water** is retained in the soil between field capacity and the permanent wilting point. It is often expressed as a volumetric percentage or in inches of water per inch of soil depth or inches of water per foot of soil depth. Approximate plant available water storage capacities are 0.6 - 1.25 inches water per foot of soil depth for fine sandy soils; 1.2 – 1.9 inches water per foot of soil for loam soils; and 1.5 – 2.3 inches water per foot of soil for clay loam soils.

To avoid drought stress, a **management allowable depletion** is often imposed as a trigger for irrigation applications. Management allowable depletion is often in the range of 50-60% of plant available water for many agronomic crops, but may be as low as 20-30% of plant available water for drought sensitive crops.

Permeability is the ability of the soil to take in water through infiltration. A soil with low permeability cannot take in water as fast as a soil with high permeability; the permeability therefore affects the risk for runoff loss of applied water. Permeability is affected by soil texture, structure, and surface condition. Generally speaking, fine textured soils (clays, clay loams) have lower permeability than coarse soils (sand). Surface sealing, compaction, and poor structure (particularly at or near the surface) limit permeability.

Information about soil water characteristics, including plant available water, soil texture, and permeability are available for most major soils in the U.S. including the Central High Plains is available free of charge from the United States Department of Agriculture Natural Resources Conservation Service on their Web Soil Survey website at http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm.

Soil Moisture Monitoring and Soil Water Measurement

Methods used to measure soil water are classified as *direct* and *indirect*. The direct method refers to the gravimetric method in which a soil sample is collected, weighed, oven-dried and weighed again to determine the sample's water content on a mass percent basis. The gravimetric method is the standard against which the indirect methods are calibrated. Some commonly used indirect methods include electrical resistance, capacitance and tensiometry (Enciso, et al., 2001).

Electrical resistance methods include gypsum blocks or granular matrix sensors (more durable and more expensive than gypsum blocks) that are used to measure electrical resistance in a porous medium. Electrical resistance increases as soil water suction increases, or as soil moisture decreases. Sensors are placed in the soil root zone, and a meter is connected to lead wires extending above the ground surface for each reading. For most on-farm applications, small portable handheld meters are used; automated readings and controls may be achieved through use of dataloggers (Enciso, et al., 2001).

Capacitance sensors measure changes in the *dielectric constant* of the soil with a capacitor, which consists of two plates of a conductor material separated by a short distance (less than 3⁄8 of an inch). A voltage is applied at one extreme of the plate, and the material that is between the two plates stores some voltage. A meter reads the voltage conducted between the plates. When the material between the plates is air, the capacitor measures 1 (the dielectric constant of air). Most solid soil components (soil particles), have a dielectric constant from 2 to 4. Water has higher dielectric constant of 78. Hence, higher water contents in a capacitance sensor are indicated by higher measured dielectric constants. Changes in the dielectric constant provide an indication of soil water content. Sensors are often left in place in the root zone, and they can be connected to a datalogger for monitoring over time (Enciso, et al., 2001).

Tensiometers measure tension of water in the soil (soil suction). A tensiometer consists of a sealed water-filled tube equipped with a vacuum gauge on the upper end and a porous ceramic tip on the lower end. As the soil dries, soil water tension (suction) increases; in response to this increased suction, water is moved from the tensiometer through the porous ceramic tip, creating a vacuum in the sealed tensiometer tube. Water can also move from the soil into the tensiometer during or following an irrigation. Most tensiometers have a vacuum gauge graduated from 0 to 100 (centibars, cb, or kilopascals, kPa). A reading of 0 indicates a saturated soil. As the soil dries, the reading on the gauge increases. The useful limit of the tensiometer is about 80 cb. Above this tension, air enters through the ceramic cup and causes the instrument to break suction with the soil and fail reading on the gauge. Therefore, these instruments are most useful in sandy soils and with drought-sensitive crops because they have narrower operational soil moisture ranges (Enciso, et al., 2001).

Alternately, a soil's moisture condition can be assessed by observing its **feel and appearance**. A soil probe, auger, or spade may be used to extract a small soil sample within each foot of root zone depth. The sample is gently squeezed manually in the palm of a hand to determine whether the soil will form a ball or cast, and whether it leaves a film of water and/or soil in the hand. Pressing a portion of the sample between the thumb and forefinger allows one to observe whether the soil will form a ribbon. Results of the sample are compared with guidelines described by the USDA-NRCS (1998).

Soil water monitoring methods have advantages and limitations. They vary in cost, accuracy, ease of use, and applicability to local conditions (soils, moisture ranges, etc.) Most require calibration for accurate moisture measurement. Proficiency of use and in interpreting information results from practice and experience under given field conditions.

CONCLUSIONS AND RECOMMENDATIONS

Crop water requirements are crop-specific, and they vary with weather and growth stage. Water management is especially important for critical periods in crop development. Knowledge of the root zone should be applied to optimize irrigation management taking into account the crop’s effective rooting depth, the soil moisture storage capacity, and field-specific conditions (shallow soils, caliche layers, etc.). In the use of irrigation scheduling, soil moisture monitoring, evapotranspiration information, and/or plant indicators can be used to fine-tune water applications to meet crop needs.

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