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Center-pivot irrigation systems: high pressure to low pressure

¹Israel Broner

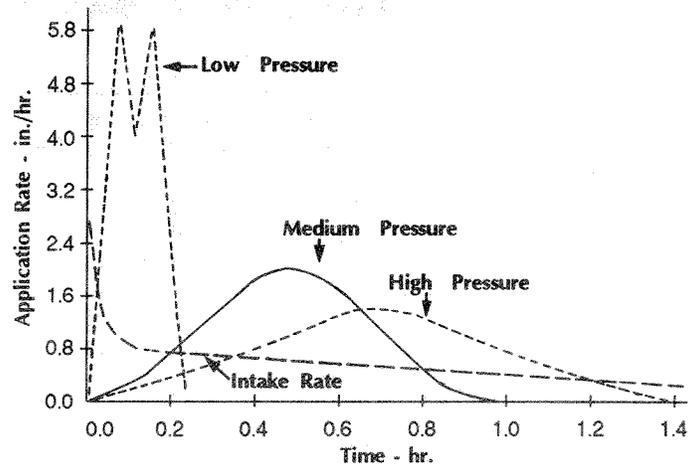
Quick Facts

- The application rate of an irrigation system depends on the water requirements of the crop and the application time.
- The application time is the time it takes to sprinkle any place in the field.
- Center-pivot sprinkler systems are classified by pressure and nozzle type.
- A trade-off exists between the radius of throw of the sprinkler and the application rate of the irrigation system.
- High application rates increase the potential for runoff and decrease irrigation efficiencies.

A center pivot is a moving irrigation system (lateral) that rotates around a fixed point (pivot). The application rate is the inches of water that the irrigation system applies per hour. The application rate varies laterally because the center-pivot lateral covers more area per-unit-length toward the outer end. This characteristic of the center pivot complicates its design. With proper design and installation, a center-pivot sprinkler system can achieve high irrigation uniformity. When designing a sprinkler irrigation system, the systems application rate should match the soil's intake rate (in/hr) and surface storage. Soils intake rate is the rate at which a soil can absorb or take in water. Match is not always possible with movable irrigation systems.

The desired application rate of an irrigation system depends on crop water requirements and the application time. Application time is the time it takes to sprinkle any place in the field. The application time

Figure 1: Typical application rates at a radius of 1000 feet from the pivot.



depends on the radius of throw of the sprinkler head. The larger the radius of throw, the longer any point in a field will receive water under a given speed of travel.

There is a trade-off between the application rate and the radius of throw of the sprinkler head used. The smaller the radius of throw, the higher the instantaneous application rate has to be. This is due to the shorter application time that each point of the field receives. When center pivots were introduced, high-pressure impact sprinklers were used. The application time was longer and the application rates were lower because of the larger radius of throw. The high-pressure high-angle impact sprinklers had lower irrigation uniformities, especially under windy conditions. As energy costs increased, lower pressure sprinkler systems were developed to reduce rising energy costs and increase irrigation efficiencies. The main drawback of a low-pressure sprinkler system is

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it's reduced radius of throw. This reduction significantly increases the instantaneous application rate to enable the system to apply the same application depth at the same time. A high application rate can often lead to runoff if proper tillage is not applied, resulting in reduced irrigation efficiencies.

Classification of Sprinkler Systems

Center-pivot sprinkler systems are classified according to pressure or nozzle-type. Although there is no definite boundary between high, medium and low pressures, it is commonly accepted to have the following classifications. High-pressure systems have pressures of more than 50 psi at the pivot, medium-pressure systems have 35 to 50 psi at the pivot, and low-pressure systems have less than 35 psi at the pivot. This is not as low as low-pressure systems can get. The newer developed LEPA (Low-Energy Precision Application) and LDN (Low Drift Nozzle) can operate on pivot pressures of 15 to 25 psi. Nominal operating pressures at the sprinkler head or water-emitting devices are constant for a particular head. Nominal pressures for LEPA devices are 6 to 10 psi; spray nozzles, rotators and spinners 10 to 25 psi; small impact heads with modified nozzles operate at 20 to 45 psi; small impact sprinklers with round nozzles operate at 30 to 60 psi; and large impact sprinklers operate at a pressure range of 45 to 80 psi. The range for large impact sprinklers depends on nozzle type and size. Pressures needed at the pivot depend on pressure losses in the lateral due to friction losses and elevation differences along the lateral.

To find the necessary pressure at the pivot work back from the last emitting device and add pressure losses or gains due to friction and elevation changes.

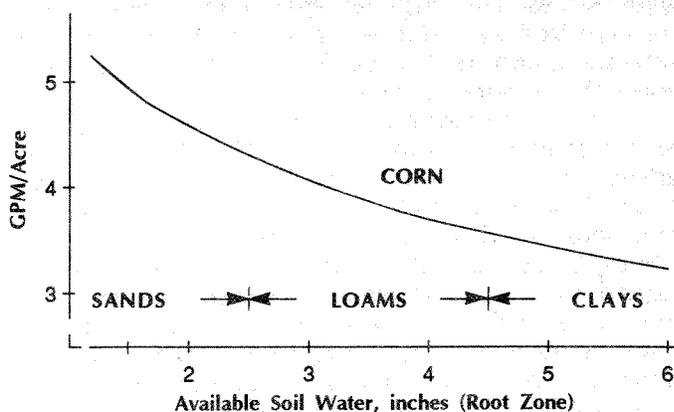
For nozzle-type systems, center-pivot sprinkler systems are either impact sprinklers, spray nozzles, rotary nozzles, or the newer ground level LEPA nozzles. Impact sprinklers usually operate at high to medium pressures, are installed on the lateral pipe, and irrigate over the crop. Spray and rotary nozzles operate at medium to low pressures, are installed on the lateral pipe or on drop tubes or pipes, and result in "down in the crop" irrigation. Irrigation down in the crop reduces evaporation and wind drift. Figure 1 shows the effect of different sprinkler packages (nozzle-type and pressure) on the application rate. There is a definite trend of higher application rates for lower pressures. Application rates can be as high as 10 to 14 inches per hour for spray nozzles and much higher for LEPA systems.

A user should select a sprinkler package with an application rate that matches the soil's intake rate, satisfies crop water requirements, and functions under local climatic conditions (wind). Proper tillage might overcome possible runoff problems.

Irrigation System Capacity Requirement

Crop water requirement (ET) is the amount of water a crop uses during a period. Crop water requirements change seasonally and usually peak in July for warm season annual crops (not winter wheat). An irrigation system should satisfy the peak

Figure 2: Net irrigation system capacities for corn in eastern Colorado.



crop water requirements or net irrigation requirement. To find the gross irrigation requirement (irrigation system capacity), divide the net irrigation requirement by the irrigation system efficiency (fraction of one). To calculate irrigation system capacity allow for expected down time for maintenance and expected failures. This approach doesn't consider available water-stored in the soil and water added from rainfall.

Irrigation system capacity should be calculated with an approach that considers the soil water-holding capacity and rainfall probability. The analysis in Figure 2 represents 60 years of climatic records that used this approach. The net capacities meet corn water needs nine out of ten years, without depleting more than 50 percent of the available soil water.

The data from Figure 2 was used to calculate required irrigation system capacities in GPM/acre for three soils and three center-pivot systems (Table 1). Irrigation system efficiencies for the three systems were found in a comprehensive study conducted on the high plains of Texas. If you design, operate and manage your system properly, you can assume the same irrigation system efficiencies if no runoff occurs. If you see water runoff in or out of the field, the water distribution in the soil will not be uniform and areas of over-irrigation and under-irrigation will appear. The required system capacities in Table 1 assume a seven-day per week operation (24 hours per day) with no down time during the period of peak ET. Required irrigation system capacities should be increased to allow for expected down time. For example, if you consider one day per week down time, divide the required irrigation system capacity by 0.84 (1 - 1/7) to allow for expected down time.

The available water stored in the soil is a reservoir that supplies water during peak water-use periods. The higher the available soil water, the less irrigation system capacity required (Figure 2). This approach uses the available soil water in determining the required irrigation system capacity. It also assumes the system will replenish the soil profile to field capacity before peak use. Thus, when the peak water-use period begins, the soil profile is full and the water stored in the soil can compensate for the system capacity that is lower than the water use rate. Nine out of 10 years, the length of the peak water-use

period will be short enough to deplete no more than 50 percent of the available water, thus not causing water stress. The irrigation system efficiency affects the required irrigation system capacity as well. As seen in Table 1, the higher the system efficiency, the lower the required irrigation system capacity.

The required system capacity values in Figure 2 are based on the assumption that the capacity will be adequate nine out of 10 years. In the year the system capacity is inadequate, the crop is water-stressed and some yield reduction will occur. If the user is willing to take a higher risk, a system can be designed to meet crop water requirements less frequently by reducing the system capacity. This will result in a smaller initial investment in the irrigation system. Table 2 gives required system capacities for two probabilities that do not exceed 50 percent depletion of the available soil water in eastern Colorado. When designing a new system, consider: the trade-off between initial system cost, energy demand and power-use charges, system capacity, and the chance of yield reduction from water stress.

High-Pressure to Low-Pressure Conversion

A change from high-pressure to low-pressure systems, if done properly, reduces pumping costs. However, low-pressure systems require sprinkler heads (water-emitting devices) that usually have a smaller radius of throw that results in higher instant application rates (Figure 1). Higher application rates for lower pressures is the main trade-off between high- and low-pressure systems. However, there are several other factors to consider if you change from high- to low-pressure systems or to LEPA systems. Table 3 summarizes the trade-offs between high-, low- and LEPA-pressure systems. Table 3 also compares the energy costs for a typical center-pivot with an irrigation efficiency of 85 percent. Energy costs were calculated using the following equation:

$$\text{Energy Cost (\$)} = \frac{A \times I \times P \times C \times 0.2}{E_i \times E_p}$$

where:

- A = irrigated area (acres)
- I = net water requirement (inches)
- P = pressure required for lift and pressurization at the pivot (psi) (to convert lift from feet to psi divide by 2.31)
- C = cost of electricity (\$/kwh)
- E_i = irrigation system efficiency (fraction)
- E_p = pump plant efficiency (fraction)

Table 3 shows irrigation efficiencies with high uniformity (no runoff) for three typical sprinkler packages. If irrigation efficiency increases by 10 percent (for example, when changing from one system to the other) an additional 10 percent of the total energy costs is saved. The effectiveness and efficiency of an irrigation system greatly depends on management and operation. The designed irrigation system efficiency can be accomplished if the system is managed and operated properly. If not, expect lower irrigation efficiencies and higher pumping and other costs. In many instances, conversion to low pressure may increase energy costs if runoff losses increase.

Once designed and installed, the only system parameter you can control in a center-pivot is the speed of travel. The speed of travel regulates the application depth. The faster the speed of travel, the lower the application depth. By controlling the speed of travel you can alleviate runoff problems. However, a practical lower limit to the application depth exists. Application depths lower than 1/4 inch are not very effective. The result is little contribution to the soil water storage.

Important components of proper irrigation systems management are irrigation scheduling and monitoring the depth of applications. This ensures that you don't over-irrigate or under-irrigate. Do not operate high-pressure center pivot systems under windy conditions. Give consideration to the soil water-intake rate that can be reduced through soil sealing caused by the impact of big water droplets.

Runoff is the main management consideration for low-pressure center pivot systems. If these systems are used on low-intake rate soils or sloping terrain, apply tillage practices to catch water at the point where it hits the ground. The effect of elevation changes on water distribution uniformity along the lateral is more severe in low-pressure than high-pressure systems. For example, in a 35 psi system at the pivot and 20 psi at the last sprinkler, the discharge will drop 18 percent for a 15-foot rise in elevation. In a 75 psi system at the pivot and 45 psi at the last sprinkler, a 15-foot elevation rise will cause only 7 percent discharge drop. Application rates of low-pressure systems can vary and depend on nozzle placement and mode. LEPA nozzles have different modes of operation that can affect the application rate. A popular feature of the LEPA and LDN nozzles is the chemigation mode: it sprays an upward stream of water, washing insects off the lower side of the leaf, and applying chemicals to the under side of leaves.

If you convert an existing center-pivot system, you must consider changing pump characteristics. Each pump works most efficiently at a certain pressure and flow rate. Do not overlook changes in the pump if the conversion of an existing system changes the required pressure.

References

Information and data presented in this SIA were taken from papers published in the proceedings of the Central Plains Irrigation Short Course and from work that was done by the USDA-ARS Water Management Research group in Fort Collins.

Table 1: Required irrigation system capacity for three soils and three irrigation systems in gallons per minute per acre.

	Impact low angle 85%*	Spray nozzle 90%*	LEPA 95%*
Sand (2 in)	5.4	5.1	4.8
Loam (3.5 in)	4.6	4.3	4.1
Clay (5 in)	4.1	3.9	3.7

*Expected irrigation system efficiency.

Table 2: Required irrigation system capacities in GPM/acre for two probabilities with no down time and no runoff.

Probability	Available soil water will not be depleted more than 50% (1 year out of 100)			Available soil water will not be depleted more than 50% (1 out of 2 years)		
	Impact sprinkler 85%*	Spray nozzle 90%*	LEPA 95%*	Impact sprinkler 85%*	Spray nozzle 90%*	LEPA 95%*
Sandy	6.2	5.9	5.6	4.2	4.0	3.8
Loam	5.3	5.0	4.8	3.6	3.4	3.2
Clay	5.1	4.8	4.6	2.9	2.7	2.6

* Expected irrigation system efficiency.

Table 3: Trade-offs between high-pressure, low-pressure and LEPA systems.

System (pressure)	High	Low	LEPA
Typical pivot pressure (psi)	80	35	25
Application rate	Low	High	Very high
Droplet size	Large	Small	Variable
Evaporation and drift losses	Depends on wind speed	Small if using drop tubes	None
Potential runoff	Small	Moderate	Very high
Effect of elevation differences	Small	High	High
Energy Cost* \$ (lift of 200 feet)	\$13,530	\$10,465	\$9316
Energy Cost* \$ (lift of 400 feet)	\$20,164	\$17,100	\$15,950

* Pumping cost for applying 24 inches, system capacity 850 GPM irrigating 126 acres, pump efficiency 65 percent and power cost of \$0.07 kwh.