SPRINKLER PACKAGE WATER LOSS COMPARISONS

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INTRODUCTION

Sprinkler packages that are available and used in the Great Plains of the United States are widely varied from older impact heads to more modern spray heads or various rotator designs and have an assortment of application and/or placement modes. This paper will mainly address common sprinkler packages in use on center pivot sprinklers and linear (lateral move) machines. Sprinkler packages are designed and selected (purchased) for a variety of reasons. Often high irrigation uniformity and application efficiency are cited as priority goals in selecting a particular sprinkler package or sprinkler application method. In practice, many sprinkler packages can achieve the desired design and operational goals equally well at or near the same costs. Management, maintenance, and even installation factors can be as important as the selection of a package or application method.

This paper discusses the desired traits of various sprinkler packages and sprinkler application modes and discusses the anticipated water losses that might impact both irrigation uniformity and efficiency. In most cases “generic” descriptions are used rather than individual commercial names of sprinkler manufacturers. End-gun effects are not discussed or addressed to a significant degree.

TYPES OF SPRINKLER PACKAGES

Sprinkler Spacing

The first sprinklers used on center pivots were impact heads adopted from hand-move, portable sprinkler lines that had a large angle (~23 degrees from horizontal) of discharge to maximize the water jet trajectory. Many of these were single nozzle types, but some used double nozzles to improve the uniformity for the pattern. Early center pivot design sprinkler spacing was about 32 ft (9.8 m) with impact sprinklers while some later designs used a variable spacing (closer towards the outer end of the pivot). Two principal design modes were commonly used for these packages – 1) constant (uniform) spacing with variable nozzle diameters along the center pivot to vary the sprinkler discharge or 2) almost constant nozzle discharge and head selection with variable spacing (e.g., farther apart near the pivot point and closer together on the outer lengths of the pivot). It was common to mount larger sprinklers on the ends of the pivot (end guns) to cover more land area with a fixed pivot length. A third design mode – called the semiuniform spacing (Allen et al., 2000) is a combination of these two other design modes. The variable spacing mode is easier to apply to rotator-spinner-spray heads but complicates the center pivot pipeline design and the sprinkler package installation and maintenance. These spacing types are illustrated in Fig. 1.

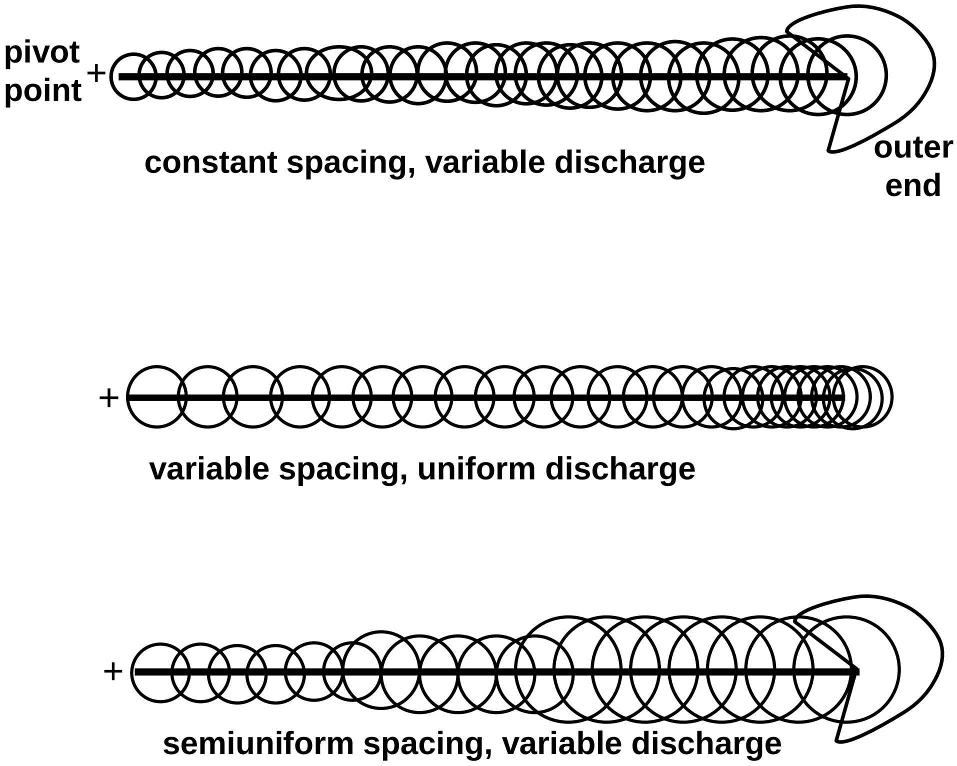

Figure 1. Diagram of typical sprinkler spacing and discharge designs. Modified and adopted from Allen et al. (2000).

The constant outlet spacing is quite common, particularly for closely spaced systems (~5 ft or 1.5 m) used with LEPA (low energy, precision application), LESA (low elevation, spray application), or LPIC (low pressure, in-canopy) methods of application. The sprinkler outlet spacing for non LEPA/LESA type systems with the constant spacing are often spaced up to 10 ft (3 m) apart. This spacing type is still used for pipeline mounted low angle impact sprinklers or spray heads on drops (typically mounted just below the truss rods). One concern with this spacing design can be the larger sprinkler discharge rate at the outer end requiring large nozzles with larger droplets. It can result in the requirement for higher operating pressures in some cases. These two factors — larger nozzles and higher operating pressures — can cause infiltration problems due to soil crusting and/or runoff difficulties from the high instantaneous application rates.

When LEPA and LESA are not used, the semiuniform spacing can rather conveniently be used with a 10 ft (3 m) outlet spacing uniformly along the pivot pipeline. Allen et al. (2000) suggested that the first third of the pivot length might use a 40 ft (12 m) sprinkler spacing, the middle third might use a 20 ft (6 m) sprinkler spacing, and the outer third might use a 10 ft (3 m) sprinkler spacing with the unused outlets plugged. This concept would also work with a 5 ft (1.5 m) outlet sprinkler spacing along the pipeline that might offer conversion options to LEPA, LESA, or LPIC application methods. This semiuniform spacing mode avoids many of the problems with larger nozzles.

The application uniformity will depend on many factors of the design and several operational factors (e.g., wind speed, pivot alignment and the wind direction, topography (tilt of the sprinkler axis in relation to the ground slope), effect on pressure at the outlet, etc., soil type, etc.) The main sprinkler factors affecting uniformity are the sprinkler spacing and the parameters associated with the sprinkler device type. These include its diameter of throw, application pattern type, operating pressure, nozzle and spray plate design, the elevation of the application device above the ground, and any crop canopy interference.

Sprinkler Types

Center pivot sprinklers can be classified generally into two broad types –impact sprinklers and spray heads. Within the impact type, nozzle angles can vary from the older type heads with higher trajectory angles (~23 degrees) to lower angle impact sprinklers (~6-15 degrees) that are typically mounted on top of the center pivot pipeline. Impact sprinklers are usually constructed using brass or plastic materials. They operate with a spring and heavy jet deflector arm with each arm return (from the spring) imparting a momentum to rotate the nozzle jet slightly. It may take up to 100 or more deflector arm returns to cause the impact sprinkler head to make a full rotation. The rotation speed depends on several design factors of the deflector arm; its mass and the bearing in which the sprinkler rotates. Nozzles can be simple “straight bore” types (that operate according to basic orifice principles where discharge depends on the nozzle diameter and the operating pressure) or can be of various design types that provide flow controls by compensating for alterations in the nozzle discharge –pressure relationship to provide a more constant discharge independent of the operating pressure. The operating pressure of most impact sprinklers is typically in the range of 25 to 40 psi (170 to 280 kPa), but the operating pressure is higher for larger sized nozzles. Impact sprinklers typically have a 3/4 in. NPT male end (18 mm), but some larger nozzles may require a 1 in. NPT (25 mm) size to reduce pressure losses across the pipeline mounting coupling.

Impact sprinklers have an advantage over lower pressure devices because they typically have a large radius of “throw”, thereby having a larger wetted area and smaller instantaneous application rate (equivalent to the “precipitation” intensity) that can more adequately match the soil infiltration rate with fewer runoff and erosion difficulties. Because they must rely on the hydrodynamics of the water jet and its breakup for the irrigation application and transport mechanism, they are affected to a greater degree by winds and subject to greater pattern distortions because of their higher application elevation above the ground or crop. Also, they typically have a higher pumping cost due to their greater operating pressure.

Spray heads are a much more diverse classification of application of devices. They can range from simple nozzles and deflector plates to more sophisticated designs involving moving plates that slowly rotate or types with spinning plates to designs that use an oscillating plate with various droplet discharge angles and trajectories. The rotator types are similar to small, low angle impacts sprinklers, except the sprinkler rotation is controlled by the nozzle jet with a hydraulic “motor.” Most spray heads have a near 360 degree coverage and can have deflector plates designed with differing groove sizes to affect the spray streams (deeper grooves with fewer jets to have larger diameter streams for windy applications, shallower grooves with more streams for smaller droplets, or flat to have a greater droplet diameter range), and they can have streams that are discharged almost horizontal (flat), upward (concave) or downward (convex) with downward orientated spray heads. They can be designed with plates that direct water streams upward at various angles for chemigation of tall or short crops. Spray heads can have partial coverage (i.e., not a complete 360 degree pattern), which are often used near towers to minimize track wetting. Spray heads can be mounted upward on the center pivot pipeline itself. On some linear (lateral move) machines, truss lateral manifolds with three to five spray heads may extend the wetting pattern to achieve a lower instantaneous application rate. Typically, spray heads are mounted on “drops” from “goose-neck” fittings that make a 180-degree bend from the top of the center pivot mainline. Wider “goose-necks” may be used to allow precise matching of LEPA or LESA drops to the furrows. These drops are basically constructed from flexible hoses. For longer drops (LEPA, LESA, or LPIC), the drop hose will typically have a weight (1-2 lb or 1/2 to 1 kg) to minimize swaying from the wind and assist in maneuvering through the plant canopy . Usually, the “goose-necks” and drops are installed on alternating sides of the center pivot pipeline. Figure 2 illustrates a typical LESA system with its drops.

Spray heads typically operate at pressures from 10 to 30 psi (70 to 200 kPa), but LEPA or LESA systems can operate at pressures as low as 6 psi (40 kPa). Lower pressure systems or ones with significant elevation changes are usually equipped with pressure regulators to achieve higher uniformities. Spray heads are often constructed from plastic, and the various parts are color-coded (varies by manufacturer). Allen et al. (2000) describes many of the common types of spray heads from several manufacturers and their characteristics. Table 1 provides a summary of some of the typical sprinkler heads used on center pivots. The list of advantages and disadvantages is intended solely as a guide, and individual situations may have unique situations not characterized here. Readers are encouraged to seek local advice from technical advisors (e.g., irrigation dealers, irrigation extension specialists, consultants, county extension agents, USDA-NRCS specialists, etc.) before making any sprinkler design selection or changes. Figure 3 illustrates the relative application rates under various sprinkler types after (King and Kincaid (1997). The values in Fig. 3 are conceptual. The peak application rate linearly increases along the center pivot radius and is maximum at the outer end. The X-axis presented as a distance scale in Fig. 3 can be converted to a time scale based on the speed of the center pivot at that

Figure 2. Typical example of a LESA system with spray heads on drops spaced 5 ft (1.5 m) apart).

Table 1. Characteristics of common center pivot sprinkle types.

Sprinkler Type	Pressure Range psi (kPa)	Typical Height ft (m)	Advantages	Disadvantages
Impact, high angle	25-50 (170-300)	6-15 (1.8-4.5)	Low application rate.	High energy requirement. Exposure to wind effects.
Impact, low angle	25-35 (170-250)	6-15 (1.8-4.5)	Low application rate.	High energy requirement. Still impacted by winds.
360°Spray head, Rotator, Spinner; high location	10-30 (70-200)	6-15 (1.8-4.5)	Lower energy requirement. Closer spacing.	High application rate. Only over canopy chemigation.
360°Spray head, low location LESA or LPIC	10-30 (70-200)	1-6 (0.3-1.8)	Lower energy requirement. Less wind effect. Close spacing. Some have LEPA drag hose adapters. Under canopy chemigation.	High application rate.
Low Drift and Multiplate Spray Heads	10-30 (70-200)	Varied Pipeline Truss Level. LPIC	Lower energy requirement. Lower drift and wind effects. Many configurations. Some have LEPA drag hose adapters and chemigation plates.	High application rate.
Rotator	15-50 (100-300)	Varied. Pipeline. Truss Level. LPIC	Larger wetted diameter, lower application rate. Good resistance to wind effects.	Can have higher energy requirement. Limited in-canopy chemigation applications.

Table 1 (Continued). Characteristics of common center pivot sprinkle types.

Sprinkler Type	Pressure Range psi (kPa)	Typical Height ft (m)	Advantages	Disadvantages
Spinners	10-20 (70-150)	Varied. See Rotators	Low energy requirement. Gentler droplet applications.	Limited in-canopy chemigation applications.
Oscillating/Rotating Spray Plates	10-20 (70-150)	3-6 (0.9-1.8)	Low energy requirement. Low misting from small droplets. Low application rate and gentler applications.	Limited in-canopy chemigation applications.
LEPA Bubble	6-10 (40-70)	1-3 (0.3-0.9)	Low energy requirement. Usually, alternate furrow applications and less evaporation. Multi purpose (convertible from spray to bubble to drag sock). Excellent in-canopy chemigation options.	Extremely high application rate. Requires furrow dikes or surface storage (~1-2 in., 15-50 mm of water volume).
LEPA Drag Sock	6-10 (40-70)	0 (0)	See LEPA Bubble. Less erosion of furrow dikes.	See LEPA Bubble.

point (e.g., divide the distance wetted by the speed (ft/hr) to achieve the time course of the application as the pivot passes a particular point). The area under each of the transformed curves will be a constant along the center pivot's length representing the application amount (in. or mm).

Sprinkler Application Modes

The application modes for center pivot “sprinkler packages” can be described as either 1) overhead or over-canopy methods or 2) near-canopy or in-canopy methods. The sprinkler type selected is influenced by the mode of the desired application method. The mode and sprinkler type may influence the required spacing. Thus, these are not independent alternatives. Hence, they have been called “sprinkler packages” because all aspects of design, installation, maintenance, and management affect the “package” performance.

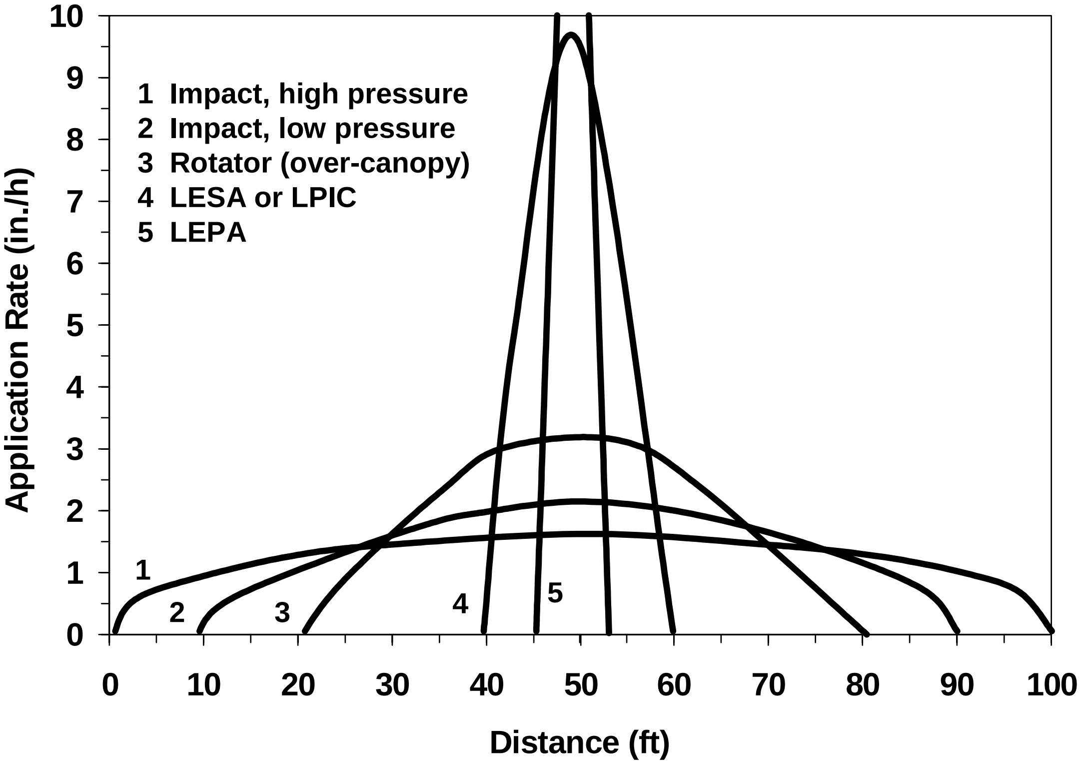

Figure 3. Illustration of the relative application rates for various sprinkler types under a center pivot. Modified and adopted from King and Kincaid (1997). The LEPA application rate is difficult to show because it is essentially a “point” discharge, and its peak was illustrated to exceed the rate range of this graph.

The overhead or over-canopy methods are those application types mounted on the center pivot pipeline itself or those mounted on drops that are typically just below the truss rod elevation above ground. Of course these descriptions are still arbitrary depending on the system height and the crop height. One of the main decision factors for this mode is whether only overhead or over-canopy chemigation is desired or if no chemigation option is desired. Impact sprinklers, spray heads, and rotators are typically considered for this application mode. This mode and application method is well suited to rolling topography, low intake soil types, and crops tolerant of overhead wetting.

The near- canopy or in-canopy application methods are always mounted on drop tubes from the center pivot mainline. The main difference is whether the sprinkler devices are mounted near the ground (LEPA or LESA), within the crop canopy or the mature crop canopy (LPIC), or just above the maximum height of the crop. Of course, a LPIC system designed for a tall crop may not be a LPIC system in a shorter crop (e.g., a corn LPIC system will not be a LPIC system in cotton, peanut, or soybean crops; Fig. 4). For that reason, we (USDA-ARS Bushland) have preferred to use the name — LESA for a system with the spray heads

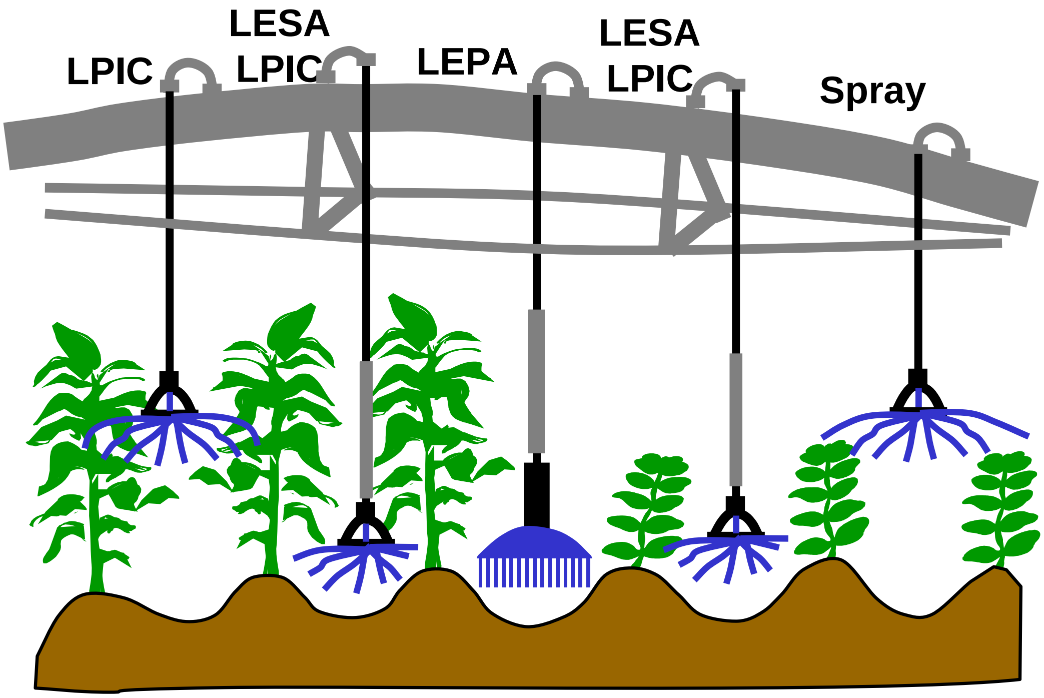

Figure 4. Illustration of the LEPA, LESA, LPIC, and spray application concepts in tall and short crops. The illustration has drops in each furrow to conserve space while actual systems typically use drops in alternate furrows either 60-in. or 80-in. (1.5-m or 2-m) apart depending on the crop row spacing.

mounted 1-2 ft (0.3-0.6 m) above the ground or MESA (mid elevation spray application) for a system with spray heads mounted 5-8 ft (1.5-2.4 m) above the ground. The name LEPA should only be used for a system with bubblers (e.g., an adjustable multi-purpose head) or drag socks mounted on a flexible hose. LEPA hoses can be attached with commercial adapters to many types of spray heads whether the spray heads are mounted low near the ground like LESA or at a higher elevation like a LPIC or MESA system. Although Lyle and Bordovsky (1981) originally used LEPA in every furrow, subsequent research (Lyle and Bordovsky, 1983) demonstrated the superiority for alternate furrow LEPA. The reasons aren't always evident, but they may result from the deeper irrigation penetration (twice the volume of water per unit wetted area compared with every furrow LEPA), possible improved crop rooting and deeper nutrient uptake, and less surface water evaporation (~30-40% of the soil is wetted). LEPA and LESA work best with either LEPA heads or 360° spray heads. These systems (LEPA or LESA) also have flexibility to chemigate either a tall crop (e.g., corn) or shorter crops (e.g., sorghum, soybean, wheat, cotton, or peanut). LPIC and MESA systems have the conversion potential to LEPA, but they don't have the under canopy chemigation potential of LEPA or LESA systems. LEPA and LESA systems are typically located in or above alternate furrows or between alternate rows if furrows are not used. LEPA requires a furrow with furrow dikes according to the concepts described by Lyle and Bordovsky (1981) while LESA can be effective without furrows in no-till or conservation till systems. This doesn't imply LEPA heads cannot be used without furrow dikes, but it shouldn't be described as "LEPA". LPIC or MESA systems are typically spaced for a desired uniformity and may not be bound by the row spacing. LPIC systems may require a narrower spacing to compensate for crop interference (Spurgeon et al., 1995).

Lyle and Bordovsky (1981) developed the LEPA concept as a "system" comprising irrigation combined with furrow diking (basin tillage). In fact, all advanced center pivot sprinkler application packages need to be incorporated into a complete agronomic package involving tillage, controlled traffic, residue management, fertility, harvesting, etc. (Fig. 5). Table 2 summarizes several of the typical center pivot "sprinkler packages" and their "system" components.

WATER LOSS COMPARISONS

The efficiency of an irrigation application depends on many factors. The water losses depend on the application technology and operation and include other agronomic cultural aspects. The interpretation and characterization of water loss estimates or measurements involves the conservation of mass applied to sprinkler irrigation as outlined by Kraus (1966). He presented the components as

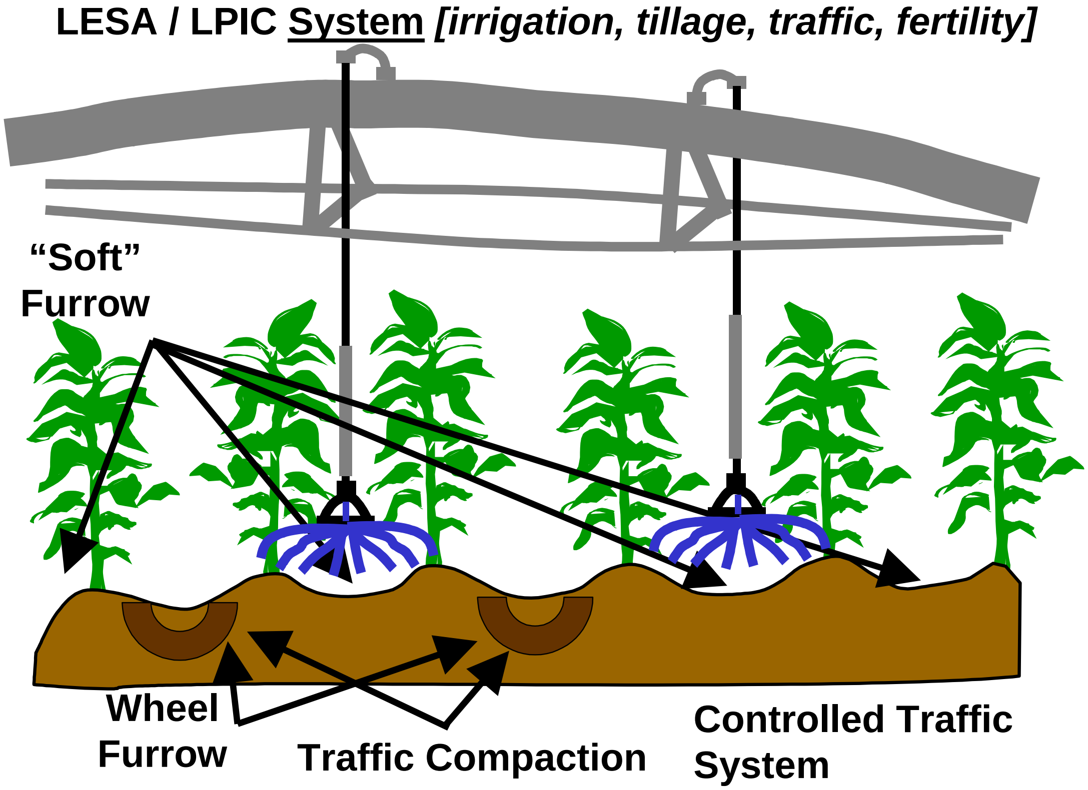

Figure 5. Illustration of the "agronomic system" concept involving irrigation, controlled tillage, fertility, etc.

$$Q_s = Q_{ae} + Q_{ad} + Q_{fi} + Q_{gi} \qquad \text{...[1]}$$

where Q_s is the sprinkler discharge, Q_{ae} is the droplet evaporation during travel from the nozzle to the target surface, Q_{ad} is the water drift outside the target area, Q_{fi} is the intercepted water on the foliage, and Q_{gi} is the water reaching or intercepting the ground. The units for these components can be expressed on a rate, mass, or volume basis. Q_{fi} represents the sum of water evaporated from foliage at the end of then irrigation (Q_{fs}). The water reaching the ground (a defined unit area) can be partitioned into its components characterized as

$$Q_{gi} = Q_{si} + Q_{ge} + Q_{gs} + Q_{gwe} + Q_{gri} + Q_{gro} \qquad \text{...[2]}$$

where Q_{si} is the infiltrated water, Q_{ge} is the water evaporated from the ground during the irrigation, Q_{gs} is the water stored on the ground during the irrigation, Q_{gwe} is the water evaporated from the water stored on the ground prior to infiltration during irrigation, Q_{gri} is the water that runs onto the unit area, and Q_{gro} is the water that runs off the unit area. In its simplest case, irrigation application efficiency is the ratio Q_{si}/Q_s because percolation beneath the root zone can

Table 2. Example sprinkler packages with desired tillage and agronomic systems.

Sprinkler Package	Tillage System	Agronomic System
Overhead		
Impact Sprinklers Rotators, Spinners	Any	Any
MESA or Spray	Any. Controlled traffic desired. Basin tillage with ridge-till, reservoir tillage with or without beds. No-till, ridge-till, or conservation till compatible.	Any
Within canopy		
LPIC 360° Spray head Low drift head Spinner Oscillating plate	Any. Controlled traffic desired. Basin tillage with ridge-till, reservoir tillage with or without beds. No-till, ridge-till, or conservation till compatible.	Any
LESA 360° Spray head Low drift head Spinner	Any. Controlled traffic desired. Basin tillage with ridge-till, reservoir tillage with or without beds. No-till, ridge-till, or conservation till compatible.	Any, circular rows desired
LEPA (bubble)	Controlled traffic desired. Basin tillage with ridge-till, reservoir tillage with beds.	Circular rows
LEPA (drag socks)	Controlled traffic desired. Basin tillage with ridge-till, reservoir tillage with beds. (basin tillage is more effective)	Circular rows

usually be ignored. Percolation beneath the root zone depends on irrigation scheduling and other water management issues. Percolation can be significant in low lying areas in the field that accumulate runoff from upland areas.

Generally for a center pivot, drift outside the area is small and is often ignored; however, it could be more significant with systems equipped with end guns or in extremely high wind situations. Typically, irrigation application efficiency can only be measured after the water application has been completed and perhaps several hours after the irrigation (perhaps a day later). Dynamic measurement of these various components is practically impossible, and their “static” measurement remains complex in most cases unless major simplifications are used. Sprinkler applications usually involve water transport through the air and the integral vapor transfer of water vapor into the atmosphere through the evaporative process affect the Q_{ae}, Q_{fe}, and Q_{ge} components. For methods that wet the foliage, transpiration will decline, and generally the “net” evaporation (evaporative loss offset by the reduced transpiration) is the component of interest. Also, the movement of the water vapor downwind humidifies the drier air reducing the crop evapotranspiration rates, even before the area is wetted by the irrigation. In addition evaporation continues after the completion of the irrigation event from the foliage intercepted water (Q_{fi}) and surface storage water (Q_{gs}) and the evaporation from the ground during the irrigation (Q_{ge}) and

Table 3. Water loss components associated with various sprinkler packages.

	Sprinkler Package			
Water Loss Component	**Overhead**	**MESA or Spray**	**LESA LPIC**	**LEPA**
Droplet evaporation	Yes	Yes	Yes	No
Droplet drift	Yes	Yes	No	No
Canopy evaporation	Yes	Yes	Yes, (not major)	No, (chemigation mode only)
Impounded water evaporation	No	Yes	Yes	Yes, (major)
Wetted soil evaporation	Yes	Yes	Yes	Yes, (limited)
Surface water movement	No, (but possible)	Yes, (not major)	Yes	Yes, (not major)
Runoff	No, (but possible)	Yes	Yes	Yes, (not major unless surface storage is not used)
Percolation	No	No	No	No

following the event (Q_e, total evaporation of water from the ground surface). At the typical observation time, the intercepted water on the foliage and the ground will already have evaporated and these amounts are largely unknown, except by some inference methods (qualitative comparisons; e.g., estimating Q_{ge} from evaporation from an "open" water body near the site). Table 3 outlines the possible water loss components common for various sprinkler packages. Howell et al. (1991) reviewed many of the studies that had measured evaporative losses from sprinkler systems, especially those using lysimeters. They noted the great difficulty in making measurements of evaporative losses, but they found major differences in the application losses for differing sprinkler methods – low angle impacts, LEPA, and over canopy spray (MESA or LPIC) due to their different wetted times, differing wetted surfaces (e.g., LEPA only wetted a small portion of the soil surface with minimal or no canopy wetting). Tolk et al. (1995), using measured corn transpiration, found net canopy evaporation of intercepted water was 5.1 to 7.9% of applied water for a one-inch (25-mm) application volume. McLean et al. (2000) reviewed several past evaporation studies and evaluated above canopy evaporation losses from center pivots using the change in electrical conductivity of sprinkler catch water as an indicator of evaporation. They reported impact and spray losses from –1 to 3%. The negative losses were attributed to atmospheric condensation on the droplets due to the cool groundwater temperatures that were less than the atmospheric dew point temperature. Schneider (2000) reviewed the evaporation losses from LEPA and spray systems (LESA, LPIC, and MESA types). He summarized the limited studies reporting "net" canopy evaporation that had values ranging from 2 to 10% (some of these were simulated and/or based on a theoretical model). Evaporation from LEPA systems ranged from 1 to 7% of the applied amounts with application efficiencies ranging from 93 to 100%. His review of evaporation losses from spray irrigation studies had values that ranged from 1 to 10%, while their mean application efficiencies ranged from 85 to 100%.

Surface water redistribution (runoff from one area to a lower area but not perhaps leading to runoff leaving the field) and field runoff should not occur in most cases. Yet, they regularly happen and affect the infiltration uniformity, deep percolation, and ultimately the efficiency of the application. Spray systems (LESA, LPIC, or MESA) or LEPA systems (despite the use of surface tillage designed to enhance surface water storage volume) are most prone to runoff problems. Soil type and slope play a central role in the surface water redistribution and runoff potential of a particular site in addition to the sprinkler package and system capacity (system flow rate per unit area) (Fig. 6). Either surface storage (basin or reservoir tillage) or crop residues from no-till or profile modification tillage (chiseling, para-till, etc.) may be needed to reduce or eliminate surface water redistribution and runoff. Increasing the system speed (decrease the application depth) generally reduces the potential runoff volume but may affect the "effective percolation" of the applied water. Both water redistribution and field runoff that occur from rainfall can further impact irrigation water requirements. Few studies are published on rainfall runoff from sprinkler-irrigated fields or that have measured the total season water balance components.

Schneider (2000) reviewed many of the previous studies on irrigation runoff and surface storage as influenced by tillage systems for LEPA and spray application methods. Runoff or water redistribution without basin or reservoir tillage ranged from 3 to over 50% in several studies with the greatest runoff losses occurring from LEPA modes without basin tillage (most in the bubble mode). LEPA applications in alternate furrows will require twice the storage volume needed for equivalent LESA or LPIC systems (representing full wetting like rain or MESA). Runoff from LESA or LPIC systems may be critical on steeper slopes (>1-2%), low intake soils (heavier textures like clay loams), and higher capacity systems (>6 gpm/ac or 0.32 in./d or 8.1 mm/d).

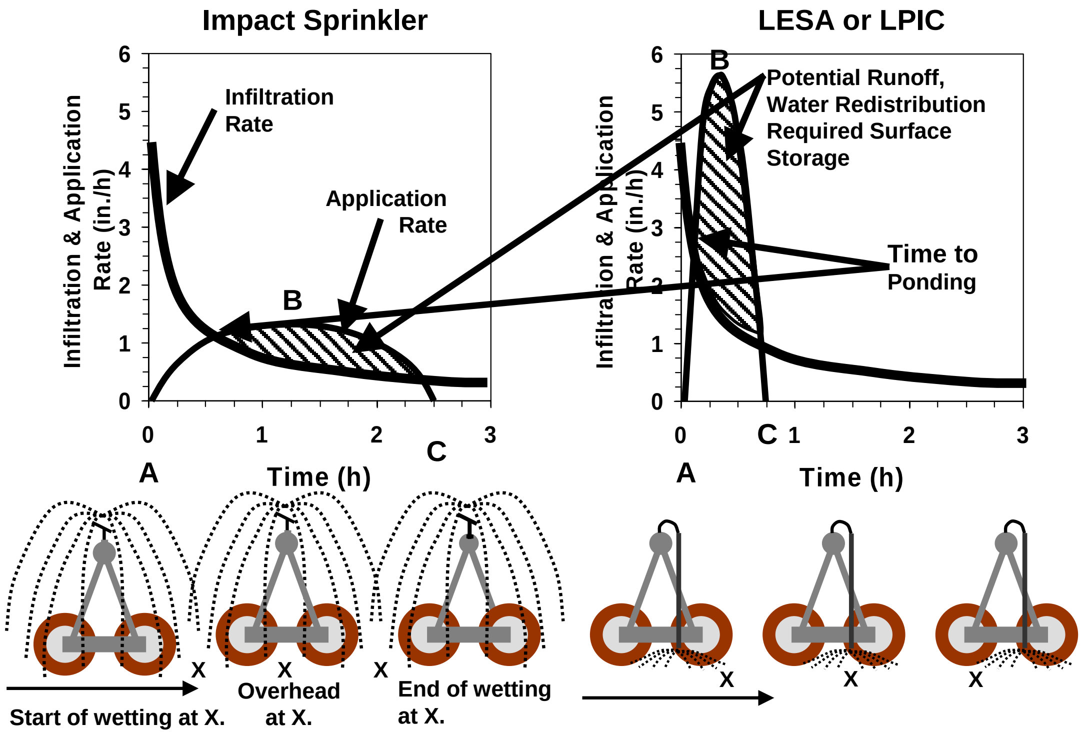

Figure. 6. Illustration of runoff or surface water redistribution potential for impact sprinkler and spray (LESA or LPIC) center application packages for an example soil. (A) represents the start of the irrigation, (B) is the peak application rate (usually when the system is directly overhead), and (C) is the completion of the irrigation**.** The first intersection point of the infiltration curve and the application rate curve represents the first ponding on the soil surface.

CONCLUSIONS

The sprinkler package is a combination of the sprinkler applicator, the application mode, and the applicator spacing. The system capacity determines the peak application rate of the particular sprinkler application package. The sprinkler package should be designed together with the tillage and agronomic system of the operator. The particular soil and slope conditions will define the infiltration rate. The intersection area between the infiltration curve and the application rate curve illustrates the “potential” runoff or surface water redistribution that may require surface storage from basin or reservoir tillage needed to reduce or eliminate runoff from LESA, LESA, or LPIC systems.

The type of sprinkler applicator and the mode of application determine the particular components of water losses. “Net” canopy evaporation may be in the 5-10% range. Overall evaporation losses in several cases ranged between 10-20%. Irrigation efficiency of LEPA systems without runoff were in the 93 -99% range, but without basin tillage, LEPA systems in several cases had large runoff (or surface water redistribution) amounts. LESA or LPIC systems can be efficient with evaporative losses less than 10% in most cases, particularly with basin, reservoir tillage or with a no-till system.

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