The More You Expose, the More You Lose: Limiting Center Pivot Irrigation Water Losses

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Abstract

This is written for farmers, and water managers and planners to discuss the very significant water losses from sprinklers to wind drift and evaporation. The relationships between these losses and sprinkler nozzle size, pressure, and weather conditions are shown. Growers are encouraged to move sprinklers closer to the ground and choose sprinkler configuration settings that allow water droplets as large as possible and reduce air and wind exposure without compromising irrigation uniformity or creating runoff problems.

Figure 1. Mid Elevation and Low Elevation Spray Application (MESA and LESA). The difference in wind drift between the two systems is clearly visible. Losses from the droplets to evaporation are not visible (water vapor is transparent).

Introduction

Growing food takes a huge amount of water. Although we do not interact with it in our homes, approximately 95% of the water needed to support us is used to grow the food we eat. Agricultural irrigation accounts for about 90% of the water diverted from streams or rivers or pumped from groundwater. However, unlike water that is used in our homes where most of it goes down the drain and is cleaned up and returns to streams or groundwater, irrigation water is almost 100% consumptively used (evaporates) and does not return to local water sources. Although low water use appliances and turning the water off while brushing your teeth is important for water conservation, and especially to municipal water suppliers, it is a comparative drop in the bucket compared to the importance of irrigation efficiency and irrigation water management.

Washington has about 1.8 million acres of irrigated agricultural land including commercial and residential landscapes (Lane and Welch, 2015). 80% of this area is irrigated by sprinklers, and about 80% of the sprinklers are center pivots or linear moves.

Sprinkler Irrigation Losses

Sprinklers send water under pressure through nozzles of different diameters and ejects the water into the atmosphere with a speed that depends on the pressure at the nozzle. The sprinkler can distribute the water onto the ground in the form of a single or multiple rotating streams. As this water stream passes through the atmosphere it is often dispersed into small droplets because of the friction between the air and the water (Figure 2).

Figure 2. Water break-up on leaving an impact sprinkler.

As the water travels through the air some of it is lost to wind drift and evaporation. The more the water is exposed to the air, the more is lost. Therefore, the amount of loss and the water distribution pattern of a sprinkler depend very much on the nozzle type, the height from the ground, the operating pressure, and the weather conditions. The losses due to different operating conditions, and the methods for estimating these losses were compiled in monographs by (Frost, and Schwalen, 1955). These were used to estimate the sprinkler losses due to sprinkler nozzle size (Figure 3), pressure (Figure 4), and weather (Figure 5) as discussed below.

Sprinkler Nozzles

At the same pressure, smaller diameter nozzles tend to break the water up into smaller diameter droplets. Many smaller droplets result in more of the water's surface area being exposed to the atmosphere compared to the same volume of water but with larger droplets. The smaller droplets also are more influenced by the wind. Both result in greater water loss to wind drift and evaporation (Figure 7).

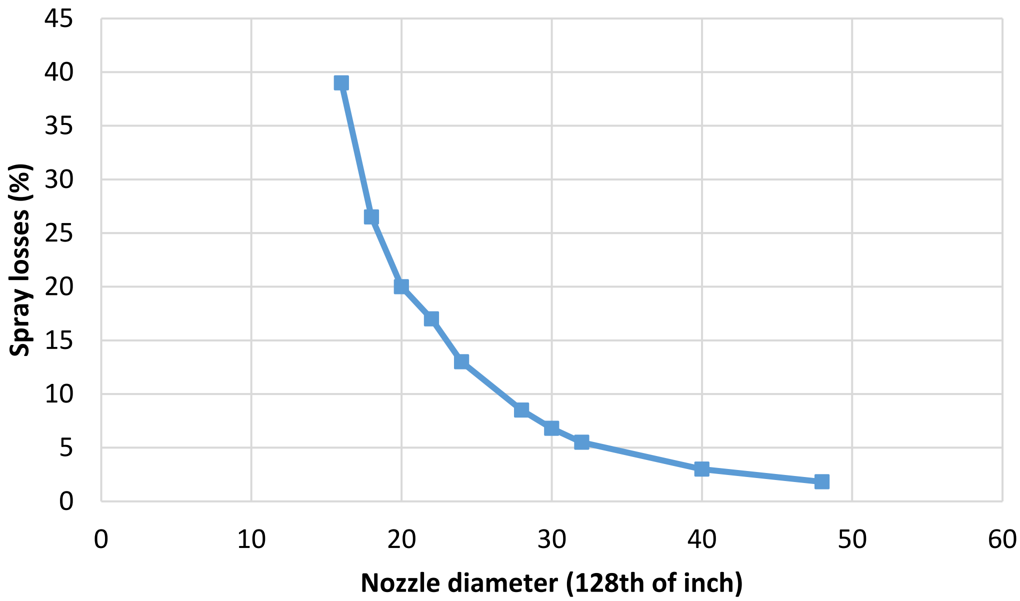

Figure 3. Calculated spray losses versus nozzle diameter for July at 20psi nozzle pressure at Prosser, WA.

Operating Pressure

The effect of the sprinkler operating pressure on spray losses is less than other factors. However, extreme variations of pressures change the rate of spray losses because higher pressures create greater water velocities through the nozzle and greater water droplet breakup after leaving the nozzle resulting in more, smaller droplets. In contrast, low pressure sprinklers tend to produce fewer, but larger droplets and therefore less water loss (Figure 4).

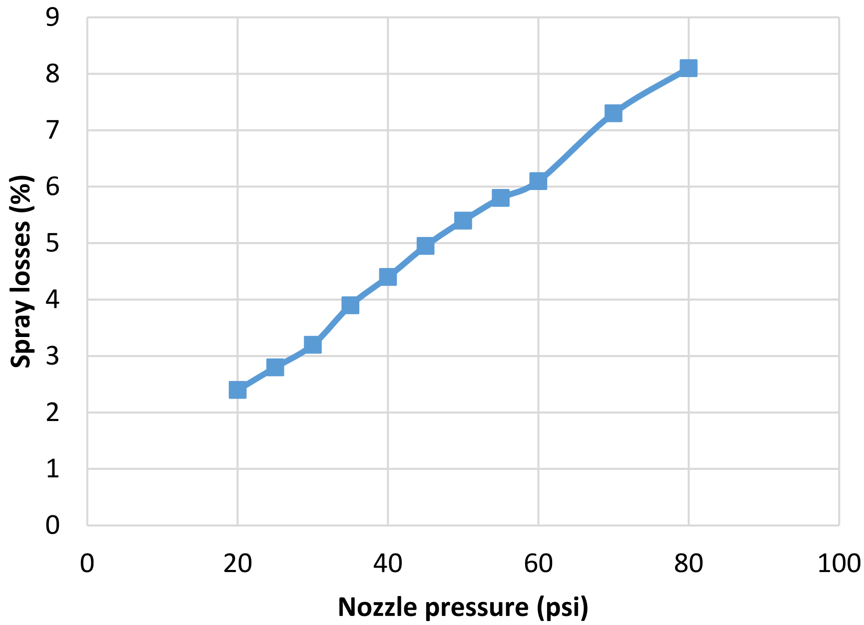

Figure 4. Calculated spray losses against nozzle pressure for July climate with nozzle #22 at 20 psi pressure in Prosser, WA.

Weather Conditions

The energy to evaporate water from droplets flying through the air comes primarily from the heat in the air (air temperature). Wind speed increases the exposure of the water droplets to more air for evaporation in the same way a hair drier accelerates the evaporation of water from your hair. The amount of water in the air (water vapor) compared to how much water the air can hold at that same temperature (relative humidity, or vapor pressure deficit) also affects the rate that water is evaporated from flying water droplets. All these unfortunately combine to make sprinkler irrigation water losses greatest during the times of greatest crop water demand and the greatest water shortages, i.e. the middle of the summer (Figures 5, 6, and 7).

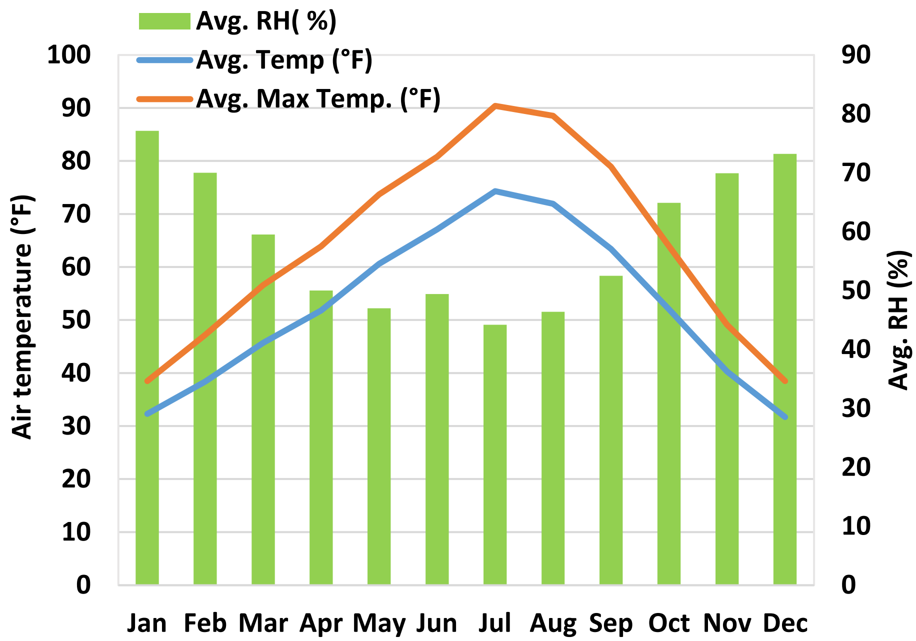

Figure 5 Long term average air temperature (Ta) and relative humidity (RH) for Prosser, WA. July is the warmest month.

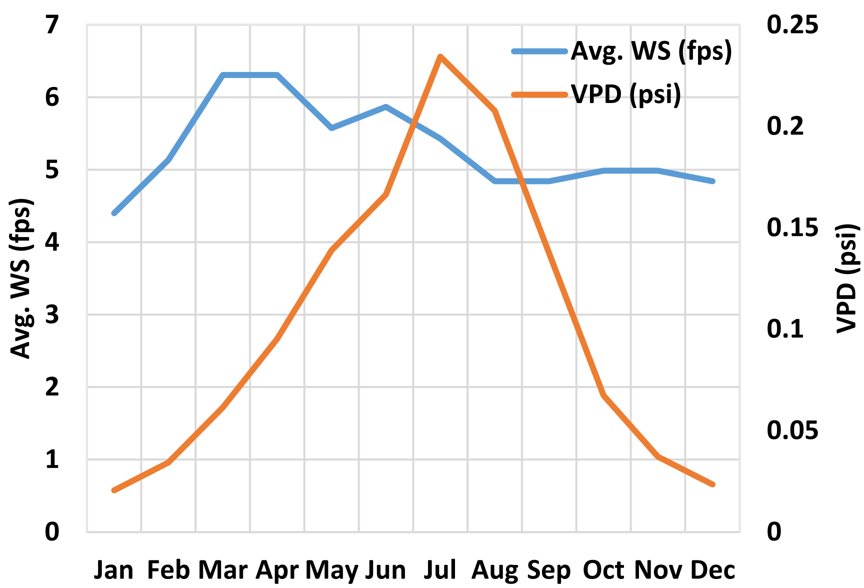

Figure 6 Long term average wind speed (WS) and vapor pressure deficit (VPD, a measure of aridity) for Prosser, WA.

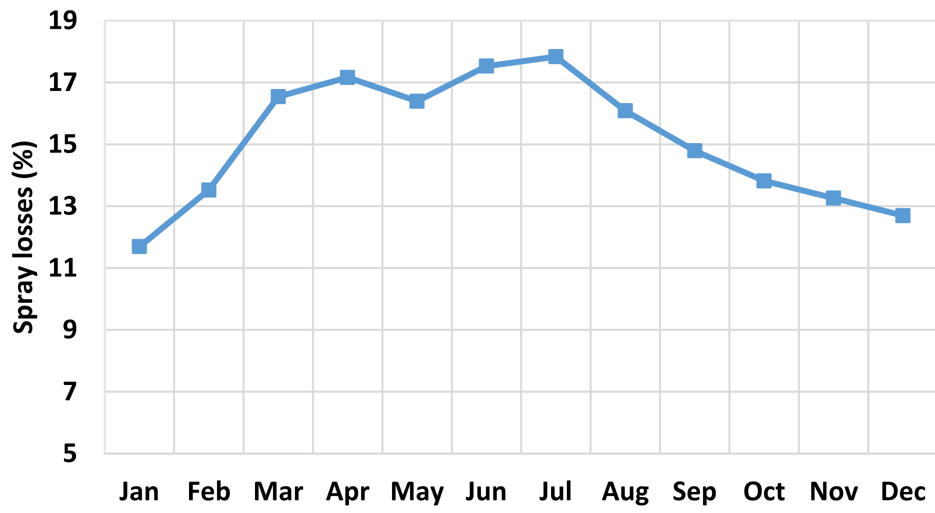

Figure 7. Spray losses for long term averages of the entire year at 20 psi nozzle pressure and #22 nozzle in Prosser, WA.

Although the wind drift of small droplets is slightly visible (appears as a haze), water vapor is not. Because of this, the large losses of irrigation water to evaporation are not visible to the eye, and consequently most people do not think about these very significant water losses (up to 40% in some cases).

For all of the reasons discussed above drip irrigation, and sprinklers that operate very close to the ground, like low energy precision application (LEPA) and low elevation spray application (LESA) on center pivots, are much more efficient than most sprinkle irrigation. Standard impact sprinklers are less efficient, and big gun sprinklers are often tested to be the least efficient (Table 1).

Table 1. Average water loss (%) from different irrigation systems

Sprinkler irrigation type	**Typical measured water losses (%)**
Drip (surface)	2-3
Drip (subsurface)	0
Micro-spray	15
Big guns	40
Impact sprinklers on hand lines and wheel lines	30
Center pivot with impact sprinklers on the top of the pipe	40
Center pivots with mid elevation spray application (MESA)	10-20
Center pivots with LESA/LEPA	2-5

Water Application Relative to the Target

The more air that a droplet is exposed to, the more water will be evaporated from that droplet before it can move into the soil where it is much more protected from evaporation and the crops roots can absorb it. Droplets from sprinklers mounted closer to the ground spend much less time in the air and therefore have less evaporation (Figure 8). Also, wind speed decreases with height from the soil (Figure 9). Water is also evaporated from a wet crop canopy. Thus, irrigation systems such as LEPA/LESA (Figure 1) that apply water very close to the ground, and often below the top of the canopy will be much more efficient than typical mid elevation spray application (MESA) sprinklers, especially if the LEPA/LESA sprinklers are operating below the canopy.

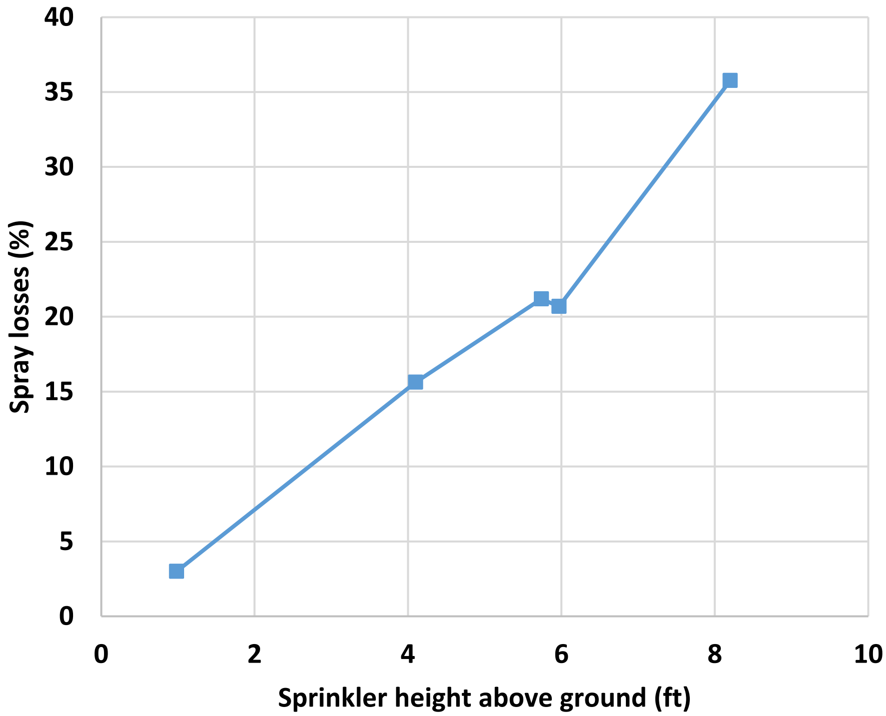

Figure 8. Spray losses against sprinkler height from the ground adapted from (Abo-Ghobar, 1992; Sarwar et al., 2018).

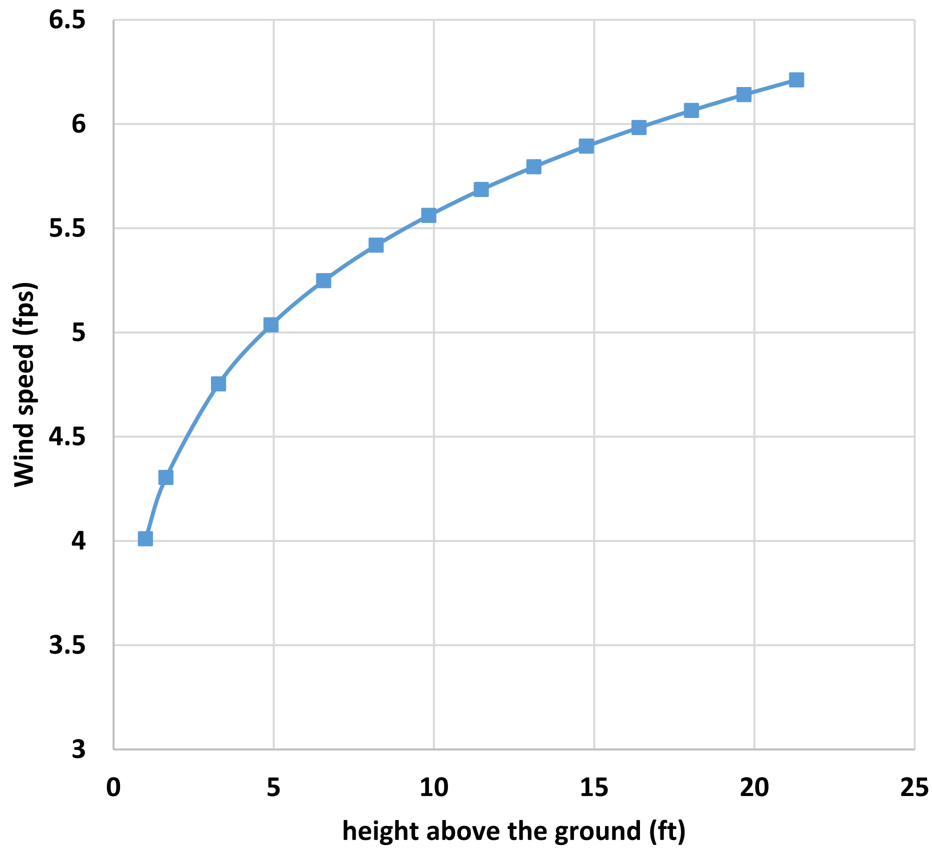

Figure 9. Wind speed measurement at different heights above the ground for Prosser, WA (“Wind profile power law,” 2017).

How to Measure Sprinkler Irrigation Losses

Wind drift and evaporation losses are the difference between the amount of water that would get to the ground if there were no losses (d_{gross} in inches) and the net amount that can be collected on the ground (d_{net} in inches). We can use the sprinkler nozzle flow rate to calculate d_{gross} for a center pivot as follows:

$$d_{gross} = \left[\frac{1.604 * q_{avg}}{L * S}\right] \quad (1)$$

where, q_{avg} is the discharge in gallons per minute (gpm) from each nozzle, L is spacing between sprinklers in ft and S is the speed of the moving irrigation system (pivot) in ft/min. The nozzle flow rate can either be measured directly using a graduated cylinder and a stopwatch (be sure to not lose any water out of the cylinder) as shown in Figure 10, or it can be approximated from the pressure and the sprinkler manufacturer’s performance tables.

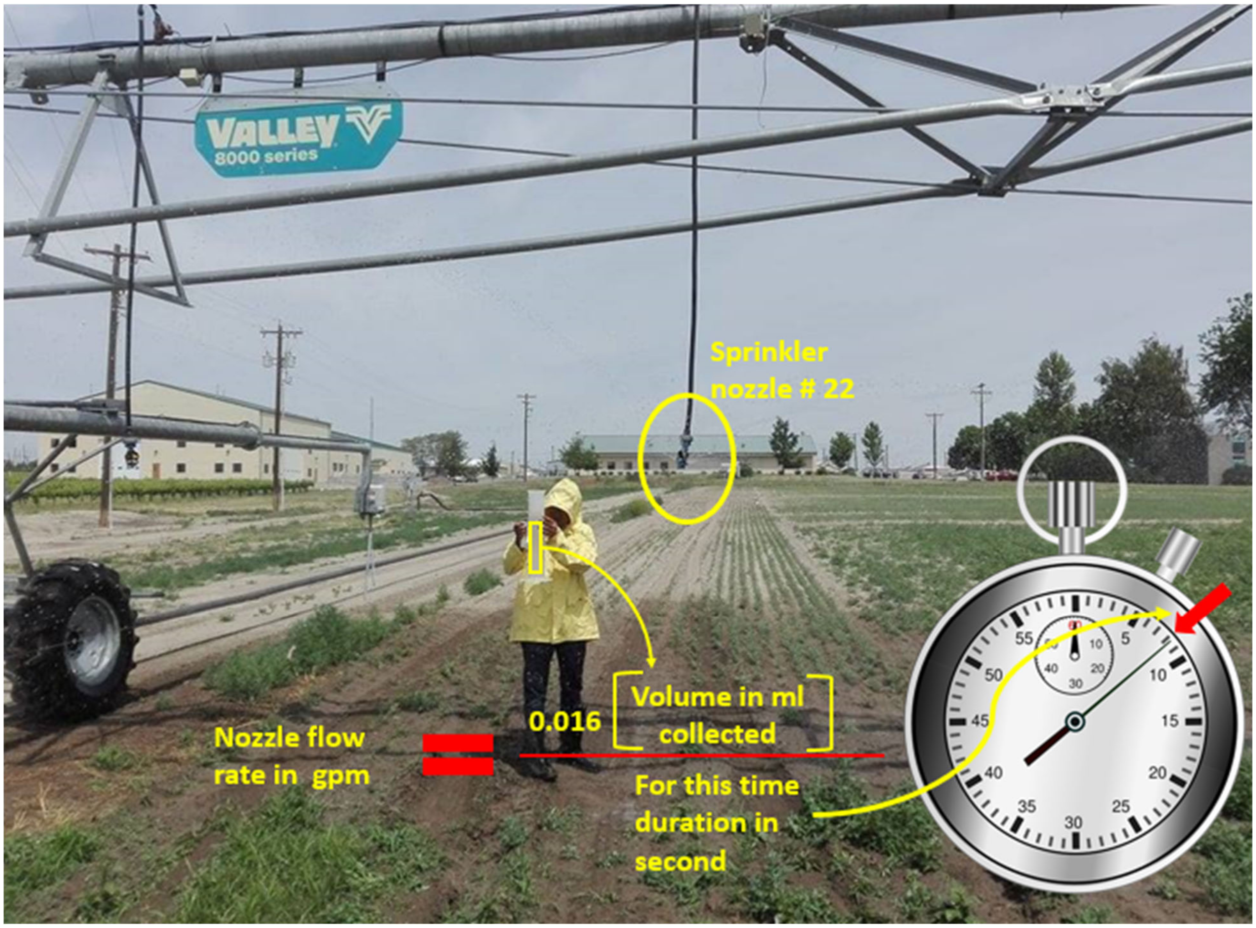

Figure 10. Nozzle pressure measurement for center pivot/linear move irrigation systems.

We can use the catch can method (Figure 11) to find the average depth of water that makes it to the ground. Place the catch cans about 10 ft apart and run the system over the cans for known amount of time and pivot speed (percent setting). It will be important to accurately measure the pivot speed since it greatly affects Equation 1. Record the volume of water in each can and take the average then convert this to depth of water applied (in inches). You will need to measure the catch can opening diameter. For example: if using a 4 inches diameter catch can and the average collected volume in the cans was 60 ml then,

$$Area\ of\ catch\ can\ (in^2) = \frac{3.14 * (catch\ can\ diameter\ in\ inches = 4.00)^2}{4}$$

$$depth\ of\ water\ (d_{net}\ in\ inches) = \frac{0.061 * (avg.volume\ collected\ in\ catch\ cans = 60.0\ ml)}{Area\ of\ catch\ can\ (in^2)}$$

$$depth\ of\ water\ (d_{net}\ in\ inches) = 0.29\ in$$

The percent spray losses from evaporation and wind drift can be calculated using Equation (3).

$$Spray\ losses\ (\%) = \left[\frac{d_{gross} - d_{net}}{d_{gross}}\right] * 100 \quad (3)$$

Irrigation application efficiency (E_a) is also calculated as:

$$E_a\,(\%) = \frac{d_{net}}{d_{gross}} * 100 \qquad (4)$$

Figure 11. Catch can method to estimate the sprinkler water losses.

How to Increase Center Pivot Efficiency and Reduce Spray Losses

To increase center pivot efficiency and reduce spray losses, move sprinklers as close to the ground as possible, decrease pressure, increase nozzle sizes, and choose sprinklers that throw large droplets without compromising irrigation water distribution uniformity and runoff. This has the potential to save large amounts of water and energy but is limited by soil's infiltration rates and sprinkler's ability to uniformly distribute water (Figure 12). Be aware that while the breakup of sprinkler droplets is not ideal for efficiency, at least some breakup is usually necessary for irrigation uniformity.

When possible, run sprinklers during times of high humidity, low temperatures, and low wind speeds. This will result in lower sprinkler losses. These times are usually at night or early in the morning. However, it is recognized that many agricultural irrigation systems have limited ability to shut off during non-ideal climate conditions due to large water requirements and the irrigation system's delivery limitations, and water and labor availability limitations.

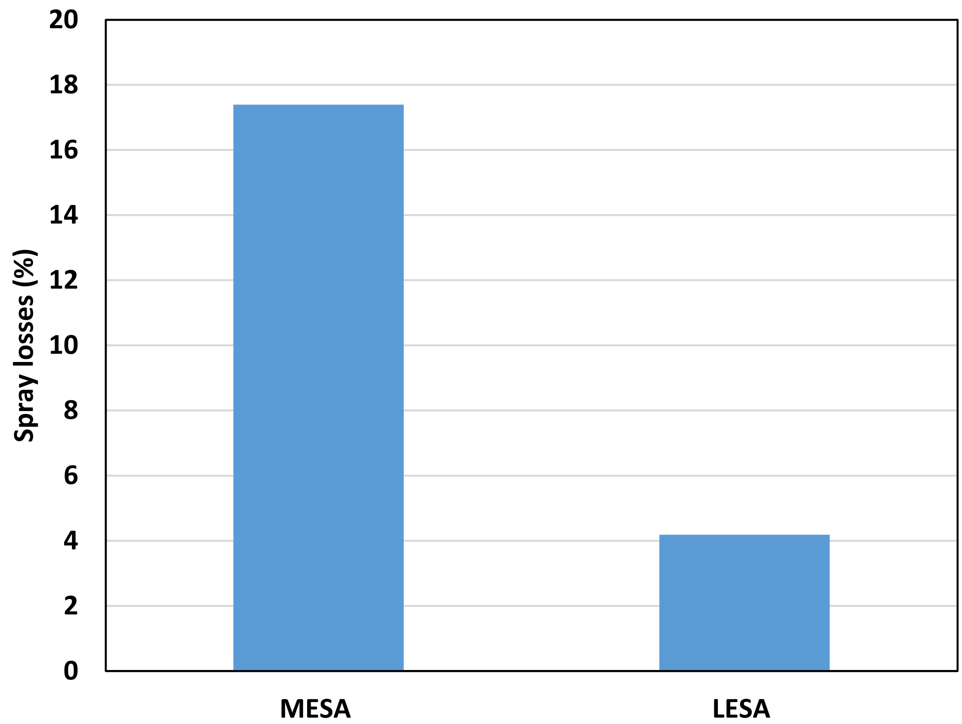

Figure 12. Spray losses for low elevation spray application (LESA) and mid elevation spray application (MESA) in 2015-2017 for the duration of May to September in Prosser, WA.

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