In the United States, nearly 55 million acres of crop land were irrigated in 2008 [1]. The large amount of acreage under irrigation indicates that water and energy efficiency and conservation can have great impact. This fact sheet details different types of irrigation systems and their water and energy efficiency. The reference section lists publications that are useful for determining what type of irrigation system will work best for particular operations. Refer specifically to Scherer [2] and Thomas [3] for help in selecting the type of irrigation system appropriate for specific farming conditions.

**Center-pivot and Linear or Linear/ Lateral-Move Systems**

Center-pivot and lateral-move systems can cover large areas with a very high degree of uniformity [4, 5]. Center-pivot systems (Figure 1) have a radial pipe supported by towers that pivot around a center point. These systems can cover about 130 acres with a straight system and about 155 acres with a corner or swing-arm system. The sprinklers near the pivot cover less area so their water flow rates are less than those located near the end of the pivot where each sprinkler covers a much larger area.

A linear-move system travels in a straight line down the field so all nozzles cover the same area and have the same flow rate (Figure 2) provided the nozzle spacing is equal.

Energy for irrigation can be reduced by lowering the system operating pressure and by testing the well pump to ensure it is operating efficiently and water is flowing into the well at a sufficient rate.

Converting a system from high-pressure (greater than 60 psi), to low-pressure (30 psi or less), can reduce energy costs by up to 40 percent. The system pressure affects how far the water can be thrown but not the volume of water being pumped. Lowering the system pressure will affect the wetted diameter that a single nozzle covers. As the pressure is reduced, more sprinklers will be needed, spaced closer together to provide uniform application. Since the water flow rate entering the pivot is not impacted by the operating pressure but the area covered by the sprinklers is reduced, the instantaneous application rate will increase (same amount of water - distributed over a shorter period of time), which can lead to runoff and erosion if the soil infiltration rate is lower than the water application rate. Runoff is usually not a problem for irrigation systems installed in fields with low slopes and coarse soils with high infiltration rates.

Converting to a lower operating pressure requires replacing the sprinklers and modifying the well pump to adjust the flow rate and pressure generated. As
the system pressure is reduced the pump output will increase. If the well replenishment capacity is lower than the pumping capacity at the lower pressure, then the pump will need to be modified or replaced to match the well’s capacity. If the well has higher replenishment capacity, the pumping flow rate can be allowed to increase resulting in shorter irrigation cycles. Runoff and erosion are concerns with increased application rates so assessing if the soil infiltration rate and soil surface storage capacity are high enough to prevent erosion is critical [6]. The slope of the field also needs to be taken into consideration because as slope increase the soil surface storage capacity decreases and erosion potential increases. Sandy soils are most commonly irrigated and have the highest infiltration rates so they can often accommodate increase application rates. Too often the impact that reduced operating pressure has on the pumping plant efficiency is forgotten or overlooked. If the pump and motor are not included in redesigning the system, the energy saved by reducing the operating pressure can be lost due to the pump becoming less efficient at the new operating point.

Side-Roll Systems

Side- or wheel-roll systems consist of a lateral pipe mounted on four to eight foot diameter wheels (Figure 3) [7]. The pipe acts as an axle and sections of pipe with wheels can be connected together to increase the length up to about 1,320 feet. A small onboard power unit is located near the center of the system to move the system from set to set by rotating the wheels. Once in position, the system operates similarly to a solid set or hand-move system with the only moving parts being the sprinklers. The sprinklers are attached to the pipeline at equal distances and are weighted so they are always right side up as the pipeline/axle rotates when moving the system from one position to another. To irrigate a field, the lateral position, (referred to as a “set”) covers two or three acres and one system is used to irrigate up to 50 acres. The distance between sets is typically 50 to 80 feet based on the operating pressure and the type of sprinkler being used. A side-roll system is basically a hand-move system on wheels. Side-roll systems are not recommended for slopes greater than 5 percent or rolling topography because of alignment issues. When not in use, they can be moved by the wind. They adapt well to low-growing crops and require medium water pressures of 35 to 60 psi at the inlet. Lower pressure can be used but it will reduce the throw distance of the water, so more sets would be needed per acre. The well pump should be tested every two to three years to identify potential problems and ensure it is operating efficiently.

Solid-set or Hand-move Systems

Hand-move and solid-set sprinkler irrigation systems are similar, in that they have piping with sprinklers laid out in a grid pattern to apply water to crops (Figure 4) [8]. The sprinkler layout can be in a square, rectangle or triangle pattern, with overlapping spray patterns to increase the uniformity of application. Historically, medium- and high-pressure impact sprinklers have been used. Lowering the system pressure will save energy while delivering the same amount of water, but the laterals and sprinklers may need to be spaced closer together to ensure adequate coverage because of the smaller wetted diameters at lower pressures. After each section is watered, a hand-moved system is moved manually to the next area. Solid-set systems are often installed in high value vegetable and perennial crops such as cranberries, orchards and pastures.
One downfall of these types of systems is that wind distorts the water pattern, and because the systems are stationary, non-uniform water applications result in some areas not being fully irrigated. The impact of non-uniform water application tends to accumulate as the growing season progresses and often reduces the yield of grain, fruit, or forage.

**Traveling Gun**

Traveling guns have the advantages of being portable, requiring less labor to setup than a hand-move system, covering a wider swath per pass (up to 300 feet) and offering versatility for covering irregularly shaped fields (Figure 5) [9,10]. Swath lengths can range up to 1575 feet. There are two types: a hose-reel system or a cable-tow system. With the hose-reel system, the hose is attached to a cart that has the gun sprinkler mounted to it, and as the hose winds up on the reel, the sprinkler is moved down the field as it distributes water. A cable-tow system uses a cable to drag the sprinkler gun cart instead of the hose. The water is supplied by a soft hose that is dragged along behind the cart. Traveling guns require high system pressure to overcome friction losses in the long run of hose and high sprinkler pressures, 90 to 150 psi. Lowering the irrigation system pressure would reduce the power requirements but also reduce the wetted area, requiring more passes to irrigate an area. Irrigating with a traveling gun will require the most energy of any irrigation system and is generally used on smaller acreages. A well pump should be tested every two to three years to identify potential problems and to ensure it is operating efficiently.

**Boom Cart Systems**

A new alternative to the traveling gun is the boom cart [11]. This is a four-wheel cart fitted with a horizontal folding boom that uses low-pressure nozzles to apply water (Figure 6). A hose reel is typically connected to the cart to move the cart down the field. This type of system can cover a swath of up to 210 feet. These systems operate at lower pressures, reducing pressures up to 70 psi compared to travelling guns. Aside from reducing energy costs, these systems apply water more uniformly and gently compared to a traveling gun.

**Flood Irrigation**

Flood irrigation consists of level or graded border and basin systems used in the production of small grains like rice or wheat and fruits, forage crops, and vegetables for harvest but can also be used on other crops as long as the soil does not stay waterlogged too long [12]. Water is discharged into a levee-surrounded field along the highest elevation and allowed to run down slope (Figure 7). Valves are used to control water flow into the field based on the set time assigned to the border or basin. Once the flooding time period is
completed, water can be reclaimed by allowing it to leave the field by gravity flow or by pumping it into a storage pond for re-use. This conserves water and saves energy if water is pumped from a well. This is a low cost method but precise field grading is essential or the water application uniformity will be very poor.

Furrow Irrigation

Furrow irrigation requires precisely graded fields with furrows or small ditches formed between crop rows for the water to flow by gravity from one side of the field to the other (Figure 8) [13, 14, 15]. The crops can be planted on a ridge between the furrows or furrows can be established after plant emergence in fields where off-season tillage is performed. When irrigation is desired, water is pumped, siphoned from supply ditches or flows by gated pipe into the furrows. As the water fills the furrow it flows towards the down slope side of the field. The water infiltrates into the soil based on the length of time water is ponded on the soil surface. Often the entire root zone is refilled with each irrigation event. This method of irrigation is very energy efficient but the uniformity of the water distribution along the length of the furrow can vary widely. Shorter furrow lengths and appropriate set times typically help increase the uniformity of water distribution as do management practices like cut-back or surge irrigation.

Trickle and Drip Irrigation

Drip irrigation is the most energy- and water-efficient of all the irrigation systems. Water savings of up to 50 percent compared to sprinkler irrigation are common [17]. Ideally, water is applied in the proper amount to the root ball of the plant, minimizing water leaching from the root zone and minimizing evaporation of water since the water isn’t sprayed into the air [16, 17, 18, 19]. The water can be emitted at uniform distances along a pipe or a tube with an emitter that directs water to one plant volume of soil. The drip hose can be placed above ground (Figure 9) or buried in the ground, which is called sub-surface drip irrigation [20] (Figure 10). Sub-surface irrigation has the advantage of nearly zero evaporation, but it can be harder to tell if an emitter becomes plugged or damaged. Drip irrigation operates at low pressures, 10 to 20 psi at the emitter. The system pressure will need to be higher to overcome pressure loss in filters, valves, backflow preventers, pressure regulator and tubing. Typically, about 40 psi is needed at the pump outlet. Drip irrigation can be designed to fit any situation or field. It can also reduce disease problems, because it doesn’t get the plant wet. It does require some experience to learn how much water to apply, but a soil water sensor in the row or next to the plant can provide feedback to aid in determining the correct amount of water. Drip irrigation requires understanding of the system to assure good management and maintenance.
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