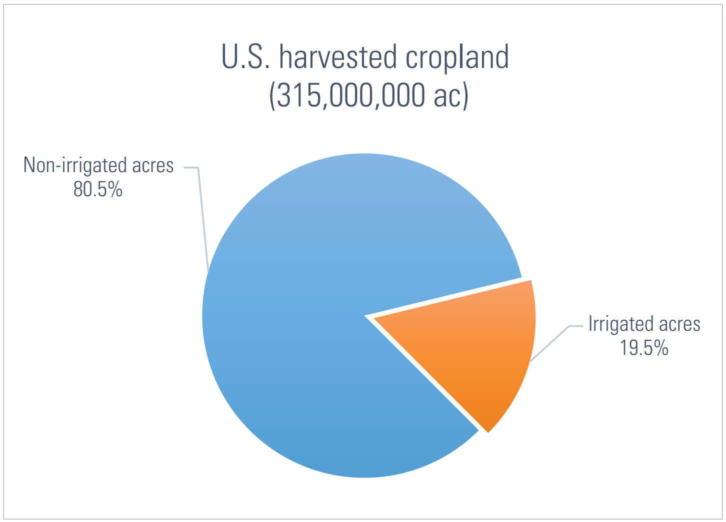
Principles of Efficient Agricultural Irrigation

As the worldwide population continues to grow, irrigated agriculture will be an increasingly important contributor to meet the worldwide demands for food, fiber, animal feed and biofuels. In the United States, irrigated farmlands comprise just 17 percent of crop acres, which contributes about half the value of total crops sales. However, irrigated farmland is credited with the largest share of the national consumptive use. While striving to meet the growing demand for more crops, the competing demands on the available water supply for human well-being and protecting the environment have to be resolved. Efficient irrigation is an integral part of meeting these future challenges.

According to the 2012 Census of Agriculture, there are 2.1 million farms with about 915 million acres of land — or about 40 percent of all land area in the United States is farmland. Of that, 315 million acres are harvested cropland. The 2013 Farm and Ranch Irrigation Survey reveals that there are 229,237 farms (11 percent of all farms) using irrigation. Based on the various irrigation methods being used, more than 61 million acres are irrigated. Included in the irrigated acreage are more than 500,000 acres and 1.4 billion square feet of protected growing space for horticultural crops.



Source: 2012 Census of Agriculture, 2013 Farm and Ranch Irrigation Survey

The Irrigation Association recognizes that there are many experts who have devoted their careers to improving agricultural crop production. While adequate water applied at the correct time is necessary to produce significant yields, irrigation is just one part of all that a grower must take into account. The principles for irrigation efficiency must work in harmony with other best practices for growing plants, including soil, nutrient and pest management.

The *Principles of Efficient Agricultural Irrigation* identifies the key concepts that a grower or producer should follow to attain the most efficient use of water. The following are principles for efficient agricultural irrigation:

1. **Use qualified professionals.** While demand increases for food, fiber, animal feed and biofuels, there is equally as much demand that agricultural growers be good stewards for all resources — including water used to produce a crop. The marketplace is becoming much more complicated and sophisticated, and the need for good advice is essential for success. There are many sources a grower can turn to for education, information and help in making good decisions on how to best use resources. This is especially true as growers adopt precision agriculture methods and strive to be more sustainable in their operations. According to reports from the United States Department of Agriculture, only about 10 percent of growers seek advice to help them manage water resources better.

   Irrigation professionals who are engineers and designers trained in irrigation systems are a great advantage when managing water resources for irrigation. All irrigation systems should be evaluated to determine the best method for applying water to a field. Irrigation professionals are trained in understanding the details and specifics of various types of irrigation systems. A grower can obtain valuable information by consulting with an irrigation equipment dealer or manufacturer for design, installation, maintenance and management of the system. Seek out professional agricultural engineers or certified irrigation designers to help select an appropriate irrigation system and equipment to match the needs of farm operations.

   In addition to irrigation professionals, Natural Resources Conservation Service personnel, many universities, state extension agents and independent crop advisors are trained in many aspects of agricultural production. Often, they are aware of programs that are available for implementing or improving irrigation efficiency and how that would integrate into the overall crop production. They can provide expertise in soils and nutrient management that can influence irrigation management decisions.

2. **Know the water supply.** Understanding the source of water is a key part of selecting an irrigation method or system that will deliver water efficiently. The availability, quantity and reliability of the various sources of water are extremely important in planning an irrigation system. Growers should first maximize the

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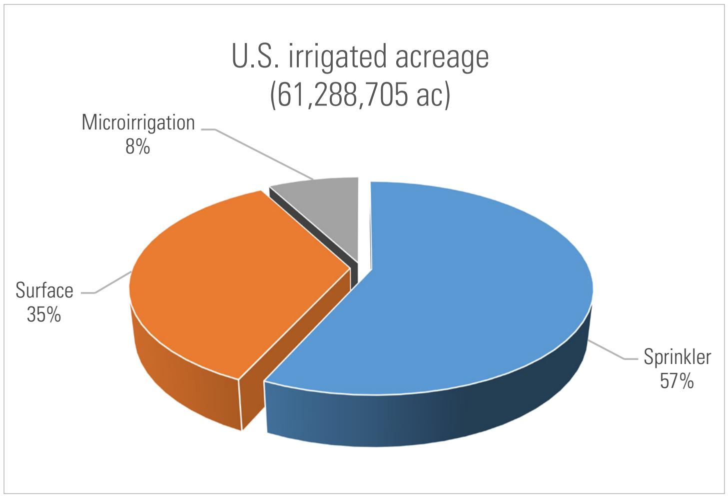
benefit of rainfall, but the challenges of ever-changing weather patterns complicates determining when and how much rainfall will be available. Irrigation systems provide a producer with a method to apply water when it is needed. However, the source of the water can also change or depend upon advanced notification for delivery to the field. If surface water is the source for the grower, it is likewise influenced by changing weather patterns. Many irrigation systems rely on pumped groundwater, and as water tables change, the quantity of water available from a well can change. As important as a reliable source of water is, it is also important to understand the quality of the water so that 1) crops are selected that can work well with the water source, and 2) the water is safe for producing food crops. Additionally, a grower must understand and comply with local water laws and water rights.

3. **Identify the soil type.** A fundamental requirement for efficient irrigation is to know the type of soil or soils in the field. A few simple soil tests can provide valuable information that impact irrigation efficiency, such as soil type and the water-holding capacity and infiltration rate of that soil. Having access to soils maps and/or surveying the soil to identify variations within the field are useful for making adjustments to the nutrient and water application requirements during the growing season. Additionally, understanding some of the soil chemistry and how it may interact with the water source can influence the effectiveness of irrigation scheduling events. While not a specific soil property, understanding the topography of the field will influence the selection of the most appropriate irrigation method or system depending on the type of crops being grown.

4. **Understand crop water needs.** As crops grow, it is important to account for the stages of development and response to changes in weather. Some stages of growth are very sensitive to having an adequate amount of soil water to achieve the best yield. One of the best methods to determine and plan for crop water needs is to use evapotranspiration [ET] data. Accessing reference ET data and modifying it to fit the particular crop can be used by the grower to estimate the next irrigation event and the amount of water that will need to be applied. This needs to include accounting for the current level of available water in the root zone. The irrigation water requirements determined by using ET data should be field-verified with site measurements and observations to maximize the benefit of each irrigation event. Using sensors of different types, probing the soil and observing crop conditions all work together to provide the grower with essential information that will contribute to improved irrigation efficiency.

5. **Select appropriate irrigation methods.** Irrigation methods fall into two basic categories: pressurized irrigation and surface or gravity-fed irrigation. Pressurized irrigation involves the use of pumps, piping, valves and either sprinklers or low-volume emission devices. Surface systems rely on slope, contours and field geometry so that the water moves to cover the intended area by gravity. An efficient irrigation system or method must consider the soil type and properties, field topography and the type of crops being grown. Another consideration is how the irrigation system integrates into other farm operations such as planting, cultivating and harvesting. Additionally, water quantity, availability and reliability will influence the type of system that best meets the needs of the area to be irrigated.

   A short review of the most common types of pressurized systems and surface irrigation methods is included in appendix A for quick reference. The type of crop, cost of water and energy, availability of skilled labor, and long-term cost of system ownership should be part of the evaluation process when selecting the irrigation system. Usually, several methods can be used for a given field, but often the economics influence the final selection of the irrigation method. Properly designed and maintained systems will have a positive impact on the expected application efficiency of any system, but the management skill



Source: 2013 Farm and Ranch Survey, tables 29, 30, 31

of the operator in implementing irrigation schedules will impact the overall irrigation efficiency the most.

6. **Implement irrigation scheduling.** Irrigation scheduling is a planning and decision-making process used to determine the amount and timing of irrigation applications. Because water is such a critical component for a good yield, and depending on the cost of water and energy, the grower can have different motivations or goals that will influence irrigation scheduling and the amount of water applied.

   Depending on the grower's goals, irrigation scheduling can achieve:

   - highest yield.
   - optimum yield per unit of water applied.
   - maximum net return.

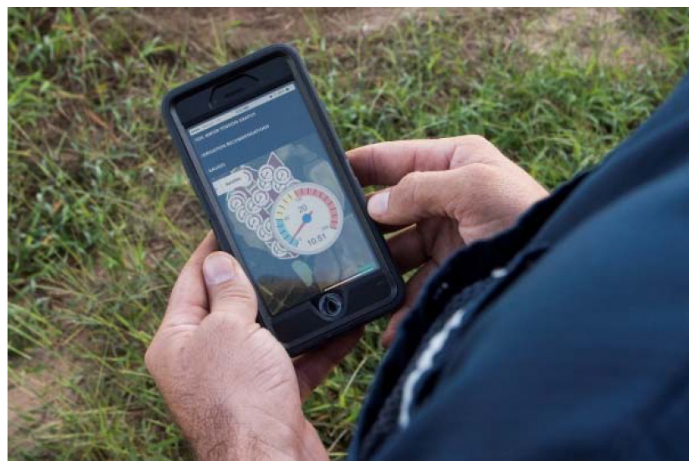
   Usually the goal of highest yield is pursued when water and energy costs are relatively low. However, when the available water supply is restricted or energy costs are high, the goals of optimum yield and maximum return begin to influence the decision of when and how much to irrigate. Sometimes a reduced yield is preferred when the net return improves because the cost of additional irrigation is not offset by an increase in yield.

   Irrigation scheduling can be either reactive or predictive. The reactive approach is usually based on a visual indication such as plant stress, soil water measurements or canopy temperature. The reactive approach doesn't determine how much water should be applied nor anticipate when the next irrigation event should be. The predictive method of irrigation scheduling estimates the amount of water to be applied and when it should be applied based on recent crop water use, soil water properties and depth of the rooting system. Efficient irrigation will strive to maximize the benefit of rainfall. Accounting for rainfall and even anticipating the next rainfall will greatly influence irrigation scheduling.

   Irrigation scheduling requires knowing two things: 1) the appropriate amount of water to apply, and 2) when to apply that water. For most irrigation events, a fixed amount of water is applied allowing only a certain fraction of the available water to be used by the plant. The variable becomes the interval between irrigation events. If the irrigation event timing or interval is fixed, then the quantity of water to apply becomes the variable, which becomes more challenging to manage, especially for most surface irrigation methods.

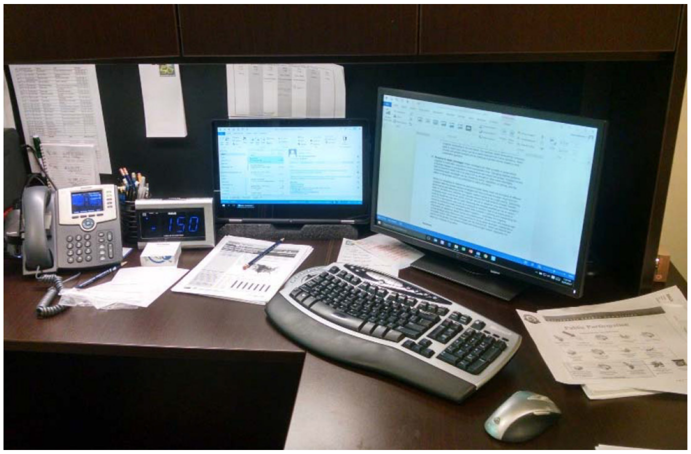
   The main methods of irrigation scheduling include climate-based, soil-based or plant-based. Soil-based and plant-based indicate when irrigation is needed. Climate-based scheduling, on the other hand, determines the amount of water to apply and can then be used to predict the next irrigation event. A more detailed description of scheduling methods is listed in appendix B.

7. **Apply technology.** There are and have been many new innovations and advances in technology, which can be utilized by the grower/producer and will help in using water resources more efficiently to achieve desired yield goals. The concept of "precision agriculture" relies extensively on technology to maximize the benefit of resources being used to grow a crop. The challenge of being able to grow enough food, fiber, feed and fuel for a growing world population will rely on the innovations in technology that can be applied to agriculture and adopted by the grower.



Advances in wireless technology have greatly facilitated getting information from the field. Wireless technology such as Wi-Fi or cloud-based is being incorporated into other technologies such as soil moisture sensors and plant canopy sensors, making it easier for the grower to access the data and get real-time feedback on field conditions. Irrigation controllers on center pivot or linear move machines can utilize GPS and customize water application to areas of the field. Other technologies such as thermal imaging in different spectrums from instruments on unmanned aerial vehicles can affordably survey an entire crop so that a grower or a consultant/advisor can make better and quicker management decisions. The key to success for using any of the technologies is making it practical for the grower to use. The evolution of smart technology allows a grower to use mobile devices such as smart phones and tablets to access information readily. Getting data from field instruments or accessing weather data or irrigation scheduling programs enables a grower to respond quickly to changing conditions. Timely decisions can have a profound impact on improving irrigation efficiency and crop yields.

In addition to technology that can directly affect the amount of water used for irrigation, many pressurized irrigation systems can be combined with other technologies to deliver fertilizers and other chemicals to the crop. Fertigation and chemigation can save time, energy and products, but success is very dependent on the proper equipment and the skill and knowledge of the irrigator.



8. **Maintain accurate records.** Keeping records is not the favorite activity of most growers, but careful record keeping is essential to comply with numerous regulations or to meet the requirements of crop buyers. However, good records that are organized and easily accessed are a great management tool. Good records provide the information that influence the decision-making process and guide future planning. For efficient irrigation, the following types of records and data are useful:

    i. **weather data** — Access to a nearby weather station to obtain recent weather such as ET data is needed for irrigation scheduling. ET data along with stages of crop development help estimate the root zone soil moisture balance. Tracking area rainfall is also important, but a way to track rainfall at the field is best, since weather stations can be located a number of miles from where the crop is located.

    ii. **water measurement** — Keeping water use records is essential to truly identify how efficient the irrigation events are. Estimating how much water to apply and then comparing it to the water actually applied will give the grower valuable information for making any necessary adjustments in the irrigation schedule. It can also provide good information about the reliability of the source of water. Having a reliable meter or flow sensor can make this job easier. Having it accessible from a remote location such as the grower's office makes collecting and recording the quantity of water use easier. Maintaining thorough water use records also provides growers an invaluable tool to defend and justify the amount of water being used, especially when combined with energy costs and yield records. In some jurisdictions, accurate water use records are currently required.

    iii. **water quality** — Having water samples tested is necessary to ascertain what is in the water. Poor water quality can have a negative effect on the crop. Water quality can impact what type of crops could be successfully planted and grown. It is important to know information about the water chemistry and document how it might react with the soil chemistry. If leaching is necessary, the data can help determine how much additional water is needed to minimize damage to the crops and the soils.

    iv. **system performance** — Documenting how a system is performing can help reveal how well water is being distributed across the field. It can provide an indication of the performance by the emission devices and how well the systems are being maintained. Performing system audits can give guidance on system maintenance procedures and longevity of emission devices. As system performance degrades over time, it will impact the amount of water being used or how effective the water is being applied. Systems performing well facilitate management strategies such as deficit irrigation and its impact for lower water use.

    v. **system maintenance** — Part of system maintenance is doing inspections and keeping track of identified problems and when they are corrected. System maintenance is done so that the system is operating or functioning optimally. Broken pipes, fittings, sprinklers and emission devices, as well as banks and furrows, allow water to be wasted or used ineffectively. A proactive approach to system maintenance anticipates problems and takes corrective action ahead of time. This will have a positive impact on irrigation efficiency, whereas a reactive approach to problems when they are obvious usually means water has already been wasted. Tracking the maintenance procedures and the associated costs can influence when a system needs to be modified, upgraded or replaced.

    vi. **energy costs** — The embedded energy in water to make it useful has to be considered not only in the initial design and installation but also over the long term to properly operate the system. Timing irrigation events carefully and potentially skipping an event or reducing the run time can save a significant amount of money and water.

    vii. **efficiency analysis** — There are many types of efficiency associated with water and irrigation that can be analyzed. Each type has a useful purpose. The key efficiency measurements that should be considered, depending on the irrigation method, include

        a. water conveyance efficiency, which is an especially important consideration for surface irrigation methods. Conveyance efficiency is the amount of water delivered to the field boundary compared to the amount of water diverted at its source. There can be many losses if there is a long ditch and if the type of ditch is lined or an earthen or unlined ditch.

b. application efficiency, which is the amount of water stored in the crop root zone compared to the volume of water delivered to the field. This can be evaluated after every irrigation event. Wind drift, canopy interception, runoff and deep percolation are examples of losses that will impact application efficiency.

c. irrigation efficiency, which is defined as the amount of water beneficially used compared to the amount of water delivered to the field. Water used for leaching salts out of the root zone, frost protection, crop cooling, and pesticide or fertilizer applications are all examples of beneficial uses of water that are not directly linked to crop growth. Losses similar to those listed under application efficiency also negatively affect irrigation efficiency.

viii. **Other analysis** that could be done includes comparing the goals identified in irrigation scheduling to the end result. For example, water productivity compares yield to water input, which can be a useful data point for future decisions. Good records and proper analysis will be useful as a grower moves toward a more sustainable operation.

9. **Respond to water shortages.** Water shortages are often a reality in areas where irrigation is most often required to have a successful crop. Changing weather patterns including changes in precipitation or temperature can impact the grower. Irrigation is one way to ensure a viable crop if an area is hit by drought or other water shortages. Sometimes water shortages can be created by policy, regulation or pricing, and the effect on the grower and crop production is nearly the same.

   When it is necessary to reduce the amount of water being used, the principles of efficient irrigation offer the grower several strategies that may promote success. Improving the performance and efficiency of the irrigation system needs to be a high priority. Delivering water to the field very uniformly can actually reduce the total amount of water needed. Changing crops could be an option if it is an annual or seasonal crop and if the grower's existing equipment can still be used. Reducing the acreage planted can be an option, but if it is a permanent crop such as a vineyard or orchard, that is not easily done or would be extremely costly considering the time invested in growing and establishing the plants. Another option is to practice deficit irrigation — purposely not irrigating adequately at opportune times during crop development. Some crops will respond well to that strategy while others are very sensitive to being water-stressed, making this a nonviable option. Some water shortages can be planned for, while others are beyond the control of the grower, and severe drought will have a huge impact, especially if it becomes multiyear in duration.

Summary

A report from the United Nations Food and Agriculture Organization states,

> *Irrigated land is more than twice as productive as rainfed cropland. Today, only 16 percent of the world's croplands are irrigated, but those lands yield some 36 percent of the global harvest. … In the developing countries, irrigation increases yields for most crops by 100 to 400 percent. Irrigation also allows farmers to reap the economic benefits of growing higher-value cash crops. … Half or even two-thirds of future gains in crop production are expected to come from irrigated land.*

According to the Economic Research Service of the United States Department of Agriculture in a report updated in October 2016, irrigated agriculture accounts for the largest share of the nation's consumptive water use and makes a significant contribution to the value of U.S. agricultural production. In 2012, irrigated farms accounted for roughly half of the total value of crop sales on just 17 percent of U.S. cropland.

The ERS/USDA report also states that, "The future of irrigated agriculture will depend in part on producers' ability to improve on-farm water management for crop production. Upgrades in irrigation system technologies and improved water-management practices can enhance on-farm water-use efficiency."

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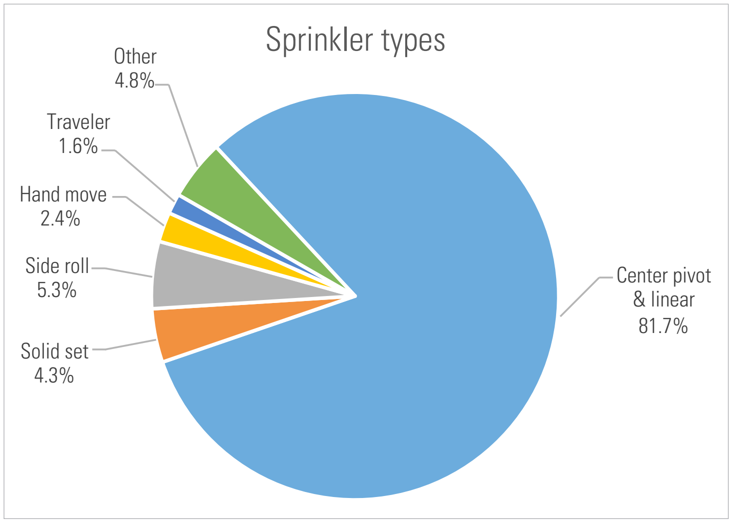
Appendix A. Irrigation Methods

Using qualified professionals who are familiar with the various irrigation methods can help growers select the most efficient technique for their operations. Sprinkler and microirrigation systems must be pressurized to deliver water to the target areas of the field for plants to use. Surface irrigation relies primarily on gravity to move the water into the field. Energy costs must be included in the evaluation of irrigation methods, as well as the quality of the available water.

Sprinkler irrigation typically can be used on any topography that can be farmed. Sprinkler systems require the use of pipes and valves to deliver water to the sprinklers and an energy source to pressurize the water sufficiently to operate the sprinklers. Many modern systems can operate on lower pressures thus saving energy. Sprinkler systems have a higher initial cost compared to most surface irrigation methods, but they offer the advantage of reduced labor inputs and the ability to automate irrigation events, increasing the potential for better efficiency.



Source: 2013 Farm and Ranch Survey, table 29

1. **Center pivot** and **linear move** sprinkler machines require a significant investment into the equipment and power supply but require the least labor and have the potential to be extremely efficient in applying water. With proper maintenance and operation, these machines have a very long useful life. Center pivot and linear move machines cover more than 80 percent of all sprinkler-irrigated acreage.

   These machines are composed of a single lateral supported by a series of towers on wheels. The wheeled towers are self-propelled, and on a center pivot, the lateral moves in an arc. On a linear move, the whole machine moves along the field in a direction perpendicular to the machine. Linear move machines are best used for long, narrow fields.

   The emission devices can include sprinklers on top of the lateral or lowered closer to the ground with hose drops attached to the lateral. Other techniques such as low energy spray application

   [LESA] and low energy precision application [LEPA] have been added to center pivot machines to apply water very close to or on the soil surface of the field to improve application efficiency.

   Advances in irrigation controllers allows for these machines to be controlled remotely. The ability to speed up or slow down the machine, as well as turn on or off specific sprinklers, can more precisely apply water to meet the needs of the crop, depending on its location in the field. Addition of end guns and swing arms increases the area being irrigated by the center pivot machines and reduces the nonirrigated portion of the field for a modest increase in cost.

   Center pivot or linear move machines can be used on many crops, but they are limited for use on some permanent crops such as vineyards or orchards or where the wheeled towers would have trouble travelling through the crop or clearing the height of the crop.

2. **Hand move** or **portable** sprinkler systems are widely used for occasional and if-needed irrigation. Equipment cost is relatively low, but the labor requirement is high. Hand move systems typically use sections of aluminum pipe that are coupled together, with sprinklers installed on risers at regular intervals. Run time is for some fraction of a day. Then, the pipe must be uncoupled, drained and moved to the next zone to be irrigated by lifting and carrying each section to its next zone or set point in the field. With good management, this system is capable of high application efficiency, but care needs to be taken that set times are not so long that water runs off of the field.

3. **Side roll** or **wheel line** sprinklers are similar to hand move systems, except the periodic moving of the pipe is mechanized thus reducing the time and labor needed to irrigate the next zone. Heavier or thicker-walled aluminum pipe is used for the lateral, which also serves as an axel for the wheels. A gas-powered

engine in the middle or at one end is used to move the lateral. Cost of the equipment is higher than for hand move, but the labor requirement is much less. Efficiency is similar to the hand move system, but it is very dependent on the skill of the irrigator to know how long to run a zone to apply the correct amount of water.

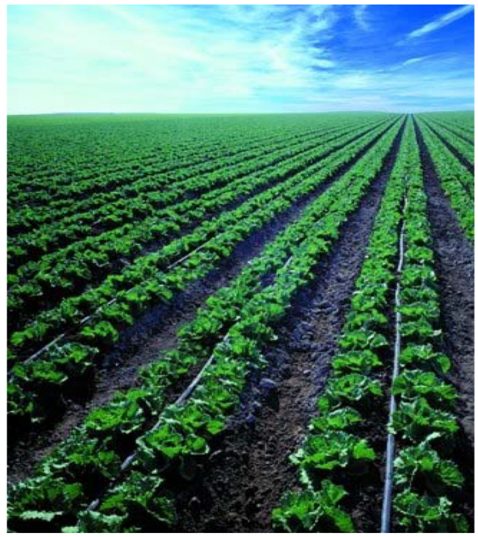
4. **Solid set** sprinkler systems are similar in concept to hand move systems, except that there is enough equipment placed in the field that moving of the pipe is not needed. The systems can be on the field surface to facilitate removal at the end of the season, or the pipe can be buried in the ground and become a permanent system. Valves are used to direct water to the zones as needed. The capital outlay is much higher for solid set systems, and they are typically used on high-value crops, but the labor requirement is greatly reduced. Proper spacing of the lateral lines and sprinklers contribute to good application efficiency.

5. **Traveler** or **big gun** sprinklers utilize a large-volume, high-pressure part-circle sprinkler mounted to a cart that is capable of throwing water a great distance. A large hose is connected to the cart to deliver the water. The cart with the sprinkler travels the area being irrigated. Because this system delivers a large volume of water at fairly high pressures, it has a high energy requirement. The cart and hose can be moved to different parts of a field and are very adaptable to odd-shaped and/or sloping fields.

Besides irrigating crops, sprinkler systems can also be used to help provide germination of seeds in fields normally irrigated by microirrigation, frost protection, crop cooling, application of fertilizers or other chemicals, dust control, or waste disposal.

Microirrigation is the precise, slow application of water as discrete drops, continuous drops, small streams, or miniature sprays through an emission device located at selected intervals along water delivery lines. The flow rate of the emission devices is rated as gallons or liters of water per hour, whereas sprinklers are rated in gallons or liters per minute. The water can be applied at the soil surface, below the soil surface, or just above the soil surface within the area of root system development. Microirrigation uses the capillary and gravity forces within the soil-water relationship to move the water into the root zone. Within the microirrigation category of pressurized irrigation there are some general types of emission devices that have unique qualities for certain applications. Because of the very small openings for each emission device, the water must be extremely clean to avoid plugging. Proper filtration and maintenance are mandatory. Microirrigation systems are pressurized; consequently, pumps, pipes and valves become part of the system, which can also include controllers that can be programmed to deliver a set amount of water. Advanced controllers can be operated and monitored remotely. The following types of emission devices are utilized in microirrigation systems:

1. **Drip tape** is a relatively inexpensive product that incorporates a series of engineered emission devices into thin-walled, lay-flat tubing, usually of polyethylene plastic. The emission devices are typically spaced 4 – 24 inches apart. The spacing is influenced by the soil type and the crop being irrigated. The emission devices can be either nonpressure compensating or pressure compensating and are often used in vegetable production or row crops. Drip tape can be installed below the soil surface and can last for many years with careful farm operations for field preparation and cultivation. Drip tape can also be retrieved from the field and reused thus reducing the cost per acre for the system on an annual basis. The product can be recycled when it reaches the end of its useful life.



2. **On-line** or **point source** emitters are small plastic emitters that convey drops or small streams of water when attached to rigid polyethylene tubing. They can be placed exactly where the installer wants them in order to match plant spacing and location. They are available as pressure compensating or nonpressure compensating depending on the field needs. Inserting the emitters can be labor intensive when thousands are used on a particular application, but most emitters can be serviced or replaced if needed. The tubing and emitters are

meant to be for a permanent installation and can last for many years. They are often used in applications such as vineyards.

3. **In-line** or **dripline** emitters use small emission devices that emit water similar to on-line emitters but are pre-inserted into the polyethylene tubing at a specified spacing at the time of tubing extrusion. This saves installation labor, but emission devices could be inserted where they are not needed. The emission devices cannot be serviced, but again, the system can last many years on a permanent-type crop. This type of product can be used on top of the ground or installed subsurface.

4. **Microspray** is a general term that includes jets, foggers, microbubblers or microsprinklers. The emission devices are attached to a riser, and water is emitted through the air as a spray or as separate streams of water. Compared to emitters in tubing, a microspray single emission device can cover a larger area of the root zone. Many of the emission devices can be regulated for the distance of throw or flow rate, and because they will have a higher flow rate than the drip emitters, it takes fewer emission devices to wet the root zone area. Tree-type crops in orchards or groves are examples of where microspray emitters work well.

Surface irrigation methods are used extensively in many areas, and they can be very energy efficient but tend to be less water efficient. They typically have a lower initial cost to create but are more labor intensive to be acceptably water efficient. The effectiveness of these methods is greatly dependent on soil type, field topography and the skill of the irrigator to time the duration of an irrigation event and uniformly wet the root zone. Especially important to surface irrigation methods is subsurface drainage so that excess water from rainfall or irrigation can be removed to minimize damage to the crops if the root zone becomes water-logged. Surface irrigation can be categorized into several general types:

1. **Basin** irrigation is a completely level area enclosed by dikes or borders made of soil. Use of this method is dependent on soil uniformity, topography and the degree of leveling that needs to be done. If the top horizon of soil is too thin, major grade changes in parts of the field to level it may expose areas that will not support good crop development. Depending on the topography, level grading could be fairly expensive to do initially. Growing rice is an example where the basin method is successfully used. Rice is one of the major irrigated crops in the United States.

2. **Border strip** is similar to basin irrigation except that the basin slopes gently in one direction. Field geometry is also a factor that needs to be considered. Water is applied at the upper end of the border strip. Too steep of slope will cause the water to move too quickly to the bottom of the field and may cause erosion and runoff. The efficiency of border strip is very dependent upon the skill of the irrigator tending the field.

3. **Furrows** are sloping channels formed into the soil between rows or beds of plants. Water is delivered at the upper end of the furrows by siphon tubes from an open ditch, by dam gates in aluminum or polyvinyl chloride [PVC] piping, or through holes punched into large diameter, thin-walled collapsible tubing. Irrigation efficiency can be improved with the use of a surge valve that will control water delivery to enhance soaking of the water into the root zone and advancing the water to the end of the field. Furrows are created new for each crop each season, and severe compaction can occur in the rows where tractor wheels roll.

Appendix B. Irrigation Scheduling Methods

A combination of all the following methods helps the grower become the most efficient:

1. **Climate-based scheduling** methods rely on weather information to estimate how much water has been depleted from the root zone soil moisture reservoir. Typically, in locations where irrigation is used extensively, the amount of water evaporated from the soil surface or transpired by the plant exceeds the amount of precipitation received. When a critical amount of water has been depleted, but before the plants show significant signs of stress or wilting, the field is irrigated to replace the depleted water.

   The general approach to climate-based irrigation scheduling is to maintain a running balance of plant-available soil moisture compared to field capacity. This is done by having a source of ET data (usually calculated from weather station data) to indicate the amount of water withdrawn by the plants. Accounting for effective rainfall, the deficit in soil moisture then becomes the amount of water to be applied through irrigation. Tracking the root zone soil moisture balance then helps determine the amount of water to apply and when the water should be applied.

   The basic steps to calculate the amount of water to apply are as follows:

   i. Determine the amount of available water [AW] based on soil water properties.
   ii. Measure the depth of the root zone.
   iii. Determine the amount of water that can be depleted without affecting yield. This is often referred to as management allowed depletion [MAD].
   iv. Determine the net irrigation depth with which the crop is to be irrigated.
   v. Collect reference evapotranspiration data [ET_0].
   vi. Determine the proper crop coefficient [K_c] to modify ET_0.
   vii. Calculate crop water use [ET_c] by multiplying ET_0 and K_c data together.
   viii. Calculate the root zone soil moisture balance by subtracting ET_c and adding in effective rainfall and irrigation.
   ix. Irrigate when the soil moisture balance equals step iv.
   x. Validate the calculated soil moisture with soil moisture sensor readings or by probing the soil for a visual confirmation.

   Steps i – iv are determined initially, and step iv should represent the desired amount of water to apply per irrigation event. Steps v – viii are repeated throughout the growing season so that when the managed soil water depletion equals step iv, then an irrigation event is scheduled to take place. Step x is done occasionally to verify that the root zone soil moisture balance reflects field conditions. This is done using soil moisture sensors or a probe that can be pushed into the ground a day or two after irrigation to determine if the soil is moist to the depth of the root system. If the calculated soil moisture balance and the field conditions don't agree, adjustments to the K_c in step vi usually need to be made to better reflect crop development.

   The next step of irrigation scheduling is to calculate the run time or set time to apply the amount of water discussed above by using the application rate (if using pressurized irrigation) or the set time (if using surface irrigation). The application rate of sprinklers and microirrigation requires knowing a flow rate and the area to which the water is being applied. There are different equations to determine application rate depending on the type of sprinkler system. For surface irrigation, the set time will be determined by knowing the stream size and the dimensions of the field.

   Understanding how the irrigation system is performing then provides valuable information to determine how application efficiency will influence the total amount of water needed. Measuring actual application rates, as well as how uniformly water is distributed, will provide the best information for scheduling. Run/set times need to consider soil type so that runoff or deep percolation below the root zone can be minimized. Irrigation efficiency is a reflection of how much of the water applied can be put to beneficial use.

   The other common methods — soil-based and plant-based irrigation scheduling — are great indicators of when irrigation needs to take place, but they don't necessarily calculate how much water to apply. The depth of water needed will hopefully correlate to the first four steps of the scheduling process. The advantage of soil-based scheduling and plant-based scheduling is that they provide the feedback needed to validate the calculated root zone soil moisture balance.

   Soil-based and plant-based scheduling take into account all of the factors impacting crop development, many of which are difficult to quantify yet are reflected in a mathematical equation. Typically, if there is a disagreement between the calculated soil moisture balance and actual observations from the field, adjustments to the crop coefficient need to be made and refined. This is where the skill of the irrigator is extremely valuable to achieving the best irrigation efficiency.

2. **Soil-based scheduling** methods rely on sensors that monitor the moisture level in the soil at appropriate locations and depths. As the plant uses water, the root zone soil moisture reservoir is depleted, typically from top to bottom. When the sensors indicate that the remaining soil moisture has reached critical levels, irrigation water is applied. Some sensors can also indicate when desired moisture levels have been achieved and stop an irrigation event. Soil moisture sensors are generally used to tell when irrigation needs to take place but not how much water needs to be applied.

3. **Plant-based scheduling** can utilize several different technologies, but the most common method for determining irrigation is measuring canopy temperature. As plants transpire, they cool themselves. When water is readily available, they typically remain cooler than ambient air temperature during the day. As soil moisture levels decrease, transpiration also decreases, leaving the plants less able to cool themselves. Monitoring changes in canopy temperature provides an indication for when the next irrigation event needs to take place, but again, it does not calculate how much water to apply.