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Texas A&M AgriLife Extension

SOUTH TEXAS IRRIGATION TRAINING PROGRAM MANUAL

Texas Water Resources Institute EM-121
Spring 2016 | twri.tamu.edu

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Acknowledgments

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PREFACE

Goal

- Equip irrigation managers and technical support personnel with information and resources to support improved irrigation management and water conservation.

Objectives

1. Provide participants with core knowledge base, including irrigation fundamentals, irrigation technologies, and best management practices.
2. Compile currently available and new educational materials into a convenient resource package.
3. Develop a series of educational events to deliver the information to the target audiences to improve their knowledge base.

Chapter 1: Economic issues in irrigation

Economic issues in irrigation reflect complex and highly dynamic factors. Energy costs, commodity markets, weather patterns, and other issues are difficult to predict and impossible to control. Irrigation is as much a risk management tool as a (sometimes expensive) production input. Equipment selection, irrigation management, and other decisions need to be made with economics in mind.

Objectives

- Increase understanding of factors that affect economics of irrigation systems.
- Increase understanding of costs and associated benefits of commonly used irrigation systems.
- Increase understanding of methods for evaluating and comparing irrigation systems.

Key points

1. When considering investing in an irrigation system, several major factors should be noted: availability (reliability, quantity, and quality) of water; the system's application efficiency; the depth from which water must be pumped (pumping lift); operating pressure of the system; financing; savings in field operations; energy sources; energy prices; crop mix/rotations; economies of scale; fixed and variable costs; labor availability; management capabilities; commodity prices, and, of course, the site-specific layout and physical conditions.
2. Overlaying these factors are differences in the costs and water application efficiencies of the various irrigation systems.
3. Generally speaking, low pressure center pivot irrigation systems and microirrigation systems are more efficient than high pressure sprinkler systems or surface irrigation systems. Good management and maintenance are critical to realizing the benefits of any system.

Economics of irrigation systems

Investing in a new irrigation system can be expensive, and factors affecting the feasibility of systems are complex. In addition to initial capital and installation investment costs, water availability (reliability, quantity, quality); pumping lift and system pressure requirements; system efficiencies; labor and fuel cost; tax and interest rates; operation specific considerations (crop rotations, soil type, field topography, management capabilities, etc.) determine the relative economic feasibility and practical suitability of the options.

A Texas-based evaluation of costs and associated benefits of six commonly used irrigation systems in Texas (conventional furrow, surge flow, mid-elevation spray application center pivot, low elevation spray application center pivot, low energy precision application center pivot, and subsurface drip irrigation) indicated that:

- Furrow irrigation requires less capital investment but has lower water application efficiency and is more labor intensive than the other irrigation systems.

- Adding surge flow valves increases water application efficiency enough to increase returns per acre. However, before purchasing surge equipment, growers should closely evaluate the ability to provide the required management of irrigation scheduling with surge flow systems.
- Compared to furrow irrigation, center pivots generally offer more than enough benefits in application efficiency and reduction in labor requirements to offset the additional costs.
- Advanced irrigation technologies are most advantageous to crops with high water needs, particularly in areas with deep pumping lifts. Producers using advanced systems will have not only lower pumping costs but also potential savings from chemigation and the need for fewer field operations.
- Compared to center pivot irrigation systems, subsurface drip irrigation (SDI) generally is significantly more expensive to install (on a per acre basis). SDI shows greater potential in situations less suited to center pivot irrigation (low water capacities, small or irregularly shaped fields, etc.).
- The less efficient the irrigation system, the more effect fuel price, pumping lift, and labor costs have on the cost of producing an irrigated crop.
- As more water is pumped, the fixed cost per acre-inch drops.

Chapter 2: Irrigation scheduling

Evapotranspiration

Objectives

- Increase understanding of fundamentals of evapotranspiration (ET).
- Increase familiarity with ET resources, including ET networks and internet-available data and online tools.
- Apply these concepts to optimizing water management in crop production.

Key points

1. Meteorological factors most often used to estimate ET are solar radiation (irradiance), air temperature, humidity, and wind speed.
2. ET can be limited by soil moisture availability.
3. Plant factors that affect ET include plant type, plant health, growth stage, plant population, and crop variety (affecting canopy and geometry). Successful application of ET models to irrigation scheduling requires appropriately relating the reference crop ET to the target crop ET through use of crop growth information and crop coefficients.
4. ET is most accurately measured through use of weighing lysimeters.
5. Alternate methods of estimating ET include water balance estimation techniques, including soil moisture monitoring, remote sensing, and eddy covariance and scintillometry methods.
6. All methods require understanding of the fundamentals and applications. ET-based crop water use estimates provided by ET networks (where available) require little or no investment in instrumentation and data collection on the part of the end-user.

What is evapotranspiration (ET)?

Evapotranspiration (ET) is a term that describes crop water demand by combining evaporation and transpiration. Evaporation is the process through which water is removed from moist soil and wet surfaces (such as dew on leaves). Transpiration is the process through which water is drawn up through the plant (roots extract water from the soil, and water is eventually removed through stomata on the leaves).

What is Reference ET?

Reference crop ET, also sometimes referred to as Potential Evapotranspiration (PET), is an estimate of the water requirement for a well-watered reference crop. This reference crop (an idealized cool season grass “short crop” or alfalfa “tall crop”) is essentially a model crop used as a basis for the ET model. Reference ET is calculated by applying climate data (temperature, solar radiation, wind, humidity) in a model (equation). Reference ET is only an estimate of the water demand for this model crop, based upon weather station data at a given location.

How is crop evapotranspiration calculated?

Crop-specific ET is estimated by multiplying the Reference ET by a crop coefficient.

Crop ET = Reference ET x Crop Coefficient

The crop coefficient accounts for the crop's water use (at a given growth stage) compared with the reference crop. For instance, seedling corn does not use as much water as the idealized grass reference crop, but during silking, the corn can use more water than the grass reference crop. The crop coefficient is understood to follow a pattern (curve) of the general shape (Figure 1). Each crop (wheat, sorghum, cotton, etc.) will have its own crop coefficient curve. Important to note, the crop coefficient curve is SPECIFIC to the ET equation used. The preferred equation is the ASCE-EWRI Standardized Reference ET Equation* (Allen, et al., 2005), but some ET networks in Texas use other models.

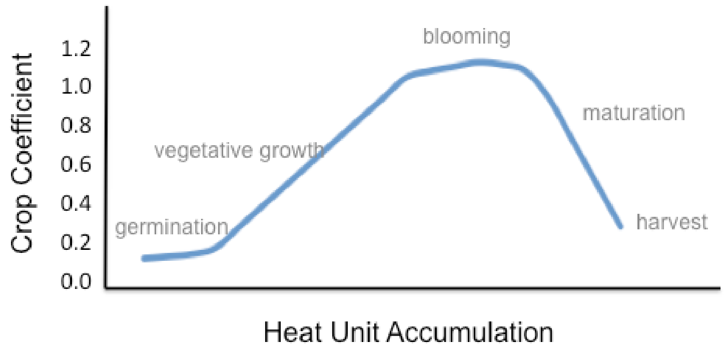


Figure 1. Generalized crop coefficient curve.

*Allen, Richard G., Ivan A. Walter, Ronald L. Elliott, Terry A. Howell, Daniel Itenfisu, Marvin E. Jensen, and Richard L. Snyder. 2005. ASCE Standardized Reference Evapotranspiration Equation. American Society of Civil Engineers, Baltimore, MD. 216 pp.

The reference crop ET model (equation) and the crop coefficient curves were developed from long-term research at various locations. Actual crop water demand can be affected by many factors, including available soil moisture, the crop's health, and likely by plant populations and crop variety traits. Models do not account for these factors. These additional factors are sometimes addressed through use of stress coefficients and other methods generally not reflected in simple ET network models. Hence, ET data provided by online networks are best used as guidelines for irrigation scheduling, and, where applicable, for integrated pest and crop management. The predicted growth stage and estimated water use should be verified with field observations. The actual crop water use may be less than the predicted value due to less than optimal field conditions.

How is estimated ET used to schedule irrigation?

A variety of irrigation scheduling methods, models, and tools are available. Many are essentially based upon a "checkbook" approach; water stored in the soil (in the crop's root zone) is withdrawn by evapotranspiration and deposited back into the soil through precipitation and irrigation. When soil moisture storage falls below a given threshold value (management allowable depletion), irrigation should be applied to restore the moisture. The threshold value may be determined by crop drought sensitivity, irrigation system capabilities, or other farm-level criteria.

Where can I find additional information on ET and related topics?

Reference Evapotranspiration (grass reference, ETo) and related agricultural weather data are available for some locations in South Texas on the Texas ET website: http://texaset.tamu.edu/. For locations without ET Network service, Reference ET (grass reference ET, ETo or alfalfa reference ET, ETr) can be calculated with local weather data and the Bushland Reference ET Calculator (smartphone app), available free of charge from iTunes. With reference ET and a reasonable crop coefficient, crop ET can be used with widely available ET-based irrigation scheduling tools, including KanSched, available at http://www.bae.ksu.edu/mobileirrigationlab/kansched-microsoft-excel.

Soil moisture management and monitoring

Objectives

- Increase understanding of soil physical properties that affect soil moisture storage and permeability.
- Increase familiarity with local soils and their characteristics as well as information resources addressing local soils.
- Apply these concepts to optimizing water management in crop production.

Key Points

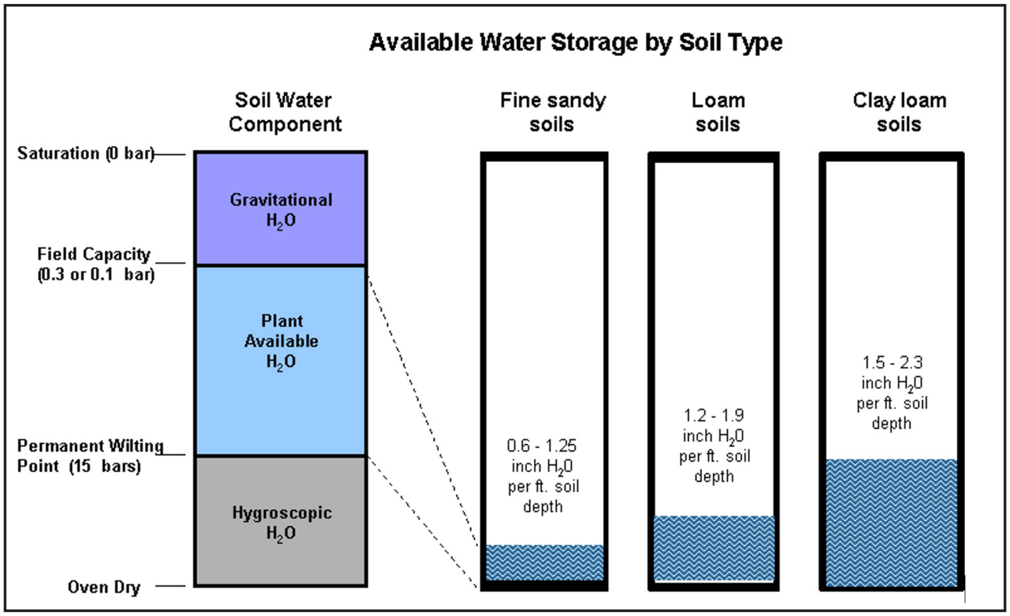
1. Soil permeability is affected by soil texture, structure, and moisture.
2. Plant available water in the root zone is water that can be stored in the soil between field capacity and permanent wilting point. Plant available water storage capacity is soil-specific.
3. Water in the soil is subjected to gravity, osmotic potential (suction), and matric (capillary) potential (suction).
4. There are several methods available for measuring or estimating soil moisture. These include gravimetric (oven dry), soil feel and appearance, resistance (WaterMark™ sensors), tensiometry, capacitance, time domain reflectometry, and other methods. Factors affecting the selection of a soil moisture monitoring method include costs, convenience, ease of use, required precision and accuracy, suitability for the soil texture, and personal preference of the operator.

Soil moisture storage capacity

Soil moisture characteristics: A soil's capacity for storing moisture is affected by its structure and organic matter content, but it is determined primarily by its texture.

Field capacity is the soil water content after soil has been thoroughly wetted when the drainage rate changes from rapid to slow. This point is reached when the *gravitational water* has drained. Field capacity is normally attained 2-3 days after irrigation and reached when the soil water tension is approximately 0.3 bars (30 kPa or 4.35 PSI) in clay or loam soils, or 0.1 bar in sandy soils.

Permanent wilting point is the soil moisture level at which plants cannot recover overnight from excessive drying during the day. This parameter may vary with plant species and soil type and is attained at a soil water tension of 10-20 bars. *Hygroscopic water* holds tightly onto the soil particles (below permanent wilting point) and cannot be extracted by plant roots.



Plant available water is retained in the soil between field capacity and the permanent wilting point. It is often expressed as a volumetric percentage or in inches of water per foot of soil depth. Approximate plant available water storage capacities for various soil textures are shown to the right.

If the goal is to apply water to moisten the root zone to some target level (75% field capacity, for instance, depending upon local factors), it is essential to know how much water the soil will hold at field capacity and how much water is already in the soil. Estimating soil moisture can be accomplished through direct methods (gravimetric soil moisture determination) or indirect methods. A variety of commercially available soil moisture monitoring instruments provide the means to estimate soil moisture relatively quickly and easily. Alternately, a soil's moisture condition can be assessed by observing its feel and appearance. A soil probe, auger, or spade may be used to extract a small soil sample within each foot of root zone depth. The sample is gently squeezed manually to determine whether the soil will form a ball or cast, and whether it leaves a film of water and/or soil in the hand. Pressing a portion of the sample between the thumb and forefinger allows one to observe whether the soil will form a ribbon. Results of the sample are compared with the following guidelines.

Table 1. How soil feels and looks at various soil moisture levels.

Soil moisture level	Fine sand, loamy fine sand	Sandy loam, fine sandy loam	Sandy clay loam, loam, silt loam	Clay loam, clay, silty clay loam
0%–25% available soil moisture	Appears dry. Will not retain shape when disturbed or squeezed in hand.	Appears dry. May make a cast when squeezed in hand but seldom holds together.	Appears dry. Aggregates crumble with applied pressure.	Appears dry. Soil aggregates separate easily, but clods are hard to crumble with applied pressure.
25%–50% available soil moisture	Slightly moist appearance. Soil may stick together in very weak cast or ball.	Slightly moist. Soil forms weak ball or cast under pressure. Slight staining on finger.	Slightly moist. Forms a weak ball with rough surface. No water staining on fingers.	Slightly moist. Forms weak ball when squeezed, but no water stains. Clods break with applied pressure.
50%–75% available soil moisture	Appears and feels moist. Darkened color. May form weak cast or ball. Leaves wet outline or slight smear on hand.	Appears and feels moist. Color is dark. Forms cast or ball with finger marks. Will leave a smear or stain and leaves wet outline on hand.	Appears and feels moist and pliable. Color is dark. Forms ball and ribbons when squeezed.	Appears moist. Forms smooth ball with defined finger marks. Ribbons when squeezed between thumb and forefinger.
75%–100% available soil moisture	Appears and feels wet. Color is dark. May form weak cast or ball. Leaves wet outline or smear on hand.	Appears and feels wet. Color is dark. Forms cast or ball. Will smear or stain and leaves wet outline on hand. Will make weak ribbon.	Appears and feels wet. Color is dark. Forms ball and ribbons when squeezed. Stains and smears. Leaves wet outline on hand.	Appears and feels wet. May feel sticky. Ribbons easily. Smears and leaves wet outline on hand. Forms good ball.

Root zone depth: Roots are generally developed early in the season and will grow in moist (not saturated or extremely dry) soil. Soil compaction, caliche layers, perched water tables, and other impeding conditions will limit the effective rooting depth. **Most crops will extract most (70%–85%) of their water requirement from the top 1 to 2 feet of soil, and almost all of their water from the top 3 feet of soil, if water is available**. Deep soil moisture is beneficial primarily when the shallow moisture is depleted to a water stress level. Commonly reported effective root zone depths by crop are listed in Table 2.

Table 2. Root zone depths reported for various crops.*

Crop	Approximate Effective Rooting Depth (feet)
Alfalfa	3.3–6.6+
Corn	2.6–5.6
Cotton	2.6–5.6
Peanut	1.6–3.3
Sorghum	3.3–6.6

**These values represent the majority of feeder roots.*

Permeability is the soil's ability to take in water through infiltration. Soil with low permeability cannot take in water as fast as soil with high permeability; the permeability, therefore, affects the risk for runoff loss of applied water. Permeability is affected by soil texture, structure, and surface condition. Generally speaking, fine textured soils (clays, clay loams) have lower permeability than coarse soils (sand). Surface sealing, compaction, and poor structure (particularly at or near the surface) limit permeability.

Using soil moisture information to improve irrigation efficiency

Deep percolation losses are often overlooked, but they can be significant. Water applied in excess of the soil's water storage capacity can drain below the crop's effective root zone. In some cases, periodic deep leaching is desirable to remove accumulated salts from the root zone. However, generally deep percolation losses can have a significant negative impact on overall water use efficiency — even under otherwise efficient irrigation practices such as low energy precision application (LEPA) and SDI. Furrow irrigation poses increased deep percolation losses at upper and lower ends of excessively long runs. Surge irrigation can improve irrigation distribution uniformity, reducing deep percolation losses in furrow irrigation. Coarse soils are particularly vulnerable to deep percolation losses due to their low water-holding capacity. Other soils may exhibit preferential flow along cracks and in other channels formed under various soil structural and wetting pattern scenarios.

Runoff occurs when rainfall or the irrigation rate exceed the soil's permeability. Sloping fields with low permeability soils are at greatest risk for runoff losses. Vegetative cover, surface conditioning (including furrow dikes), and grade management (land leveling, contouring, terracing, etc.) can reduce runoff losses. Irrigation equipment selection (nozzle packages) and management can also help to minimize runoff losses.

Soil moisture monitoring

Methods used to measure soil water are classified as *direct* and *indirect*. The direct method refers to the gravimetric method in which a soil sample is collected, weighed, oven-dried and weighed again to determine the sample's water content on a mass percent basis. The gravimetric method is the standard against which the indirect methods are calibrated. Some commonly used indirect methods include electrical resistance, tensiometry, capacitance, time domain reflectometry (TDR) and time domain transmissivity (TDT).

Electrical resistance methods include gypsum blocks or granular matrix sensors (more durable and more expensive than gypsum blocks) that are used to measure electrical resistance in a porous medium. Electrical resistance increases as soil moisture decreases. Sensors are placed in the soil root zone (and remain in place), and a meter is connected to lead wires extending above the ground surface for each reading. For most on-farm applications, small portable handheld meters are used; automated readings and controls may be achieved through use of dataloggers.

Tensiometers measure the tension of water in the soil (soil suction). A tensiometer consists of a sealed water-filled tube equipped with a vacuum gauge on the upper end and a porous ceramic tip on the lower end. As the soil dries, soil water tension (suction) increases; in response to this increased suction, water is moved from the tensiometer through the porous ceramic tip, creating a vacuum in the sealed tensiometer tube. Water can also move from the soil into the tensiometer during or following irrigation. Most tensiometers have a vacuum gauge graduated from 0 to 100 (centibars, cb, or kilopascals, kPa). A reading of 0 indicates a saturated soil. As the soil dries, the reading on the gauge increases. The useful limit of the tensiometer is about 80 cb. Above this tension, air enters through the ceramic cup and causes the instrument to fail. Therefore, these instruments are most useful in sandy soils and with drought-sensitive crops, because they have narrower soil moisture ranges than other sensor types.

Capacitance sensors, time domain reflectometry (TDR), time domain transmissivity (TDT), and related technologies have become more popular in recent years. Sensors must be carefully installed in the root zone, and they are left in place during the entire monitoring period (crop season, for instance). They are typically connected to a datalogger for monitoring over time, and data are often accessible remotely. Advanced "packaging" of the data has improved adoption of these technologies. Initial costs of the sensors plus subscription fees in some cases make these sensors more expensive than simpler sensors, necessitating balance between cost(s) and numbers of sensors, and increasing the importance of the careful placement (installation and siting) of sensors.

All soil water monitoring methods have advantages and limitations. They vary in cost, accuracy, ease of use, and applicability to local conditions (soils, moisture ranges, etc.) Most require calibration for accurate moisture measurement. Practice and experience under given field conditions increases proficiency of use and interpreting information.

Chapter 3: Irrigation technologies and best management practices

Surface irrigation

Objectives

- Increase understanding of irrigation efficiency, losses, and distribution uniformity associated with surface irrigation.
- Increase understanding and application of best management practices to improve efficiency and uniformity of surface irrigation.

Key points

1. Surface irrigation uses gravity flow to spread water over a field. With flood irrigation, the entire land area to be irrigated is covered with water. Furrow irrigation uses small channels or ditches between planted rows to convey water across a field.
2. Using pipe systems to convey and distribute water increases on-farm irrigation efficiency, provides better irrigation control, and reduces labor costs.
3. The correct amount of water to apply at each irrigation event depends on the amount of soil water used by the plants between irrigations (soil water depletion), the water-holding capacity of the soil, and the depth of the crop root zone. Applying the right amount of water to an irrigation set does not guarantee efficient irrigation. Water also must be uniformly applied from one end of the irrigation run (field) to the other.
4. Best management practices to consider include precision land leveling, gated pipe, surge flow irrigation, irrigation scheduling, recirculating irrigation runoff (tailwater reuse), and alternate furrow application.

Surface irrigation uses gravity flow to distribute water over a field. Surface systems are the least expensive to install but have relatively high labor requirements for operation compared to other irrigation methods. Skilled irrigators also are needed to achieve good efficiencies. Even if properly designed, surface systems tend to have lower water application efficiencies than more advanced irrigation technologies.

Surface methods

With **flood irrigation,** the entire land area to be irrigated is covered with water. There may be no method of controlling water flow other than the topography of the land.

Furrow irrigation uses small channels or ditches between planted rows to convey water across a field. As water travels down the furrow, infiltrated water moves into the soil both laterally and vertically to saturate the soil profile.

With **level basin** irrigation, water is applied over a short period to a level area enclosed by dikes or borders. The basin's floor may be flat, ridged, or shaped into beds. Basin irrigation is most effective on uniform soils precisely leveled when large stream sizes relative to basin area are available (high flow turnouts).

Selection and applications

Application rates

The correct amount of water to apply at each irrigation event depends on the amount of soil water used by the plants between irrigations (soil water depletion), the water-holding capacity of the soil, and the depth of the crop root zone. Applying the right amount of water to an irrigation set does not guarantee efficient irrigation. Water also must be uniformly applied from one end of the irrigation run (field) to the other. Crop yields can be reduced by over-irrigation and/or under-irrigation, which is more likely to occur in fields with poor irrigation application uniformity.

In general, to avoid completely refilling the root zone in sandy textured soils, gross application amounts should not exceed 1.5 to 2 inches. On medium to fine textured soils, they should not exceed 2.5 to 3 inches.

Set time-stream size

Appropriate stream size should account for field slope, intake rate, and length of run. Runoff and the uniformity of water infiltrated along the furrow are related to the cutoff ratio. This is the ratio of the time required for water to advance to the end of the furrow to the total set time used for the irrigation. A cutoff ratio of 0.5 is desired. For example, for a 12-hour set time, the advance time should be about 6 hours. The easiest way to change the advance time is by altering the furrow stream size, i.e. by changing the size of the irrigation set. This change will affect the cutoff ratio and hence the uniformity of water application.

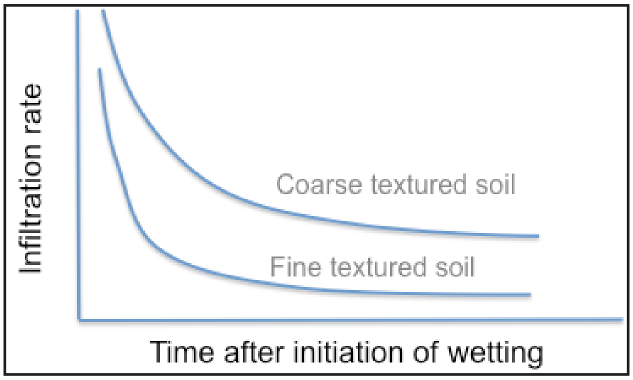
The best combination of furrow stream size and set time moves water to the end of the furrow within the requirements of the cutoff ratio, is less than the maximum erosive stream size, and results in gross applications that are not excessive.

Length of run

Excessively long irrigation runs result in water loss through deep percolation at the head of the furrow by the time the lower end is adequately irrigated. The length of irrigation runs should not exceed 600 feet on sandy soils and about 1300 feet on clay soils. However, on some low intake rate soils, the length of run may be as long as 2600 feet, provided the water can be distributed uniformly between the upper and lower end of the field. The time required for advance increases dramatically with furrow length.

Intake rates

The rate at which water infiltrates into the soil varies with slope, soil texture, spacing of furrows, and soil compaction. The rate at which the soil will absorb water also varies with time and soil moisture. At first, water will penetrate rapidly into the soil, but with time, it will decrease to a rate that stays relatively consistent for the remainder of the irrigation. (See figure to the right.) This fairly consistent rate is called basic intake rate. If the basic intake rate is 0.5 inches per hour or less, the length of run can be 1300 feet long. Higher intake rates require shorter water runs.



Generalized infiltration rate decrease with soil wetting. The infiltration curve is soil-specific.

Distribution and delivery systems

Using pipe systems (rather than earthen ditches) to convey and distribute water to fields offers several advantages:

- Increased on-farm irrigation efficiency due to reduced losses through deep percolation from earthen conveyance ditches.
- Better irrigation control and labor savings.

Surface method best management practices

Precision land leveling improves water application efficiency and uniformity. Leveling land generally is cost effective through increased yields and reduced water losses.

Gated pipe can result in a 35% to 60% reduction in water and labor costs. Gated pipe provides a more equal distribution of water into each furrow and eliminates seepage and evaporative losses that occur in unlined irrigation ditches. Gated pipe is available as the traditional aluminum pipe, the less expensive low-head PVC pipe, and the inexpensive "lay-flat" plastic tubing (also called "poly-pipe").

Surge flow irrigation is a variation of continuous-flow furrow irrigation. Water is usually applied in cycles of 1 to 3 hours of alternating on-off periods. Surge works by taking advantage of the natural surface sealing properties of many soils. Surge often results in increased irrigation efficiencies and gives the grower the ability to apply smaller amounts of water at more frequent intervals. Automatic surge valves reduce labor requirements.

Irrigation scheduling by use of evapotranspiration estimates (based upon weather data), soil moisture monitoring, or plant monitoring methods improves water use efficiency by aiding the manager to provide the right amount of water at the right times to reduce losses and improve crop response to water.

Recirculating irrigation runoff water (also called "tailwater reuse") effectively decreases the amount of water that needs to be pumped or delivered to the field.

Alternate furrow application effectively reduces the wetted surface area from which evaporation can occur.

Center pivot irrigation

Objectives

- Increase understanding of irrigation efficiency, losses, and distribution uniformity associated with center pivot irrigation.
- Increase understanding and application of best management practices to improve efficiency and uniformity of center pivot irrigation.

Key points

1. Low pressure center pivot and linear sprinkler irrigation systems are more water efficient and energy efficient than high pressure systems.
2. Low pressure systems, which include LEPA, Low Elevation Spray Application (LESA), Mid-Elevation Spray Application (MESA), and Low Pressure In-Canopy (LPIC), are well suited to automation and offer the potential to apply relatively precise irrigation amounts (from light, frequent irrigations to heavy, less frequent applications) as needed by the crop or for other field activities (such as chemigation applications).
3. Sprinkler nozzle packages should be inspected periodically and updated as needed.
4. Management and maintenance are key to good results with any pressurized sprinkler system.

Center pivot irrigation systems are used widely, especially in the Texas High Plains where most of the systems are low pressure systems, including LEPA, LESA, MESA, and LPIC.

LEPA

This type applies to the management system as well as to the actual hardware. LEPA irrigation applies water directly to the soil surface primarily through drag hoses or through "bubbler" type applicators. Notably LEPA involves more than just the hardware through which water is applied. It involves farming in a circular pattern (for center pivot irrigation systems) or straight rows (for linear irrigation systems). It also includes use of furrow dikes and/or residue management to hold water in place until it can infiltrate into the soil.

LEPA irrigation generally is applied to alternate furrows, reducing overall wetted surface area, and hence reducing evaporation losses immediately following an irrigation application. Because a relatively large amount of water is applied to a relatively small surface area, there is risk of runoff losses from LEPA, especially on clay soils and/or sloping ground. While furrow dikes and circular planting patterns help reduce the runoff risk, LEPA is not universally applicable; some slopes are just too steep for effective application of LEPA irrigation.

LESA and MESA

These similar irrigation application systems embody the LEPA technology but do not meet one or more of the criteria to be called LEPA. Low pressure spray systems — LESA, MESA, and LPIC — offer more flexibility in row orientation, and may be easier for some growers to manage, especially on clay soils or sloping fields. Objectives with these systems include applying water at low elevation (generally 1-2 feet from the soil surface for LESA; often 5-10 feet for MESA) to reduce evaporation losses from water droplets (especially important in windy conditions); applying water at a rate not exceeding the soil's infiltration capacity (preventing runoff); and selecting a nozzle package that provides uniform distribution and appropriate droplet size and wetting pattern.

Low pressure systems offer cost savings, compared with high pressure systems, due to reduced energy requirements. They also facilitate increased irrigation application efficiency due to decreased evaporation losses during application. Considering high energy costs and, in many areas, limited water capacities, high irrigation efficiency can help lower overall pumping costs and improve crop yield/quality return relative to water and energy inputs.

Other considerations

In sloping fields, pressure regulators may be warranted to improve irrigation distribution uniformity in the field. This reduces occurrence of "wet spots" and "dry spots" in the field. Good uniform distribution is also essential to effective chemigation/fertigation.

In many semi-arid areas, pre-season irrigation or excess early season irrigation is used to provide moisture from crop establishment and to fill soil moisture storage capacity to augment often deficit irrigation during peak crop water use periods. Pre-season irrigation water losses through evaporation and deep percolation can be quite high. Hence, it is important for growers to understand how much water their soil root zone will hold, taking into account effective root zone depth and soil moisture storage capacity per foot of soil. Applying more water than the soil can hold can result in deep percolation losses or runoff; starting irrigation too early increases opportunity for evaporation losses. These risks need to be balanced with irrigation system capacity issues.

LEPA vs. LESA

Properly managed, LEPA is potentially more water-efficient than LESA. Both systems, when properly managed, can be very efficient. LEPA allows for alternate furrow irrigation — there are alternate dry "traffic" furrows that are more accessible for timely field applications. By limiting field operation traffic to the dry furrows, the infiltration capacity of soil in the "wet" irrigated furrows is maintained. LEPA allows for irrigation without foliar wetting. For some crops, this can reduce foliar disease risk. If water quality (salinity) is an issue, LEPA can reduce salt damage to foliage.

In very coarse soils, there sometimes may be insufficient lateral soil water movement from alternate furrow LEPA applications. This is mainly a concern for seed germination, shallow-rooted crops, and peanuts that require a moist zone near the soil surface for pegging and pod development. Spray irrigation (LESA and MESA) wet the soil surface more uniformly than LEPA. It is possible to apply LESA for crop germination/establishment, then convert to LEPA to take advantage of the higher irrigation application efficiency in season, and finally convert back to spray applications for chemigation or for uniform wetting of the shallow root zone as needed. Hardware is readily commercially available to accommodate these applications.

Recommendations for realizing the benefits of advanced irrigation technology

New irrigation systems

- Start with a good design.
- Work with a qualified designer (Certified Irrigation Designer or licensed Professional Engineer).
- Design for realistic well capacities.
- Consider whether the water delivery is likely to decrease during the season.
- Compare "apples to apples" on designs; a cheaper package may not be better.
- Things to look for in a design include adequate pressure/vacuum relief; flexibility to accommodate crop rotations and well capacity fluctuations as needed; ease of maintenance; and appropriately sized underground pipelines (consider friction losses, especially in longer pipeline runs).
- Consider whether pressure regulators are needed; they are more likely to be justified in sloping fields. Install the system correctly, and follow design specifications.

Older systems

- Periodically evaluate the irrigation system to determine if it is performing according to design specifications. Consider wear and maintenance requirements on electrical, mechanical, and hydraulic components; replace worn parts, and upgrade or replace them as needed. Applicators (nozzles, splash pads, etc.), pressure regulators, and other components wear out over time, and severe conditions (poor water quality, for instance) can accelerate wear.
- Consider whether the sprinkler should be re-nozzled. Has there been a significant drop in well capacity? Has the nozzle package departed from the original design over time? Broken or lost nozzles may be "temporarily"

replaced with the wrong size nozzle. Over time, these quick fixes can lead to poor distribution uniformity. Are pressure regulators or nozzles functioning properly? Replace them as needed.

- Calibrate the pivot system and conduct a distribution uniformity test periodically to ensure the correct application rates are applied and applications are uniform over the field. These are especially important for chemigation applications. Pressure gauges and flow meters can simplify pivot evaluation and trouble-shooting.

Irrigation management

Crop water requirements are crop-specific, and they vary with weather and growth stage. Water management is especially important for critical periods in crop development. Apply knowledge of the root zone to optimize irrigation management; account for the crop's effective rooting depth, the soil moisture storage capacity, and field-specific conditions (shallow soils, caliche layers, etc.). In irrigation scheduling, consider using soil moisture monitoring, evapotranspiration information, and/or plant indicators to fine-tune water applications to meet crop needs.

Microirrigation

Objectives

- Increase understanding of irrigation efficiency, losses, and distribution uniformity associated with microirrigation.
- Increase understanding and application of best management practices to improve efficiency and uniformity of microirrigation.

Key points

1. Microirrigation offers potential for high water, energy, and fertilizer efficiency and uniform distribution. These can result in a good crop response (yield and/or quality) to irrigation and agronomic inputs.
2. Microirrigation, like other advanced irrigation technologies, yields best results when properly designed, installed, maintained, and managed.
3. Microirrigation is well suited to automation. While it can offer labor savings, these savings can be offset by increased management requirement.
4. Water quality is especially important in microirrigation applications. Biological, chemical, and physical clogging of emitters generally can be prevented through appropriate filtration and use of chemical additives as needed.
5. Flow meters and pressure gauges are essential for monitoring system performance and in trouble-shooting.
6. Some potential problems encountered with microirrigation include rodent and insect damage to tape and components; clogging of emitters and components; and problems with germination and crop establishment.

Microirrigation, including microspray, surface drip, and subsurface drip irrigation methods, can deliver water precisely and efficiently. Microirrigation is commonly used for irrigation of high value horticultural crops, orchards, and vineyards. SDI is gaining popularity in production of agronomic "row" crops, especially in areas with limited well capacities and where small or irregularly shaped fields give SDI a competitive advantage over other irrigation technologies and methods.

Key components

Microirrigation systems typically work at relatively low pressures. A **pump** should be correctly sized to deliver required flow and pressure, taking into account system operating pressure, lift(s), friction and dynamic pressure losses, and required flushing volumes/velocities.

Filters are key to protecting the irrigation system from plugging by suspended solids in the water.

Depending on the type of filtration system, a **pressure-sustaining valve** may be needed to facilitate flushing of the filters.

Pressure gauges should be used at the inlet and outlet points of the filters to show pressure differential for initiating flushing of the filters.

A **backflow preventer** prevents backflow of fertilizers, chemicals, or particulates into the water supply and are installed between the water supply or pump and the chemical injection line.

A **regulation valve** helps to maintain proper operating pressure in the irrigation lines.

A **chemical injector** precisely injects chlorine, acid, fertilizers, and other agrichemicals into the irrigation stream.

A **flow meter** measures the volume of water moving through the system, either as a flow rate or as an accumulated total volume basis.

A chemigation line check valve is installed between the injector and the water source. It prevents backflow of water into the chemical supply tank in case of injector failure. This valve is often an integral part of an injector unit and can handle both backpressure and backsiphonage.

Zone valves are opened or closed to control the flow to appropriate zones. They may be manual or automatically controlled using an electronic control system.

Pressure regulators are typically located on the manifold to help regulate operating pressure for emitters.

Air and vacuum relief valves prevent soil or particulate material from being sucked back into emitters when the irrigation system is turned off or when driplines are drained.

Main line and sub-main lines supply water from the system head to the **manifolds,** which subsequently distribute the water to the **driplines.** The dripline is the polyethylene tubing that includes built-in **emitters.** Emitter spacing and rate are selected to match crop demands and soil water-holding capacity.

Flush lines at the system's tail end allow sediments and contaminants to be flushed from dripline laterals at a centralized location; equalize pressure in the dripline laterals; and allow positive pressure on both sides of a dripline break to prevent soil ingestion into the dripline.

Connectors are needed to attach the dripline to the manifold or sub-main.

Electronic **controllers** allow for automation of irrigation applications to irrigate selected zones based upon set times or volumes.

Maintenance considerations

A properly designed and maintained microirrigation system may last more than 20 years. A maintenance program includes cleaning the filters, flushing the lines, and injecting disinfectants and/or acids as needed according to water quality.

Suspended solids, magnesium and calcium precipitation, manganese-iron oxides and sulfides, algae, bacteria, and plant roots can plug emitters. Every system should contain a flow meter and pressure gauges. Daily monitoring of these gauges will indicate whether the system is working properly. A low pressure reading on a pressure gauge can indicate leaks in the system. Gradual increasing pressure with reduced flow can indicate clogging of emitters and/or laterals.

Maintaining filters

Filters remove suspended solids (sediments) from the water. There are three main types of filters: cyclonic filters (centrifugal separators or hydrocyclones); screen and disk filters; and media filters. It is common practice to install a combination of filters to deal with various particulate sizes effectively. Filtration requirements depend upon the water source and quality, and upon the emitter size.

Flushing lines and manifolds

Very fine particles pass through the filters and can eventually clog laterals and emitters. As long as the water velocity is high and the water is turbulent, these particles remain suspended. If the water velocity slows or the water becomes less turbulent, these particles may settle out. This commonly occurs at the distant ends of the lateral lines. If they are not flushed, the emitters will plug and the line eventually will be filled with sediment from the downstream end to the upstream end. Systems must be designed so that mainlines, sub-mains, manifolds, and laterals can all be flushed. Mainlines, sub-mains, and manifolds are flushed with a valve installed at the end of each. Lateral lines can be flushed manually or automatically. It is important to flush the lines at least every 2 weeks during the growing season, or as needed based upon local conditions (water quality and system layout).

Injecting chlorine

At a low concentration (1 to 5 ppm), chlorine kills bacteria and oxidizes iron. At a high concentration (100 to 1000 ppm), it oxidizes organic matter and effectively removes it from the system.

Injecting acid

Acids are injected into irrigation water to prevent or treat plugging caused by precipitation of calcium carbonate (lime), magnesium, and some other salts. Water with a pH of 7.5 or higher and a bicarbonate level of more than 100 ppm is likely to have problems with lime precipitation, depending on the hardness of the water. Maintaining a low pH (6.5 or less) can generally prevent chemical precipitation and subsequent plugging of emitters; alternately periodic shock acid injection (temporarily lowering the pH below 4) can prevent build-up of precipitates.

An excellent resource for maintenance and troubleshooting of microirrigation systems is the University of California Agriculture and Natural Resources Maintenance of Microirrigation website: http://micromaintain.ucanr.edu/.

Advantages and limitations of microirrigation

Advantages of microirrigation (properly designed, installed, maintained, and managed)

1. High efficiency and uniformity of water application.
2. Precise application of fertigation and chemigation. (Note: caution must be exercised to prevent precipitation of agrichemicals that may react with constituents in water. Read and comply with all chemical labels.)
3. Reduced labor requirement compared to other irrigation technologies.
4. Relatively high water use efficiency (water conservation and/or crop yield/quality response to water).
5. Applicability to operations with large or small water capacities and over a range of field sizes and topographic and soil conditions. Microirrigation is readily “scalable” to the field and water supply.
6. Reduced problems with annual weeds.
7. Suitability to automation.

Limitations of microirrigation (depending upon local conditions)

1. High initial cost.
2. Maintenance and operation require higher level of skilled management than other irrigation systems.
3. Potential problems with emitter clogging, root intrusion, and rodent and insect damage.
4. Potential problems with germination of a crop.
5. Limited root zone.
6. Limited options for deep tillage and deep injection of chemicals that may be needed for pest and disease management.

Chapter 4: Water quality issues in irrigation

Salinity management

Objectives

- Increase familiarity with terminology and interpretation of water quality analysis and soil salinity analysis reports.
- Increase understanding of how salts affect soils and plants.
- Apply these concepts to management of lightly to moderately saline water in crop production.

Key points

1. Salts occur naturally in water. The concentrations and specific ion species depend upon the water source. Some groundwater sources can have naturally high levels of some salts.
2. Some salts can affect soil properties or can interfere with the availability of essential plant nutrients.
3. Salt accumulation in the root zone can hurt soil productivity.
4. Some salts in high concentrations can be toxic to plants.
5. Plants' susceptibility to salt injury may vary with growth stage.
6. Leaching of salts is often recommended for removing excess accumulations from the root zone. This requires sufficient water; it may be facilitated with soil additives, depending upon the specific salt species.
7. Irrigation methods that limit leaf wetting may reduce risk of foliar salt injury.

One of the most common water quality concerns for irrigated agriculture is salinity. Recommendations for effective management of irrigation water salinity depend upon local soil properties, climate, and water quality; options of crops and rotations; and irrigation and farm management capabilities.

What is salinity?

All major irrigation water sources contain dissolved salts. These salts include a variety of natural occurring dissolved minerals, which can vary with location, time, and water source. Many of these mineral salts are micronutrients, having beneficial effects. However, excessive total salt concentration or excessive levels of some potentially toxic elements can have detrimental effects on plant health and/or soil conditions.

The term "salinity" is used to describe the concentration of (ionic) salt species, generally including calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), bicarbonate (HCO_3^{-}), carbonate(CO_3^{2-}), sulfate (SO_4^{2-}), and others. Salinity is expressed in terms of electrical conductivity (EC), in units of millimhos per centimeter (mmhos/cm), micromhos per centimeter (μmhos/cm), or deciSiemens per meter (dS/m). The electrical conductivity of a water sample is proportional to the concentration of the dissolved ions in the sample; hence, EC is a simple indicator of total salt concentration.

Another term frequently used in describing water quality is total dissolved solids (TDS), which is a measure of the mass concentration of dissolved constituents in water. TDS generally is reported in units of milligrams per liter (mg/l) or parts per million (ppm). Specific salts reported in a laboratory analysis report often are expressed in terms of mg/l or ppm; these represent mass concentration of each component in the water sample. Another term used to express mass concentration is normality; units of normality are milligram equivalents per liter (meq/l). The most common units used in expressing salinity are summarized in Table 3.

Table 3. Units commonly used to express salinity.*

Mass Concentration (Total Dissolved Solids): mg/l = milligrams per liter   ppm = parts per million   ppm ≅ mg/l
<u>Electrical Conductivity (increases with increasing TDS):</u> conductivity = 1/resistance   (mhos = 1/ohm) mmhos/cm = millimhos per centimeter µmhos/cm = micromhos per centimeter dS/m = deciSiemens per meter 1 dS/M = 1 mmhos/cm = 1000 µmho/cm
<u>Salinity Conversions:</u> 0.35 X (EC mmhos/cm) = osmotic pressure in bars 651 X (EC mmhos/cm) = TDS in mg/l* 10 X (EC mmhos/cm) = Normality in meq/l 0.065 X (EC mmhos/cm) = percent salt by weight * Also has been related as: TDS (mg/l) = EC (dS/m) X 640 for EC < 5 dS/m TDS (mg/l) = EC (dS/m) X 800 for EC > 5 dS/m
<u>Normality</u> meq/l = milligram equivalents per liter (*aka* milliequivalents per liter) meq/l = mg/l ÷ equivalent weight equivalent weight = atomic weight ÷ electrical charge Example: To convert 227 ppm calcium concentration to meq/l: ppm = mg/l; therefore 227 ppm = 227 mg/l Calcium atomic weight = 40.078 g/mol valence: +2 (charge = 2) equivalent weight = 40.078 / 2 = 20.04 meq/l = 227 / 20.04 = 11.33 Therefore 227 mg/l = 11.33 meq/l for calcium.
** Compiled from various sources*

Why is salinity a problem?

High salinity in water (or soil solution) causes a high osmotic potential. In simple terms, the salts in solution and in the soil "compete" with the crop for available water. Some salts can have a toxic effect on the plant or can "burn" plant roots and/or foliage. Excessive levels of some minerals may interfere with relative availability and plant uptake of other micronutrients. Soil pH, cation exchange capacity (CEC), and other properties also influence these interactions.

High concentration of sodium in soil can lead to the dispersion of soil aggregates, thereby damaging soil structure and interfering with soil permeability. Hence, special consideration of the sodium level or "*sodicity"* in soils is warranted.

How do you know if you have a salinity problem?

Water and soil sampling and subsequent analysis are key to determining whether salinity will present a problem for a particular field situation. If wastewater or manure are applied to a field regularly or if the irrigation water source varies in quality, soil salinity should be monitored regularly for accumulation of salts.

Water quality and soil chemical analyses are necessary to determine which salts are present and their concentrations. Standard laboratory analyses include total salinity reported as EC or as TDS. Salinity indicates the potential risk of damage to plants. General crop tolerances to salinity of irrigation water and soil are listed in Table 4. These values should be considered only as guidelines, since crop management and site specific conditions can affect salinity tolerance.

Table 4. Tolerance* of selected crops to salinity in irrigation water and soil.

Crop	Threshold EC in irrigation water in mmhos/cm or dS/m		Threshold EC in soil (saturated soil extract) in mmhos/cm or dS/m	
	0% yield reduction	50% yield reduction	0% yield reduction	50% yield reduction
Alfalfa	1.3	5.9	2.0	8.8
Barley	5.0	12.0	8.0	18.0
Bermudagrass	4.6	9.8	6.9	14.7
Corn	1.1	3.9	1.7	5.9
Cotton	5.1	12.0	7.7	17.0
Sorghum	2.7	7.2	6.8	11.0
Soybean	3.3	5.0	5.0	7.5
Wheat	4.0	8.7	6.0	13.0
* After Rhoades, et. al. (1992); Fipps (2003) and various sources				

Additional information, including concentrations of specific salt components, indicates the relative risk of sodicity and toxicity. High sodium can present a risk of toxicity to plants. It can also indicate a risk of soil aggregate dispersion, which can result in breakdown of soil structure, reducing the soil's permeability. Relative risk of soil damage due to sodicity is indicated by the sodium adsorption ratio (SAR), which relates the relative concentration of sodium $[Na^+]$ compared to the combined concentrations of calcium $[Ca^+]$ and magnesium $[Mg^+]$. SAR is calculated by the following equation:

$$SAR = \frac{[Na^+]}{(([Ca^+] + [Mg^+]) / 2)^{1/2}}$$

Managing irrigation to mitigate salinity

Minimize application of salts

An obvious, simple, option to minimize effects of salinity is to minimize irrigation applications and the subsequent accumulation of salts in the field. This can be accomplished through converting to a rain-fed (dryland) production system; maximizing effectiveness of precipitation to reduce the irrigation required; adopting highly efficient irrigation and tillage practices to reduce irrigation applications required; and/or using a higher quality irrigation water source (if available). Since some salts are added through fertilizers or as components (or contaminants) of other soil additives, soil fertility testing is warranted to refine nutrient management programs.

Crop selection

Some crops and varieties are more tolerant of salinity than others. For instance, barley, cotton, rye, and Bermudagrass are classified as salt tolerant (a relative term). Wheat, oats, sorghum, and soybean are classified as moderately salt tolerant. Corn, alfalfa, many clovers, and most vegetables are moderately sensitive to salt. Some relatively salt tolerant crops (such as barley and sugarbeet) are more salt sensitive at emergence and early growth stages than in their later growth stages. Currently, crop breeding programs are addressing salt tolerance for several crops, including small grains and forages.

Some field crops are particularly susceptible to particular salts or specific elements or to foliar injury if saline water is applied through sprinkler irrigation methods. Elements of particular concern include sodium (Na), chlorine (Cl), and boron (B).

Irrigation leaching

The classical "textbook" solution to salinity management in the field is through leaching (washing) accumulated salts below the root zone. This is often accomplished by occasional excessive irrigation applications to dissolve, dilute, and move the salts. The amount of excess irrigation application required (often referred to as the "leaching fraction") depends upon the concentrations of salts within the soil and in the water applied to accomplish the leaching. A commonly used equation to estimate leaching fraction requirement (expressed as a percent of irrigation requirement) is:

$$\text{Leaching fraction} = \frac{\text{electrical conductivity of irrigation water}}{\text{permissible electrical conductivity in the soil}} \quad \text{X } 100\%$$

Where irrigation water quantity is limited, sufficient water for leaching may not be available. The combined problem of limited water volume and poor water quality can be particularly difficult to manage.

Soil additives and field drainage can be used to facilitate the leaching process. Site specific issues, including soil and water chemistry, soil characteristics, and field layout, should be considered in determining the best approach to accomplish effective leaching. For instance, gypsum, sulfur, sulfuric acid, and other sulfur-containing compounds, as well as calcium and calcium salts, may be used to increase the availability of calcium in soil solution to "displace" sodium adsorbed to soil particles, facilitating the sodium leaching for remediation of sodic soils. In soils with insufficient internal drainage for salt leaching and removal, mechanical drainage (subsurface drain tiles, ditches, etc.) may be necessary.

Irrigation method selection

Where foliar damage by salts in irrigation water is a concern, irrigation methods that do not wet plant leaves can be very beneficial. Furrow irrigation, LEPA irrigation, surface drip irrigation, and SDI methods can be very effective in applying irrigation without leaf wetting.

Wetting patterns by different irrigation methods affect patterns of salt accumulation in the seedbed and in the root zone. Evaporation and root uptake of water also affect the salt accumulation patterns. Often the pattern can be detected by a visible white residue along the side of a furrow, in the bottom of a dry furrow, or on the top of a row. Additional salt accumulations may be located at or near the outer/lower perimeter (outer wetting front) of the irrigated zone in the soil profile.

Seedbed and field management strategies

In some operations, seed placement can be adapted to avoid planting directly into areas with the highest salt accumulation. Row spacing and water movement within the soil can affect the amount of water available for seedlings as well as the amount of water required and available for the dilution of salts.

Irrigation scheduling

Light, frequent irrigation applications can result in a small wetted zone and limited capacity for dilution or leaching of salts. When salt deposits accumulate near the soil surface (due to small irrigation amounts combined with evaporation from the soil surface), crop germination problems and seedling damage are more likely. In arid and semi-arid conditions, a smaller wetted zone generally results in a smaller effective root zone; hence, the crop is more vulnerable to salt damage and drought stress injury.

Although excessive deep percolation losses of irrigation are discouraged for their obvious reduction in irrigation efficiency and their potential to contribute to groundwater contamination, occasional large irrigation applications may be required for leaching of salts. Managing irrigation schedules (amounts and timing) to support an extensive root zone helps to keep salt accumulations dispersed and away from plant roots, provides for better root uptake of nutrients, and offers improved protection from short-term drought conditions.

Advantages of organic matter

Organic matter offers chemical and physical benefits to mitigate the effects of salts. Organic matter can contribute to a higher CEC and therefore lower the exchangeable sodium percentage and help mitigate negative effects of sodium. By improving and preserving soil structure and permeability, organic matter helps to support the ready movement of water through the soil and maintain higher water-holding capacity of the soil. Where feasible, organic mulches also can reduce evaporation from the soil surface, thereby increasing water use efficiency (and possibly lowering irrigation demand). Because some organic mulch materials can contain appreciable salts, sampling and analysis for salt content of these products are recommended.

Special considerations: SDI maintenance

Some salts, including calcium and magnesium carbonates that contribute to water hardness, merit special consideration for SDI systems. These salts can precipitate out of solution and contribute to significant clogging of drip emitters and other components (such as filters). Water quality analysis, including acid titration, is necessary to determine appropriate SDI maintenance requirements. Common maintenance practices include periodic acid injection (shock treatment to prevent and/or dissolve precipitates) and continuous acid injection (acid pH maintained to prevent chemical precipitation).

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Protecting water resources from contamination

Objectives

- Increase awareness of the potential for contamination of groundwater and surface water resources as a result of irrigated agriculture.
- Increase familiarity with terminology, processes, and pathways associated with common agricultural sources of water resource contamination.
- Increase understanding and application of best management practices to reduce risk of groundwater or surface water contamination.

Key points

1. Water losses due to surface runoff or deep percolation can transport sediments, salts, and/or agricultural chemicals to groundwater or surface water.
2. Efficient irrigation and management to optimize rainwater can reduce runoff and deep percolation (leaching) losses.
3. Physical, chemical, and other properties of the soil and potential contaminants affect the relative risk of water contamination.
4. Safe and appropriate storage, handling, and application of agricultural chemicals and wastes are key to reducing risk of contamination.

Best management practices to prevent pesticide contamination of water resources

Groundwater and surface water resources are active components of a dynamically interrelated hydrologic system. In Texas, there are increasing demands on limited water resources, thus it is especially critical that they be protected from contamination.

Pesticide properties that affect risk of contamination

- **Solubility** determines how readily a chemical dissolves in water.
- **Adsorptivity** determines how strongly a chemical is adsorbed to soil particles.
- **Volatility** determines how quickly a chemical will evaporate in air.
- **Degradation** describes how quickly a chemical breaks down due to biological and environmental factors.

Local conditions that affect risk of contamination

- **Soil texture** affects how quickly water moves through soil, how much water can be stored in the soil, and relative particle surface area for chemical adsorption. Coarse (sandy) soils pose higher risk of groundwater contamination than finer textured soils (loam and clay soils).
- **Organic matter** in soil reduces water pollution risk, because it increases chemical adsorption potential and supports higher populations of microorganisms for biodegradation of pesticides.
- **Topography, soil structure, soil surface condition, and soil moisture** affect water movement into and through the soil, influencing relative risks of leaching contaminants to groundwater or runoff of contaminated water to surface water.
- **Distance** from groundwater and surface water resources, depth to groundwater, and the proximity of abandoned or poorly constructed water wells affect risk of contamination.

Pesticides in the environment

After application, pesticides may be evaporated (volatilized), adsorbed onto soil particles, broken down by sunlight (UV degradation), broken down by microorganisms (biodegradation), taken up in or attached to plants, or dissolved in water.

Pesticides dissolved in water may be transported to groundwater through leaching or to surface water through runoff. Pesticides adsorbed to soil particles also may move to surface water through erosion and sedimentation.

Pesticides in water may also undergo evaporation, UV degradation, or biodegradation. They may become diluted or dispersed in the water. They may even move within the groundwater or surface water.

Best management practices

Integrated pest management (IPM)

- Optimize pest management strategies, chemical selection, and application timing for efficient and effective control.
- Consider crop rotations, tillage practices, planting and harvest dates, and other strategies as applicable to achieve good crop results while minimizing the need for pesticide applications.

Pesticide storage, handling, and disposal

- Read and follow the pesticide label.
- Store, handle, mix, apply, and dispose of chemicals according to label instructions — not near water wells or water drainage areas.
- Purchase and mix only the amount of chemical that is required to minimize need for disposal.
- Contain and clean spills quickly to minimize risk of water contamination.
- Consider installing a concrete pad, detention storage, or berms to contain chemicals, spills, and rinsates in the mixing and tank filling area.
- Avoid spraying, mixing, and rinsing tanks near a wellhead; use a longer hose or use a water spigot away from the wellhead, if possible.

Pesticide application

- Read and **follow label directions**.
- Calibrate, clean, and maintain all application equipment properly.
- Follow all label instructions regarding registered crops and rates, methods and timing of pesticide application.
- Observe all restrictions on location, soil types, depths to water table, and other limitations as noted on the label.

Additional best management practices

- **Manage irrigation** to minimize potential for runoff or deep percolation (leaching) losses.
- Consider using **conservation tillage**, setback areas, vegetative filter strips, contour farming, and other practices as appropriate to reduce runoff losses from irrigation or rainfall.
- **Practice wellhead protection.**
- Prevent back-siphoning; use adequate backflow protection devices in mixing chemicals and filling tanks. Use backflow protection (chemigation check) valves in chemigation operations. Properly close abandoned water wells.
- **Plan ahead to minimize risk.**
- Identify water wells, surface drainage, and other potential pathways for contamination. Avoid using, storing, or mixing pesticides near these areas.
- **Identify potential sources of contamination,** including chemical storage and mixing areas. Secure these areas to minimize risk of accidental spills.
- Prepare an **Emergency Response Plan.**

Appendix: Recommended information resources

Irrigation best management practices and comprehensive resources

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Texas Water Resources Institute
make every drop count

Soil Water TSSWCB
Texas State Soil and Water Conservation Board

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