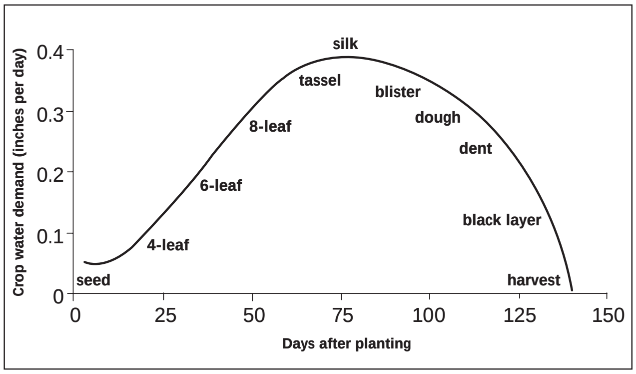
Water Demand
and Irrigation Management

Corn uses a relatively large amount of water and is highly sensitive to drought. In the Texas High Plains, corn uses approximately 28 to 32 inches per season. Peak water use occurs a few days before tasseling (concurrent with maximum leaf area index). Water demand begins to decline about midway through the grain-fill period (dent stage). The most critical period—when water stress has the greatest effect on yield—occurs about 2 weeks before and after silking. The general trend of crop water demand during the season is shown in Figure 1.

Figure 1. Approximate corn water demand (inches per day) in the Texas High Plains.



According to research in the Texas High Plains, the yield return per water input (Water Use Efficiency, or WUE) is 250 to 450 pounds of grain per acre-inch of water (4.5 to 8 bushels per acre-inch). Under deficit irrigation management, the WUE may be as high as 10 to 15 bushels per acre-inch. WUE depends on factors such as crop variety, irrigation method, irrigation management, pest pressures, fertility management, and field and climate conditions.

Soil Moisture Management

The **root zone** of corn can be as deep as 5 to 6 feet if soil conditions allow. Roots usually develop early in the season and grow best in moist soil. They will not grow in saturated or extremely dry soil. Like most crops, corn will extract 70 to 85 percent of the water it requires from the top 2 feet of soil, and almost all of its water from the top 3 feet if water is available. Deep soil moisture is beneficial primarily when the shallow moisture is depleted during periods of peak water demand.

The soil moisture profile, plow pans, caliche layers, etc. often limit the depth of the root zone. A shallow-rooted crop is more susceptible to drought injury.

The properties and condition of soil affect how much water can be retained in the root zone and at what rate water can enter the soil.

Permeability is the ability of the soil to take in water through infiltration. A soil with low permeability cannot take in water as fast as a soil with high permeability. Therefore, the permeability of the soil affects how quickly applied water will run off the surface. Permeability is affected by soil texture, soil structure and surface condition. Generally, 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.

Soil moisture storage capacity describes how much water can be retained in the soil between the two extremes of field capacity and permanent wilting point. Once soil reaches field capacity, excess water applied will run off or be lost through deep percolation. When the soil moisture is below the permanent wilting point, water is held too tightly to soil particles for the plants to extract it. The only water available to plants is that stored between those two critical levels. Some soils can store more water than others. At field capacity, a sandy soil may hold 0.6 to 1.25 inches and a clay loam 1.5 to 2.3 inches of water per foot of soil. Table 3 shows representative soil properties of selected soils. Note the ranges and changes of permeability, available water storage capacity and soil textures between soil layers (depths).

Producers should manage soil moisture so that the crop's water demand is met without allowing soil to become waterlogged. Soil moisture can be monitored in a number of ways, including

- physical sampling and monitoring by feel and appearance (summarized in Table 4),
- resistance-based sensors (gypsum blocks and granular matrix sensors),
- tensiometers, and
- capacitance probes.

The goal is to monitor soil moisture in the effective root zone so that irrigation can be better matched to crop water demand.

Example: Given the following conditions, estimate the available soil moisture storage capacity in the effective root zone.

Estimated effective root zone depth: 4 feet

Soil properties:

Soil layer depth from surface, inches	Permeability inches/hour	Soil water storage capacity (inches H_2O/ inches soil)	Potential available soil water storage in the layer
0 – 14	2.0 – 6.0	0.08	1.12
14 – 46	0.6 – 2.0	0.15	4.8
46 – 80	0.6 – 2.0	0.13	4.4

In the top 4 feet (48 inches) of soil, water holding capacity = (14 x 0.08) + ((46-14) x 0.15) + ((48-46) x 0.13) = 1.12 + 4.8 + 0.26 = **6.18 inches of water.**

Table 3. Representative soil properties of selected soils in Texas.

Soil series	**Depth from surface** (inches)	**Soil texture**	**Permeability (inches/hour)**	**Available water capacity** (in H_2O per inch soil)	**Available H_2O per foot soil** (inches)	**Available H_2O per 3-foot root zone** (inches)	**Available H_2O per 5-foot root zone** (inches)
Acuff	0 - 10	Loam	0.63 - 2.0	0.14 - 0.17	1.86	5.7	9.1
	10 - 36	Sandy clay loam	0.63 - 2.0	0.15 - 0.17	1.92		
	36 - 80	Sandy clay loam	0.63 - 2.0	0.13 - 0.15	1.68		
Amarillo	0 - 9	Fine sandy loam	2.0 - 6.0	0.11 - 0.15	1.56	5.5	8.9
	9 - 44	Sandy clay loam	0.6 - 2.0	0.15 - 0.17	1.92		
	44 - 102	Sandy clay loam	0.6 - 2.0	0.11 - 0.15	1.56		
Estacado	0 - 15	Clay loam	0.63 - 2.0	0.13 - 0.15	1.68	5.0	8.4
	15 -25	Clay loam	0.63 - 2.0	0.13 - 0.15	1.68		
	25 - 80	Clay loam	0.63 - 2.0	0.13 - 0.15	1.68		
Houston Black Clay	0 - 6	Clay	< 0.06	0.15 - 0.20	2.1	5.5	8.7
	6 - 35	Clay	< 0.06	0.12 - 0.18	1.8		
	35 - 80	Clay	< 0.06	0.10 - 0.16	1.56		
Olton	0 - 13	Clay loam	0.63 - 2.0	0.16 - 0.18	2.04	6.1	9.6
	13 - 39	Clay loam	0.20 - 0.63	0.16 -0.18	2.04		
	39 - 80	Clay loam	0.20 - 0.63	0.14 - 0.15	1.74		
Pullman	0 - 8	Clay loam	0.20 - 0.63	0.15 - 0.18	1.98	5.7	9.0
	8 - 46	Clay	< 0.06	0.15 - 0.16	1.86		
	46 - 84	Silty clay loam	0.06 - 0.20	0.14 - 0.16	1.80		

(Source: USDA Natural Resources Conservation Service Soil Surveys.)

Table 4. Estimating soil moisture by feel and appearance.

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 and 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.

Irrigation Efficiency

Irrigation efficiency suffers when there are transmission losses (seepage from ditches, leaks from pipelines, etc.) or application losses (deep percolation below the crop root zone; evaporation and drift, especially in hot, windy conditions; run-off). Low-pressure, advanced irrigation technologies (described below) are generally more efficient than surface irrigation and high-pressure sprinkler irrigation systems. However, the water source, farm layout and lack of operational resources may prevent a grower from fully adopting these technologies.

Management and maintenance are critical to optimizing any irrigation system. At the same time, soil moisture storage must be maximized and runoff minimized to improve overall water use efficiency.

Surface irrigation systems (furrow and flood irrigation) can be improved by

- leveling and grading the land,
- using high-flow turnouts (from ditch irrigation systems),
- using surge irrigation (for furrow irrigation systems),
- alternating furrow irrigation, and
- recovering and reusing tailwater, as appropriate to the individual farming operation.

High-pressure, overhead sprinkler systems (center pivot or linear move) should be designed, maintained and managed to ensure uniform applications with minimal losses from runoff or deep percolation. Selecting the right applicators and nozzles for the specific system (considering soil intake rate, flow, pressure, etc.) is important. Because high winds can cause excessive evaporation and drift, converting to a lower pressure, lower elevation applicator may be advisable, especially where the amount of irrigation water available is a concern.

Advanced technologies have made irrigation more manageable, more efficient and more uniform. Newer systems also are more automated, easier to control, and require less labor. Low-Energy Precision Application (LEPA) and Low-Elevation Spray Application (LESA) are considered experimental in much of the U.S. (and the world, for that matter), but are common in the Texas High Plains and Texas Southern High Plains. LEPA and LESA systems use less energy and apply water more efficiently. They are especially beneficial in dry areas with relatively deep aquifers and, therefore, high pumping costs. Variations on LESA technology, such as Mid-Elevation Spray Application (MESA) and Low-Pressure In-Canopy (LPIC) systems, are other efficient alternatives. Recently, subsurface drip irrigation has been gaining ground. It is highly efficient and increases crop yield and quality noticeably in deficit irrigation situations.

Deficit irrigation generally returns more yield per water input (WUE) than full irrigation.

Tillage and Other Conservation Practices

Furrow diking is an integral part of a LEPA irrigation system and is recommended for other overhead sprinkler systems. This tillage method forms small embankments within furrows to hold irrigation and rain water until it can infiltrate into the soil. Furrow dikes can even be used in dryland and alternate furrow irrigation systems to increase the retention of precipitation. Furrow impoundments reduce run-off, improve water use efficiency, and distribute water uniformly in the field.

Conservation tillage practices (strip till, reduced till, no till, etc.) can increase off-season soil moisture storage by reducing rainfall run-off.

Irrigation Management

Pre-plant and Early-season Irrigation

Where crop acreage and yield are limited by irrigation capacity, it is common practice to irrigate before planting. The objectives are to provide adequate moisture for seed germination and crop establishment and to store enough water in the soil profile to meet peak water demand (which is often greater than the irrigation system capacity) later in the season. Research indicates that pre-plant irrigation can be very inefficient, regardless of the method used. Any irrigation applied or precipitation received in excess of the soil moisture storage capacity will be lost through run-off and/or deep percolation. Evaporation from the surface of moist, bare soil and losses during irrigation also can be significant. Therefore, pre-plant and early-season irrigation should be targeted to achieve crop establishment and promote early root development, while reserving some soil moisture storage capacity (15 to 25 percent) for rainfall that may be received. The crop needs less water early in the season, so there may be time before the peak water demand period to fill the soil profile after the crop is established. The irrigation system capacity, crop rotations used and other issues will affect decisions about early-season irrigation.

Example: Given the following conditions, how long will it take to achieve the desired soil moisture (80 percent field capacity)?

Estimated effective root zone depth: 3 feet

Approximate soil water at field capacity: 1.7 inches of water per foot of soil

Target soil moisture: 80 percent field capacity

Estimated soil moisture before irrigation: 40 percent

Irrigation capacity: 5 gpm/acre (1.86 inches per week, Table 3)

Irrigation efficiency: 80 percent (estimated)

Water to be applied: 3 ft x 1.7 in/ft x (0.80 – 0.40) = 2.0 inches

Adjust for irrigation application efficiency: 2.0 ÷ 0.8 = 2.5 inches

Time to apply 2.5 inches: 2.5 inches ÷ 1.86 inches per week = 1.34 weeks

It will take between 1 and 2 weeks to apply 2.5 inches of water at a rate of 5 gpm per acre.

Late-season Irrigation

The amount of moisture stored in the root zone, the flexibility of the irrigation system, the amount of water being lost to evapotranspiration (ET), and the probability of rainfall will determine whether corn should be irrigated late in the season. Water demand decreases from the dent stage to harvest, although some moisture will be required as the crop matures. Long-term and real-time crop ET estimates, explained below, can be very useful in projecting how much water will be needed to complete the crop season. Advanced irrigation technologies (subsurface drip irrigation and center pivot methods) make it possible to apply water at reduced rates as the end of the season nears.

Irrigation Capacity to Meet Peak Water Demand

Where the capacity of the irrigation system is limiting, a grower may be able to plant only the acreage that can be supplied by that capacity and the moisture stored in the soil. Peak water demand for corn can exceed 0.35 inches per day (6.4 gpm per acre) in some areas of the state. Because soil moisture storage (3 to 6 inches of water in the top 3 feet of soil) can help meet demand during the peak period, irrigation capacities of 5 to 6 gpm per acre are generally adequate for corn production, provided the irrigation equipment and management are very efficient.

Table 5. Irrigation capacities and equivalent irrigation depths.

Gallons per minute to acre-inches per day		Gallons per minute per acre to inches per day or inches per week		
gpm	**ac-in/day**	**gpm/ac**	**in/day**	**in/week**
100	5.3	1	0.053	0.37
200	10.6	2	0.11	0.74
300	15.9	3	0.16	1.11
400	21.2	4	0.21	1.48
500	26.5	5	0.27	1.86
600	31.8	6	0.32	2.23
700	37.1	7	0.37	2.60
800	42.4	8	0.42	2.97

Estimating Crop Water Demand with Evapotranspiration Data

Evapotranspiration (ET) is the loss of water from a combination of evaporation (water vaporized from moist surfaces) and transpiration (water in plants removed through stomata on the leaves).

Reference ET, also known as Potential Evapotranspiration (PET), is an estimate of the water required by a well-watered reference crop. This reference crop (grass or alfalfa) is an idealized crop used as a basis for the ET model. Reference ET is calculated by applying climate data (temperature, solar radiation, wind, humidity) in an equation.

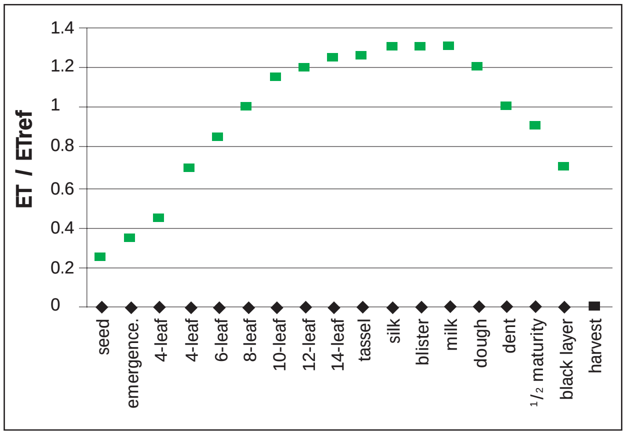
Reference ET is only an estimate of the water demand for this idealized crop, based on weather data at a given location.

The ET of a specific crop is estimated by multiplying the Reference ET by a crop coefficient.

Crop ET = Reference ET x Crop Coefficient

The crop coefficient takes into account the crop's water use (at a given growth stage) compared to that of the reference crop. For instance, seedling corn does not use as much water as the idealized grass reference crop, but during silking corn can use more water than the grass reference crop. The crop coefficient follows a pattern (curve) of the general shape shown in Figure 2.

Figure 2. Crop coefficients for corn grown in the Texas High Plains.

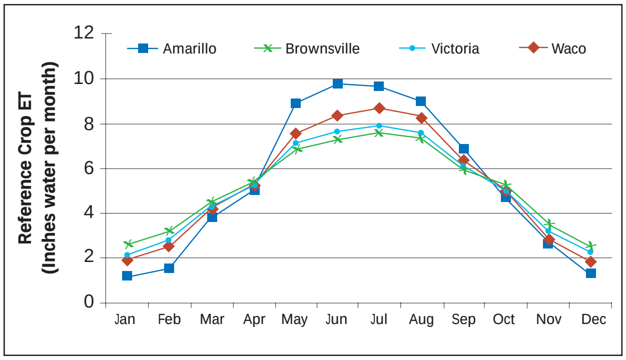


The reference crop ET model and the crop coefficient curves were developed from long-term research at various locations. Actual crop water demand can be affected by many factors, including soil moisture, crop health, and probably by plant populations and variety traits. These factors are not taken into account by the models. Hence, ET data provided by online networks are best used as guidelines for irrigation scheduling and (where applicable) for integrated pest management and integrated crop management. The growth stage and water use predicted by the data should be verified with field observations. The actual crop water use is likely to be somewhat less than the predicted value.

There are a variety of irrigation scheduling methods, models and tools that use ET data. 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 falls below a given threshold, the crop should be irrigated to restore the moisture. The threshold may be determined by the crop's drought sensitivity, by irrigation system capabilities, or by other criteria.

There are several ET weather station networks in Texas, each serving a particular region. The Texas High Plains is served by two networks—the North Plains ET Network (*http://amarillo2.tamu.edu/petnet1.htm* based at Amarillo) and the South Plains ET Network (*http://lubbock.tamu.edu/irrigate/* based at Lubbock). The South Plains and North Plains ET networks have merged most of their operations to form the Texas High Plains ET Network. South and central Texas are served by the Texas ET Network (*http://texaset.tamu.edu* based at College Station). There are other local networks from which data are available. Long-term average monthly reference crop ET values for selected locations are summarized in Figure 3.

Figure 3. Long-term average monthly reference crop evapotranspiration demand (inches water per month).



Water Quality

Salinity

Corn is moderately sensitive to salinity in soil and irrigation water. Grain yield is reduced if the salinity of irrigation water is greater than 1.1 dS/m electrical conductivity (EC), or the salinity of the soil is greater than 1.7 dS/m EC. A 50 percent reduction in yield can be expected with irrigation water EC of 3.9 dS/m.

Corn is also moderately sensitive to foliar injury from sodium (tolerance between 230 and 460 ppm) and chloride (tolerance between 350 and 700 ppm) in irrigation water. If water quality is marginal, spray irrigation is more likely to injure foliage than other irrigation methods. If the crop receives excess water periodically (by irrigation and/or rainfall) some accumulated salts will be leached from the root zone. Learn more about salinity management in Texas Cooperative Extension publication B-1667, "Irrigation Water Quality Standards and Salinity Management Strategies," available at *http://tcebookstore.org.*

Protecting Water from Contamination

Agricultural chemicals, including fertilizers and pesticides such as atrazine, have been detected in wells and surface waters in Texas. The herbicide atrazine is a special concern because it is widely used, it persists in the environment, and it can move readily into surface and ground waters. Farmers can prevent the contamination of surface and groundwater resources by using the following best management practices.

Storing and handling agricultural chemicals. Storage facilities should protect chemicals from extreme temperatures, sunlight, moisture, etc., to preserve their efficacy. Storage should be organized, with materials segregated to prevent cross-contamination and make access easy. Handling facilities must be able to contain all spills and rinsate. Farms should have written emergency response plans and the equipment required for responding to fires, spills, and exposure to hazardous conditions. Personnel must be trained to respond correctly to emergencies.

Protecting wellheads. Groundwater can be contaminated through wells if chemicals are not stored and handled correctly, if wells are not maintained, and if abandoned wells are not properly closed. Chemicals should not be stored in a well house or mixed, handled or applied near a well. Abandoned wells and those with cracked well casings should not be left open.

Applying pesticides. To reduce the risk of agricultural chemicals entering water resources, all personnel involved with pesticide application should read the product labels and understand the instructions, restrictions, application rates, and other critical information they contain.

Other best management practices are

- preventing back-siphoning,
- containing and cleaning spills,
- maintaining and calibrating application equipment properly,
- reducing run-off and erosion losses from fields, and
- minimizing deep percolation losses of irrigation water that can carry dissolved chemicals below the root zone.

Managing nutrients. Good nutrient management practices will maximize the benefits of fertilizers and other crop amendments while preventing water contamination. Before fertilizing, soil and/or plants should be tested to determine the need for nutrients. Fertigation (fertilizer application through irrigation water) can be used to optimize the rates and timeliness of fertilizer applications. Of course, using a check valve to prevent backflow is essential for keeping the water source safe from possible contamination.

For additional information, refer to these publications from Texas Cooperative Extension, available at *http://tcebookstore.org.*

B-1667, "Irrigation Water Quality Standards and Salinity Management"

B-6096, "Center Pivot Irrigation"

L-6023 – L-6032, "Tex-A-Syst Rural Well Water Assessment" series

Also see:

Natural Resources Conservation Service, United States Department of Agriculture. Soil Surveys. *http://soils.usda.gov/survey*