Efficient Irrigation Management for High Plains Dairies

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INTRODUCTION

Water is frequently a limiting factor in crop production systems in the High Plains, where the constraints may be primarily physical (limited or declining aquifers, limited well capacities, irrigation system limitations); economic (capital costs of irrigation systems, energy costs, crop yields and prices); water quality (salinity or other); or regulatory (pumping limits, permits). Efficient irrigation management is essential to mitigating limited and declining irrigation water resources, optimizing crop water use efficiency, and improving overall crop response to inputs.

IRRIGATION TECHNOLOGIES AND BEST MANAGEMENT PRACTICES

Efficient advanced irrigation technologies, such as low pressure center pivot and subsurface drip irrigation systems, are widely used in the High Plains, especially in areas such as the Texas Southern High Plains where well capacities have long been a limiting factor. Important considerations for selecting these technologies are

1. suitability or adaptability of the technology to local production systems and conditions;
2. economic feasibility; and
3. availability of irrigation industry, research and educational infrastructure and resources to support applications in the field.

While these technologies present great potential for high efficiency, it is worth noting that successful application of these technologies requires good design, installation, maintenance, and management.

Surface Irrigation

Surface irrigation uses gravity flow to distribute water over a field. Surface systems are the least expensive to install, but have high labor requirements for operation compared to other irrigation methods. Surface systems tend to have lower water application efficiencies and distribution uniformities than more advanced irrigation technologies, but good design and skillful management can improve both irrigation efficiency and distribution uniformity. Depending upon local conditions (field layout, soil conditions, topography and management/labor capabilities), land grading and leveling, tailwater reuse, surge irrigation, alternate furrow irrigation, high flow turnouts, gated pipe, ditch lining, cut-back flows, or adjusting row (run) lengths may offer significant improvements. These practices are discussed in Rogers (1995) and Yonts (2007).

Center Pivot Irrigation

Center pivot and lateral move sprinkler irrigation systems are used widely throughout the High Plains, especially in the Texas High Plains where most of the systems are low pressure center pivot systems. Low pressure systems generally are more efficient, requiring lower energy to operate and reducing evaporation losses compared to high pressure systems. Specific applications of low pressure center pivot irrigation include Low Energy Precision Application (**LEPA**); Low Elevation Spray Application (**LESA**); Mid-Elevation Spray Application (**MESA**); and Low Pressure In-Canopy (**LPIC**).

 **Figure 1a**. Use of flexible hose or gated pipe reduces conveyance losses compared to ditches. Alternate furrow application reduces evaporation losses by limiting the wetted soil surface area.	 **Figure 1b**. LEPA irrigation typically applies water to alternate furrows through drag hoses directly to the ground surface, minimizing evaporation losses.
 **Figure 1c**. Commercially available LEPA applicators are easily adapted between LEPA (bubbler mode, shown here) and spray mode.	 **Figure 1d**. Center pivot LEPA systems include circular planting pattern. Furrow dikes reduce runoff losses and improve distribution uniformity.
 **Figure 1e**. Low pressure LESA spray nozzles deliver water near the soil surface and with large water droplet sizes to reduce evaporation losses compared to high pressure sprinkler systems.	 **Figure 1f**. LPIC and MESA apply water at low pressure, yet allow for application above (MESA) or within (LPIC) the crop canopy.
 **Figure 1g**. Subsurface drip irrigation applies water through emitters in flexible drip tape. Since water is applied in the root zone, evaporation and runoff losses are minimized.	 **Figure 1h**. Adequate filtration and maintenance are essential to longevity of subsurface drip irrigation systems.
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Figures 1a-1h. Irrigation systems, components, and best management practices.

Low Energy Precision Application or **LEPA** irrigation applies as much to a management package as the actual hardware. LEPA irrigation applies water directly to the soil surface through drag hoses (primarily) or through *bubbler* type applicators. By definition, LEPA also involves farming in a circular pattern under center pivot irrigation systems or straight rows under 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; 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. Furrow dikes and circular planting patterns help reduce the runoff risk. While very high application efficiencies are achievable with the system, LEPA is not universally applicable; some slopes are too steep for effective application of LEPA irrigation. LEPA applicators are often easily adaptable to LESA *spray* mode for chemigation applications or for other spray needs.

Low Elevation Spray Application (**LESA), Low Pressure In-Canopy (LPIC)** and **Mid-Elevation Spray Application (MESA)** describe similar irrigation application systems that include the LEPA technology but do not meet one or more of the criteria to be called LEPA. Strictly interpreted, LESA systems have spray applicators within 18 in of the ground (USDA-NRCS, 2003), while MESA systems apply water from between 5 and 10 ft above the ground. LPIC systems apply water at a height < 7 ft above ground and discharge water within the crop canopy for a considerable portion of the crop season. Low pressure LESA, LPIC, and MESA spray systems are generally somewhat less efficient than LEPA, primarily due to increased evaporation from a larger wetted soil surface area and potential for evaporation of spray droplets during application.

Properly managed, LEPA, LESA, LPIC and MESA can be very efficient. LEPA allows for alternate furrow irrigation, in which alternate dry *traffic* furrows are more accessible for timely field applications. By limiting field operation traffic to the dry furrows, infiltration capacity of soil in the *wet* irrigated furrows is preserved. LEPA also allows for irrigation without foliar wetting. For some crops this can offer reduced foliar disease risk. If water quality (salinity) is an issue, LEPA can reduce risk of 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. Spray irrigation (LESA, LPIC, MESA) wet the soil surface more uniformly than LEPA. Commonly available nozzles are easily exchanged between LEPA and spray modes, making it possible to apply LESA for crop germination/establishment, then convert to LEPA to take advantage of the higher irrigation application efficiency in season, and convert back to spray applications for chemigation or for uniform wetting of the shallow root zone as needed.

Subsurface Drip Irrigation

Subsurface drip irrigation (**SDI**) is gaining popularity in production of agronomic *row* crops, especially in areas of limited well capacities and/or small or irregularly shaped fields not well suited to center pivots. Microirrigation systems typically work at relatively low pressures, so energy requirements are comparable to low pressure center pivot systems. Initial cost of SDI is high, but a properly designed and maintained microirrigation system can last more than 20 yr. A recommended maintenance program includes adequate filtration and maintenance (cleaning) of filters; flushing lines and manifolds; and injecting chemicals (chlorine and/or acid) as necessary to prevent emitter clogging. Specific maintenance requirements depend upon the irrigation system components and water quality; additional information on maintaining SDI systems is included in Enciso et al. (2004) and Alam et al. (2002). Frequently cited ***advantages*** of SDI include:

- high efficiency and uniformity of water application;
- precise application of fertigation and chemigation;
- reduced labor requirement compared to other irrigation technologies;
- applicability to operations with large or small water capacities and over a range of field sizes, topographic and soil conditions; and
- ease of automation.

Disadvantages may include:

- relatively high initial cost;
- requirement of higher skill level for operation and management;
- potential problems with emitter clogging, root intrusion, rodent and insect damage to driplines;
- potential problems with germination of a crop;
- limited root zone; and
- limited options for deep tillage and deep injection of chemicals that may be needed for pest and disease management.

Other Technologies and Considerations

In selection of irrigation application equipment, there are many factors that should be considered. Water application efficiency and uniformity; energy efficiency and access; labor and management capabilities; economics and site-specific/operation-specific factors should be addressed. Where effluents or other lower quality water sources will be used, additional considerations of salinity and nutrient management; suspended solids content (affecting filtration requirements and/or suitability of applicator type); and material compatibility (risk of chemical precipitation, clogging of applicators, or corrosion of irrigation components) must be taken into account.

IRRIGATION BEST MANAGEMENT PRACTICES

Irrigation Management

Crop water requirements vary with weather conditions, crop type, and growth stage. Water management is especially important for critical periods in crop development. Efficient irrigation management takes into account crop water requirements, as well as effective rooting depth, soil moisture storage capacity, and field-specific conditions (shallow soils, caliche layers, etc.). Good irrigation management can reduce economic risk, optimize water use efficiency, and minimize risk of water resource contamination.

Crop-Specific Irrigation Considerations

Corn is a relatively drought-sensitive and salt-sensitive crop with a relatively high water demand. Where water from irrigation and rainfall are insufficient or unreliable, extra care in risk management assessment is recommended. Drought-stressed corn not only produces lower yield, but also is more likely to be contaminated with aflatoxin. Seasonal water use (from rainfall, stored soil moisture, and irrigation) for corn is approximately 28 to 32 in in the Texas High Plains (Porter et al., 2005) or 24 to 28 in in Nebraska (Kranz et al., 2008). Peak water use can exceed 0.35 in/d

(6.4 gpm/acre) and occurs a few days before tassel; water demand begins to decline about midway through the grain-fill period (dent stage). The most critical period during which water stress will have the greatest effect on yield corresponds with the maximum water demand period, approximately 2 wk before and after silking. Because corn is moderately sensitive to salinity, special management considerations are warranted for use of lower quality water.

Cotton is relatively tolerant to drought and salinity. Seasonal water demand is generally 24 to 28 in, but since cotton is drought-tolerant, it is often grown under rainfed (dryland) or deficit irrigation management; hence seasonal water use for cotton in the Texas High Plains ranges from approximately 13 to 27 in per season. Peak water use (0.3 to 0.4 in/d) for cotton occurs during flowering and boll development. Research indicates that cotton responds very well to high-frequency deficit irrigation. The most critical period during which water stress will have the greatest effect on yield is early in the season when drought stress can cause square shedding. Excessive irrigation and excess available nitrogen can encourage excessive vegetative growth, necessitating use of plant growth regulators.

Grain sorghum is drought-tolerant; however profitable sorghum production requires sufficient water at critical growth stages. Sorghum can produce an extensive fibrous root system as deep as 5-6 ft, but it generally extracts most of its water and nutrients from the top 3 ft of soil. Water availability is most critical during the rapid growth stage and before the reproductive stage. If plant maturity is delayed due to water stress, the crop may face frost damage in the event of an early freeze. Late-season water stress during grain filling can result in shriveled seeds, which reduces yield. Peak use begins at approximately initiation of the reproductive stage; this peak can be 0.3 in/d (or temporarily higher in hot, dry weather conditions). Seasonal water demand for grain sorghum is 24-28 in (from rainfall, stored soil moisture and irrigation), but its drought tolerance makes it suitable for limited (deficit) irrigation.

Alfalfa is well adapted to arid regions, but it requires more water for profitable production than most crops. Alfalfa can develop a very deep root system. It can tolerate periods of drought stress, but this stress will result in yield loss. Similarly, alfalfa can tolerate some salinity, but poor quality irrigation water will result in yield loss. With efficient irrigation methods and management, alfalfa requires 5-7 acre-in of water per ton of alfalfa produced. Seasonal water demand can exceed 36 to 40 in/season.

Managing Soil Moisture

Soil moisture management is key to optimizing crop production. Plants extract water and nutrients from the soil through roots; hence a healthy and extensive root system affords the plant greater access to water and nutrients. Roots grow in moist soil; they can be limited by excessively wet or dry soil conditions. Good soil moisture management promotes extensive root development; it provides sufficient available water to prevent drought stress while avoiding over-watering, and hence promotes high water use efficiency, crop yield, and quality.

Soil moisture storage capacity is affected by soil structure and organic matter content, but it is determined primarily by soil texture. Figure 2 illustrates general ranges of plant available soil moisture storage capacities by soil texture. **Field capacity** is the soil water content after soil has been thoroughly wetted when the drainage rate due to gravity becomes negligible (usually 1-3 d). This point is reached when the *gravitational water* has drained. Field capacity is assumed when the soil water tension is approximately 0.3 bars in clay or loam soils, or 0.1 bar in sandy soils. **Permanent wilting point** is the water content below which plants cannot readily obtain water and permanently wilt. This parameter may vary with plant species and soil type but generally is assumed to occur at a soil water tension of 10-20 bars. *Hygroscopic water* is held tightly on 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 in Figure 2. **Management Allowable Depletion (MAD)** is a management concept that represents a fraction of soil water depletion that will trigger an irrigation application before significant drought stress occurs. For most agronomic crops, 50 % plant available water depletion (50 % MAD) is recommended; for drought sensitive crops, a value less than 50 % of the soil's plant available water holding capacity should be used.

If the goal is to apply water to moisten the root zone to some target level (for instance to fill the root zone to field capacity but avoid leaching losses), 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. Soil moisture monitoring instruments, discussed in more detail in Enciso et al. (2007); Evett et al. (2006); and the Soil Water Content Sensors and Measurement discussion group website (Metelerkamp, 2002), provide the means to estimate soil moisture quickly and easily. Soil moisture sensors and technologies vary greatly in cost, ease of use, and accuracy. Alternately, soil moisture can be assessed by observing feel and appearance of soil samples manually squeezed 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. Results of the sample are compared with the guidelines summarized in Table 1, and the method is described in detail in USDA-NRCS (1998).

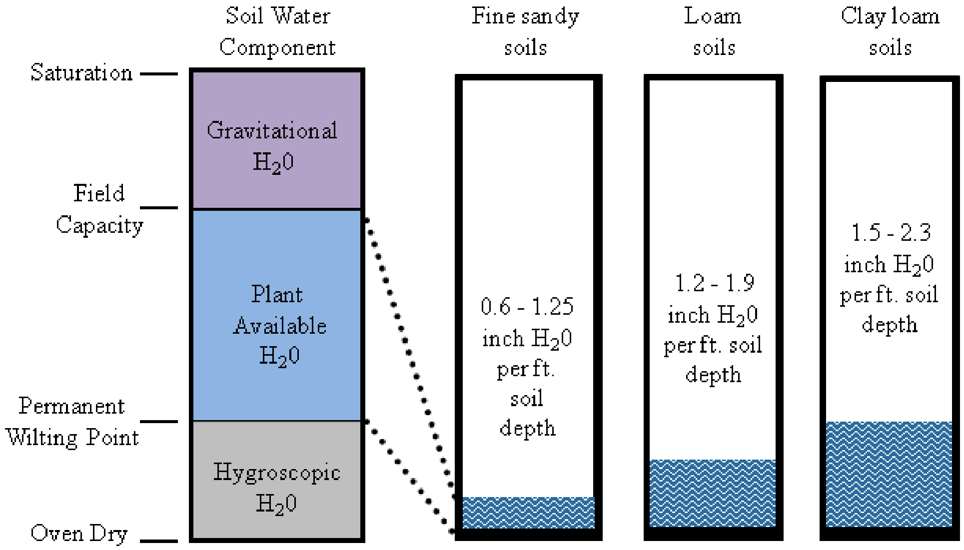

Figure 2. Available water storage by soil type.

Table 1. Soil feel and appearance by moisture level and texture (Adapted from USDA-NRCS, 1998)

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	Appears slightly moist. Soil may stick together in very weak cast or ball.	Appears slightly moist. Soil forms weak ball or cast under pressure. Slight staining on finger.	Appears slightly moist. Forms a weak ball with rough surface. No water staining on fingers.	Appears 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.

Table 2. Root zone depths reported for various crops.

Crop	**Effective Rooting Depth* (ft)**
Alfalfa	3.3 – 6.6+
Corn	2.6 – 5.6
Cotton	2.6 – 5.6
Sorghum	3.3 – 6.6
Soybeans	3 – 4
Wheat	3 – 6+
Perennial pasture/turf	~ 1 - 2.5+

** Active root zone depths, compiled from various sources. These values represent the majority of feeder roots. Actual root depth will be affected by local soil conditions (texture, structure, moisture). Most water uptake will occur in the top 1-3 ft of soil, especially under irrigated conditions.*

Roots are generally developed early in the crop 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. Commonly reported **effective root zone depths** by crop are listed in Table 2, however most crops will extract most (70 – 85 %) of their water requirement from the top 1 – 3 ft of soil, if water is available. Deeper soil moisture is beneficial primarily when the shallow moisture is depleted.

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 moisture 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. Excessive deep percolation losses (leaching) increase risk of nutrient losses and can have a significant negative impact on overall water use efficiency - even under otherwise efficient irrigation practices such as 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, and hence reduce deep percolation losses. Coarse soils are particularly vulnerable to deep percolation losses due to their low water holding capacity. Other soils may exhibit preferential flow deep percolation along cracks and in other channels formed under various soil structural and wetting pattern scenarios.

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; permeability therefore affects the risk for runoff loss of rainfall or irrigation. 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. **Runoff losses** occur when water application rate (from irrigation or rainfall) exceeds soil permeability. Sloping fields with low permeability soils are at greatest risk for runoff losses. Vegetative cover, surface conditioning (residue management, furrow dikes), and grade management (land leveling, contouring, terracing) can reduce runoff losses. Irrigation equipment selection (nozzle packages) and management can help to minimize runoff losses.

Managing Irrigation to Mitigate Salinity

All major irrigation water sources contain dissolved salts. These salts include a variety of naturally 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. 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 is applied to a field, or if the irrigation water source varies in quality, soil salinity should be monitored regularly for accumulation of salts, as well as for nutrient accumulation and/or leaching. Irrigation management strategies to mitigate salinity in irrigation water include:

- minimizing application of salts,
- selecting salt-tolerant crops or varieties, and

- use of appropriate soil amendments and leaching of salts.

Crop-specific salinity tolerances and management strategies are addressed in Fipps (2003), Porter and Marek (2006), and other sources. Special water quality concerns for management of subsurface drip irrigation is addressed in Rogers et al. (2003).

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