GETTING THE MOST FROM CENTER PIVOTS

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ABSTRACT

This paper provides an overview of center pivot irrigation for forage crops. Advice is provided on what to look for when purchasing a pivot, and important design guidelines are presented. A description of LESA (low elevation spray application) and other types of water applicators are provided. Guidelines on pivot operation, management, scheduling, and fertigation are also presented.

Key Works: center pivot, irrigation, LESA, pasture, forage, fertigation

INTRODUCTION

In Texas, irrigation of forages is widespread, with about 600,000 acres irrigated with sprinklers. Everything from big guns to side-rolls to center pivots are used. Increasingly, the center pivot is the system of choice due to its low labor and maintenance requirements, and its flexibility and ease of operation. When equipped with high efficient water applicators, the use of two precious resources, energy and water, can be maximized with careful planning and proper system design and operation.

Manufacturers have made many improvements in center pivot systems in recent years, including in the drive mechanisms (motors and shafts), control devices, and structural strength of the machines. The early pivots of the 1950s were propelled by water motors, operated at pressures of 90 - 100 psi, and sprayed water high into the air, resulting in large evaporation losses and high energy costs. Today, electric or hydraulic motors at each tower drive the machine. Pressures as low as 15 psi (at the pivot point) are adequate for properly designed LESA (low elevation spray application) systems which have application efficiencies of 90 - 95%.

PIVOT CONSIDERATIONS AND CHOICES

Options to consider before buying a center pivot system include: mainline size, length, outlet spacing, and the types of water applicator and drive mechanism. These choices affect the investment costs, operating costs, effectiveness, and flexibility for future changes.

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COST OF PIVOTS

In central Texas, complete center pivot systems (using surface water) can be purchased for $300-$325 per acre for a quarter mile (1250') system which irrigates about 120 acres. The costs for groundwater users will be more due to larger pumps and well construction costs. Longer systems usually cost less per acre than shorter systems. This relatively high cost is offset by low labor requirements and convenience. For instance, remote control via phone lines or radio can start and stop irrigations. Fertilizers and certain plant protection chemicals (check labels) can be applied through the pivot, which improves the value of the system. Towable pivots are also available, so that additional blocks of land can be irrigated with the same machine.

TYPES OF PIVOTS

The inefficient water-drive systems of the 1950s have been replaced by two types of drive systems: electric and hydraulic. In electric drive pivots, individual electric motors power the wheels at each tower. Typically, the outer-most tower moves to its next position and stops; then each seceding tower moves in line. This start-stop action is eliminated by hydraulic-move systems, where all towers remain in motion throughout the circle. Theoretically, the continuous-move hydraulic systems should have greater uniformity (distribution efficiency) than electric pivots. However, the choice between electric and hydraulic drive usually depends on the type of power sources available, what's being sold in the local market, and the service record of your local dealers.

MAINLINE PIPE SIZING

The size of the pipeline on top of the pivot (or the *mainline*) influences the total operating costs of the pivot. Smaller pipe sizes, while less expensive to purchase, may have higher friction losses and energy costs. Plan new center pivots to operate at minimum pressure in order to minimize pumping cost. For example, for a pivot nozzeled at 1000 gpm, some rules of thumb are as follows.

> each additional 10 psi pivot pressure requires approximately 10 horsepower.
>
> each additional 10 psi pivot pressure increases fuel costs about $0.50 per hour (or $0.22 per acre-inch) at natural gas costs of $4.00 per MCF.
>
> with $0.08 per KWH electricity, the cost is $0.65 per hour ($0.30 per acre-inch) for each additional 10 psi pressure.

(Note: horsepower is proportional to system flow rates of about 1,000 gpm. For example, when the system flow rate is 700 gpm, seven horsepower is needed for each 10 psi pivot pressure)

Table 1 gives the total friction loss for different mainline sizes and flow rates. For quarter-mile systems on flat-to-moderately sloping fields, total friction loss in the pivot mainline should not exceed 10 psi. Some dealers will undersize the mainline in order to reduce costs and lower their

Table 1. Approximate friction loss (psi) in center pivot sprinklers.				
	Mainline pipe diameter, inches			
	6	6-5/8	8	10
Flow rate, gpm	Mainline pressure loss, psi			
A. Quarter-mile system:				
600	1	7		
700	14	9		
800	18	11	4	
900	23	14	5	
1000	28	17	7	
1100	33	20	8	
1200	39	24	9	
B. half-mile system:				
2200		146	57	21
2500			72	27
3000				38
3500				60

Source: New (1986).

bids. Check the printout and have the dealer try larger pipes or "telescoping" (see below) to reduce pressure loss. Otherwise, you will pay the price in increased energy costs over the life of the system by saving money on the initial cost of the system.

Telescoping

Telescoping involves using larger pipe at the beginning of the mainline, and then smaller pipe sizes as the flow rate decreases away from the pivot point. The advantages are low friction loss for a moderate increase in the cost of the machine. Table 2 illustrates the benefits of telescoping for a pivot approximately 1300 ft long, nozzeled at flow rates ranging from 750 - 2000 gpm. For example, with a flow rate of 1250 gpm, friction loss can be reduced by 19 psi with different combinations of pipe sizes. Frequently, the telescoping option must be specifically requested, since dealers do not automatically consider telescoping when providing bids.

Table 2a. Pressure loss (psi) in pivot mainlines*.					
Option	Flow Rate (gpm)				
	750	1000	1250	1500	2000
1	9.0	15.3	23.0	32.4	55.1
2	4.0	6.8	10.2	14.4	24.5
3	1.6	2.7	4.0	5.6	9.6

*based on outlets every 80" along the mainline; Source: James P. Bordovsky, Research Associate, Texas A&M Research and Extension Center, Halfway.

Table 2b. Description of telescoping options in Table 2a.			
Option	No. of Spans	Span Length (ft)	Pipe ID (in)
1	8	160.0	6.383
	1	44.0	6.000
2	4	160.0	8.330
	4	160.0	6.385
	1	44.0	6.000
3	4	127.8	10.420
	4	135.2	8.330
	2	135.2	6.357

PRESSURE REGULATORS

Pressure regulators are "pressure killers"; that is, they are designed to reduce the pressure at the nozzle. Pivot regulators also require energy to operate, and pressure losses in low-flow regulators can be 3 psi or higher. As with other sprinkler systems, pressure regulators are not necessarily needed for all sites. Pressure variations created by differences in land elevation can be controlled by either the design pressure or with pressure regulators. Table 3 shows the pressure variations that will occur at the nozzle for different elevation changes and pivot operating pressures. The pressure at the nozzle should not vary more than 20% from the design pressure.

Table 3. Percent variation in system operating pressure created by changes in land elevation. Maintain less than 20 percent variation.

Elevation change Ft	psi	System design pressure (psi)* 6.0	10.0	20.0	30.0	40.0
		%				
2.3	1	16.5	10.0	5.0	3.3	2.5
4.5	2	33.0	20.0	10.0	6.6	5.0
6.9	3	50.0	30.0	15.0	10.0	7.5
9.2	4		40.0	20.0	13.3	10.0
11.5	5		50.0	25.0	16.6	12.5
13.9	6			30.0	20.0	15.0
16.2	7				23.3	17.5
18.5	8				26.6	20.0

* pressure at the nozzle; Source: New (1986)

Generally, systems can be designed without regulators when the maximum elevation change is 5 feet or less from the pad to the end of the pivot without significantly increasing operation pressure and pumping costs. Where elevation changes are greater than 5 feet, the choice is to increased the system operating pressure (and potentially, pumping costs) or to use pressure regulators. This decision should be based on comparing the extra costs of regulators to the energy savings associated with a lower operating pressure.

Of special concern are locations where flow rate or pressure varies significantly during the growing season, such as changes due to seasonal variations in water tables. For these situations, the design flow rate (or system capacity) and the use of pressure regulators should be evaluated carefully. If the pressure drops below that required to operate the regulator, then poor water application and uniformity will result. In contrast, if the design operating pressure is high, pumping costs will also be unnecessarily high.

WATER APPLICATORS

High pressure impact sprinklers mounted on the top of the center pivot mainline were prevalent in the 1960s when we had low energy prices and water conservation did not seem as important. Now high pressure impacts are only recommended for special situations, such as in land application of wastewater, where large nozzles and high evaporation is a benefit. In recent years, manufacturers have developed a whole family of low-pressure water applicators which reduce energy demands and lose less water to evaporation. End guns are **not** recommended since they are prone to wasting water (low application and distribution efficiencies) and have high energy requirements.

The choice is which low pressure applicator to use and how close to the ground it should be. Generally, the lower the operating pressure requirements, the better. Many applicators now operate in the 25 psi range, which is acceptable. However, manufacturers also offer applicators which operate at just 10 psi while providing adequate overlap (Note: pivots should always be operated at their designed pressures and flow rates, or poor irrigation efficiencies may result, particularly on systems with pressure regulators).

Field testing has shown under still (i.e., no-wind) conditions, new designs of low pressure applicators (rotators, wobblers and low-drift sprays, for example), positioned 5 to 8 feet above the ground, can have efficiencies up to 90%. However, as the wind speed increases, the amount of water lost by evaporation increases rapidly. For instance, Clark and Finley (1975) found that at a wind speed of 15 miles per hour, evaporative losses were 17%, and at speeds of 20 miles per hour losses were over 30%. In the Southern High Plains of Texas, losses on a linear-move system have been measured as high as 94% when wind speed averaged 22 miles per hour with gusts of 34 miles per hour (Lyle and Bordovsky, 1981).

LESA

I recommend positioning the applicators as close to the ground as possible according to manufacturer recommendations. Locating the applicators near the ground also eliminates water losses caused by wetting the foliage. Research has shown that about 10% of the water applied with overhead sprinklers is lost by wetting the crop canopy.

For irrigating forages, use a LESA (low elevation, spray application) system and locate spray-type applicator from 1.5 - 2 ft above the ground. Two manufacturers (Nelson and Senninger) have spray applicators which require only 10 psi at the nozzle and which can be located at this height. Many growers prefer a "flat" plate with large grooves which produces large drops sprayed horizontally (i.e., not upward). A single flexible "poly-drop" connects the applicator to the gooseneck on the mainline. Special "poly-weights" (plastic weights) are available to help keep the drops hanging straight in high winds. The first LESA system for forage irrigation was installed in Yancey, Texas at the Petty Ranch in 1992 . To date, the cattle have never bothered the drops.

LESA drops can be spaced 8 - 10 ft apart, the same spacing as with the conventional applicators. This spacing also has been used on densely-planted row crops, such as corn, with excellent results. Some research is indicating the optimal spacing, in terms of distribution efficiency, is 5 - 6 ft.

LESA's low operating pressure and high application efficiency provide the lowest pumping costs of all pivot applicators except LEPA. Note: LEPA, or *low energy precision application*, systems discharge water directly into furrows and require only 6 psi operating pressure. LEPA applicators are not frequently used on pastures due to the higher costs of the applicator and the increased number of drops. For additional information on LEPA, see New and Fipps (1990).

THE PIVOT DESIGN PRINTOUT

The local irrigation dealer collects information on your site and system requirements, and then submits this information to a distributor or manufacturer who runs the computer design software. Needed information includes the amount of water (gallons per minute) and pressure available, size of the field, elevation changes in the field, size of existing supply pipelines, row spacings, crops and water requirements, soil type (for sizing tower motors), etc.

The most commonly data omitted by dealers are the elevation changes in the field. This information is crucial for the proper design of your system and will usually determine whether pressure regulators are needed. A buyer should check the information that the dealer submits to ensure that the system is designed according to his needs and specific site conditions. Always check the total pressure loss in the pivot. If high, ask for another printout with larger or telescoping mainline sizes.

REQUIRED ACCESSORIES

A permanently-installed flow meter measures the actual amount of water being applied and is highly recommended. Pressure gauges are used to monitor the system performance and, in combination with the flow meter, can alert you to leaks and other failures in the system before too much water (and money) is lost. Two pressure gauges are needed on the pivot, one positioned at the end of the system, usually in the last drop just above the applicator, and one at the pivot point.

OTHER CONSIDERATIONS

Conventional outlet spacings on the center pivot mainline vary from 8 - 10 ft. However, consider ordering a closer outlet spacing even if it is not required by the chosen water applicator. The reason is that manufacturers are continuing to develop more efficient applicators, and we expect that applicators and drops will continue to be placed closer together. A closer outlet spacing (60 or 80 inches) will ensure that your system can be quickly and inexpensively converted to a new applicator design sometime in the future.

As with any other large investment, the purchase of a center pivot should only be made after careful analysis. It may be helpful to think in terms of costs per acre and cost per acre inch of irrigation, and compare these to expected production increases or reduction in labor costs of an existing irrigation system. Also, remember that personal preferences is one of the most important considerations.

PIVOT MANAGEMENT AND SCHEDULING

Pivot management is centered around knowing how much water the pivot puts out in *inches.* The pivot printout provides a table of the amount of water applied and the time to make a circle for different speed settings. Growers without the design printout should contact the dealer who first sold the pivot, as they keep such records for many years. If a printout is not available, use Table 4 to determined output based on flow rate and time to complete a circle. For other sizes of pivots or travel times, output can be calculated with the equations listed below. Keep in mind that these application rates assume 100% application efficiency. Reduce these amounts by 5 - 10% for LESA, 20% for low pressure drops, and 40% for impact sprinklers.

Table 4. Inches water applied by 1,290-foot center pivot* with 100% application efficiency.

Pivot GPM	Hours to complete 120-acre circle 12	24	48	72	96	120
400	0.09	0.18	0.36	0.53	0.71	0.89
500	0.11	0.22	0.44	0.67	0.89	1.11
600	0.13	0.27	0.53	0.8	1.06	1.33
700	0.16	0.31	0.62	0.93	1.24	1.55
800	0.18	0.36	0.71	1.07	1.42	1.78
900	0.2	0.4	0.8	1.2	1.6	2
1000	0.22	0.44	0.89	1.33	1.78	2.22
1100	0.24	0.49	0.98	1.47	1.95	2.44
End tower ft/hr	667	334	167	111	83	67
Ac/hr	10	5	2.5	1.7	1.3	1

* 1,275 feet from pivot to end tower + 15-foot end section; Source: New (1990)

Calculations for other length pivots can be made using the formulas below.

1. **Inches** = $\dfrac{\text{Pivot GPM x hours to complete circle}}{\text{450 x acres in circle}}$

2. **Acres per hour** = $\dfrac{\text{Acres in circle}}{\text{Hours to complete circle}}$

3. **End tower speed in feet per hour** = $\dfrac{\text{Distance from pivot to end tower in feet x 2 x 3.14}}{\text{Hours to make circle}}$

4. **Feed end of machine must move per acre** = $\dfrac{87.120}{\text{Distance from pivot to outside wetting pattern}}$

RUNOFF

The basic method of controlling runoff is to match the application rate of the pivot (by changing the speed setting) to the infiltration rate of the soil. Other methods include furrow diking (or "chain" diking for pastures), farming in a circular pattern, deep chiseling of clay sub-soils, adding organic matter to the soil, and using tillage practices that leave the soil "open."

Farming in the round is one of the best methods of reducing runoff and improving water distribution for both LESA and conventionally-equipped pivot systems. When crops are planted in a circle, the pivot never dumps all the water in a few furrows as it can when it parallels straight planted rows. Circle farming begins by marking the circular path of the pivot wheels by making a revolution without water. The tower tire tracks are then used as a guide for laying out rows and planting.

Furrow diking is a mechanical tillage operation that places mounds of soil at selected intervals across the furrow between beds to form small storage basins. Rainfall or irrigation water is trapped and stored in the basins, so that it soaks into the soil rather than running off. Furrow diking has been found to reduce runoff and to increase yields in both dryland and irrigated crops (Jones and Clark, 1988; Lyle and Dixon, 1977). A complete discussion of furrow diking is given by Gerard (1987). A similar practice for permanent pastures, called chain diking, involves dragging a chain-like implement which leaves depressions to collect water.

IRRIGATION SCHEDULING

Research in Texas over the last 10 years has shown that frequent irrigation with amounts matching the ET (evapotranspiration) of row crops result in the maximum production levels and quality. Irrigating twice weekly with center pivots is common. The water use (or ET) of the crop over the previous 2 - 4 days is summed, and the pivot is set to apply this amount of water by adjusting the speed accordingly. Texas has three PET Networks where this data can be obtained (see the Texas ET Web Site for more information at **http://texaset.tamu.edu**). For pivots that cannot apply enough water to meet peak crop consumption, soil water "banking" is recommended. See Fipps (1992) for more information.

CHEMIGATION

Chemigation is the process of injecting an approved chemical into irrigation water, and applying it through the irrigation system to a crop or field. Chemigation is not a new concept, and has been used for years. The earliest work on applying chemicals through sprinklers was with fertilizers, known as *fertigation*. *Herbigation* soon followed, which is the application of herbicides through an irrigation system. Next came *insectigation* with insecticides, *fungigation* with fungicides and *nematigation* with nematicides. The term *chemigation* describes the application of all these chemicals through the irrigation system.

The U.S. Environmental Protection Agency's Label Improvement Program became effective in April 1998. Pesticide labels must now state whether the product is approved to be applied through the irrigation system. If so, application instructions are provided. In addition, these regulations require the use of specific safety equipment and devices designed to prevent accidental spills and contamination of water supplies. Proper chemigation safety equipment and procedures also aid the grower by providing for consistent, precise and continuous chemical injection, thus reducing the amounts (and costs) of chemicals applied. Also, States may have additional requirements related to chemigation. For more information, see New and Fipps (1992), New (1990), or contact your local county Extension office or state Department of Agriculture.

Advantages of chemigation

Uniformity of application - With a properly designed sprinkler irrigation system, both the water and chemicals can be uniformly applied, resulting in excellent distribution of the water-chemical mixture.
Precise application - Chemicals can be applied where they are needed and in the correct concentrations.
Economics - Applying chemicals through chemigation is usually less expensive than conventional application methods. Often, the amount of chemicals needed can be reduced.
Timeliness - Chemicals can still be applied when other methods cannot be used due to wetness, excessive wind, applicator availability or other factors.

Reduced soil compaction and crop damage - Conventional in-field spray equipment is not needed, often resulting in less soil compaction from tractor wheels and crop damage.
Operator safety - Because the operator is not continuously in the field during applications, reduced human contact with the chemicals from drift, frequent tank fillings and other exposures occur.

Disadvantages of Chemigation

High management - Chemical application requires safe use of chemicals, skill in calibration, knowledge of the irrigation and chemigation equipment and understanding of irrigation scheduling concepts.
Additional equipment - Proper injection and safety devices are essential. Legal equipment requirements have been established and must be used.

FERTIGATION

The application of fertilizers through sprinkler irrigation is often referred to as "spoon-feeding" the crop. Fertigation is very common and offers many cost-saving and yield-boosting advantages.

Advantages of Fertigation

Nutrients can be applied any time during the growing season on the basis of crop need.

Placement of mobile nutrients, such as nitrogen, can be regulated in the soil profile by the amount of water applied and, thus be readily available for rapid plant uptake.

Nutrients can be applied uniformly over the field, if the irrigation system has good water distribution uniformity.

Some tillage operations may be eliminated, especially if fertilizer is applied at the same time as irrigation, herbicides or insecticides.

Groundwater contamination is less likely when spoon-feeding, since less fertilizer is applied at any given time, and the timing corresponds to periods of maximum crop uptake.

Minimal crop damage during fertilizer application.

Disadvantages of Fertigation

Uniformity of fertilizer distribution is only as good as irrigation system water distribution uniformity.

Lower cost fertilizer materials such as anhydrous ammonia often cannot be used.

Localized fertilizer placement such as banding cannot be accomplished.

Most fertigation involves soluble or liquid formulations of nitrogen, phosphorus, potassium, magnesium, calcium, sulfur and boron. Nitrogen is the principal element applied by fertigation due to the large amounts used by crops, and its high water solubility and potential to leach. There are several nitrogen formulations that may be used for fertigation as shown in Table 5. When using a solid fertilizer, be sure the fertilizer is completely dissolved in water before it is metered into an irrigation system. In some cases, it may require several hours and agitation to completely dissolve. Normally up to three, 80-pound bags of nitrogen fertilizer can be dissolved in a 55-gallon drum.

Ammonia solutions are not recommended for fertigation because (1) a high loss of volatile ammonia will occur, and (2) ammonia solutions tend to precipitate lime and magnesium salts which are common in irrigation water. Such precipitants can build-up on the inside of the irrigation pipelines and clog sprinkler nozzles.

Water Quality and Precipitants

The quality of irrigation water needs to be evaluated before using fertilizers that may cause precipitants. Of particular concern are salts and interactions with anhydrous ammonia, various polyphosphates (i.e., 10-34-0), and iron carriers. All three tend to react with soluble calcium, magnesium, and sulfate salts to form relatively stable precipitates.

Corrosion of Equipment

Many fertilizer solutions are corrosive. Pumps and fittings constructed of cast iron, aluminum, and some forms of plastic are less subject to corrosion. Stainless steel is relatively unaffected by fertilizer solutions, while brass, copper and bronze are strongly affected. Know the materials of all pump, mixing, and injector components which come into direct contact with concentrated fertilizer solutions. Table 6 gives the relative corrosion of various metals by some common commercial fertilizer solutions.

Table 5. Amount of fertilizers needed to apply specific amounts of nitrogen.						
		Rate of N per acre lb.				
Kind of Fertilizer	**% Nitrogen**	**20**	**40**	**60**	**80**	**100**
		---lbs/ac---				
Solid						
Ammonium Nitrate	33.5	60	120	180	240	300
Ammonium Sulfate	20.5	98	196	294	392	488
Urea	45	44	89	133	177	222
		---gal/ac---				
Solutions						
Urea-Ammonium Nitrate	28	6.7	13.4	20.0	26.8	33.4
Urea-Ammonium Nitrate	32	5.7	11.4	17.0	22.8	28.5
Ammonium Nitrate	21	8.9	17.8	26.7	35.6	44.5

Source: New (1990).

Table 6. Relative corrosion of various metal after four days of immersion in solutions* of commercial fertilizers

Fertilizer	PH of solution	Kind of Metal Galvanized Iron	Sheet Aluminum	Stainless Steel	Bronze	Yellow Brass
		---Relative Corrosion---				
Calcium Nitrate	5.6	Moderate	None	None	Slight	Slight
Sodium Nitrate	8.6	Slight	Moderate	None	None	None
Ammonium Nitrate	5.9	Severe	Slight	None	High	High
Ammonium Sulfate	5.0	High	Slight	None	High	Moderate
Urea	7.6	Slight	None	None	None	None
Phosphoric Acid	0.4	Severe	Moderate	Slight	Moderate	Moderate
Di-Ammonium Phosphate	8.0	Slight	Moderate	None	Severe	Severe
Complete Fertilizer 17-17-10	7.3	Moderate	Slight	None	Severe	Severe

*Solutions of 100 lbs. material in 100 gallons of water; Source: New (1990).

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