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Texas Agricultural Extension Service
THE TEXAS A&M UNIVERSITY SYSTEM

Center Pivot Irrigation

Contents

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The center pivot is the system of choice for agricultural irrigation because of its low labor and maintenance requirements, convenience, flexibility, performance and easy operation. When properly designed and operated, and equipped with high efficiency water applicators, a center pivot system conserves three precious resources—water, energy and time.

Manufacturers have recently improved center pivot drive mechanisms (motors, gears and shafts), control devices, optional mainline pipe sizes and outlet spacings, span lengths, and structural strength. The first pivots produced in the 1950s were propelled by water motors. They operated at high pressures of 80 to 100 psi and were equipped with impact sprinklers and end guns that sprayed water toward the sky, resulting in significant evaporation losses and high energy use. Today, pivots are driven by electric or oil hydraulic motors located at each tower and guided by a central control panel. Pressures as low as 10 to 15 psi (at the pivot mainline) are usually adequate for properly designed LESA (low elevation spray application) and LEPA (low energy precision application) pivots that are 1/4 mile long operating on level to moderately sloping fields. Water application efficiency with such systems is 85 to 98 percent.

Pivot Design Choices

When purchasing a center pivot system one must select:

- mainline size and outlet spacing;
- length, including the number of towers;
- drive mechanisms;
- application rate of the pivot; and
- the type of water applicator.

These choices affect investment and operating costs, irrigation efficiency, and crop production. Wise decisions will result in responsible water management and conservation, flexibility for future changes, and low operating costs.

Switching from furrow to pivot irrigation can save water and money. For example, on the Texas High Plains, field measurements show that corn is irrigated an average of 16 to 17 hours per acre per year with furrow irrigation. With center pivot MESA irrigation (over canopy applicators), similar corn yields are produced with 12 to 13 hours per acre per year. LEPA and LESA applicators further reduce irrigation to an average of 10 to 11 hours per acre per year.

Costs

A quarter-mile (1,300-foot) system that irrigates about 120 acres typically costs $325 to $375 per acre excluding the cost of groundwater well construction, turbine pumps and power units. Longer systems usually cost less on a per-acre basis. For example, half-mile systems (2,600 feet) that irrigate approximately 500 acres cost about $200 to $250 per acre.

This relatively high cost is often offset by a number of advantages, including reduced labor and tillage, improved water distribution, more efficient pumping, lower water requirements, more timely irrigation, and convenience. Programmable control panels and remote control via phone lines or radio can start and stop irrigations, identify location, increase or decrease travel speed, and reverse direction.

Fertilizers and certain plant protection chemicals can be applied through the center pivot, which increases the value and use of the system. Programmable injection unit control, monitoring, and safety are compatible with center pivot control systems. Towable pivot machines are available, so that additional tracts of land can be irrigated with the same machine. When considering a towable machine, remember that sufficient water is needed to irrigate all tracts. Plan the irrigated circle and position the pivot so that it can be moved to drier soil at the location from and in the path in which it is to be towed.

Types of Drive Systems

Electric

In electric drive pivots, individual electric motors (usually 1.0 or 1.5 horsepower) power the two wheels at each tower (Fig. 1). Typically, the outermost tower moves to its next position and stops; then each succeeding tower moves into alignment. Thus, at any time a tower can be in motion. (Where electricity is provided by on-site generation, the generator must operate continuously.) The rotation speed (or travel time) of the pivot depends on the speed of the outermost tower and determines the amount of water that is applied. The operator selects the tower speed using the central power control panel, normally located at the pivot point. At the 100 percent setting, the end tower moves

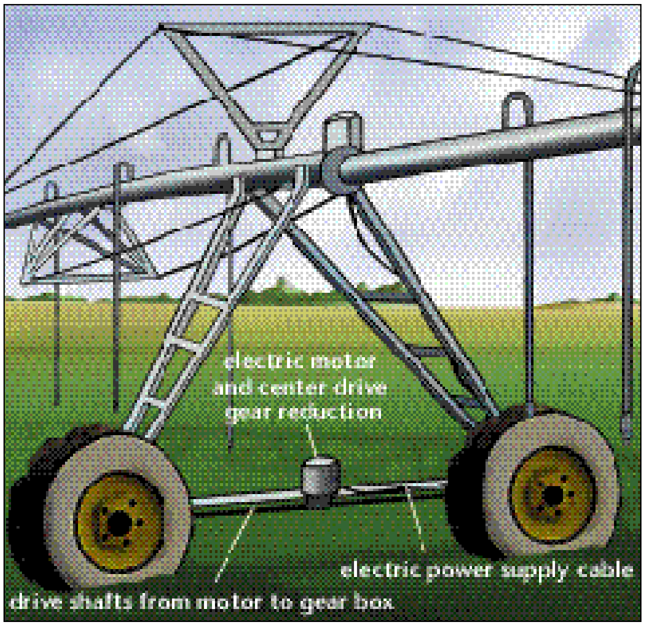

Figure 1a. Electric drive.

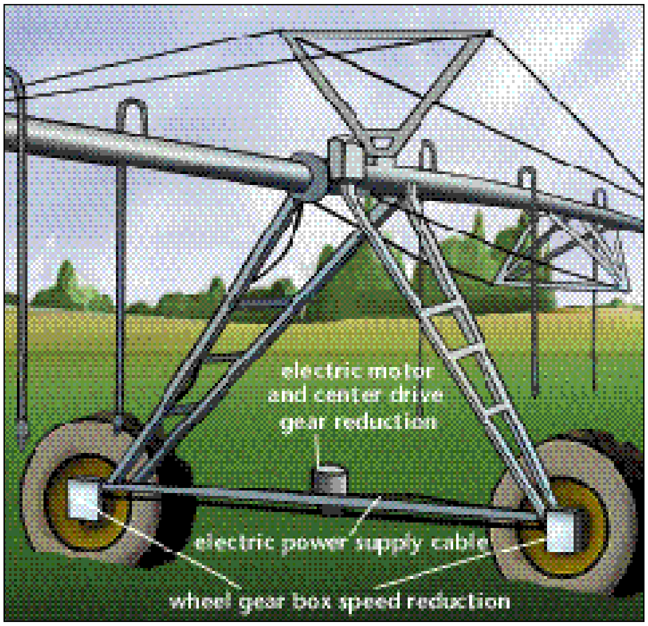

Figure 1b. Electric drive.

continuously. At the 50 percent setting, the outer tower moves 30 seconds and stops 30 seconds each minute, etc. The speed options on most central power control panels range from approximately 2 to 100 percent.

Hydraulic

With oil hydraulic drive systems, all towers remain in continuous motion. The outermost tower speed is the greatest, and each succeeding tower moves continuously at proportionally reduced speeds. As with electric drive machines, the center pivot travel speed is selected at a central control. It is a master control valve that increases or decreases oil flow to the hydraulic motor/s on the last tower. Two motors per tower are used with the planetary drive, one for each wheel (Fig. 2). One motor per tower powers the optional worm drive assembly (not shown). The required hydraulic oil pressure (1,500 to 1,800 psi) is maintained by a central pump usually located near the pivot pad. The central pump may be powered by natural gas, diesel or electricity. The number of towers and maximum travel speed determine the hydraulic oil flow and the central pump power requirement, which usually ranges from 7.5 to 25 horsepower for quarter-mile systems. Additional site specific travel speed options are available (contact your local dealer for more information).

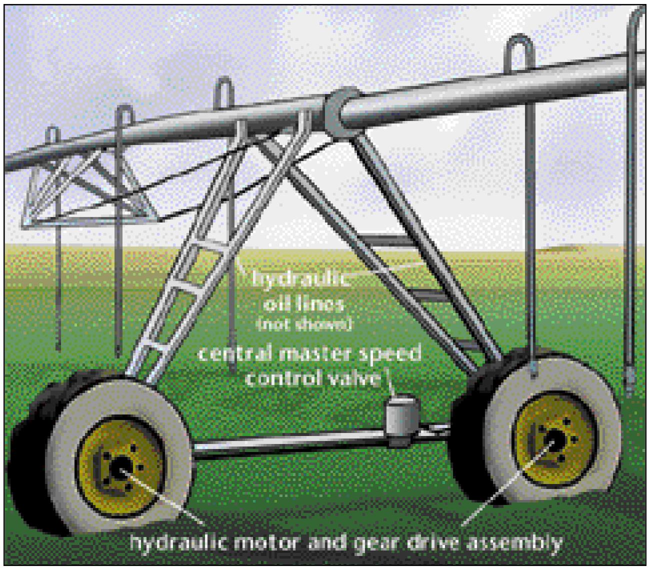

Figure 2. Hydraulic move.

Which is Better?

Theoretically, continuous move systems provide greater irrigation uniformity. However, other factors influence uniformity, including travel speed (and thus, the amount of water applied), system design, type of water applicator, and operator management, in combination with the amount of water (gallons per minute or GPM) the machine is nozzled to deliver. In field tests, both electric and hydraulic drive systems work well. The choice is often guided by available power sources, personal preference in servicing and maintaining the system, the service history of local dealers, what is being sold in the local market and why, purchase price, and dependability.

Wheel and Drive Options

The travel speed is determined by the wheel size in combination with the power drive mechanism, and is set at the central control panel. The speed of the pivot determines the amount of water applied as specified on the corresponding system design precipitation chart. (See the following discussions on the system design precipitation chart and system management as related to travel speed. Gear drives should be checked for proper oil levels and any water in the gear boxes removed at least once each year.)

Electric power drive has two gear reductions. One gear reduction is in the drive shafts connecting the electric motor to a gear box located at each of the two tower wheels. The second gear reduction is the gear box driving each wheel. The maximum center pivot travel speed depends on the:

- electric motor speed or rotation in revolutions per minute (RPM);
- speed reduction ratios in both the center drive shafts and gear boxes; and
- wheel size.

Table 1 gives examples of electric center drive and gear box reductions, wheel circumference, travel distance for each revolution, and representative maximum travel speed in feet per hour.

Hydraulic drive pivots have one gear reduction. Two configurations are used—a hydraulic motor in each wheel hub, or a single motor located at one wheel coupled to a right angle gear drive with a connecting drive shaft that also powers the second wheel. A hydraulic valve meters oil flow to each set of drives at each tower to maintain system alignment. Total oil flow is determined by the travel speed, number of drive units (towers), gear reduction, and tire size. Table 1 lists typical hydraulic drive center pivot oil pump horsepower, tire size, and end tower travel speed.

Design Printout

The design computer printout provides required information about the center pivot and how it will perform on a particular tract of land. A portion of a typical design printout is shown in Figure 3. It includes:

- the pivot design flow rate (or system capacity) in GPM;
- irrigated acreage under the pivot;
- elevation changes in the field as measured from the pivot point;
- operating pressure and mainline friction losses;
- the pressure regulator rating in psi (if used);
- the type of water applicator, spacing and position from the mainline;
- nozzle size for each applicator;
- water applicator nozzle pressure;
- maximum travel speed; and
- the precipitation chart.

A sample precipitation chart is shown in Figure 4. It identifies irrigation amounts (in inches of water applied) for optional travel speed settings, gear reduction ratios and tire size. It corresponds with Figure 3.

Table 1. Typical gear reduction, wheel drive RPM and maximum end tower travel speed.

Drive	Motor RPM	Center drive ratio	Gear box ratio	Wheel diam.–inch		Rim & tire circum. ft.	Last wheel drive - RPM	End tower feet per hour
				Rim	Rim & tire			
Electric	1740	58:1	52:1	24	40	10.47	.5769	362
Electric	1740	40:1	50:1	24	40	10.47	.8700	546
Electric Hi-Speed	3450	40:1	52:1	38	54	14.13	1.6586	1406

	No. towers	Hydraulic pump drive HP	Tire size	Rim & tire circum. ft.	Last wheel drive - RPM	End tower feet per hour
Hydraulic	8	10	16.9 X 24	10.47	.5730	360
Hydraulic	8	15	14.9 x 24	10.47	.9312	585
Hydraulic **Hi-Speed**	8	25	11.2 x 38	14.13	1.5723	1333
Hydraulic **Hi-Speed**	18	25	11.2 x 38	14.13	.6286	533

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Pivot identification          J & J Farms          Overall length                        1309.00 ft
Pivot location                Section 130          Drop tube length                      12.50 ft
Design flow rate              625.00 GPM           Regulator position (from mainline)    12.00 ft
Design Pressure at the end    4.00 PSI             Design elevation of end tower         +7.0 ft, -8.0 ft
Pressure at pivot             13.67 PSI            End gun GPM                           0

 SPAN     SPAN    MAINLINE  NUMBER OF   DROP      DROP     1st DROP  REGULATOR
 NO.     LENGTH   DIAMETER    DROPS   SPACING   DIAMETER   POSITION    SIZE       ACRES
          (ft)    (inches)              (ft)    (inches)     (ft)      (psi)
-----------------------------------------------------------------------------------------
  1       160       6.38       19       6.67      0.75      36.60        6          1.84
  2       160       6.38       24       6.67      0.75       3.335       6          5.53
  3       160       6.38       24       6.67      0.75       3.335       6          9.23
  4       160       6.38       24       6.67      0.75       3.335       6         12.92
  5       160       6.38       24       6.67      0.75       3.335       6         16.61
  6       160       6.38       24       6.67      0.75       3.335       6         20.30
  7       160       6.38       24       6.67      0.75       3.335       6         23.99
  8       160       6.38       24       6.67      0.75       3.335       6         27.68
  9        29       5.78        5       6.67      0.75       3.335       6          5.41
 Total   1309                 192                                                123.51
-----------------------------------------------------------------------------------------
```

1. Mainline outlet number from pivot point
2. Distances in feet between outlets or span length between towers
3. Distance in feet from pivot point to outlet or tower
4. GPM needed based on the area covered by the applicator
5. Actual GPM delivered by the applicator based on the applicator's nozzle size and operating pressure
6. Pressure in psi in the mainline at the outlet
7. Pressure at the nozzle (when pressure regulators are used, the pressure at the nozzle should be no less than the psi of the regulator's rating)
8. Brand name and/or type of applicator and nozzle size (nozzle size is reported either by number or actual size in inches)
9. Applicator number or position on mainline
10. Pressure regulator's brand name, psi rating, and flow capacity (GPM) often expressed as LF (low flow), HF (high flow), etc.
11. Plug number, if outlet is plugged
12. Distance from furro
arm to applicator, i

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   ①         ②          ③         ④       ⑤       ⑥       ⑦          ⑧                ⑨       ⑩      ⑪        ⑫
 OUTLET     LAST     DISTANCE    GPM      GPM     PIPE   NOZZLE   SPRINKLER LABEL      SPRK     REG    PLUG     DROP
   NO.     OUTLET    TO PIVOT    NEED     DEL.    PSI     PSI     & NOZZLE SIZE        NO.     SIZE    NO.     LENGTH
------------------------------------------------------------------------------------------------------------------------
   1                   6.08 -------------------------------------------------------------------------- 1
   2       36.60      36.60      0.18     0.29   13.27    6.66         4.0               1      6LF             150
   3        6.67      43.27      0.21     0.29   13.20    6.66         4.0               2      6LF             156
   4        6.67      49.94      0.24     0.29   13.13    6.66         4.0               3      6LF             156
   5        6.67      56.61      0.27     0.29   13.05    6.66         4.0               4      6LF             162
   ↓
  20        6.67     156.66      0.76     0.76   11.86    6.66         6.5              19      6LF             144
```

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-----------------------------------------------------------------------------------------------------------
Tower 1   160.00    160.00
  21        6.67    163.33     0.79     0.76    11.79    6.66         6.5        20      6LF           144
  22        6.67    170.00     0.82     0.88    11.72    6.66         7.0        21      6LF           144
  23        6.67    176.67     0.85     0.88    11.65    6.66         7.0        22      6LF           150
  24        6.67    183.84     0.89     0.88    11.58    6.66         7.0        23      6LF           150
  25        6.67    190.01     0.92     0.88    11.50    6.66         7.0        24      6LF           156
  ↓
  44        6.67    316.67     1.53     1.61    10.20    6.66         9.5        43      6LF           144
-----------------------------------------------------------------------------------------------------------
Tower 2   160.00    320.00
  45        6.67    323.33     1.56     1.61    10.03    6.66         9.5        44      6LF           144
  46        6.67    330.00     1.59     1.61     9.96    6.66         9.5        45      6LF           144
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Figure 4. Sample precipitation chart.

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                  IRRIGATOR — XXXXX

                  MOTOR SIZE (HP) = 1                            WHEEL GEAR BOX RATIO = 50T01
                  LOADED MOTOR RPM = 1745                        TIRE SIZE = 11.2 X 24.0
                  CENTER GEAR BOX RATIO = 58T01                  LAST TOWER MAX. SPEED (FPM) = 5.90

                                 **Irrigation Precipitation Chart**
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① 1. Total amount of water applied in inches at this speed setting

② 2. Timer (or speed) setting on the control usually indicated as a percentage of the maximum speed

③ 3. Time in hours to make a complete circle at this speed setting

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*********************************************************************************************************
    PRECIPITATION — INCHES       |           TIMER SETTING — %            |           TIME — HOURS
---------------------------------------------------------------------------------------------------------
            0.25                 |                100.00                  |              22.70
            0.32                 |                 80                     |              28.38
            0.36                 |                 70                     |              32.44
---------------------------------------------------------------------------------------------------------
            0.42                 |                 60                     |              37.84
            0.51                 |                 50                     |              45.41
            0.64                 |                 40                     |              56.76
---------------------------------------------------------------------------------------------------------
            0.85                 |                 30                     |              75.68
            1.02                 |                 25                     |              90.82
            1.27                 |                 20                     |             113.53
---------------------------------------------------------------------------------------------------------
            1.42                 |                 18                     |             126.14
            1.70                 |                 15                     |             151.37
            2.12                 |                 12                     |             189.22
---------------------------------------------------------------------------------------------------------
            2.55                 |                 10                     |             227.06
*********************************************************************************************************
```

It is essential that correct information about available water supply (in GPM) and changes in field elevation are used in designing the pivot so that accurate irrigation amounts, operating pressure requirements, and the need for pressure regulators can be determined. Give this information to your dealer, and then inspect the resulting computer design printout before placing your order to ensure that the system is designed to accommodate your site conditions and will perform as expected. Always look at the design mainline operating pressure at the pad to determine if it is what you want. If not, inquire about ways to lower it.

System Capacity

System irrigation capacity is determined by the gallons per minute (GPM) and the number of acres irrigated. System capacity is expressed in terms of either the total flow rate in GPM or the application rate in GPM per acre. Knowing the capacity in GPM per acre helps in irrigation water management. Table 2 shows the relationship between GPM per acre and irrigation amounts. These irrigation amounts apply for all irrigation systems with the same capacity in GPM per acre. The amounts do not include application losses, and are for systems operating 24 hours a day. To determine your system's capacity, select the desired irrigation amounts in inches and multiply the corresponding GPM per acre by the number of acres you are irrigating. For example, if you irrigate 120 acres with 4 GPM per acre, 480 GPM (120 acres x 4 GPM per acre) are required to apply 0.21 inches per day, 1.50 inches per week, and 6.40 inches in 30 days.

Mainline Pipe Sizing

Mainline pipe size influences the total operating cost. Smaller pipe sizes, while less expensive to purchase, may have higher water flow friction pressure loss, resulting in higher energy costs. Plan new center pivots to operate at minimum operating pressure to minimize pumping cost. For a pivot nozzled at 1,000 GPM, 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 $0.35 per hour (or $0.16 per acre-inch) at natural gas costs of $3.00 per MCF.
- At $0.07 per KWH for electricity, the cost is $0.60 per hour ($0.27 per acre-inch) for each additional 10 psi pressure.
- It costs $0.48 per hour ($0.22 per acre-inch) for each additional 10 psi pressure for diesel priced at $0.80 per gallon.

(Note: Horsepower is proportional to system flow rates of 1,000 GPM. For example, when the system flow rate is 700 GPM, 7 horsepower is needed for each 10 psi pivot pressure.)

Table 3 lists friction pressure losses for different mainline sizes and flow rates. Total friction pressure in the pivot mainline for quarter-mile systems (Table 3, section A) on flat to moderately sloping fields **should not exceed 10 psi**. Therefore:

- For flows up to approximately 750 GPM, 6 5/8-inch diameter mainline can be used.
- Friction pressure loss exceeds 10 psi when more than 575 GPM is distributed through 6-inch mainlines.
- Some 8-inch spans should be used when 800 GPM or more are delivered by a quarter-mile system.

For center pivots 1,500 feet long (Table 3, section B), 6 5/8-inch mainline can be used for 700 GPM while keeping friction pressure loss under 10 psi.

Some dealers may undersize the mainline in order to reduce their bids, especially when pushed to give the best price. Check the proposed design printout. If operating pressure appears high, ask the dealer to provide another design using proportional lengths, usually in spans, of larger pipe, or to telescope pipe (see below) to reduce operating pressure. Table 3, section C shows how friction and operating pressure for half-mile systems can be reduced with size 8- and 10-inch mainline pipe. Saving money on the initial purchase price often means paying more in energy costs over the life of the system.

Table 2. Daily and seasonal irrigation capacity.

GPM/ acre	Inch/day	Inch/week	Inches in irrigation days 30	45	60	80	100
1.5	.08	.55	2.4	3.8	4.8	6.4	8.0
2.0	.11	.75	3.2	4.8	6.4	8.5	10.6
3.0	.16	1.10	4.8	7.2	9.5	12.7	15.9
4.0	.21	1.50	6.4	9.5	12.7	17.0	21.2
5.0	.27	1.85	8.0	11.9	15.9	21.2	26.5
6.0	.32	2.25	9.5	14.3	19.1	25.4	31.8
7.0	.37	2.60	11.1	16.7	22.6	29.7	37.1
8.0	.42	2.97	12.7	19.1	25.4	33.9	42.4

Telescoping

Telescoping involves using larger mainline pipe at the beginning and then

Table 3. Approximate friction loss (psi) in center pivot mainlines.

Flow rate, GPM	Mainline pipe diameter, inches: 6	6 5/8	8	10
	Mainline pressure loss, psi			
A. Quarter-mile system:				
500	8	5		
600	11	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. 1500-foot system:				
600	13	8	3	
700	16	10	4	
800	21	13	5	
900	26	16	6	
C. Half-mile system				
1600	134	83	31	10
2000		125	48	15
2400			67	22
2800				29

smaller sizes as the water flow rate (GPM) decreases away from the pivot point. Typical mainline sizes are 10, 8 1/2, 8, 6 5/8 and 6 inches. Mainline pipe size governs options in span length (the distance between adjoining towers). Span length options are usually:

- 100 to 130 feet for 10-inch;
- 130 to 160 feet for 8 1/2- and 8-inch; and
- 160 to 200 feet for 6 5/8- and 6-inch.

Telescoping mainline pipe size is a method of planning a center pivot for minimum water flow friction loss and low operating pressure, and thus, lower pumping costs. Telescoping uses a combination of pipe sizes based on the amount of water (GPM) flowing through. Telescoping is usually accomplished in whole span lengths. Its importance increases with both higher flow rates (GPM) and longer center pivot lengths. Dealers use computer telescoping programs to select mainline pipe size for lowest purchase price and operating costs. If your dealer does not offer this technology, request it.

Table 4 shows examples of telescoping mainline size to manage friction pressure loss. Example 1 shows that for a center pivot 1,316 feet long, fric-

Table 4. Telescoping to reduce mainline friction pressure with outlets spaced at 60 inches.

GPM	Feet of mainline size: 10-inch	8 1/2-inch	8-inch	6 5/8-inch	Total feet	Friction pressure - PSI
Example 1						
1100	0	0	0	1316	1316	19
1100	0	0	640	676	1316	10
Example 2						
2500	0	0	1697	927	2624	73
2500	0	897	800	927	2624	63
2500	897	0	800	927	2624	48
2500	1057	640	540	387	2624	32
2500	1697	0	540	387	2624	25

tion pressure loss is reduced from 19 to10 psi by using 640 feet of 8-inch mainline rather than all 6 $^5/_8$-inch to deliver 1,100 GPM. Example 2 lists friction pressure losses for various lengths and combinations of mainline pipe size for the delivery of 2,500 GPM by a 2,624-foot system irrigating 496 acres. Friction pressure loss is reduced from 73 to 25 psi by using more 10- and 8- and less 6 $^5/_8$-inch mainline pipe. When designing your system, compare the higher cost of larger mainline pipe to the increased pumping costs associated with smaller pipe. (Higher pumping costs are caused by higher operating pressure requirements. Total operation pressure is the sum of friction and system design pressures and terrain elevation; pressure gauges located at the pivot pad and on the last applicator drop will identify system operating pressure.)

Pressure Regulators

Pressure regulators are “pressure killers.” They reduce pressure at the water delivery nozzle so that the appropriate amount of water is applied by each applicator. Selection of nozzle size is based on the rated delivery psi of the pressure regulators. Nozzles used with 10 psi regulators are smaller than those used with 6 psi regulators when the same amount of water is applied. Low rated (psi) pressure regulators, if used, allow center pivot design to be appropriate at minimum operating pressure.

Pressure regulators require energy to function properly. Water pressure losses within the regulator can be 3 psi or more. So, entrance (or inlet) water pressure should be 3 psi more than the regulator rating. Six-psi regulators should have 9 psi at the inlet; 10-psi regulators, 13 psi; 15-psi regulators, 18 psi; and 20-psi regulators, 23 psi. Regulators do not function properly when operating pressure is less than their rating plus 3 psi. Pressure regulator operating inlet pressure should be monitored with a gauge installed upstream adjacent to the regulator in the last drop at the outer end, and should be checked when the machine is upslope. Another gauge located in the first drop in span one will monitor operating pressure when the center pivot is located on downslope terrain.

Pressure regulator psi rating influences system design, appropriate operating pressure, the total energy requirements, and the costs of pivot irrigation. (See the discussion of water applicator arrangement for more information on pressure regulators.)

As with other spray and sprinkler systems, pressure regulators are not necessarily needed for all sites. Table 5 shows how variations in terrain elevations influence mainline operating pressure.

Table 5. Percent variation in system operating pressure created by changes in land elevation for a quarter-mile pivot. Maintain less than 20 percent variation.

		System design pressure (psi)*				
Elevation change		6	10	20	30	40
Feet	psi	% variation				
2.3	1	16.5	10.0	5.0	3.3	2.5
4.6	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

Elevation changes in the field have the largest impact with lower design pressures. From the first to last drop on a pivot, the operating pressure at the nozzle should not vary more than 20 percent from the design operating pressure. Without regulators, operating pressure and pumping cost usually will not increase significantly if the elevation does not change more than 5 feet from the pad to the end of the pivot. Where elevation changes are greater than 5 feet, the choice is to increase operating pressure (and probably pumping costs) or to use pressure regulators. This decision is site specific and should be made by comparing the extra costs of pressure regulators to the increased pumping costs without them. (Note: As shown in Table 5, every additional 2.3 feet of elevation requires an additional 1 psi of operating pressure).

Where the water flow rate, and thus the operating pressure, vary significantly during the growing season, perhaps from seasonal variations in groundwater pumping levels, the design flow rate (or system capacity) and the use of pressure regulators should be evaluated carefully. If water pressure drops below that required to operate the regulators, then poor water application and uniformity will result. In contrast, if the design operating pressure is high, pumping costs will be unnecessarily high. When operating pressure decreases to less than required, the solution is to renozzle for the reduced gallons per minute. The amount of water flow in the mainline decreases or increases operating pressure for the nozzles installed.

Water Applicators

Pads

There are various types of spray applicators available, each with pad options. Low-pressure spray applicators can be used with flat, concave or convex pads that direct the water spray pattern horizontally, upwards and downwards at minimum angles. Spray applicator pads also vary in the number and depth of grooves they have, and, thus, in the size of water droplets they produce. Fine droplets may reduce erosion and runoff, but are less efficient because of their susceptibility to evaporation and wind drift. Some growers prefer to use coarse pads that produce large droplets, and control runoff and erosion with agronomic and management practices. There is little published data on the performance of various pad arrangements. In the absence of personal experience and local information, following the manufacturer's recommendations is likely the best strategy in choosing pad configuration. Pads are very inexpensive. Some growers purchase several groove configurations and experiment to determine which works best in their operation.

Impact Sprinklers

High-pressure impact sprinklers mounted on the center pivot mainline were prevalent in the 1960s when energy prices were low and water conservation did not seem so important. Now, high-pressure impacts are recommended only for special situations, such as the land application of wastewater, where large nozzles and high evaporation can be beneficial.

Impact sprinklers are usually installed directly on the mainline and release water upward at 15 to 27 degrees. Undistorted water pattern diameters normally range from 50 to more than 100 feet. Water application losses average 25 to 35 percent or more. Low-angle, 7-degree sprinklers reduce water loss and pattern diameter somewhat, but do not significantly decrease operating pressure.

End guns are not recommended because they are higher volume (GPM) impact sprinklers with lower application and distribution efficiencies and high energy requirements.

Low-Pressure Applicators

Very few center pivots in Texas are now equipped with impact sprinklers. There are improved applicators and design technology for more responsible irrigation water management. These new applicators operate with low water pressure and work well with current center pivot designs. Low-pressure applicators require less energy and, when appropriately positioned, ensure that most of the water pumped gets to the crop.

The choice is which low-pressure applicator to use and how close to ground level the nozzles can be. Generally, the lower the operating pressure requirements the better. When applicators are spaced 60 to 80 inches apart, nozzle operating pressure can be as low as 6 psi, but more applicators are required than with wider spacings (15 to 30 feet). Water application is most efficient when applicators are positioned 16 to 18 inches above ground level, so that water is applied within the crop canopy. Spray, bubble or direct soil discharge modes can be used.

Field testing has shown that when there is no wind, low-pressure applicators positioned 5 to 7 feet above ground can apply water with up to 90 percent efficiency. However, as the wind speed increases, the amount of water lost to evaporation increases rapidly. In one study, wind speeds of 15 and 20 miles per hour created evaporative losses of 17 and 30+ percent, respectively. In another study on the southern High Plains of Texas, water loss from a linear-move system was as high as 94 percent when wind speed averaged 22 miles per hour with gusts of 34 miles per hour.

Evaporation loss is significantly influenced by wind speed, relative humidity and temperature.

The following sections describe three types of low-pressure application systems that can significantly reduce operating pressure and deliver most of the water pumped for crop production.

MESA

With Mid-Elevation Spray Application (MESA), water applicators are located approximately midway between the mainline and ground level. Water is applied above the crop canopy, even on tall crops such as corn and sugar cane. Rigid drops or flexible drop hoses are attached to the mainline gooseneck or furrow arm and extend down to the water applicator (Fig. 5). Weights should be used in combination with flexible drop hose. Nozzle pressure varies depending on the type of water applicator and pad arrange-

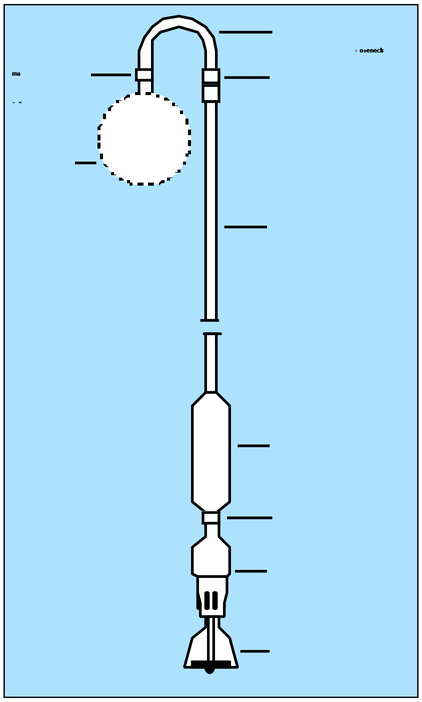

Figure 5. Drop arrangement.

ment selected. While some applicators require 20 to 30 psi operating pressure, improved designs require only 6 to10 psi for conventional 8 $^{1}/_{2}$- to 10-foot mainline outlet and drop spacing. Operating pressures can be lowered to 6 psi or less when spray applicators are positioned 60 to 80 inches apart. With wider spacings, such as for wobbler and rotator applicators, manufacturers' recommended nozzle operating pressure is greater.

Research has shown that in corn production, 10 to 12 percent of the water applied by above-canopy irrigation is lost by wetting the foliage. More is lost to evaporation. Field comparisons indicate that there is 20 to 25 percent more water loss from MESA above-crop-canopy irrigation than from LESA and LEPA within-crop-canopy center pivot systems.

LESA

Low Elevation Spray Application (LESA) applicators are positioned 12 to 18 inches above ground level, or high enough to allow space for wheel tracking. Less crop foliage is wet, especially when planted in a circle, and less water is lost to evaporation. LESA applicators are usually spaced 60 to 80 inches apart, corresponding to two crop rows. The usual arrangement is illustrated in Figure 6. Each applicator is attached to a flexible drop hose, which is connected to a gooseneck or furrow arm on the mainline (Fig. 7). Weights help stabilize the applicator in wind and allow it to work through plants in straight crop rows. Nozzle pressure as low as 6 psi is best with the correct choice of water applicator. Water application efficiency usually averages 85 to 90 percent, but may be less in more open, lower profile crops such as cotton. LESA center pivots can be converted easily to LEPA with an applicator adapter that includes a connection to attach a drag sock or hose.

Figure 6. Drops with LESA applicators.

Figure 7. LESA applicator.

The optimal spacing for LESA drops is no wider than 80 inches. With appropriate installation and management, LESA drops spaced on earlier, conventional 8 $^{1}/_{2}$- to 10-foot spacing can be successful. Corn should be planted in circle rows and water sprayed underneath the primary foliage. Some growers have been successful using LESA irrigation in straight corn rows at conventional outlet spacing when using a flat, coarse pad that sprays water horizontally. Grain sorghum and soybeans also can be planted in straight rows. In wheat, when plant foliage causes significantly uneven water distribution, swing the applicator over the truss rod to raise it. (Note: When buying a new center pivot, choose a mainline outlet spacing of 60 to 80 inches, corresponding to two row widths.)

LEPA

Low Energy Precision Application (LEPA) irrigation discharges water between alternate crop rows planted in a circle. Water is applied with:

- applicators located 12 to 18 inches above ground level, which apply water in a "bubble" pattern; or
- drag socks or hoses that release water on the ground.

Socks help reduce furrow erosion; double-ended socks are designed to protect and maintain furrow dikes (Fig. 8). Drag sock and hose adapters can be removed from the applicator and a spray or chemigation pad attached in its place when needed. Another product, the LEPA "quad" applicator, delivers a bubble water pattern (Fig. 9) that can be reset to optional spray for germination, chemigation and other in-field adjustments (Fig. 10).

LEPA applicators typically are placed 60 to 80 inches apart, corresponding to twice the row spacing. Thus, one row middle is wet and one is dry. Dry middles allow more rainfall to be stored. Applicators are arranged to maintain a dry row for the pivot wheels when the crop is planted in a circle. Research and field tests show that crop production is the same whether water is applied in every furrow or in alternate furrows. Applicator nozzle operating pressure is typically 6 psi.

Field tests show that with LEPA, 95 to 98 percent of the irrigation water pumped gets to the crop. Water application is precise and concentrated, which requires a higher degree of planning and management, especially with clay soil. Center pivots equipped with LEPA applicators provide maximum water application efficiency at minimum operating pressure. LEPA can be used successfully in circles or in straight rows. It is especially beneficial for low profile crops such as cotton and peanuts, and even more beneficial where water is limited.

Converting Existing Pivots to LEPA

Water outlets on older center pivot mainlines are typically spaced 8 $^{1}/_{2}$ to 10 feet apart. Because LEPA drops are placed between every other crop row, additional outlets are needed. For example, for row spac-


Figure 8. Double-ended sock.


Figure 9. LEPA bubble pattern.

ings of 30 inches, drops are needed every 60 inches (5 feet). Likewise, for 36-inch row spacings, drops are placed every 72 inches (6 feet). Two methods can be used to install additional drops and applicators: 1) converting the existing outlets with tees, pipe and clamps; or 2) adding additional mainline outlets. Installation is quicker if a platform is placed underneath the pivot mainline. The platform can be planks placed across the truss rods or the side boards of a truck. A tractor equipped with a front end loader provides an even better platform.

Using Existing Outlets. First, the existing gooseneck is removed and crosses, tees or elbows are connected to the mainline outlets as needed. Galvanized or plastic pipe is cut to extend from the outlet point to the drop location. A galvanized elbow is used to connect the drop to the extension pipe. This elbow should be clamped to the mainline to maintain the drop position (Fig. 11).

Adding Outlets. It is less costly to convert to LEPA by adding outlets than to purchase the tees, plumbing, clamps and labor required to convert existing outlets. New mainline outlets can be installed quickly using a swedge coupler made of metal alloy. An appropriate size hole is drilled into the pivot mainline at the correct spacing (Fig. 12). The swedge coupler is then inserted into the hole. The manufacturer recommends that a small amount of sealant be used with the coupler to ensure a leak-proof connection. A standard hydraulic press (body hydraulic punch equipped with a pull-type cylinder) is attached to the coupler with a special fitting that screws into the coupler. The press is used to compress the coupler against the inside of the mainline pipe to make a water-tight seal (Fig. 13). The swedge coupler compresses quite easily; be careful not to over-compress the coupler. Regular goosenecks or furrow arms are then screwed into the coupler (Fig. 14).

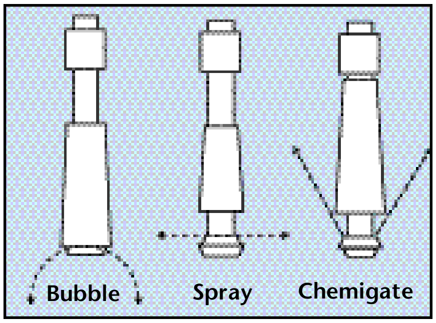

Figure 10. Multi-functional LEPA head.

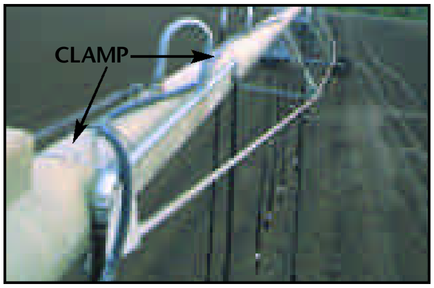

Figure 11. Adding drops.

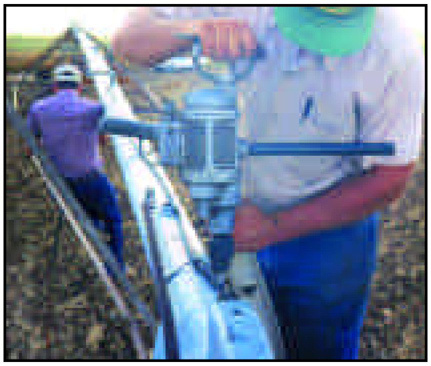
Figure 12. Drilling for swedge coupler.

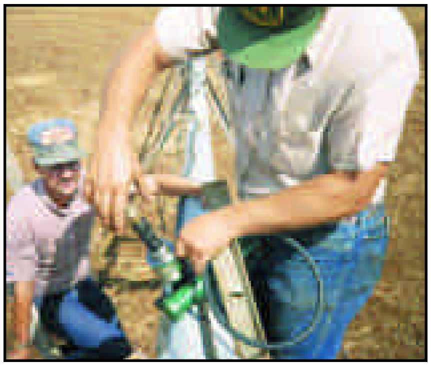
Figure 13. Installing swedge coupler.


Figure 14. Swedge coupler installed.

Outlets also can be added by welding threaded $^{3}/_{4}$-inch female couplings into the existing mainline. Since welding destroys the galvanized coating, welded couplings should be used only on ungalvanized main lines. As with the swedge coupler, goosenecks and drops can be used with the welded couplings.

Other Conversion Tips. When water is pumped into a center pivot, it fills the mainline and drops. The weight of the water causes the pivot to "squat." With 160-foot spans, the pivot mainline will be lowered approximately 5 inches at the center of the span. Likewise, a 185-foot span will be about 7 inches lower at the center when filled with water. The length of the hose drops should be cut to account for this change so that all LEPA heads are about the same height above the ground when the system is running. Center pivot manufacturers can provide appropriate drop hose cut lengths.

Goosenecks or furrow arms and drops are installed alternately on each side of the mainline to help equalize stresses on the pivot structure for high profile crops. Also, when crops are not planted in a circle, having drops on both sides of the mainline helps prevent all the water from being dumped into the same furrows when the system parallels crop rows.

Required Accessories

A permanently installed, continuously functioning flow meter measures the actual amount of irrigation water applied, and is highly recommended. It is used in conjunction with the design printout for irrigation water management. In addition, properly located pressure gauges monitor system performance and, in combination with the flow meter, provide immediate warning of water deficiency and other system failures. Two pressure gauges are needed on the center pivot, one at the end of the system, usually in the last drop upstream from the applicator or regulator, and one at the pivot point. A third one in the first drop of span one will monitor operating pressure when the machine is downslope in relation to the pivot point.

Other Considerations

On older equipment, conventional mainline outlet spacings were 8 $^{1}/_{2}$ to 10 feet. New center pivots should have 60- or 80-inch mainline outlet spacings, even if this reduced spacing is not required by the water applicator initially selected. Manufacturers continue to develop more efficient applicators designed to be spaced closer together to achieve maximum irrigation efficiency and pumping economy. Ordering your pivot with a closer mainline outlet spacing will ensure that it can be quickly and inexpensively equipped with a new applicator design in the future. Retrofitting mainline outlet spacing typically costs $5,000 to $7,000 more than when the spacing is specified with the initial purchase.

As with any other crop production investment, a center pivot should be purchased only after careful analysis. Compare past crop production per acre-inch of irrigation applied to the projected production with center pivot (use Table 2 and consider the reduced cost of labor and tillage); also consider how much water is available. Then answer the question: Will a center pivot cost or make money in my operation? Remember, personal preference is one of the most important considerations.

Pivot Management

Pivot management is centered around knowing how much water is applied in inches. The system design printout includes a precipitation chart that lists total inches applied for various speed settings on the central control panel. If a precipitation chart is not provided (Fig. 4), contact the dealer who first sold the pivot to obtain a copy. Dealers usually keep copies of the computer design printout indefinitely. When a precipitation chart is not available, use Table 6 to identify the irrigation amount based on flow rate and time required to complete a circle. For other sizes of pivots or travel speeds, irrigation inches can be calculated using the first equation below. Keep in mind that the equations assume 100 percent water application efficiency. Reduce the amounts by 2 to 5 percent for LEPA, 5 to 10 percent for LESA, 20 percent for MESA, and 35 to 40 percent for impact sprinklers.

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

1. Inches applied =

$$\frac{\text{Pivot GPM x hours to complete circle}}{\text{450 x acres in circle}}$$

2. Acres per hour =

$$\frac{\text{Acres in circle}}{\text{Hours to complete circle}}$$

3. End tower speed in feet per hour =

$$\frac{\text{Distance from pivot to end tower in feet x 2 x 3.14}}{\text{Hours to make circle}}$$

4. Number of feet the end of machine must move per acre =

$$\frac{87{,}120}{\text{Distance (feet) from pivot to outside wetting pattern}}$$

Runoff Control

Runoff from center pivot irrigation can be controlled by changing the optional speed control setting to match water application to soil infiltration. Agronomic methods of runoff control include furrow diking (or "chain" diking for pastures), farming in a circular pattern, deep chiseling of clay sub-soils, main-

Table 6. Inches of water applied by a 1,290-foot center pivot* with 100 percent water 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	0.80	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	0.20	0.40	0.80	1.20	1.60	2.00
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 feet/hour	667	334	167	111	83	67
Acres/hour	10	5	2.5	1.7	1.3	1

*1,275 feet from pivot to end tower + 15-foot end section

taining crop residue, adding organic matter, and using tillage practices that leave the soil "open."

Farming in the round is one of the best methods of controlling runoff and improving water distribution. 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 rows. Circle farming begins by marking the circular path of the pivot wheels as they make a revolution without water. The tower tire tracks are then a guide for laying out rows and planting. If the mainline span length (distance between towers) does not accommodate an even number of crop rows, adjust the guide marker so that the tower wheels travel between crop rows.

Furrow diking is a mechanical tillage operation that places mounds of soil at selected intervals across the furrow between crop rows to form small water storage basins. Rainfall or irrigation water is trapped and stored in the basins until it soaks into the soil, rather than running off (Fig. 8).

Furrow diking reduces runoff and increases yields in both dryland and irrigated crops. A similar practice for permanent pastures, called chain diking, involves dragging a chain-like implement that leaves depressions to collect water.

Irrigation Scheduling

ET-Based

Maximum crop production and quality are achieved when crops are irrigated frequently with amounts that match their water use or ET (evapotranspiration). Irrigating twice weekly with center pivots is common. Texas has three PET (Potential Evapotranspiration) weather station and crop water use reporting networks, located at Amarillo, College Station and Lubbock. They report daily crop water use based on research. One strategy used by growers is to sum the daily crop water use (ET) reported during the previous 3 to 4 days and then set the pivot central control panel to apply that amount of water. (For more information on PET networks, contact your county Extension office.)

The daily crop water use reported by the PET networks is for full irrigation. Most center pivots operating on the Texas South and High Plains are planned and designed for insufficient capacity (GPM) to supply full daily crop water use. Growers with insufficient capacity should use a high water management strategy that ensures that the soil root zone is filled with water, by either rainfall, pre-watering or early-season irrigation, before daily crop water use exceeds the irrigation capacity. Most soils, such as Pullman, Sherm, Olton and Acuff series soils, can store approximately 2 inches of available water per foot of topsoil. Sandy loam soils typically store 1 inch or more of available water per foot of topsoil. Sandy soils store less. The County Soil Survey available from the Natural Resources Conservation Service contains the available water storage capacity for most soils. Be sure to use the value for the soil at the actual center pivot site.

Soil Moisture-Based

Soil moisture monitoring is highly recommended and complements ET-based scheduling, particularly when there is rainfall during the irrigation season. Soil moisture monitoring devices such as tensiometers and watermark and gypsum block sensors can identify existing soil moisture, monitor moisture changes, locate the depth of water penetration, and indicate crop rooting depths. These three types of sensors absorb and lose moisture similar to the surrounding soil.

Gypsum block and watermark sensors are read with resistance-type meters. Tensiometers have gauges that indicate soil moisture by measuring soil moisture pressures in units of centibars. Tensiometers are very accurate, but are most useful in lighter soils that are irrigated frequently.

Watermark sensors respond more quickly and are more accurate than gypsum blocks, but cost more.

Readings may be taken weekly during the early growing season. During the crop's primary water use periods, readings should be taken two or three times each week for more timely management.

Plotting sensor readings on a computer spreadsheet or graph paper is the best method of tracking and interpreting sensor readings and managing irrigation. An example is shown in Figure 15. It describes soil moisture measured with gypsum blocks in wheat production.

A single block or tensiometer installed at a depth of 12 to 18 inches will measure moisture in the upper root zone; another installed at 36 inches will measure deep moisture. Sensors usually are installed at three depths—12, 24 and 36 inches—and at a representative location in the field where the soil is uniform. They should not be placed on extreme slopes or in low areas where water may pond. Select a location within

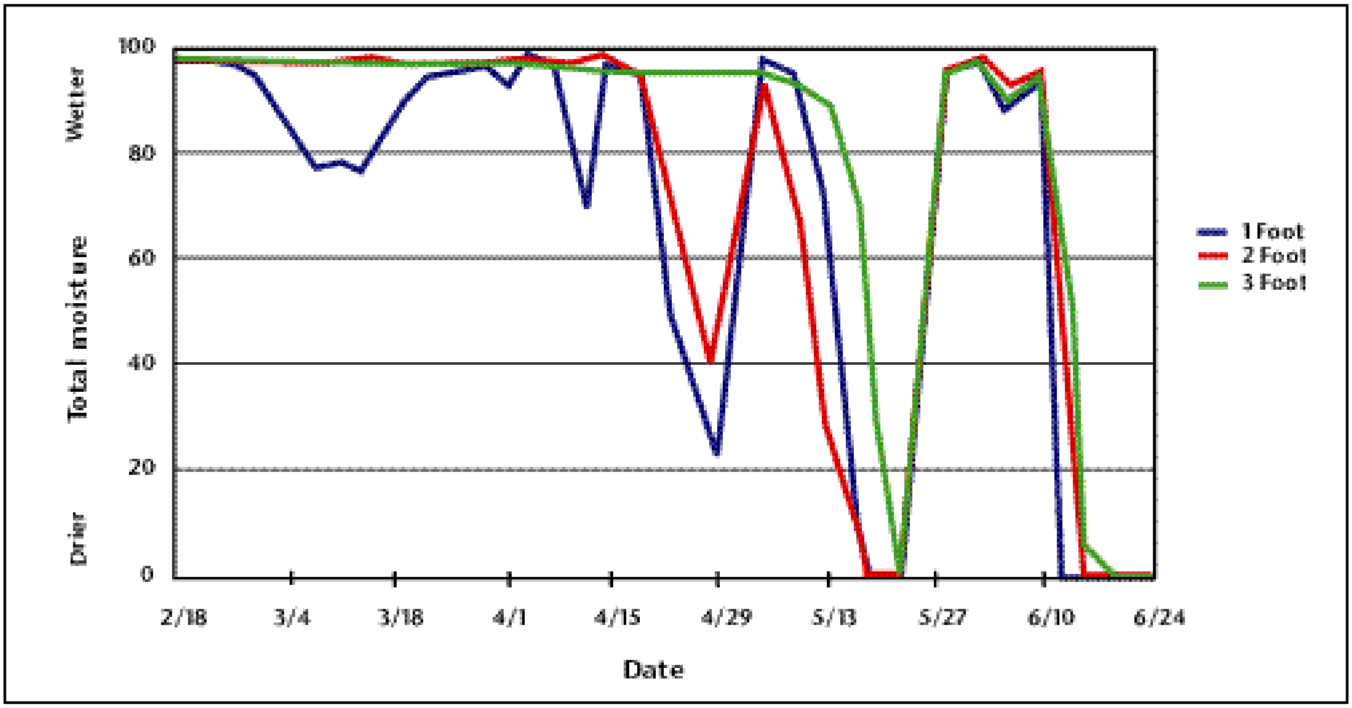

Figure 15a. Soil moisture measurements in a wheat field. Soil moisture should not fall below a reading of 40 to 60 for most soil types.

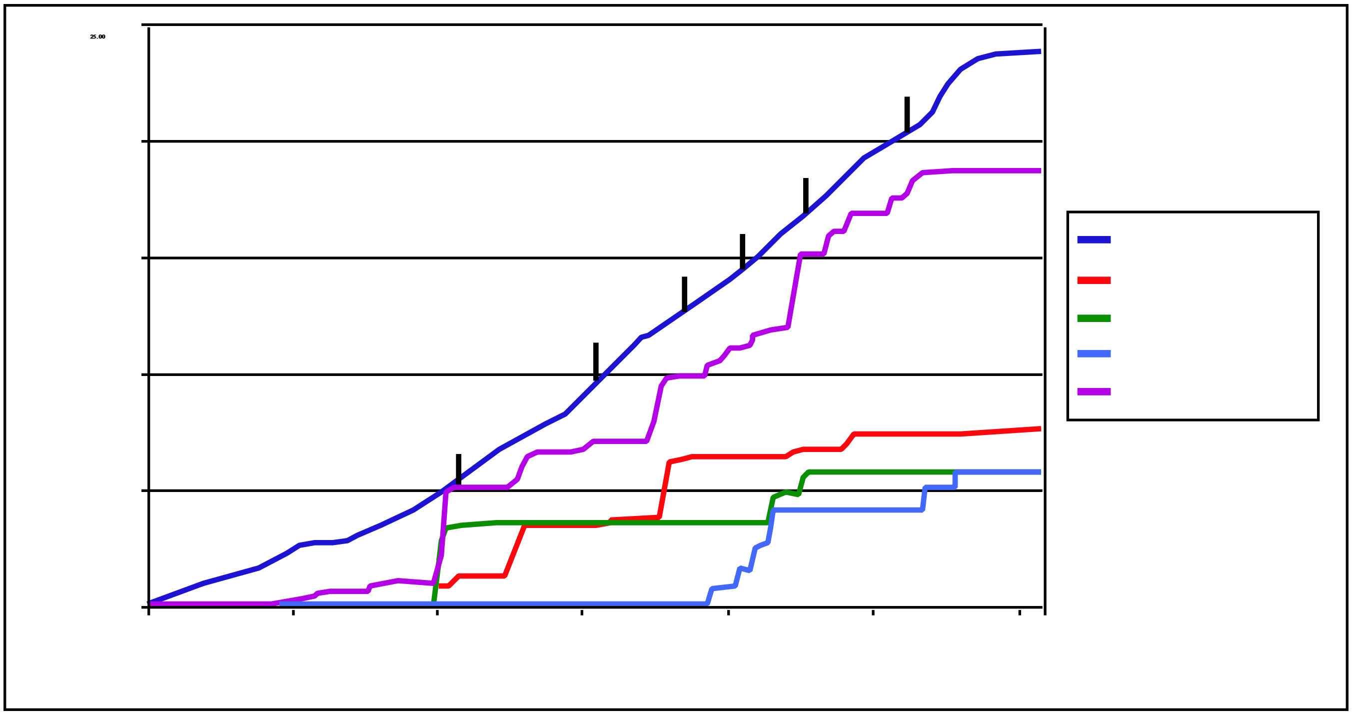

Figure 15b. Cumulative ET and total water supplied to the wheat field in Figure 15a.

the next to the last center pivot span but away from the wheel tracks.

Locate sensors in the crop row so they do not interfere with tractor equipment. Follow manufacturers' recommendations on preparing sensors. It is essential to have the sensing tip in firm contact with undisturbed soil to obtain accurate readings. The soil auger used to install sensors must be no more than $^1/_8$ inch larger than the sensing unit.

Chemigation

Chemigation is the application of an approved chemical (fertilizer, herbicide, insecticide, fungicide or nematicide) with irrigation water through the center pivot. Chemigation is an improved, advanced concept. Pesticide and other chemical labels must state whether the product is approved for application in this way. If so, application instructions are provided on the label. EPA regulations require the use of specific safety control equipment and devices designed to prevent accidental spills and contamination of water supplies. Using proper chemigation safety equipment and procedures also aids the grower by providing consistent, precise and continuous chemical injection, thus reducing the amounts (and costs) of chemicals applied. As in Texas, state regulatory agencies may have their own requirements in addition to those of the EPA. For more information contact your county Extension office or state Department of Agriculture.

Advantages of chemigation

- Uniformity of application. With a properly designed irrigation system, both water and chemicals can be applied uniformly, 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.** Chemigation is usually less expensive than other application methods, and often requires a smaller amount of chemical.
- **Timeliness.** Chemigation can be carried out when other methods of application might be prevented by wet soil, excessive wind, lack of equipment, and other factors.
- **Reduced soil compaction and crop damage.** Because conventional in-field spray equipment may not be needed, there could be less tractor wheel soil compaction and crop damage.
- **Operator safety.** The operator is not in the field continuously during applications, so there is less human contact with chemical drift, and less exposure during frequent tank fillings and other tasks.

Disadvantages of Chemigation

- **Skill and knowledge required.** Chemicals must always be applied correctly and safely. Chemigation requires skill in calibration, knowledge of the irrigation and chemigation equipment, and an understanding of the chemical and irrigation scheduling concepts.
- **Additional equipment.** Proper injection and safety devices are essential and the grower must be in compliance with these legal requirements.

Fertigation

The application of fertilizers with irrigation water, or fertigation, is often referred to as "spoon-feeding" the crop. Fertigation is very common and has many benefits. Most fertigation uses soluble or liquid formulations of nitrogen, phosphorus, potassium, magnesium, calcium, sulfur and boron. Nitrogen is most commonly applied because crops need large amounts of it. Keep in mind that nitrogen is highly soluble and has the potential to leach; it needs to be carefully managed.

There are several nitrogen formulations that can be used for fertigation, as shown in Table 7. Be sure a solid formulation is completely dissolved in water before it is metered into the irrigation system. (Up to three, 80-pound bags of nitrogen fertilizer can be dissolved in a 55-gallon drum.) This may require agitating the mixture for several hours. Continue agitating throughout the injection process.

Advantages of Fertigation

- Nutrients can be applied any time during the growing season based on crop need.
- Mobile nutrients such as nitrogen can be carefully regulated in the soil profile by the amount of water applied so that they are available for rapid use by the crop.
- Nutrients can be applied uniformly over the field if the irrigation system distributes water uniformly.
- Some tillage operations may be eliminated, especially if fertilization coincides with the application of herbicides or insecticides. However, do not inject two chemicals simultaneously without knowing that they are compatible with each other and with the irrigation water.
- Groundwater contamination is less likely with fertigation because less fertilizer is applied at any given time. Application can correspond to maximum crop needs.
- There is minimal crop damage during fertilizer application.

Table 7. Amount of fertilizers needed to apply specific amounts of nitrogen.

Kind of fertilizer	Pounds of N per acre 20	40	60	80	100
	Pounds per acre of fertilizer needed for rate of N listed above				
Solid					
Ammonium nitrate (33.5% nitrogen)	60	120	180	240	300
Ammonium sulfate (20.5% nitrogen)	98	196	294	392	488
Urea (45% nitrogen)	44	89	133	177	222
	Gallons per acre of fertilizer needed for rate of N listed above				
Solutions					
Urea-ammonium nitrate (28% nitrogen)	6.7	13.4	20	26.8	33.4
Urea-ammonium nitrate (32% nitrogen)	5.7	11.4	17	22.8	28.5
Ammonium nitrate (21% nitrogen)	8.9	17.8	26.7	35.6	44.5

Table 8. Relative corrosion of various metals after 4 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 pounds of material in 100 gallons of water.

Disadvantages of Fertigation

- Fertilizer distribution is only as uniform as the irrigation water distribution. Use pressure gauges to ensure that the center pivot is properly pressured.
- Lower cost fertilizer materials such as anhydrous ammonia often cannot be used.
- Fertilizer placement cannot be localized, as in banding.
- Ammonia solutions are not recommended for fertigation because ammonia is volatile and too much will be lost. Also, ammonia solutions tend to precipitate lime and magnesium salts, which are common in irrigation water. Such precipitates can form on the inside of irrigation pipelines and clog nozzles. The quality of irrigation water should be evaluated before using fertilizers that may create precipitates. Besides ammonia, various polyphosphates (e.g., 10-34-0) and iron carriers can react with soluble calcium, magnesium and sulfate salts to form precipitates.
- Many fertilizer solutions are corrosive. Chemigation injection pumps and fittings constructed of cast iron, aluminum, stainless steel and some forms of plastic are less subject to corrosion and failure. Brass, copper and bronze are easily corroded. Know the materials of all pump, mixing and injector components that are in direct contact with concentrated fertilizer solutions. Table 8 describes the corrosion potential of various metals when in direct contact with common commercial fertilizer solutions.

Suggested Reading

B-1670, “Soil Moisture Management.”

B-1652, “Chemigation Workbook.”

L-2422, “Chemigation Equipment and Safety.”

L-2218, “Pumping Plant Efficiency and Irrigation Costs”

Center Pivot Checklist

Pivot Design

__ Actual lowest and highest field elevation irrigated in relation to the pivot point was used in the computer design printout.

__ Actual measured or reduced flow rate and pressure available by pump or water source was used in the computer design printout.

__ Friction loss in pivot mainline for quarter-mile-long systems is no greater than 10 psi.

__ Mainline size is telescoped to achieve selected operating pressure.

__ Mainline outlets are spaced a maximum of 60 to 80 inches or, alternately, two times the crop row spacing.

__ Gauges are included at the pad and last drop to monitor operating pressure.

__ For non-leveled fields, less than 20 percent variation in system design operating pressure is maintained when pivot is positioned at the highest and lowest points in the field (computer design printout provided for each case).

__ Pressure regulators were evaluated for fields with more than 5 feet of elevation change from pad to the highest and the lowest point in the field.

__ Tower wheels and motor sizes were selected based on desired travel speed, soil type and slope, following manufacturer’s recommendations.

__ Operation control provides expected performance.

__ The dealer provided a copy of the pivot design printout.

Center Pivot Irrigation

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