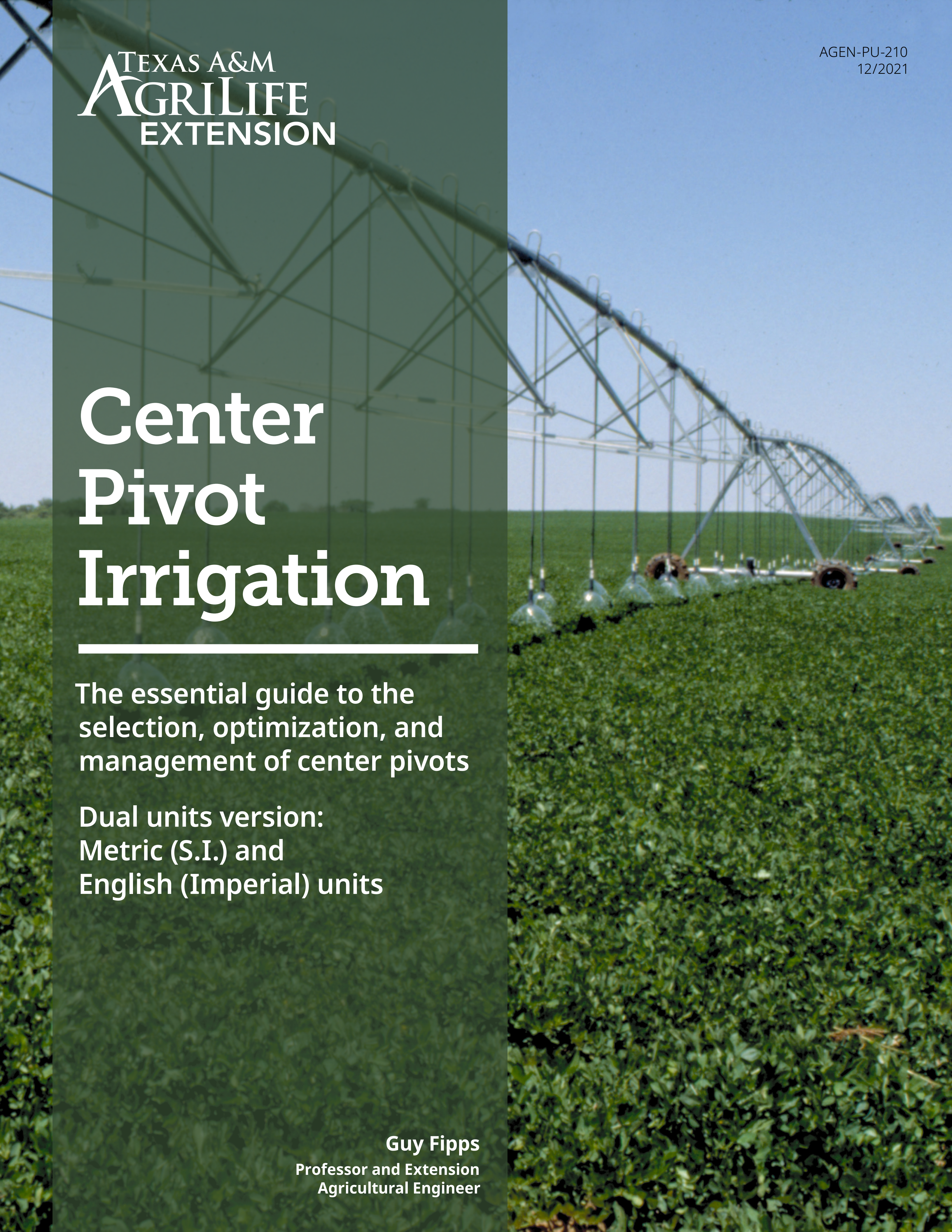

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Texas A&M AgriLife Extension

Center Pivot Irrigation

The essential guide to the selection, optimization, and management of center pivots

Dual units version:
Metric (S.I.) and
English (Imperial) units

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Contents

The center pivot is the agricultural irrigation system of choice for large areas because of its low labor and maintenance requirements, convenience, flexibility, performance, and easy operation. Center pivot systems, when properly designed and equipped, conserve valuable resources such as water, energy, money, and time.

The first center pivot systems were produced in the 1950s and were water-drive systems. These pivots operated at high pressures and had low water application efficiencies, resulting in significant evaporation losses and high energy use. Today, pivots are primarily driven by electric or oil hydraulic motors. Energy requirements have decreased, and high application efficiency is now possible with the use of close drop spacings equipped with low-elevation spray application (LESA) and low-energy precision application (LEPA) water applicators. Operating pressures as low as 6 pounds per square inch (psi, *0.4 bar*) are achievable.

Design Choices

Wise selection of a center pivot system will result in good water management and conservation, low operating costs, and future flexibility. When ordering a pivot, there are many choices and decisions that need to be made, including:

- Mainline size and outlet spacing
- Pivot height: low profile, standard, high profile, or ultra-high profile
- Pipe material: galvanized, aluminum, stainless steel, or poly-lined for adverse water quality conditions
- Length, including the number of towers
- Drive mechanisms
- Water application rate of the pivot
- Type of water applicator, operating pressure, and whether pressure regulators are needed
- Sizes of motors, driveshafts, and wheels
- Types of tires and configuration
- Type of control panel, associated sensors, and communication options

As pivots have long life spans (25+ years), taking the time to carefully consider the options and associated advantages/disadvantages will make a huge difference in the cost and level of management required for years to come.

Center pivot machines revolve around the pivot point. The amount of land they can irrigate is based upon the length of the pivot or the number of towers. Spans are available in several length options. Additional towers and spans are added to expand the length of the system and the total area irrigated. The flow rate of the water applicators changes as they move out from the pivot point, since each water applicator covers a larger area. Nozzle sizes are designed with computer software.

Corner-arm and Linear Systems

In rectangular fields, a pivot leaves the corners dry. Some growers either leave the corners dry or install a separate sprinkler or drip irrigation system in these areas. Pivots may also be equipped with a corner-arm system. This span automatically swings out at the corners and activates flow to the water applicators. The drive mechanisms are more complex for corner-arm systems, which may require more maintenance. Achieving a uniform precipitation rate and good water distribution in the corner has been a major challenge with these systems. However, variable-rate water application technology is now commercially available and can help address these problems.

Another option for rectangular fields is a linear-move system (also referred to as a lateral-move system), which moves in a straight line across the field. Water is usually supplied to the machine from a small canal that runs along one side of the field. Alternatively, water is supplied by an underground pipeline, which is equipped with quick-connect outlets installed along the pipeline. A flexible hose is attached and repositioned to the next outlet as the machine moves. Linear-move machines are more expensive than pivots due to the costs of the control and water supply systems. One major difference from pivots is that the flow rate of each water applicator is the same for the entire system. Otherwise, the design of linear-move systems is like that of pivots.

Costs

The cost of pivots has fluctuated greatly during recent years due to the price and availability of materials for their manufacturing and changing energy and transportation costs. The pivot system commonly used for general pricing purposes is a “quarter-mile system,” which is about 1,300 feet (*396 meters*) long and irrigates 120 acres (*49 hectares*). In the United States, a quarter-mile system may cost anywhere from $650 to $750 on a per-acre basis (*$1,600 to $1,850 USD per hectare*), excluding shipping, installation, and the additional expense of running power and water to the pivot. Longer systems usually cost less on a per-area basis. For example, a half-mile pivot system (2,600 feet, *793 meters*) irrigates about 500 acres (*203 hectares*) and costs $500 to $550 per acre (*$1,235 to $1,360 USD per hectare*).

The relatively high cost of a center pivot system often can be offset by advantages over other types of irrigation systems, such as:

- Reduced labor and tillage
- Improved water distribution
- More efficient water use
- More timely irrigation
- Flexibility and convenience, with such options as:
  - Remote and automatic control to start or stop irrigation, increase or decrease travel speed, reverse direction, and send alarm warning messages to the user
  - Application of chemicals and fertilizers
  - Towable pivot machines that can irrigate additional tracts of land

Types of Drive Systems

Electric

For electric-drive pivots, individual electric motors, usually 0.6 to 1.5 horsepower (*0.45 to 1.1 kilowatts*), 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. Rotation speed (or travel time) of the pivot depends on the speed of the outermost tower and controls the amount of water applied. The system operator can select the tower speed using the control panel, normally located at the pivot point. At the 100 percent setting, the end tower moves continuously. At the 50 percent setting, for each minute of operation, the outer tower moves 30 seconds and stops 30 seconds. The speed options on most control panels range from 2 to 100 percent.

Hydraulic

Unlike electric-drive pivots, all oil-hydraulic-drive towers remain in continuous motion (Fig. 2). Each tower moves continuously at a proportionally reduced speed compared to that of the outermost tower. Travel speed is selected at a central master control valve that increases or decreases oil flow to the hydraulic motors. Two types of hydraulic drives are available: worm and planetary. The planetary option provides greater strength and efficiency and uses two motors per tower—one for each wheel. One motor per tower powers an optional worm-drive assembly. Required hydraulic oil pressure usually is 1,500 to 1,800 psi (*103 to 124 bar*), maintained by a central pump, most often located near the pivot pad. This central pump may be powered by natural gas, diesel, or electricity.

Water-drive Systems

The first pivots manufactured in the early 1950s were water-drive systems. These tended to operate at very high pressures (90+ psi, *6.2+ bar*) and had very poor efficiencies. Modern water-drive pivots can operate at pressures as low as 45 psi (*3.1 bar*) and come in a towable option so the same pivot can be shared among fields. Water-drive pivots may be particularly applicable to fields without power. Maximum pivot length is limited to less than 290 feet (*88 meters*) or field sizes less than 7.5 acres (*3 hectares*). Water-driven pivots are continuous-move systems and share the same relative advantages of hydraulic-move systems.

Which is Better?

In field tests, both electric- and hydraulic-drive systems worked well. Choice of pivot type usually is guided by the power source available, personal preferences, required system maintenance, local dealer service history, local-market product availability, purchase price, and dependability. In principle, continuous-move systems provide better irrigation and water uniformity, which are particularly beneficial for chemigation, and are less likely to get stuck. However, uniformity also is influenced by other factors, including travel speed, system design,

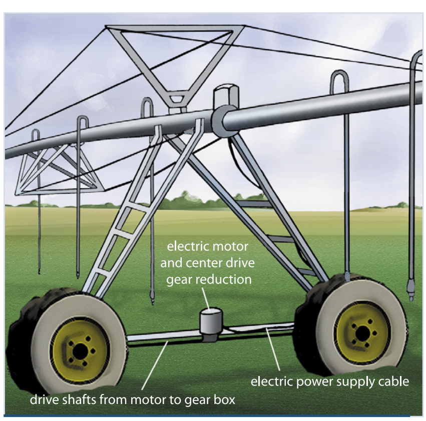


Figure 1a. Electric drive.

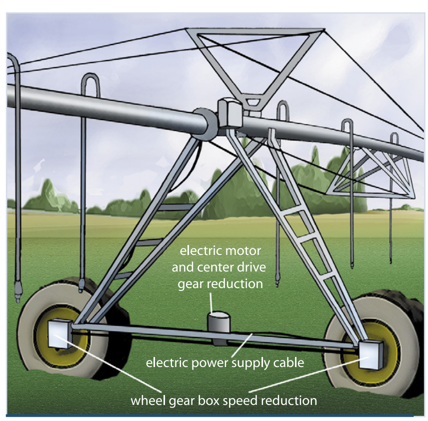


Figure 1b. Electric drive.

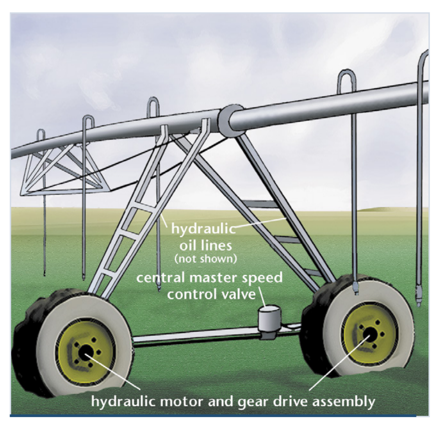


Figure 2. Hydraulic drive.

type of water applicator, and operator management. Timer settings for electric machines have a greater range of adjustment.

Wheel and Gear Options

The speed of the pivot controls the amount of water applied. Pivot travel speed depends on both the wheel size and the power-drive mechanisms. Electric power-drive systems have two gear reductions: one in the driveshaft and one in the gearbox driving each wheel. Thus, maximum center-pivot travel speed depends on:

- Electric motor speed or rotation in revolutions per minute (rpm)
- Speed reduction rotation in both the center driveshaft and the gearboxes
- Wheel size

Hydraulic-drive pivots have only one gear reduction. Tables 1a and 1b list examples of electric- and hydraulic-drive systems and the end-tower speed based upon the given specifications.

The Pivot Design Printout

The design computer printout (commonly referred to as the “pivot printout” or just “printout”) provides information required for the operation and management of a center pivot and details how it will perform on a specific tract of land. A portion of a typical design printout is shown in Figure 3. Printouts include the following:

- Pivot-design flow rate
- Irrigated area under the pivot in acres or hectares
- Maximum elevation change in the field, as measured from the pivot point

Table 1a. Typical gear reduction, wheel-drive rpm, and maximum end tower travel speed of electric-move pivots.

Center drive motor rpm	Gearbox ratio	Ratio	Wheel dimension (in)		Rim and tire circumference (ft)	Last wheel drive (rpm)	End tower (ft/hr)
			Rim	Rim and tire			
1,740	58:1	52:1	24	40	10.47	0.5769	362
1,800	40:1	50:1	24	40	10.47	0.8700	546
3,450	40:1	52:1	38	54	14.13	1.6586	1,406

Table 1a (metric). Typical gear reduction, wheel-drive rpm, and maximum end tower travel speed of electric-move pivots.

Center drive motor rpm	Gearbox ratio	Ratio	Wheel dimension (cm)		Rim and tire circumference (m)	Last wheel drive (rpm)	End tower (m/hr)
			Rim	Rim and tire			
1,740	58:1	52:1	60.96	101.6	3.19	0.5769	110
1,800	40:1	50:1	60.96	101.6	3.19	0.8700	166
3,450	40:1	52:1	96.52	137.2	4.31	1.6586	428

Table 1b. Typical gear reduction, wheel-drive rpm and maximum end tower travel speed for hydraulic drives.

Drive type	Number of towers	Hydraulic pump drive (hp)	Tire size (in)	Rim and tire circumference (ft)	Last wheel drive (rpm)	End tower (ft/hr)
Hydraulic	8	10	16.9 × 24	10.47	0.5730	360
Hydraulic	8	15	14.9 × 24	10.47	0.9312	585
Hydraulic High-Speed	8	25	11.2 × 38	14.13	1.5723	1,333
Hydraulic High-Speed	18	25	11.2 × 38	14.13	0.6286	533

Table 1b (metric). Typical gear reduction, wheel-drive rpm and maximum end tower travel speed for hydraulic drives.

Drive type	Number of towers	Hydraulic pump drive (kW)	Tire size (in)	Rim and tire circumference (m)	Last wheel drive (rpm)	End tower (m/hr)
Hydraulic	8	7.46	16.9 × 24	3.19	0.5730	110
Hydraulic	8	11.19	14.9 × 24	3.19	0.9312	178
Hydraulic High-Speed	8	18.64	11.2 × 38	4.31	1.5723	406
Hydraulic High-Speed	18	18.64	11.2 × 38	4.31	0.6286	162

Figure 3. Sample design computer printout in Metric units.

Date: xxxx/xx/xx   Chart No: JJ-XXXXX-XX   Page 2

Dealer: **Customer:**   **Comments:**

Machine

Mfg:	
Flow:	91.26 m3/h
Pivot Pressure:	1.99 bar
Base Press	2.30 bar
End Pressure:	1.38 bar
Spacing:	Span dependent
Length:	287.27 m
m3h / Hect:	3.51 m3/h
Average Drop:	2.4 m
End Gun:	No

Pipes

C Factor: 140

Pipe 1: 287.3 m, 136.37 mm ID

Sprinklers

102 (102)Std 9 Grv   IWob UP3

Elevation

Difference above(+) pivot 3.00

Difference below(-) pivot 0.00

Elevation Rise included in calculations

Regs

Position : Bottom

102 PSR-15

Spans # 5

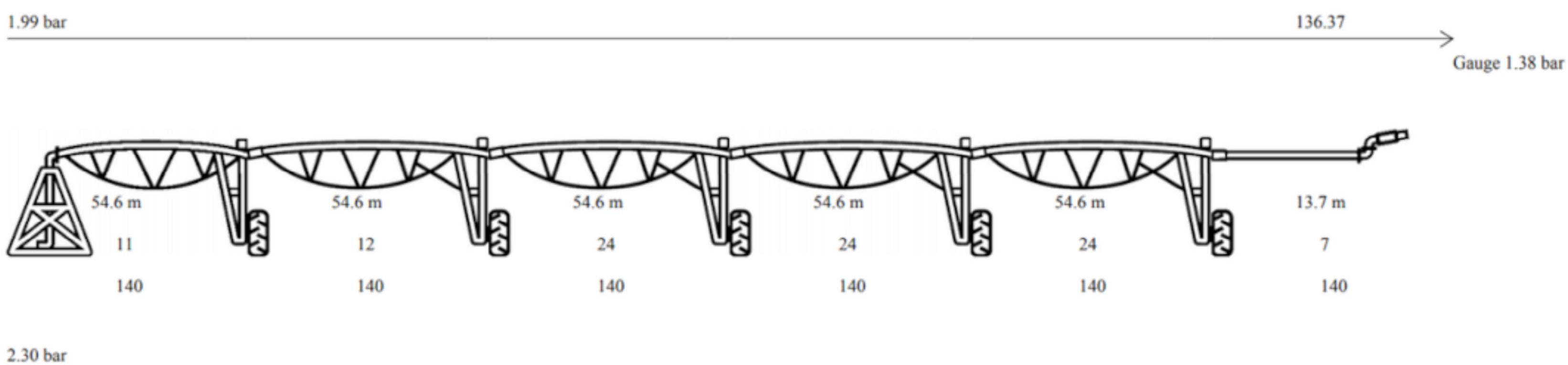
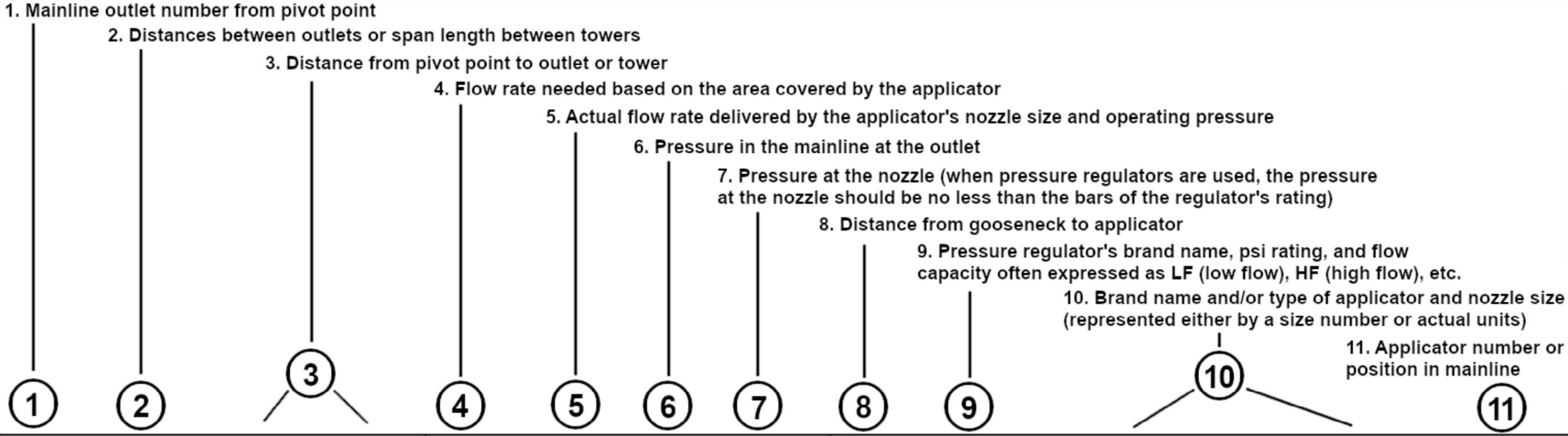


Figure 3. Sample design computer printout in Metric units (continued).



LOCATION: OUTLET COUNT	LOCATION: DISTANCE FROM LAST OUTLET (M)	LOCATION: DISTANCE FROM LAST TOWER (M)	LOCATION: DISTANCE FROM PIVOT POINT (M)	HYDRAULICS DATA: OUTLET FLOW NEEDED (M3/H)	HYDRAULICS DATA: ACTUAL OUTLET FLOW (M3/H)	HYDRAULICS DATA: MAIN PIPE PRESS (BAR)	HYDRAULICS DATA: SPR. BASE PRESS (BAR)	HARDWARE DESCRIPTION: DROP LENGTH (cm)	HARDWARE DESCRIPTION: PRESS REG MODEL	HARDWARE DESCRIPTION: XXXX SPRINKLER MODEL&PAD/Weight	HARDWARE DESCRIPTION: NOZZ SIZE (64TH INCH) &COLOR	Goose Neck: G=180°Sg Sg=125°Sg Db=125°Db NOZZ#
Pivot - Gauge												
1-Plg			1.1									
2-Plg			2.4									
3-Plg			4.7									
4-Plg			6.9									
5		9.13	9.1	0.09	0.23	1.96	1.14	211	PSR-15	IWob UP3 Std 9 Grv	6-GOLD	1 G
6-Plg			11.4									
7	4.52	13.65	13.6	0.13	0.23	1.95	1.14	224	PSR-15	IWob UP3 Std 9 Grv	6-GOLD	2 G
8-Plg			15.8									
9	4.42	18.07	18.1	0.18	0.23	1.93	1.14	234	PSR-15	IWob UP3 Std 9 Grv	6-GOLD	3 G
10-Plg			20.3									
11	4.47	22.54	22.5	0.22	0.23	1.92	1.14	239	PSR-15	IWob UP3 Std 9 Grv	6-GOLD	4 G
12-Plg			24.8									
13	4.52	27.06	27.1	0.27	0.27	1.91	1.14	241	PSR-15	IWob UP3 Std 9 Grv	6.5-GLD/*	5 G
14-Plg			29.2									
15	4.42	31.48	31.5	0.31	0.32	1.89	1.14	239	PSR-15	IWob UP3 Std 9 Grv	7-LIME	6 G
16-Plg			33.7									
17	4.47	35.95	36.0	0.36	0.37	1.88	1.14	234	PSR-15	IWob UP3 Std 9 Grv	7.5-LIM/*	7 G
↓												
Tower 5		54.56	273.59									
126	2.81	1.33	274.9	1.54	1.56	1.39	1.11	180	PSR-15	IWob UP3 Std 9 Grv	15.5-DBN/*	96 G
127	2.29	3.62	277.2	1.38	1.37	1.39	1.12	180	PSR-15	IWob UP3 Std 9 Grv	14.5-BLU/*	97 G
128	2.23	5.85	279.4	1.38	1.37	1.39	1.12	180	PSR-15	IWob UP3 Std 9 Grv	14.5-BLU/*	98 G
129	2.24	8.09	281.7	1.39	1.37	1.39	1.12	180	PSR-15	IWob UP3 Std 9 Grv	14.5-BLU/*	99 G
130	2.23	10.32	283.9	1.41	1.37	1.38	1.11	180	PSR-15	IWob UP3 Std 9 Grv	14.5-BLU/*	100 G
131	2.29	12.61	286.2	1.06	1.02	1.38	1.13	180	PSR-15	IWob UP3 Std 9 Grv	12.5-RED/*	101 G
132	1.07	13.68	287.3	0.68	0.65	1.38	1.14	180	PSR-15	IWob UP3 Std 9 Grv	10-TURQUOISE	102 G

Return to Contents page

- Operating pressure and mainline friction loss
- Pressure regulator rating in psi (*bar*)
- Type of water applicator, spacing, and position on the mainline
- Nozzle size for each applicator
- Water applicator nozzle pressure
- Maximum travel speed
- Precipitation chart

Water applicators come with stickers with numbers, which correspond to the number of the drop on the pivot printout, making it easy to install applicators in the right location. Printouts include a precipitation chart, as shown in Figure 4. The chart is often located at the end of the printout and shows the irrigation amounts (in inches or *millimeters* of water applied) for each speed setting, based upon the gear reduction ratios and tire size of the pivot.

When ordering a pivot, it is essential to specify the actual/measured (not estimated) available water supply (in gallons per minute [gpm], *cubic meters per hour* [m^3/h]), along with the changes in field elevation, from the pivot point to the lowest and highest points in the field. This information is critical to determine accurate irrigation amounts, operating pressure requirements, and whether pressure regulators are needed.

System Capacity

A pivot's irrigation-system capacity is determined by the flow rate in gpm (m^3/h) and the total area. System capacity is often expressed in terms of:

- Total flow rate of the pivot in gpm (m^3/h)
- Application rate per area in gpm/acre (*m^3/h per hectare*)

Knowing a system's capacity in flow rate per area (gpm/acre, *m^3/h per hectare*) is necessary for proper irrigation water management and in determining if the pivot can meet the water requirements of specific crops. Table 2 shows the relationship between the flow rate per area and irrigation amounts. This table applies to pivots and all other irrigation systems that have the same capacity in flow rate per area (gpm/acre, *m^3/h per hectare*). The amounts do not include application losses and assume that the pivot operates 24 hours a day. For example, if one irrigates 120 acres (*49 hectares*) with a flow rate of 480 gpm (*109 m^3/h*), and it takes 24 hours to complete a circle, then the capacity is 4 gpm/acre per day (*2.24 m^3/h per hectare per day*). From Table 2, this system would apply 0.21 inches (*5.3 millimeters*) of water in one 24-hour day, 1.5 inches (*38.1 millimeters*) each week, and 6.4 inches (*163 millimeters*) in 30 days.

Mainline Pipe Sizing

Typical mainline sizes are 10, 8⅝, 8, 6⅝, 6, and 5⁹⁄₁₆ inches (*254, 219, 203, 168, 152, and 141 millimeters*). Short and small (mini) pivots often use a 4½-inch (*114-millimeter*) pipe. The size of the mainline determines available options for span lengths (the distance between adjoining towers). Typical span length options are:

- 113 to 140 feet (*34 to 42.6 meters*) for 10-inch (*254-millimeter*) mainline
- 113 to 180 feet (*34 to 54.9 meters*) for 8⅝- and 8-inch (*219- and 203-millimeter*) mainlines
- 160 to 205 feet (*48.8 to 62.5 meters*) for 6⅝-, 6-, and 5⁹⁄₁₆-inch (*168-, 152-, and 141-millimeter*) mainlines

Selecting the correct mainline pipe size will reduce the energy costs of operating the pivot over its lifespan.

Table 2. Daily and seasonal irrigation capacity for irrigation systems operating 24 hours per day.

GPM/ acre	Inch/ day	Inch/ week	Inches in irrigation days				
			30	45	60	80	100
1.5	.08	.55	2.4	3.6	4.8	6.4	8.0
2.0	.11	.75	3.3	5.0	6.6	8.8	11.0
3.0	.16	1.10	4.8	7.2	9.6	12.8	16.0
4.0	.21	1.50	6.3	9.5	12.6	16.8	21.0
5.0	.27	1.85	8.1	12.2	16.2	21.6	27.0
6.0	.32	2.25	9.6	14.4	19.2	25.6	32.0
7.0	.37	2.60	11.1	16.7	22.2	29.6	37.0

Table 2 (metric). Daily and seasonal irrigation capacity for irrigation systems operating 24 hours per day.

m^3/h/ hectare	mm/day	mm/ week	mm in irrigation days				
			30	45	60	80	100
0.8	2.0	14.0	60	90	120	160	200
1.1	2.8	19.1	84	126	168	224	280
1.7	4.1	27.9	123	185	246	328	410
2.2	5.3	38.1	159	239	318	424	530
2.8	6.9	47.0	207	311	414	552	690
3.4	8.1	57.2	243	365	486	648	810
3.9	9.4	66.0	282	423	564	752	940

Return to Contents page

Figure 4. Standard precipitation chart in Metric units.

Date: xxxx/xx/xx | Chart No: JJ-XXXXX-XX | Page 5

Dealer: **Customer:** **Comments:**

Precipitation

Delivered Flow:	91.42 m3/h
Length:	287.27 m
Area:	26.03 ha
Distance to last tower:	273.59 m
Speed of last tower:	3.17 m
Precip. / Hect: (360)	3.51 m3/h
Time for coverage:	9.04Hrs
Tire Size	11.2 x 38
Center gear box reduction (RATIO)	40:1
Wheel gear box reduction (RATIO)	50:1

Circle Degree 360

Depth	Timer	Rotation
3.17 mm	100.00%	9.0hrs
5.08 mm	62.46%	14.5hrs
7.62 mm	41.64%	21.7hrs
10.16 mm	31.23%	28.9hrs
12.70 mm	24.98%	36.2hrs
15.24 mm	20.82%	43.4hrs
17.78 mm	17.85%	50.6hrs
20.32 mm	15.62%	57.9hrs
22.86 mm	13.88%	65.1hrs
25.40 mm	12.49%	72.4hrs
31.75 mm	9.99%	90.4hrs
38.10 mm	8.33%	108.5hrs
50.80 mm	6.25%	144.7hrs
63.50 mm	5.00%	180.9hrs

Caution**This chart is an estimate of the performance for your irrigation system. Tire inflation, tire slippage, soil conditions, flow fluctuations and other conditions can cause application and time deviations. The info above should be used as a guide and used with caution.

Return to Contents page

While smaller-diameter pipes are less expensive to purchase, they may have higher friction pressure loss from the flow of water. Friction losses cause a loss in pressure, resulting in higher energy costs. For a flow rate of 1,000 gpm (*227 m³/h*), rules of thumb are as follows for pivots in Texas with the water supplied from wells:

- Each additional 10 psi of pivot pressure requires an increase of approximately 10 horsepower. *Each additional 0.69 bar of pivot pressure requires an increase of 7.46 kilowatts in energy.*
- Each additional 10 psi of pivot pressure increases fuel costs by about $0.35 per hour or $0.16 per acre-inch for natural gas costs of $3.00 per thousand cubic feet (mcf). *Each additional 0.69 bar of pivot pressure increases fuel costs by about $0.35 USD per hour or $0.16 USD per 1,003 cubic meters (m³) of irrigation water for natural gas costs of $0.30/m³.*
- At $0.07 per kilowatt hour, electricity costs $0.60 per hour or $0.27 per acre-inch for each additional 10 psi of pressure. *At $0.07 USD per kilowatt hour, electricity costs $0.60 USD per hour or $0.27 USD per 103 m³ of irrigation water for each additional 0.69 bar of pressure.*
- For diesel fuel priced at $2.00 per gallon, it costs $1.20 per hour ($0.56 per acre-inch) for each additional 10 psi of pressure. *For diesel fuel priced at $0.26 USD per liter, it costs $0.60 USD per hour ($0.28 USD per 100 m³ of irrigation water) for each additional 0.69 bar pressure.*
- For diesel fuel priced at $3.00 per gallon, the cost for each additional 10 psi increases to $1.80 per hour ($0.84 per acre-inch). *For diesel fuel priced at $0.40 USD per liter, the cost for each additional 0.69 psi increases to $1.80 USD per hour ($0.42 USD for every 103 m³ of irrigation water).*

Table 3 lists friction losses for different mainline sizes and flow rates. Total pressure lost due to ***friction should not exceed 10 psi (0.69 bar)*** in quarter-mile systems on flat to moderately sloping fields. Therefore:

- Friction loss exceeds 10 psi (*0.69 bar*) when more than 600 gpm (*138 m³/h*) is distributed through 6-inch (*152-millimeter*) mainlines.

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

		Mainline pipe diameter (nominal size)**, inches			
		6	6⅝	8	10
Flow rate, gpm		Mainline pressure loss, psi			
A. Quarter-mile system					
(1,300 ft):	500	6.5	4		
	600	9	5.7		
	700	12	7.6		
	800	15.5	10	4	
	900	19	12	4.6	
	1,000	23.5	14.7	5.5	
	1,100	28	18	7	
	1,200	33	20.8	7.9	
B. 1,500-ft system:					
	600	10	6.7	2.5	
	700	14	9	3.3	
	800	18	11	4.2	
	900	23	14	5.2	
C. Half-mile system					
(2,600 ft):	1,600	111	70	27	9
	2,000		105	41	13.5
	2,400			57	19
	2,800				25

* C-factor = 140 used for friction loss calculations
** Actual internal pipe diameters used for these calculations are 6 in, 6.375 in, 7.79 in, and 9.79 in.

Table 3 (metric). Approximate friction loss (bar) in center pivot mainlines.*

		Mainline pipe internal diameter, millimeters			
		152	165	198	249
		Nominal pipe size, inches			
		6	6⅝	8	10
Flow rate, m³/h		Mainline pressure loss, bar			
A. Quarter-mile system					
(396 m):	114	0.45	0.28		
	136	0.62	0.39		
	159	0.83	0.52		
	182	1.07	0.69	0.28	
	204	1.31	0.83	0.32	
	227	1.62	1.01	0.38	
	250	1.93	1.24	0.48	
	273	2.28	1.43	0.54	
B. 1,500-ft system (457 m):					
	136	0.69	0.46	0.17	
	159	0.97	0.62	0.23	
	182	1.24	0.76	0.29	
	204	1.59	0.97	0.36	
C. Half-mile system					
(792 m):	363	7.65	4.83	1.86	0.62
	454		7.24	2.83	0.93
	545			3.93	1.31
	636				1.72

* C-factor = 140 used for friction loss calculations

- For flow rates less than 800 gpm (*182* m^3/h), 6⅝-inch (*168-millimeter*) diameter mainline can be used.
- Some 8-inch (*203-millimeter*) spans should be used when more than 800 gpm (*182* m^3/h) are delivered by a quarter-mile (*396-meter*) system.
- For center pivots 1,500 feet (*457 meters*) long, 6⅝-inch (*168-millimeter*) mainline can be used for 700 gpm (*159* m^3/h), while keeping friction-pressure loss under 10 psi (*0.69 bar*).
- Friction and operating pressure for half-mile (*5,280-meter*) systems can be greatly reduced by including some spans of 10-inch (*254-millimeter*) mainline pipe.

Saving money on the initial purchase price often means paying more in energy costs over the life of the system. Some dealers may undersize the mainline to reduce their bids, especially when pushed to give the best price. Check the proposed design printout. If the operating pressure appears high, ask the dealer to provide another design using proportional lengths of larger pipe, referred to as telescoping, to reduce operating pressure.

Telescoping

Telescoping involves using a larger diameter mainline pipe at the beginning of the pivot, followed by smaller sizes as the flow rate decreases away from the pivot point. Telescoping the mainline is used to obtain the lowest friction losses and operating pressure possible for the given flow rate and length of the machine, which in turn will lower energy costs over the life of the pivot. Pipe sizing is based on the velocity of the water flowing through the mainline in each span. Computer software is used to examine multiple pipe-size options to achieve the lowest purchase price and operating costs.

Table 4 illustrates how telescoping can be used to reduce friction losses.

- In Example 1, total friction loss is reduced from 18 to 9.4 psi by using 640 feet of 8-inch mainline rather than all 6⅝-inch pipe in a 1,316-feet-long pivot. *In Example 1, total friction loss is reduced from 1.24 to 0.65 bar by using 195 meters of 203-millimeter mainline rather than all 168-millimeter pipe in a 401-meter-long pivot.*
- Example 2 lists friction losses for various lengths and combinations of mainline pipe size for a 2,624-feet-long pivot nozzled at 2,500 gpm and irrigating 496 acres. Total friction loss is reduced from 70.5 to 25 psi by using more 10- and 8-inch mainline pipe and less 6⅝-inch pipe. *Example 2 lists friction losses for various lengths and combinations of mainline pipe size for an 800-meter-long pivot nozzled at 568* m^3/h *and irrigating 201 hectares. Total friction loss is reduced from 4.9 to 1.72 bar by using more 254- and 203-millimeter mainline pipe and less 168-millimeter pipe.*

When selecting a system, compare the higher initial purchase cost of larger mainline pipe sizes to the increased pumping costs associated with smaller pipe sizes. Higher operating pressure requirements result in higher costs for pumping. The total operation pressure requirement is the sum of friction loss, system design pressures, and changes in field elevation. For existing pivots, pressure gauges installed near the pivot point and on the last applicator drop will identify system operating pressure.

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

GPM	Feet of mainline size (nominal dimensions)				Total feet	Friction loss – psi
	10-in	8⅝-in	8-in	6⅝-in		
Example 1						
1,100	0	0	0	1,316	1,316	18
1,100	0	0	640	676	1,316	9.4
Example 2						
2,500	0	0	1,697	927	2,624	70.5
2,500	0	897	800	927	2,624	60
2,500	897	0	800	927	2,624	47
2,500	1,057	640	540	387	2,624	30.1
2,500	1,697	0	540	387	2,624	25

Table 4 (metric). Telescoping to reduce mainline friction loss with outlets spaced at 1.5 meters.

m^3/h	Meters of mainline pipe (nominal size)				Total meters	Friction pressure (bar)
	254 mm	219 mm	203 mm	168 mm		
	10 in	8⅝ in	8 in	6⅝ in		
Example 1						
250	0	0	0	401	401	1.24
250	0	0	195	206	401	0.65
Example 2						
568	0	0	517	283	800	4.86
568	0	273	244	283	800	4.14
568	273	0	244	283	800	3.24
568	322	195	165	118	800	2.08
568	517	0	165	118	800	1.72

Pressure Regulators

Some dealers automatically include pressure regulators regardless of whether they are actually needed. This often occurs in situations where there is uncertainty about the available flow rate and pressure that will be provided to the pivot, and in situations where there is no data on elevation changes in the field where the pivot will be located. However, pressure regulators impact the design pressure of the pivot, and in turn, the design pressure defines the energy requirements to pump water and the long-term cost of pivot irrigation. Pressure regulators are not needed for all sites, and their use should be carefully considered.

Pressure regulators have specific ratings such as 6 psi, 10 psi, 15 psi, 25 psi (*0.4, 0.7, 1.0, 1.7 bar*), etc. The rated delivery psi (*bar*) of the pressure regulators governs the size of the nozzle selected for each water applicator. For the same application rate, nozzles used with 10 psi (*0.7 bar*) regulators will be smaller than those used with 6 psi (*0.4 bar*) regulators. Lower-rated pressure regulators, if used, allow the center pivot to be designed for minimum operating pressures, which lowers energy costs.

Pressure regulators are "pressure killers." They reduce pressure at the nozzle so that the appropriate amount of water is applied by each applicator. Pressure regulators require energy to function properly. Water-pressure losses within the regulator may be 5 psi or more. Thus, the entrance (or inlet) water pressure needs to be about 5 psi (*0.35 bar*) higher than the regulator pressure rating. Six-psi regulators require 10 psi at the inlet; 10-psi regulators, 15 psi; 15-psi regulators, 20 psi; and 20-psi regulators, 25 psi. Regulators do not function properly at operating pressures less than their rating plus about 5 psi (*0.35 bar*).

Table 5 shows how variations in terrain elevations influence mainline operating pressures. Elevation changes in the field have the largest impact on center pivots with lower design pressures. From the first to the last drop on a pivot, operating pressure at the nozzle should not vary more than 20 percent from design operating pressure. Pressure regulators usually are not necessary if the elevation change from the pivot point to the end of the machine is 5 feet (*1.5 meters*) or less. The best approach is to have the irrigation dealer run pivot printouts with and without regulators. As shown in Table 5, every additional 2.3 feet (*0.7 meters*) of elevation requires an additional 1 psi (*0.07 bar*) of operating pressure. When including pressure regulators, the smallest psi-rated pressure regulator as required by elevation changes should be used.

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.

Change in feet	psi	System design pressure (psi)* elevation				
		6	10	20	30	40
		% 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

Table 5 (metric). Percent variation in system operating pressure created by changes in land elevation for a quarter-mile pivot (*396-meter*) pivot. Maintain less than 20 percent variation.

		System design pressure at nozzle (bar)				
Elevation change		0.41	0.69	1.38	2.07	2.76
meters	bar	% Variation				
0.7	0.07	16.5	10.0	5.0	3.3	2.5
1.4	0.14	33.0	20.0	10.0	6.6	5.0
2.1	0.21	50.0	30.0	15.0	10.0	7.5
2.8	0.28		40.0	20.0	13.3	10.0
3.5	0.34		50.0	25.0	16.6	12.5
4.2	0.41			30.0	20.0	15.0
4.9	0.48				23.3	17.5
5.6	0.55				26.6	20.0

*pressure at the nozzle

Special attention is required for situations where the flow rate and the operating pressure vary significantly during the growing season. This is often due to seasonal variations in groundwater pumping levels. As groundwater levels decline, the available pressure may fall below that required to operate the regulators, resulting in insufficient water application and poor uniformity. Using variable frequency drive pumps is one strategy for this situation, which may be effective depending on site-specific conditions. The more common solution is to renozzle the pivot for the reduced flow rate. Nozzles are inexpensive and can be quickly swapped out when the pressure becomes too low. Dealers will be glad to produce a new pivot printout when ordering a new nozzle package.

Water Applicators

Terminology

Figure 5 shows the typical configuration of a drop and the terminology used to refer to each component. The drop may be a rigid metal tube, a semi-rigid plastic tube, or a poly drop. Shown is a generic water applicator positioned close to the ground. Water applicators and the terminology used to describe water applicator systems on pivots continue to evolve. Since the early 1990s, common terminology consisted of the following:

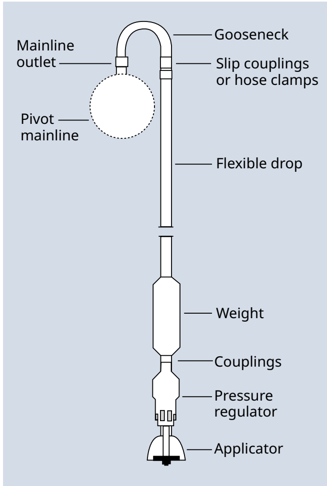


Figure 5. Drop arrangement.

- Applicators located on top of the mainline,
- Mid-elevation spray application (MESA),
- Low-elevation spray application (LESA), and
- Low-energy precision application (LEPA).

Both LESA and LEPA are also classified as low-pressure systems, with operating pressures as low as 6 psi (*0.4 bar*). MESA systems typically have operating pressures in the 20 to 25 psi (*1.4 to 1.7 bar*) range.

Today in the irrigation industry, water applicator systems are commonly referred to as:

- Over-canopy,
- In-canopy, and
- Close drop spacing.
  a. LESA
  b. LEPA

Close drop spacing systems include both LESA and LEPA. The spacing of drops is based upon the row spacing, with drop spacing equal to twice the row spacing (or a drop in every other row) for LESA, and either every row or every other row for LEPA. These water applicators are positioned within 1½ feet (*46 centimeters*) of the ground surface.

Precision Application, Residue Managed (PARM)

Included in the close-drop-spacing category is PARM, an approved conservation practice by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). PARM includes residue management using a no-till or strip-till tillage system and "flat planting." It normally consists of a LEPA drop in each row, with applicators discharging water in a bubble pattern, positioned within 1½ feet (*46 centimeters*) of the ground surface (Fig. 6). Drops in every other row are also allowable under the NRCS practice.

Pads

There are different types of spray water applicators available, each with several pad options, including flat, concave, and convex pad designs that direct the water spray pattern horizontally, upward, or downward at minimum angles. Spray applicator pads also vary in the number and depth of grooves, which affects the size of water droplets produced. Fine droplets may reduce erosion, runoff, and soil compaction, and they promote

Figure 6a. A PARM center pivot, equipped with LEPA drops in every row. *Photo provided by the USDA-NRCS.*

Figure 6b. LEPA drop with applicator discharging water in a bubble along with residue management. *Photo provided by the USDA-NRCS.*

better infiltration in heavy soils 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 to control runoff and erosion with agronomic and other management practices. Little university-based research data is available 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 for choosing pad configuration. Pads are inexpensive, and some growers purchase several groove configurations and experiment to determine which works best in their operations.

Impact Sprinklers

High-pressure impact sprinklers mounted on top of the center pivot mainline were prevalent in the 1960s when energy prices were low and water conservation did not seem so important. Now, such sprinklers are recommended only for special situations, such as land application of wastewater, where high evaporation can be beneficial. Impact sprinklers usually are installed directly on the mainline and release water upward at 15 to 27 degrees.

High-pressure impact sprinklers normally produce water pattern diameters in the range of 50 to more than 100 feet (*15 to 30 meters*). Water application losses average 25 to 35 percent or more, depending on how much wind there is. Low-angle (i.e., 7 degrees) sprinklers somewhat reduce water loss and pattern diameter but do not significantly decrease operating pressure.

Low-pressure Applicators

Very few center pivots in Texas are now equipped with impact sprinklers, as improved water applicator designs are available, resulting in more responsible irrigation water management. These applicators operate at 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.

Generally, the lower the operating pressure requirements, the better. With close drop spacing (i.e., applicators spaced no wider than 60 to 80 inches [*152 to 203 centimeters*] apart), nozzle operating pressure can be as low as 6 psi (*0.41 bar*). Water application is most efficient when applicators are positioned within 18 inches (*46 centimeters*) of ground level. Water applicators have interchangeable "deflector" pads, which allow various spray patterns and bubble modes, enabling quick and easy switching from LESA to LEPA water application modes.

Field testing has shown that when there is no wind, low-pressure applicators positioned 5 to 7 feet (*1.5 to 2.1 meters*) 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 (*6.7 and 8.9 meters/second*) 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 (*9.8 meters/second*) with gusts of 34 miles per hour (*15 meters/second*). When applicators are located near the ground surface, efficiencies of 95 to 98 percent are possible. However, evaporation loss is influenced by multiple factors such as wind speed, relative humidity, and temperature.

Above-canopy and In-canopy Water Application

With in-canopy systems, water applicators are located below the truss rods, often about midway between the mainline and ground level. However, shorter drops may be used so that water is applied above the crop canopy, even on tall crops such as corn and sugarcane. 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 are needed with flexible drop hoses. Typically, these systems operate at 25 to 45 psi (*1.7 to 3.1 bar*). However, improved designs are available, which only require 10 to 15 psi (*0.7 to 1.0 bar*) with conventional 8½- to 10-foot (*2.6- to 3.0-meter*) drop spacing.

Nozzle pressure requirements depend on both the type of water applicator and the height at which it is positioned. For a given pressure, the radius of throw (i.e., the distance that water is thrown from the nozzle, also referred to as the wetted area) depends upon how high the applicator is above the ground. Sufficient overlap is required for good distribution of water. Consult with a dealer and have a new printout run before changing the height of the water applicators.

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

Close Drop Spacing

LESA

LESA applicators are positioned 12 to 18 inches (*30 to 45 centimeters*) above ground level or high enough to allow space for wheel tracking (Fig. 7). Less crop foliage is wetted, especially when crops are planted in a circle, and less water is lost to evaporation. LESA applicators usually are spaced 60 to 80 inches (*1.5 to 2.0 meters*) apart, corresponding to two crop rows. The usual arrangement is illustrated in Figure 5. Each applicator is attached to a flexible drop hose, which is connected to a gooseneck or furrow arm on the mainline. Weights made of metal or plastic are available for each type of applicator to help stabilize the applicator in winds and allow it to work itself through crops planted in straight rows. Nozzle pressure as low as 6 psi (*0.4 bar*) is best with a correctly chosen water applicator. Water-application efficiency usually averages 90 to 95 percent. LESA center pivots can be converted easily to LEPA with an applicator adapter pad (Fig. 8).

Figure 7. Close drop spacing with LESA water applicators.

Figure 8. An example of a water applicator used for close drop spacing systems that can be easily switched to the bubble mode (LEPA) and spray mode (LESA).

Figure 9. Truss rod hose clamps/slings.

It is best to plant corn, sorghum, and other high-profile crops in circle rows, with the water sprayed underneath primary foliage. Growers have successfully used LESA irrigation in straight rows using a flat, coarse pad that sprays water horizontally. Heavier weights help keep the drops in position as they drag through high-profile crops. Truss rod sling clamps (Fig. 9) can be used to raise the drops when growing wheat and other densely planted crops.

LEPA

In the original LEPA prototypes developed in the 1980s, water was applied in every row using a drag sock/hose or an applicator that discharged water in a "bubble" pattern. Furrow diking was also used. Double-ended socks were developed to prevent these dikes from washing out during irrigation. To reduce the cost of converting existing pivots to LEPA, research was undertaken to evaluate the use of a drop in every other row. Results showed that in many situations, every-other-row irrigation was just as effective.

Figure 10 shows the original multi-functional LEPA "quad" applicator, which could deliver a bubble water pattern, spray mode (useful for germination), and chemigation mode for applying the water/chemical mixture to the underside of leaves. The quad applicator is now replaced with low-pressure applicators with interchangeable adapter pads to achieve the original LEPA modes, as well as LESA spray modes (Fig. 8). Socks help reduce furrow erosion when discharging water directly into the furrow (Fig. 11). If desired, drag-sock and hose adapters can be removed from applicators, and a spray or chemigation adaptor pad can be attached in their place.

Drops in every other row and planting in a circle result in alternate wet and dry furrows. Dry middles allow more rainfall to be stored. Applicators are arranged to maintain dry rows for the pivot wheels when the crop is planted in a circle, thereby reducing the potential

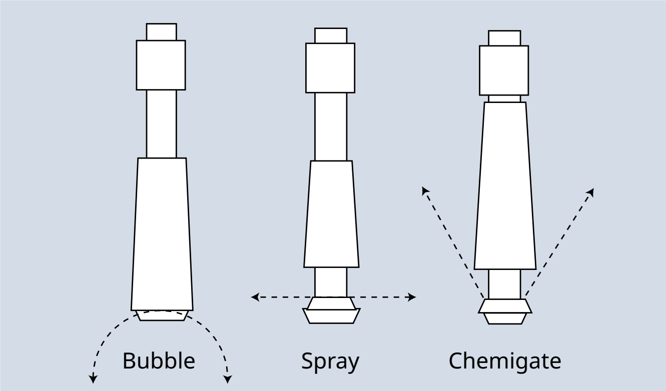


Figure 10. Original multi-functional LEPA head.

Figure 11. LEPA sock and furrow diking.

for rutting. Field tests show that with LEPA, 95 to 98 percent of the pumped irrigation water gets to the crop. Water application is precise and concentrated, requiring a higher degree of planning and management, especially in clay soils. 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 and is even more beneficial where water is limited.

Converting Existing Pivots to Close Drop Spacing

When ordering a new pivot, there are several options for water outlet spacing. However, some dealers default to a wide outlet spacing (8½ to 10 feet or *2.6 to 3 meters* apart) when ordering pivots. For pivots with wide outlet spacing, additional outlets are needed when converting to close drop spacing. For example, for row spacing of 30 inches (*76 centimeters*), drops are needed every 60 inches (*152 centimeters*). Likewise, for 36-inch (*91-centimeter*) row spacing, drops are placed every 72 inches (*182 centimeters*). Additional outlets can easily be added using truss rod hose slings and double goosenecks, as shown in Figures 9 and 12. Installation is quicker if a platform is placed underneath the pivot mainline. Planks placed across the truss rods or the sideboards of a flat-bed truck work but are not safe and may lead to accidents and injury. A tractor equipped with a front-end loader provides a more secure platform. A boom lift or a telehandler with a work basket are readily available and provide the safest platform.

Conversion Tips

First, use stakes or other items to mark the location for each drop on the ground. Begin by measuring from the center of the tower wheel. The first drop is positioned one row spacing over from the wheel. Switch out the existing gooseneck with a double gooseneck where needed. Attach the drop hose to the gooseneck and cut to the appropriate length. The plastic double gooseneck requires that the drop be slung over the truss rods. Attach the truss rod hose clamp to the drop hose before attaching to the truss rod. Some existing outlets can be used by switching out the existing gooseneck with a furrow arm.

When water is pumped into a center pivot, it fills the mainline and then drops. The weight of the water causes the pivot to lower or “squat.” With 160-foot (*48.8-meter*) spans, the pivot mainline will be lowered approximately 5 inches (*13 centimeters*) at the center of the span. Likewise, when filled with water, a 185-foot (*54.9-meter*) span will be about 7 inches (*18 centimeters*) lower at its center. Length of the hose drops should account for this change so that when the system is running, all applicators are about the same height above the ground. The new drops that are attached to the double goosenecks 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 circles, having drops on both sides of the mainline helps prevent all the water from being dumped into the same furrows as the system parallels crop rows.

Figure 12. Double barb gooseneck.

Components and Other Important Considerations

Flow Meter

All pivots should have a permanently installed, continuously functioning flow meter to measure the actual amount of irrigation water applied. A flow meter is needed to troubleshoot problems and for proper irrigation water management in conjunction with the design printout. Flow meters need to be located within a straight pipeline section that is sufficiently long. The straight pipe section needs to extend 10 pipe diameters upstream and 5 pipe diameters downstream from the flow meter. This is to reduce water turbulence in the pipe, which decreases the meter's accuracy. Due to water turbulence, small insertion meters located at the pivot point are problematic.

Pressure Gauges

Pressure gauges monitor pivot performance and, combined 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, and one at the pivot point. A third pressure gauge in the first drop of span one will monitor operating pressure when the machine is down slope in relation to the pivot point. The pressure gauge is positioned above the water applicator or regulator. Special pressure gauge drops (Fig. 13) are available to simplify gauge installation.

Figure 13. Pressure gauge drip.

To ensure the pivot is operating properly, check the pressure in the last drop when the pivot is at its up-slope position (or at the highest elevation in relation to the pivot point). If the field has downward sloping areas, check the pivot pressure in the first drop when the pivot is located at its down-slope position (lowest elevation in relation to the pivot point).

Outlet Spacing

On older equipment, conventional mainline outlets are spaced every 8½ to 10 feet (*2.6 to 3.0 meters*). When ordering a new pivot, specify close outlet spacing, 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 a pivot with closer mainline outlet spacing will ensure that in the future, it can be quickly and inexpensively equipped with new applicator designs.

Variable-rate Irrigation (VRI)

VRI, also referred to as "precision irrigation," has been successfully demonstrated in research settings over the past 30 years. In one early system, each drop was equipped with a solenoid valve, allowing each drop to be turned on and off as needed based upon soil conditions, as the pivot moved around the circle. Such systems may be particularly beneficial in fields with widely varying soil types and/or depths.

In the first commercial systems, groups of drops (often four drops) were connected to a common valve instead of a valve for each drop. The flow rate of each nozzle does not change, with the flow remaining either on or off. This reduces system costs and complexity. These systems are coupled to soil maps of the field so that water application rates are matched to varying soil types. Essentially, the irrigation prescription is set and then implemented in subsequent irrigations.

The control systems for VRI continue to evolve, simplifying operation and management. True variable-rate application systems are commercially available, in which the actual flow rate of each nozzle can be varied. Challenges to these systems are costs and complexity. It is possible to achieve good uniformity of water application with proper design. The allowable range in VRI flow rates depends upon characteristics of the pumping plant. Research is ongoing to develop real-time plant sensors for use with VRI to detect plant stress, and insect and disease pressure, among others.

Control Panels and Systems

Control panels and control systems continue to rapidly evolve. The major pivot manufacturers offer several control system options, ranging from simple panels that have limited functionality, such as turning on/off the pivot and speed settings, to complete automatic and remote control systems coupled to mobile device and computer apps, and cloud-based tools for advance management and visualization. Control panels are also able to link with crop models and real-time weather data for irrigation scheduling. Low-pressure shut-off sensors have become standard. Flow sensors shut off pivots if a leak or low-flow conditions are detected. Soil moisture sensors and evapotranspiration (ET) weather stations can be tied into the control system as well. Research

Return to Contents page

continues on the development of other in-field sensors for detecting water stress status, crop deficiencies, insects, among others. When these systems become available, they will require more sophisticated control systems.

Communication Technology

Regardless of which control system is selected, one important decision regards communications between in-field sensors, the control panel, mobile devices and remote computers, and the internet. Communication technology options include cell service, short-haul radios, other wireless technologies for short distances, microwave, satellite, and direct connect. Which technology is best depends on site-specific conditions and budgets. Some considerations are as follows:

1. Cell phone technology is widely used for remote communications. A cellular internet modem and a subscription are required for each individual device. Check with the equipment manufacturer for a modem that is compatible with area cell service. Modem size and power consumption are considerations for the use of in-field sensors.
2. Local Wi-Fi technology is evolving rapidly. Off-the-shelf Wi-Fi repeaters, extenders, and mesh systems enable Wi-Fi to cover larger areas. Short-haul radio is a term that is also applied to such systems, as Wi-Fi is, in essence, a radio communication technology. Radio components are referred to as antennas, receivers, and transmitters. Line-of-sight and distance limitations, and the number of units needed, may make Wi-Fi impractical as the primary communication method. In-field sensors with Wi-Fi connectivity have lower power requirements than modems. Combining a local Wi-Fi network with other communication technologies that can cover larger distances is feasible.
3. Direct connection is when a wire is run from the sensor to the control panel and/or from the control panel to the computer. Direct connection is an attractive option, as there is no cellular contract or other subscription required. It eliminates the need for transmitters and receivers, and it is very dependable. Devices do have maximum run lengths based on their power levels, so be sure to check the manufacturer's guidance. Potential rodent and plow damage should be evaluated with the use of buried lines.
4. Short- and long-haul radios that use public bands are relatively inexpensive, robust, have long line-of-sight distance capabilities, and require no subscription.

End Guns

End guns are not recommended due to their energy requirements to produce sufficient pressure for the gun to operate properly and their low water-application efficiency. Pressure to operate the gun is provided by increasing the design pressure of the pivot or by inclusion of a booster pump. The long-term costs of end gun operation should be evaluated carefully. End guns have poor water distribution efficiencies, and more water will be applied closer to the gun, decreasing as the water moves out to the end of the water trajectory.

Pivot Management

Pivot management is centered around knowing the volume of water (inches, *millimeters*) being applied by the machine. The system design printout includes a precipitation chart listing total inches applied for various control panel speed settings. If a precipitation chart (Fig. 4) is missing, contact the dealer who first sold the pivot to obtain a copy of the pivot printout. Dealers usually keep copies of design printouts indefinitely. However, most dealers have the software to reproduce the pivot printout as well. When a precipitation chart is not available, use Table 6 to determine irrigation amounts 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 equations listed 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.

Eq 1. Inches applied =

$$\frac{\text{Pivot gpm} \times \text{hours to complete circle}}{450 \times \text{acres in circle}}$$

Eq 2. Acres per hour =

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

Eq 3. End tower speed in feet per hour =

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

Eq 1. *Millimeters applied =*

$$\frac{\text{Pivot flow rate } (m^3/h) \times \text{hours to complete circle}}{10 \times \text{hectares in circle}}$$

Eq 2. *Hectares per hour =*

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

Eq 3. *End tower speed in meters per hour =*

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

Table 6. Inches of water applied by a 1,290-foot center pivot* on a 120-acre circle at 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
1,000	0.22	0.44	0.89	1.33	1.78	2.22
1,100	0.24	0.49	0.98	1.47	1.95	2.44
End tower speed (ft/hr)	667	334	167	111	83	67
Coverage (acres/hr)	10	5	2.5	1.7	1.3	1

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

Table 6 (metric). Millimeters of water applied by a 393-meter center pivot* with 100 percent water application efficiency.

Pivot Flow (m^3/h)	Hours to complete 49-hectare circle					
	12	24	48	72	96	120
91	2.29	4.57	9.14	13.5	18.0	22.6
114	2.79	5.59	11.2	17.0	22.6	28.2
136	3.30	6.86	13.5	20.3	26.9	33.8
159	4.06	7.87	15.7	23.6	31.5	39.4
182	4.57	9.14	18.0	27.2	36.1	45.2
204	5.08	10.2	20.3	30.5	40.6	50.8
227	5.59	11.2	22.6	33.8	45.2	56.4
250	6.10	12.4	24.9	37.3	49.5	62.0
End tower speed (m/h)	203.3	101.8	50.9	33.8	25.3	20.4
Coverage Hectares/hour	4	2	1	0.7	0.5	0.4

*389 meters from pivot to end tower + 4.5-meter end section

Runoff Management

Runoff from center pivot irrigation can often be controlled by setting the speed control so that the water application rate matches the soil infiltration rate. Agronomic methods of runoff control include furrow diking (or "chain" diking for pastures), farming in a circular pattern, deep chiseling of clay sub-soils, maintaining 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 may when it parallels straight rows. Circle farming begins by marking the circular path of the pivot wheels as the pivot makes a revolution without water. The tower tire tracks then become a guide for row layout 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. Rather than running off, rainfall or irrigation water is trapped and stored in the basins until it soaks into the soil (Fig. 11). Furrow diking reduces runoff and increases yields in both dry land and irrigated crops. A similar practice for permanent pastures, called chain diking, involves dragging a chain-like implement that leaves water-collecting depressions.

Controlling Wheel Rutting

Wheel tracks develop into ruts due the pivot traversing wet soil (Fig. 14). This is most common in heavy soils. Pivots are heavy machines, and each tower and the span it supports when full of water, can weigh up to four tons or more. Often, wet soil conditions are caused by the irrigation water itself, which can be easily controlled. However, it is important to investigate and understand the cause of wet soil conditions.

Figure 14. Wheel rut.

Surface runoff that concentrates water in low-lying areas may require land reforming. Pivots that transverse drainage or marshy areas may need special tires, multiple tires, or other traction devices, which will also require larger tower motors and stronger driveshafts. The best approach is to follow manufacturers' guidance for such situations.

New Pivot Design

When purchasing a new pivot, the design of the pivot can be adjusted in order to reduce the likelihood of ruts.

Begin by assembling a topographical and soil map of the field where the new pivot will be installed. Identify areas that may be prone to rutting, such as areas consisting of clays and other soils with high water-holding capacities and poor drainage, areas that will likely receive surface runoff, low areas where water tends to pond, etc. Working with a dealer using the pivot design software, it may be possible to select a span that will allow towers to avoid these areas.

Water Applicators

In situations where irrigation water is the primary cause of the wet soil conditions, the basic approach is to keep the applied water off the wheel tracks. Using LEPA bubble applicators and planting in a circle are effective methods of keeping the wheel tracks dry. With pivots equipped with spray applicators, the towers and wheels intercept some of the throw from the sprinklers, which runs down the towers into the wheel tracks (Fig. 15). Research has shown that up to three times the depth of water being applied in irrigation is applied to the wheel tracks through interception of water by the tower.

Figure 15. Wheels and pivot components catching and concentrating irrigation water at the towers/wheels.

To solve this problem, half-circle sprays and/or boom-backs are used. Half-sprays direct water away from the wheels, which is often effective at reducing rut problems. Boom-backs are usually used along with half-circle sprays and move the discharge point well behind the pivot. Boom-backs clamp onto the pivot mainline. There are several different designs for boom-backs. Figure 16 shows one type of boom-back that suspends and extends the flexible drop away from the mainline. Other designs include a combination flexible/galvanized pipe that functions similarly, and a U-shaped aluminum extension that holds and extends the flexible drop. New designs are expected in the coming years as boom-back use becomes more commonplace.

Figure 16. An example of a simple suspension boom-back design.

Tires

Pivot manufacturers now offer a variety of different types and sizes of tires. Little university-based research information is available on the effectiveness of different types of tires as related to rutting potential. The best approach is probably to follow the manufacturer's recommendations in absence of local experience. Be aware that retrofitting pivots with different tires may increase the stress on driveshafts and motors or require larger motors. For airless tires, a neutral tread design is recommended, in which the treads run horizontally and do not push the soil away from the tires.

It is important to ensure that the wheel toe alignment is adjusted correctly on each tower. Since the pivot travels in a circle, the wheels are not parallel to the driveshaft, but offset at a small angle, referred to as the toe alignment. The toe alignment angle is larger in the first few towers and decreases in outer towers. The first few spans are the most critical since they must turn the shortest circles. Improper toe alignment can result in the tires being dragged around the circle, worsening ruts.

Irrigation Scheduling

ET-based

Maximum crop production and quality are achieved when crops are irrigated regularly with amounts that match their water use or evapotranspiration (ET), such as twice weekly during the peak crop growth period. The TexasET Network (*http://TexasET.tamu.edu*) reports reference evapotranspiration (ETo) and has tools that allow the calculation of crop water requirements (ET) from ETo. One strategy is to sum the daily crop water use (ET) reported for the previous three to four days, then set the pivot speed setting to apply that amount of water. Another strategy is to apply water in larger volumes once per week to reduce evaporative losses and to better utilize any rainfall that occurs. This method has proven to be very successful in PARM systems.

Some center pivots, such as many on the Texas High Plains, are planned and designed for insufficient capacity (i.e., flow rates: gpm, m^3/h) to supply peak daily crop water requirements. Growers with insufficient center pivot capacity should use a high-water management strategy to ensure that the soil root zone is filled with water by rainfall, pre-watering, or early-season irrigation before daily crop water use exceeds irrigation capacity. The county soil survey available from the NRCS lists 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 recommended and complements ET-based scheduling, particularly when rainfall occurs during the irrigation season. Soil moisture sensors can identify existing soil moisture, monitor moisture changes, locate depth of water penetration, and indicate crop rooting depths. Watermark sensors are widely used by growers to manage pivot irrigations. These are classified as resistance sensors that absorb and release moisture, similarly to that of the surrounding soil.

Dielectric sensors are often used in situations where the soil moisture sensors are integrated into pivot control systems. The most common dielectric sensors used for this purpose are water content reflectometer and capacitance sensors. These cost more than resistance sensors but last longer, are more accurate, and are resistant to the effects of salts. Time domain reflectometer sensors are widely used in research applications but require more skill and expertise and are more expensive than the other options.

Watermark sensors are read using resistance meters. Readings may be taken weekly during the early growing season. During the crop's peak water-use period, readings should be taken two or three times each week for more timely irrigation water management. Plotting sensor readings with computer spreadsheets or on graph paper helps track and interpret readings to manage irrigations. An example is shown in Figure 17.

A single sensor installed at a depth of 12 to 18 inches (*30 to 45 centimeters*) measures moisture in the upper root zone. Another installed at 36 inches (*90 centimeters*) measures deep moisture. Sensors usually are installed at three depths: 12, 24, and 36 inches (*30, 60, and 90 centimeters*), and at a representative location in the field where soil is uniform. They should not be placed on extreme slopes or in low areas where water may pond. Select a location within the next-to-the-last center pivot span but away from the wheel tracks. Locate sensors within the crop row so they do not interfere with tractor equipment. Follow the manufacturer's guidelines on preparing sensors. To obtain accurate readings, the sensing tip must make good and complete soil contact.

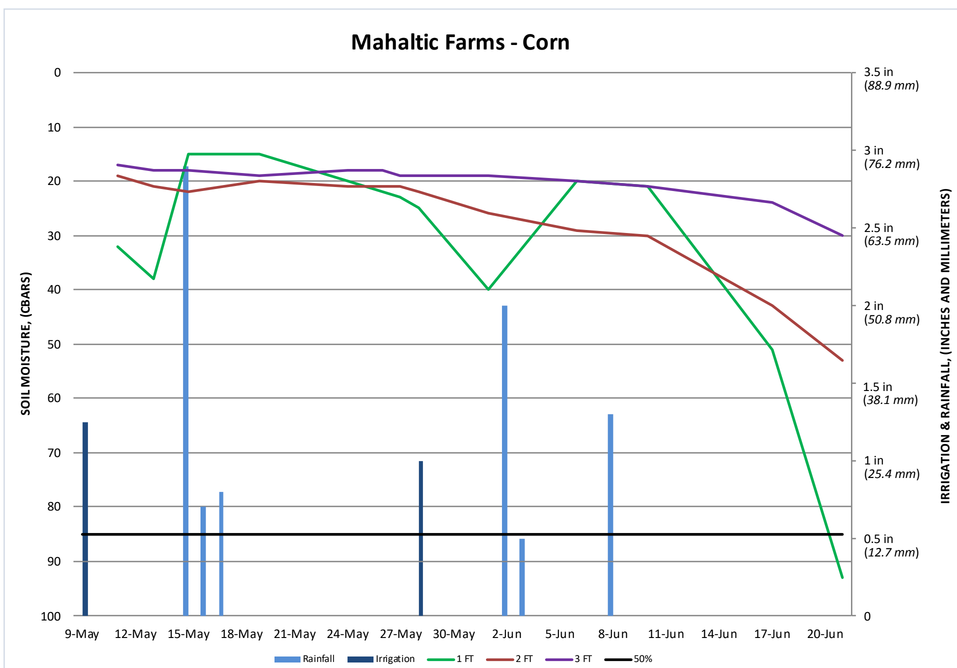


Figure 17. Soil moisture measurements in a corn field on a heavy clay soil, with sensors located at 1, 2, and 3 feet (*30, 60, and 90 cm*). Soil moisture levels should not fall below a reading of 85 for this particular soil.

The soil auger used to install sensors should be no more than ⅛ inch (*3 millimeters*) larger than the sensor. How-to preparation and installation videos are available at *http://irrigation.tamu.edu*.

Chemigation

Chemigation uses irrigation water to apply an approved chemical (fertilizer, herbicide, insecticide, fungicide, or nematicide) through the center pivot. Labels of pesticides must state whether a product is approved for application in this way. If so, application instructions are provided on the label.

The advantages of chemigation include:

- **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 in correct concentrations where they are needed.
- **Economics.** Chemigation is usually less expensive than other application methods and often requires smaller amounts of chemicals.
- **Reduced soil compaction and crop damage.** Because conventional in-field spray equipment may not be needed, chemigation may reduce tractor-wheel soil compaction and crop damage.
- **Operator safety.** Because an operator need not be continuously present in a field during applications, chemigation reduces human contact with chemical drift and reduces exposure during frequent tank fillings and other tasks.

Chemigation does have disadvantages, however, including:

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

Pesticides

The use of pesticides and herbicides is highly regulated by the United States Environmental Protection Agency (EPA), who has enacted the minimum regulations that all states must adopt and enforce. However, states may enact more stringent regulations than those required by the EPA. In Texas, pesticide use in irrigation systems is regulated by the Texas Department of Agriculture (TDA) and the Texas Commission on Environmental Quality (TCEQ). A Texas Pesticide Applicators License is required. Pesticide labels must state if the chemical is allowed to be injected through an irrigation system. If so, the label specifies requirements for the use of the chemical, including mixing and application rates. The label also states which types of irrigation systems can use the chemical. Regulations require the use of specific safety equipment and devices designed to prevent accidental spills and contamination of water supplies (Table 7), which also are listed on the chemical's label.

Table 7. Summary of Chemigation Safety Equipment Requirements for Pesticides and Herbicides. Check the chemical label for specifics on equipment requirements for that substance. Alternative safety equipment is allowed. Contact your county Extension office for details.

Components must include:
1. Irrigation Pipeline a. Check valve between well and injection points. b. Vacuum relief valve between check valve and well. c. Low pressure cut-off. d. Low pressure drain.
2. Injection Hose a. Anti-back flow injection valve—10 psi (*0.69 bar*). b. Normally closed solenoid valve between injection pump and chemical tank. c. A metering type of injection pump.
3. Power Interlock a. Interlock injection pump and water pump power. b. Interlock normally-closed solenoid valve and injection pump power.

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. For more information, contact your county Extension office.

Fertigation

Application of fertilizers through the irrigation system (fertigation) often is referred to as “spoon-feeding” the crop. Fertigation is common and has many benefits. Most fertigation uses soluble or liquid formulations of nitrogen, phosphorus, potassium, magnesium, calcium, sulfur, and boron.

Fertigation is not regulated by the EPA or TDA. The TCEQ does have rules designed to protect water supplies from pollution, and in some instances, the user is liable for any groundwater or surface water pollution that may result.

These regulations require that an appropriate backflow prevention device is used. More strict requirements exist for systems connected to a public water supply.

Nitrogen is the most common fertilizer used in chemigation because crops need large amounts of it. Keep in mind that nitrogen is highly water soluble and has the potential to leach, so its application must be managed carefully. Table 8 lists several different nitrogen formulations that are often used for fertigation. Be sure solid formulations are dissolved completely in water before injecting them into the irrigation system. Complete mixing may require initially agitating the mixture for several hours and then throughout the injection process.

The advantages of fertigation include:

- Nutrients can be applied based on crop needs at any time during the growing season.
- Mobile nutrients such as nitrogen can be regulated with the amount of water applied so that they are available for rapid use by crops.
- If the irrigation system distributes water uniformly, nutrients can be applied uniformly over the field.
- Some tillage operations may be eliminated, especially if fertilization coincides with the application of herbicides or insecticides. However, do not simultaneously inject two chemicals without knowing whether 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 periods of maximum crop need.
- There is minimal crop damage during fertilizer application.

Fertigation does have some disadvantages. These include:

- Injectors must be calibrated.
- Injectors must be sized appropriately for the large volume of fertilizer solution typically used (pesticide injectors cannot be used).
- Fertilizer distribution is only as uniform as irrigation water distribution. Use pressure gauges to ensure that the center pivot maintains proper pressures.
- Lower-cost fertilizer materials, such as anhydrous ammonia, often cannot be applied using fertigation.
- 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 during the application process. Also, ammonia solutions may precipitate lime and magnesium salts, which are common in irrigation water. Resulting precipitates can build up on the inside of irrigation pipelines and clog nozzles.
- Various polyphosphates (e.g., 10-34-0) and iron carriers can react with soluble calcium, magnesium, and sulfate salts to form precipitates. The quality of irrigation water should be evaluated before using fertilizers that may create precipitates.
- Many fertilizer solutions are corrosive.

Know the materials contained in all pump, mixing, and injector components in direct contact with concentrated fertilizer solutions. Table 9 describes the corrosion potential of various metals when they come into direct contact with common commercial fertilizer solutions.

Table 8. Amount of fertilizers needed to apply specific amounts of nitrogen (N).

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 sulfate (21% 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

Table 8 (metric). Amount of fertilizers needed to apply specific amounts of nitrogen (N).

Kind of fertilizer	Kilograms of N per hectare				
	22.4	44.8	67.3	89.7	112.1
	Kilograms per hectare of fertilizer needed for rate of N listed above				
Solid					
Ammonium nitrate (21% nitrogen)	110	220	330	439	547
Urea (45% nitrogen)	49	100	149	198	249
	Liters per hectare of fertilizer needed for rate of N listed above				
Solutions					
Urea-ammonium nitrate (28% nitrogen)	62.6	125.3	187	250.6	312.4
Urea-ammonium nitrate (32% nitrogen)	53.3	106.6	159	213.2	266.6

Table 9. Relative corrosion of various metals after 4 days of immersion in solutions of commercial fertilizers.*

Fertilizer	pH of solution	Type 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
Diammonium phosphate	8.0	Slight	Moderate	None	Severe	Severe
Complete fertilizer 17-17-10	7.3	Moderate	Slight	None	Severe	Severe

*Solutions of 100 pounds (*45 kilograms*) of material in 100 gallons (*379 liters*) of water.

Center Pivot Buyer's Checklist

Pivot Design

______ Actual lowest and highest field elevations in relation to the pivot point were used in the computer design printout.

______ Actual measured flow rate and pressure available from pump or water source were used in the computer design printout.

______ Friction loss in pivot mainline is no greater than 10 psi (*0.69 bar*) for quarter-mile (*396-meter*) long systems.

______ Mainline outlets are spaced a maximum of 60 to 80 inches (*1.5 to 2.0 meters*) apart or, alternately, no farther apart than two times the crop row spacing.

______ For non-leveled fields, less than 20 percent pressure variation in system-design operating pressure is maintained when the 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 (*1.5 meters*) of elevation change from pad to the highest or the lowest points in the field.

______ Tower wheels and motor sizes were selected based on soil type and slope, following manufacturers' recommendations.

______ Dealer has provided a copy of the pivot design printout.

Applicators

______ Design has no end gun.

______ Consideration was given to equipping the pivot with either LEPA or LESA applicators as follows:

- Water application designed for an operating pressure requirement of 6 psi (*0.4 bar*), positioned 1 to 1.5 feet (*30 to 46 centimeters*) above the ground, spaced at two times the crop row spacing. Flexible drop hose from gooseneck or furrow arm on mainline to applicator, equipped with a plastic or metal weight. The applicator can accommodate adaptor pads to allow for bubble and spray water modes and attachment of drag hose or double-ended sock.

Installation and Water and Power Supply

______ Pivot pad has been constructed to manufacturer's specifications.

______ Subsurface water-supply pipeline to pivot point is sized to keep water velocity at or below 5 feet per second (*1.5 meters/second*).

______ Power supply has been connected to pivot following manufacturer's specifications. Power supply may be a power unit alone, a power unit and generator, or subsurface power lines.

Accessories

______ System includes propeller flow meter or other type of flow measurement device, having accuracy to +3 percent and instantaneous flow rate (i.e., gpm, m^3/h) and totalizer (acre-ft, ft^3, m^3, etc.) indicators installed in the water-supply pipeline near pivot point. The flow meter should be placed in a straight section of the pipeline extending at least 10 pipe diameters upstream and 5 pipe diameters downstream from the location of the meter.

______ System includes two pressure gauges, one on the mainline near the pivot point and one in the last drop, located just above the applicator or pressure regulator.

______ System includes a computer control panel for fields with soil changes and/or multi-crop situations.

______ System has a remote control/monitoring system (optional).

______ System includes a chemigation unit meeting state regulations, which is tied into the computer control panel or power shut-off system with a positive displacement injector pump (for pesticides and herbicides) sized for the pivot flow rate and injection volumes.