Selection and Management of Efficient Center-Pivot and Linear Move Irrigation Systems

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Published by: North Carolina Cooperative Extension Service

Publication Number: EBAE-91-151

Last Electronic Revision: June 1996 (KNS)

INTRODUCTION

Rainfall is the principle source of water for North Carolina crops. However, many farmers are turning to irrigation to supplement precipitation. There are many types of irrigation systems. But, most farmers have limited choices for their particular farm or field. Some systems are inherently more water and energy efficient while others are designed to overcome limitations such as
irregular field shapes, sloping land, or limited water supplies. All of these factors should be considered before selecting a particular type of system.

The center pivot and linear-move type irrigation systems are usually the most practical system for irrigating large, rectangular or regular shaped fields. Selection and management considerations for center pivot and linear-move type systems are discussed in this article. Selection and management criteria for other types of irrigation systems are presented in articles EBAE 91-150: Self-Propelled Gun Traveler type systems; EBAE 91-152: Solid set and permanent systems; and EBAE 91-153: Low Volume (drip and trickle) systems.

The first crude but functional center pivot irrigation machine was assembled in 1949 by a tenant wheat farmer in Colorado. Commercial production of center pivots began in 1953. Since that time, the center pivot machine has had more impact on sprinkler irrigation than any other single invention in recent history. They are used to irrigate at least 20 percent of the total irrigated acreage in the United States. They are also used in several other countries.

CENTER-PIVOT

The center pivot is a self-propelled continuous move machine that rotates around a central pivot point. The propulsion system may be oil hydraulic, water hydraulic, or electric. The trend is toward electric drive machines, either 240 or 480 volt, three phase, with most being 480 volt. Electric motors of 0.5 to 1.5 horsepower are mounted on each tower with a drive shaft from the motor to a gear box on each wheel.

The lateral line on which the sprinklers or spray nozzles are located are 5- to 10-inch outside diameter (OD) galvanized steel pipe, painted steel pipe or aluminum pipe. The lateral line is supported by "A" frames spaced 90 to 200 feet apart. Guide wires or trusses help support the pipe at 8 to 16 feet above the ground. The taller machines are used for orchard irrigation. Rubber tires, metal wheels, tracks or skids are mounted under each "A" frame to move the machine. Most machines use rubber tire. with high flotatation tires used as needed.

Some center pivots are designed to permit transfer from one pivot point to another. On these "towable" machines, the wheels at each tower can be rotated 90 degrees to allow the machines to be towed from one or both ends. The towable units generally have somewhat stronger construction with the towers closer together.

Center pivots are available in sizes from one tower, that irrigates seven to thirteen acres in one circle, to multiple tower machines capable of irrigating over 500 acres. The single tower machines are towable and designed to be used on multiple pivot points. Multiple tower machines may also be towable, but there is a practical limit of approximately 150 acres for a towable machine.

Center pivot systems were originally designed to operate on square, quarter section (160-acre) fields. As growers in the southeastern United States began to purchase machines, and with the introduction of electric drive machines, center pivots are now being used on many field shapes. Figure 1 shows a schematic of a center pivot designed to irrigate a square quarter section of land. With the overhand from the end gun approximately 132 acres can be irrigated.
Corner attachments, while not used on a large number of machines, allow the corners of square fields and odd-shaped areas of irregularly shaped fields to be irrigated. The corner attachment is an additional tower that is operated only as needed. It swings out from the end of the lateral line to irrigate the corners or other odd shaped areas. Operation of the corner attachment is controlled by a signal sent through a buried electric cable. Figure 2 shows a schematic of a corner attachment center pivot machine.

Figure 1 - Schematic of center pivot with end gun on a square quarter section of land. The end gun covers part of the corners.

Figure 2. - Schematic of a center pivot with a corner attachment with an end gun. The corner attachment is only activated in the corners and irregular shapes in the field where there is adequate width for it to operate. In this field, it would be in operation for most of the field. It
would not operate on the right side of the field. The eighth tower shown is the corner attachment.

Pivots are available as low, medium and high pressure units. This refers to the sprinkler or spray nozzle operating pressure. The early pivots were high pressure units with typical sprinkler pressures of 70 to 90 psi. Later, smaller rotary impact sprinklers were used and pressures were reduced to 40 to 60 psi, with a booster pump for the end gun. Recently, low pressure spray nozzles have been introduced which can operate at pressures as low as 10 to 15 psi. The major disadvantage of the low pressure spray nozzles is a very high instantaneous water application rate. The instantaneous application rate is the rate of water application measured in inches per hour to a finite area of land as the machine moves across that area. High application rates often cause runoff from most soil types (except extremely sandy soils). Most soils have an intake rate less than 0.50 inch per hour. The instantaneous application rate can be high or 4 to 5 inches per hour. As a compromise between spray nozzle and conventional rotary impact sprinklers, some growers are now using low pressure rotary impact sprinklers that operate in the range of 30 psi.

Figure 3. Schematic of sprinkler packages available for center pivots, areas of coverage and sprinkler pressure.
Figure 3 shows the four different nozzle combinations that can be used for a center pivot. The top two are spray nozzles. Note that the area being covered at one time is small. With the low pressure impact, the same amount of water is being applied, but the area of coverage is 1.75 to 2.00 times as large. With the variable spacing impact sprinklers, the same amount of water is also being applied but the area covered is again increased. As one moves from the lowest pressure spray nozzles to the variable sprinkler spacing the instantaneous application rate is reduced by a factor of 3. Pressure to operate the system is increased, but on low intake rate soils, the higher pressure sprinklers are often required.

The speed of rotation (time it takes to complete one revolution of the circle) of the system will depend upon the system size (length), pump capacity and the amount of water to be applied at each application. The time required to complete one revolution increases as the length of the system increases. (i.e., a large system will require longer to make a complete revolution than will a small system.) A limited pump capacity or water supply can also increase the time to complete one revolution.

Pivots are best adapted to flat terrain, but units are being used satisfactorily on slopes up to 15 percent. Sloping terrain may require towers to be located closer together so that the lateral line can more closely follow the topography.

Designing a center pivot for a particular field is somewhat routine since system length is normally determined by the radius of the field. Initial sizing is done from an aerial photograph. Then a ground survey is conducted to determine the exact pivot point location and to identify obstacles that need to be removed or bridged so that they will be cleared by the machine. Next, the water source capacity is determined. With this information, plus soil infiltration capacity, and peak daily evapotranspiration (ET) (daily water use rate of the crop), the system manufacturer uses a computer program to determine the lateral line size, sprinkler spacing and capacity, pump capacity and horsepower required.

In North Carolina, the water supply for most pivots is a surface water supply such as a stream or pond. Where high capacity wells are available, water can be pumped directly from the well. Water is pumped from the supply to the pivot point through a buried supply line, normally polyvinyl chloride (PVC) plastic pipe. The pipe should have adequate diameter so that the velocity of flow does not exceed five (5) feet per second (fps). This will keep friction loss within acceptable limits and reduce the potential for pipe failure due to water hammer.

Lateral line on most pivots will consist of several sizes of pipe, depending on system capacity. Pressure loss in the lateral pipe due to friction should not exceed 20 percent of nominal sprinkler operating pressure. However, on a system equipped with pressure regulators or flow regulators at each sprinkler, it may be possible to have greater friction lose and still have uniform sprinkler discharge.

Power units for pumps to supply water to pivots can be electric or internal combustion. For the electric drive pivots, three phase power is needed to operate the motors at each tower. This can be supplied by a three-phase power line, a generator powered by an internal combustion engine, or a phase convertor to convert single-phase to three-phase power.
Safety controls on the pivot include proper wiring and grounding, especially of electric-drive units, and micro-switches at each tower to keep towers properly aligned. Speed of rotation of the machine is controlled from the main control panel. For most machines this involves controlling the speed of the outside tower, i.e., does the electric motor on that tower operate continuously or is there stop and go operation? The micro-switches at each of the other towers then control the amount of run time for the motors on each tower so that the lateral line remains properly aligned. Improper alignment usually results in automatic system shut-down to prevent system damage.

**LINEAR MOVE SYSTEMS**

The linear move machine can best be described as an adaptation of the center pivot. But instead of moving in a circle, the linear system moves in a straight line through the field, generally at right angles to the row direction. The hardware is very similar to the center pivot, but instead of a pivot point that is anchored while the machine rotates around it, there is a "boss" tower that moves with the remainder of the machine. Linear move machines use spray nozzles or low pressure impact sprinklers. An end gun may also be included at either end(s) of the lateral except where the boss tower occupies one end of the lateral.

The linear move machine is designed to be used on a rectangular field. An ideal field layout allows a travel distance which is two to three times the length of the machine. Shorter travel distances will increase the cost of ownership of the machine and will make it economically feasible only for high cash value crops. Longer travel distances can be used where two crops with different critical moisture periods (maximum ET rates occur at different times) are grown. One crop is irrigated before the other crop needs irrigation.

Since these machines use low to medium pressure, they are best suited to fields with minimal elevation differences. The low pressure machines use spray nozzles and therefore have a high instantaneous application rate and are best suited to high infiltration rate soils. The medium pressure machines use low pressure impact sprinklers, have a lower instantaneous application rate, and can be used on soils that have a moderate infiltration rate.

The linear move machine can have water supplied at any convenient place along the length of the lateral line. Of the machines currently on the market, some follow a canal and lift water directly from the canal. Others are supplied with water through a buried main line with hydrants using a 400 to 600-foot section of high pressure, flexible, rubber coated, synthetic textile hose from mainline hydrants to the boss tower of the machine.

The canal-fed machine is easier to operate and requires less labor. Figure 4 is a schematic of an end fed linear move taking water from a canal. The slope on the canal should not exceed one percent. Even with this slope, water control structures are needed to insure adequate depth of water in the canal. At each water control structure, it is necessary to manually lift the suction hose across the structure. A large self cleaning screen is needed on the suction hose to prevent clogging of spray nozzles or sprinklers. Figure 5 is a schematic of a linear move machine using a buried main line and hose. Moving a hose each time the machine moves 700 to 1100 feet is time consuming, requires a tractor, and generally takes two workers.
Pipe size on linear-move systems is 6- to 8-inch diameter depending upon the system capacity and lateral length. Tower spacing will vary from 100 to 185 feet. On a particular system, more than one tower spacing is sometimes used. The overhang beyond the last tower can also have a variable length depending upon the system. A center-feed system will use smaller diameter lateral pipe than will an end-feed system of the same gallon per minute capacity and length due to the lower friction loss since water is being distributed in two directions. Pipe is galvanized or painted steel. Figure 6 is a schematic of a center-fed machine taking water from a canal.
For the canal (ditch) feed system, lined or unlined canals may be used. The concrete lined canal develops fewer water quality problems and minimizes canal seepage losses and is usually recommended. A 1:1 side slope is used for most canals. The minimum bottom width should be 12 inches for a concrete lined canal inches and 30 inches for an unlined canal. Minimum water depth should be 20 inches and canal depth should be a minimum of 30 inches. A eloping canal requires a moveable dike or water control device to maintain the proper level of water in the canal.

The drive mechanism of the linear-move system is an electric motor at each tower. Located at the canal or boss tower will be the pump and power unit, plus a generator to provide power for the electric motors. Water pressure was used to power few early models, but electric power is most common today. The advantage of electric drive is that the machine can be moved across the field without applying water.

The design of linear-move systems is completed by the manufacturer or dealer using a computer size lateral line pipe and selected sprinkler capacities. Pipe should be sized to minimize friction loss. Since the system is low operating pressure, excessive friction loss will affect uniformity of application and cause excessive fuel costs.

The lateral system will have limited application in much of the Southeast because of small field sizes. But in the Coastal Plains where natural slope is flat. Many fields are 1000 feet or more in width and up to one mile in length, the lateral system will be comparable in cost per acre to the center-pivot system. It may be applicable on small fields where high value specialty crops are grown.

CONSERVATION STRATEGIES

When properly designed and managed, the center pivot and linear move machines are the most energy efficient type of sprinkler irrigation system. But mentioned earlier, the low-pressure center pivot and linear move machines with spray nozzles have a high instantaneous application rate which can cause runoff and erosion problems on sloping topography. To reduce this potential problem, spray booms can be mounted perpendicular to the lateral line allowing smaller spray nozzles to be mounted fore and aft of the lateral line. This reduces the instantaneous application rate, however, this
adds to the initial cost of the system thus far, growers in the southeastern United States have been reluctant to invest in this more expensive equipment. Instead, some dealers and users use low-pressure impact sprinklers, which operate 15 to 30 psi higher than the low pressure spray nozzles.

**LEPA SYSTEM**

Another adaptation that has worked in Texas is the LEPA (Low Energy Precision Application) system where drop nozzles extend to within about 12 inches from the soil surface. The special LEPA sprinkler head can be operated in one of three modes: the bubble mode for irrigation, the horizontal spray mode for germination, and the chemigation (upward spray) mode for chemigation. Normally nozzles are located in every other row, which is closer than that used for spray nozzles and considerably closer than that used for low-pressure rotary impact sprinklers. Pressure used at the nozzles is approximately six (6) psi. A pressure regulator is included as a part of the nozzle to adjust nozzle operating pressure for elevation differences or pipe losses along the lateral. The inlet pressure to the pressure regulator should be nine (9) to ten (10) psi.

Advantages of the LEPA system are lower pressure, higher irrigation application efficiency because of less wind drift, high uniformity, and reduced wetting of the foliage. Disadvantages include: higher material and installation costs, wetter soil conditions and runoff that may occur without proper management, the frequent need for pressure regulators and more intensive maintenance to repair and replace worn nozzles. Furrow diking, which is the mechanical placement of small dikes down each furrow, is usually recommended. For center pivots, it is recommended that the field be planted in a circle.

The LEPA system can also be used with a double-ended sock, which drags in the furrow. Water is discharged through the sock. However, this system is used only for irrigation, not for germination and chemigation. Existing center-pivot and linear-move machines can be converted to the LEPA system and new machines are available that are equipped with the LEPA system.

**ENERGY USE COMPARISONS**

Center pivot and linear move machines are reasonably energy efficient since they are medium to low pressure. Table 1 compares hourly systems operating cost for four different pressure center pivots, three different pressure linear move, a cable tow traveler and a hose drag traveler. Field size is 128 acres. For the center pivot and travelers, it is a square field, 236 feet on a side. Approximately 106 acres is irrigated with the center pivot. System layout for the four types of machines is shown in Figures 7-10. The systems are designed to apply two inches of total irrigation in 6 days. The center pivot and linear move operates 24 hours per day. The cable tow and hose drag operate 18 hours per day. The linear move is an end fed machine taking water from a canal.
Figure 7.- Schematic of layout for a center pivot on a square 128-acre field.

Figure 8.- Schematic for layout of a linear move system for 128-acre field.
Figure 9 - Layout for a hose drag traveler for 128-acre square field. Two machines of 536 gpm capacity each will need to be operated to irrigate this field.

Not only is the center pivot and linear move considerably less expensive to operate, but it also requires less labor. Most of the units that have been sold in North Carolina are well designed with adequate size main line, lateral line, and a high efficiency pump and engine. Main line pipe size is generally sized so that velocity does not exceed 5 to 6 feet per second (fps). Some units do apply water too fast and this can contribute to runoff and erosion. However, this is the exception rather than the rule.

Figure 10 - Layout for a cable tow traveler for a 128-acre square field. Two machines of 536 gpm capacity each will be needed to irrigate this field.

SUMMARY

On large fields, the center pivot and linear move machine offers the grower a system that is efficient in energy and water usage. It also requires the least amount of labor of any of the sprinkler systems. Unfortunately, many fields in North Carolina are not large enough to efficiently accommodate center pivots and linear-move systems. Some irregularly shaped fields are also not well suited for center pivot or linear move system. When selecting a system, it is very important to match field conditions to the attributes of the system. For additional assistance and information, contact your County Extension office or Soil Conservation Service office. Their staffs are familiar with the different types of systems and can help you select the best system for your specific field conditions.

Table 1 - Fuel Consumption Comparison of Center Pivot, Linear Move, Cable Tow Traveler and Hose Drag Traveler

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<th>System Type</th>
<th>Sprinkler Pressure</th>
<th>Pump Pressure</th>
<th>Hourly* Operating Cost</th>
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<td></td>
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<td>1.61</td>
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<td>----------------</td>
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<td>Linear Move</td>
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<th>140</th>
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<tr>
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<tr>
<td>Hose Drag Traveler</td>
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*Based on a 70 percent pump efficiency, 75 percent diesel engine efficiency and $1.00 per gallon fuel cost.

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EBAE-91-151

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