Rainmakers Gallery
A Groundwater Foundation Publication

Engineered Circles of Rainfall

By David Howe

The concept seems simple enough: Bring water to crops through a pipeline traveling in a circle about a fixed point in the center of the field.

The first such effort dates back at least to 1878, when French engineer John Winebrenner patented a water-carrying pipeline pulled by horses that did just that.

Hal D. Werner, professor and extension irrigation specialist at South Dakota State University, Brookings, S. Dak., reported that early effort in a paper he delivered on center pivot irrigation at the November 2000 National Irrigation Symposium in Phoenix, Ariz. Through this circular approach, the pipeline would complete a sweep around the field like a giant clock hand on a clock face of corresponding size, delivering water to the crop as it revolved around the field.

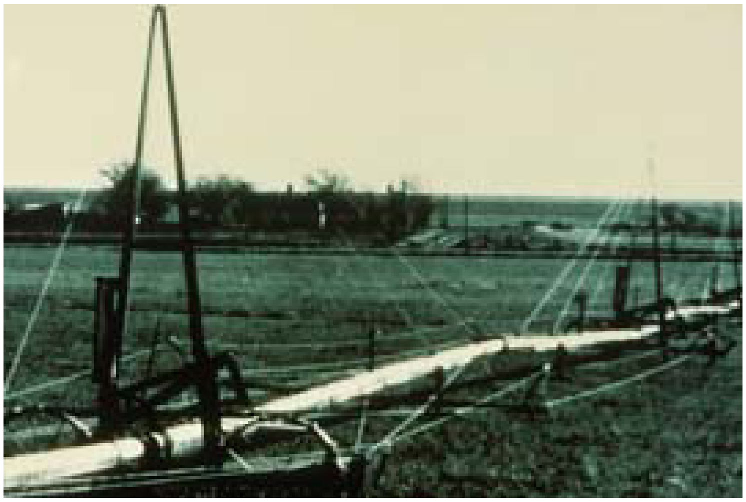
Feature article from "Rainmakers: A Photographic Story of Center Pivots"

That idea lay dormant until the early part of the 20th century, when a couple of other circular irrigation machines were patented, Prof. Werner reported in his paper titled, "Center Pivots: Transforming Irrigation in the Great Plains." But those, too, became little more than faint flickers in the annals of irrigation history.

Then, in the mid 20th century, the concept emerged again through the vision and genius of Strausburg, Colo., tenant farmer Frank Zybach. He designed and assembled a "self-propelled sprinkling irrigation apparatus" that bridged the gulf between a novel concept and a practical alternative to the backbreaking toil of shovels, ditches, and hand-moved pipe to direct water to parched crops.

Zybach's machine consisted of a pipeline, with sprinkler heads along its length, suspended by cables from towers riding on steel wheels. Hydraulic cylinders operating off water pressure in the pipeline pulled steel bars that caught lugs on the towers' steel wheels to propel the machine around the field.

A key part of Zybach's machine was a method of keeping the towers aligned as they wheeled around the pivot point in the center of the field. If, for example, one of the towers began to lag behind the rest because of wheel slippage, the flexing at that tower was sensed by



a mechanical linkage connected to controls that caused the tower to speed up and stay in alignment.

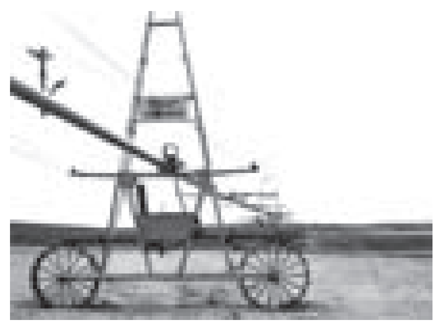
The July 22, 1952, patent awarded to Zybach for his invention marked the birth of a revolution in irrigation technology that has come to be called, simply: "the center pivot." In little more than half a century since, ever-improving center pivot technologies have driven adoption of this irrigation method throughout the world. For the first time, irrigators could water crops with a fraction of the labor required by traditional irrigation methods. And they could do it with closer control of when and how much water they applied than was possible with gravity systems. This capability made it possible for a properly managed center pivot system to meet a crop's water needs with less irrigation water than is possible with gravity irrigation.

Today's technological descendants of Zybach's concept carry water to all kinds of crops—from wheat to orchards—on a wide range of soil types and topography, some non-irrigable by other methods. At the same time, center pivots have been harnessed to other tasks such as application of fertilizers and pesticides in closely controlled amounts.

But that's getting a bit ahead of the story. The trail of the center pivot's early development can be picked up in a September 1985 Irrigation Association Educational Foundation publication titled, "The Economic Impact of Irrigated Agriculture." University of Nebraska-Lincoln agricultural economist Dr. Leslie Sheffield, who authored that publication, chronicled what happened a year after Zybach received his patent: Zybach teamed up with Columbus, Nebr., auto dealer A. E. Trowbridge in a partnership under which Trowbridge financed manufacturing of the machines at Columbus for 49% of the patent rights. The two men started building center pivots in 1953. But a year later they decided to sell their manufacturing rights to Robert Daugherty, president of Valley Manufacturing Company, a small, short-line machinery manufacturer that began making and selling the machines under the Valley name.

The center pivot era was now underway, albeit slowly. Farmers didn't immediately recognize the center pivot as a practical labor-saving alternative to traditional gravity irrigation systems. Nor was the center pivot immediately recognized for its ability to operate on hilly land where gravity irrigation is impractical, or on sandy soils that quickly "swallow" water before it flows to the far ends of the rows under gravity irrigation.

Further, center pivot irrigation was not immediately seized upon as a low-labor alternative to other sprinkler irrigation methods, such as hand-moved sprinkler systems that require lugging heavy sprinkler pipe sections from



one location to another in the field, a few acres at a time. Valley Manufacturing Company, today known as Valmont Industries, began almost immediately to make beneficial design changes in Zybach's prototype machine after purchasing manufacturing rights to it.

As the original patent neared expiration in 1969, other manufacturers were getting into the business. And, by the late 1960s, popularity of center pivot systems was beginning to soar as farmers' skepticism of them was quickly dissolving.

Dr. Sheffield describes the forces behind this change of heart in his 1985 publication: "As more and more people left farms and moved to the towns and cities during the 1950s and 1960s, labor on the farm became more scarce and higher-priced." More importantly, some far-sighted and innovative farmers and landowners "recognized the potential for center-pivot irrigation on land with sandy soils and undulating terrain, which could not be irrigated by gravity-type irrigation," Dr. Sheffield wrote.

However, some investors' confidence in what center pivots could do exceeded the machines' capabilities. Certain classes of hilly terrain and sandy soils defied even the center pivot, leading to bitter disappointment for those investors and the regrettable environmental damage caused by the technology's misapplication.

One example is an area of the Nebraska Sandhills classified as "Choppy Sandhills," an apt description of terrain with many small, steep hills or knobs. "Knob-knocking" to smooth the way for the center pivot left "open wounds" in the fragile sandy soil that began to blow. Not only was crop establishment in these areas difficult or impossible, wind-driven sand from these areas drifted over the emerging crop on adjacent portions of the topped-off knobs.

Tax incentives at the time probably led to irrigation development for corn production in some Sandhills areas that might not otherwise have been converted from rangeland, says Jerry Kovarik, a United States Department of Agriculture (USDA) soil conservationist located at O'Neill, Nebr. That's in a region of the Sandhills where some of the land and center pivots didn't come together with a gratifying outcome in the 1970s and early 1980s.

Prices this land commanded as rangeland were low relative to what cropland sold for elsewhere. Even when the cost of the irrigation well, pumping plant and center pivot was added in, the cost per irrigated acre was attractive in comparison with productive cropland already under irrigation elsewhere.

Center-pivot development often didn't fare well under other circumstances in the Nebraska Sandhills. That was where naturally occurring sub-irrigated meadows exist, says Kovarik, in USDA's Natural Resources and Conservation Service unit. Sub-irrigated meadows during dry periods might beckon seductively to irrigation development for those not familiar with the region and its soils. But wetter years or even the irrigation introduced to these parcels could raise the water table above the soil surface, submerging crops.

Besides the potential problems of pivot towers traversing these wet areas, crops could not survive where native meadow grasses adapted to the rise and fall of the high water table had thrived. "You could have a sandy knob and then, over the next knob, it's sub-irrigated, and you're drowning out the crop," Kovarik says.

With vegetative cover gone, the sandy soil was prone to be wind-blown when the high water table receded below the soil surface during dry periods. And

when it was up, pivots became stuck in these wet areas.

However, in contrast to such unhappy experiences, the center pivot's adaptability has made it a boon to farmers and ranchers under a variety of conditions, including many parts of the Nebraska Sandhills.

Once the center-pivot's labor-saving was recognized, the technology's adoption was off and running. "One man can handle eight of these self-propelled sprinklers," noted O'Neill, Nebr., center-pivot irrigator Dan Putman in a March, 2, 1968, Nebraska Farmer Magazine story about center-pivot irrigation on rolling terrain with sandy soils in north central Nebraska.

Sheffield wrote in his treatise that the center pivot eliminated 90% of the labor required by traditional gravity irrigation and 25% to 75% of the labor for any other sprinkler irrigation method except expensive buried solid-set sprinkler systems with automated controllers.

"From the late 1960s to the early 1980s, over 80 center pivot brand names were made and sold in the United States," Prof. Werner wrote in his paper on center pivot irrigation that he presented at Phoenix, Ariz., in November 2000.

Only a handful of companies remain in the business today, following attrition and consolidation of companies that were in the hunt for a piece of the center pivot market during the 1960s and 1970s. But the heated competition among those companies drove rapid advancements in center pivot systems' reliability and capabilities. And the competition continues today among the several surviving manufacturers of these systems.

"A multitude of patents have been filed for center pivots and their components. Many of these patents were by individuals or small firms. Patents have covered pivot points, structure, tower drives, alignment controls, tower couplers and just about any imaginable part of the center pivot," Prof. Werner wrote in his paper.

By the 1970s, the story of center pivot irrigation's success was already being written across North America's heartland in the language of circular fields visible to aircraft pilots and passengers and even to astronauts peering back at earth through their spacecraft windows.

The first earth resources data satellites (LANDSAT satellites) in the early 1970s

were mapping these circles, which were relatively easy to identify from space. (The standard center-pivot length of about 1,300 feet irrigates a circle approximately ½ mile in diameter, which encompasses about 130 acres. Larger systems, ½ mile long or longer and capable of irrigating circles of 500 or more acres are not unheard of.)

Satellite mapping chronicled the center-pivot's steady climb in numbers: 2,725 pivot systems in 1972, 8,903 systems 5 years after that, and 22,820 pivot circles by 1982, Dr. Sheffield reported in the aforementioned 1985 publication by the Irrigation Association Educational Foundation publication.

By 2002, an estimated 170,000 center-pivots and linear or lateral-move systems (center pivots adapted to move laterally the length of rectangular fields) were irrigating about 21 million acres of U.S. land. Another 88,000 center pivots and linear systems were operating in more than a dozen countries around the globe, according to Nick Mizaur at Valmont Industries. His estimate includes about 21,000 systems in Saudi Arabia, 15,000 in South Africa, 10,000 in Spain and 8,500 in Brazil.

Although a few companies outside the U.S. now make and market center pivots, the several U.S. manufacturers still in the business account for the bulk of the center pivot and lateral-move/linear systems around the world. The lion's share of the center pivot technology has come from the drafting boards and, more recently, the computer design software of U.S. center-pivot manufacturers.

Valmont Industries, T-L manufacturing, Lindsay Manufacturing, and Reinke Manufacturing Company, are today's major U.S. center pivot makers—all located in Nebraska, where an estimated 42,000 center pivots now irrigate about 63 percent of the state's 8 million irrigated acres. (Center pivot numbers taken from the 1998 Farm and Ranch Irrigation Survey released by the National Agricultural Statistics Service and total irrigated acreage from the 2000 Irrigation Journal Annual Irrigation Survey.)

Another U.S. center pivot maker, Pierce Manufacturing, is located in Oregon.

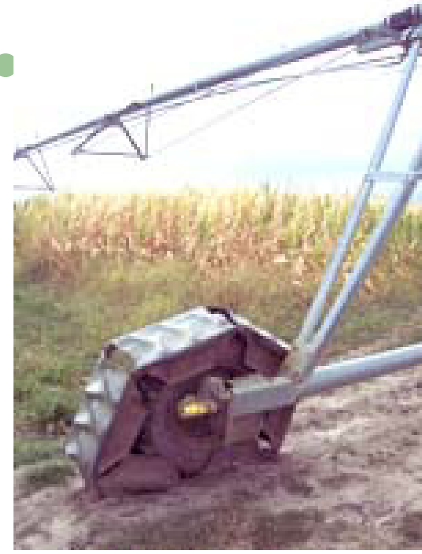
All of today's center pivots are propelled by either electric motors connected by drive shafts to gearboxes on the tower wheels (Valmont Industries, Reinke Manufacturing, Lindsay Manufacturing Company, and Pierce Manufacturing Company) or hydraulic motors on the tower wheels (T-L Manufacturing).

Other drive systems have come and gone, including air drives; rotating spinners driven off water pressure in the sprinkler line to power the tower wheels; and even cables pulling on towers to "walk" the towers around the field on skis in place of wheels.

Most of today's center pivots travel on rubber-tired wheels in a variety of diameters and tire widths. Wheel and tire dimensions are generally chosen with the idea of minimizing depth of wheel tracks for soil type and other field conditions, since those tracks must be crossed with equipment during field operations.

A host of aftermarket types of tower wheels and track-type devices are sold to center pivot





irrigators as the answer to minimizing the circular tracks worn into the field surface by the center pivot towers' repeated trips around the field.

Today's electric and hydraulic motor propulsion enable center pivot operators to send their pivots around the field in either direction—clockwise or counter-clockwise—with or without water being applied through them while they're moved. That capability allows center pivots to be operated in a windshield-wiper pattern to alternate between two different crops requiring irrigation water at different times within the circle.

The speed at which the center pivot's outside tower is set to run determines the amount of water applied during a trip around the field. The faster the center pivot rotates around the field, the lighter the application of water. Since electric and hydraulic drive systems permit adjusting center pivot speed in small increments, an irrigator has precise control over how much water is applied, anything from a fraction of an inch to incorporate an herbicide, for example, to heavier amounts to meet a crop's water needs.

The operator simply makes a quick setting at the control panel to select the desired direction and speed of the center pivot. In short, the operator has the ability to closely regulate when, where and how much water is applied to any given pie-shaped sector of the circle under the pivot.

Electrical components, including wiring and switches on the controls of early center pivots, came from various manufacturers and lacked standardization.

Consequently, operating and working on some of those early center pivots was hazardous enough to prompt the U.S. Department of Agriculture to initiate an effort to bring about electrical safety standards, says retired Valmont Industries center pivot engineer John Chapman.

The job fell to agricultural engineer Lavern Stetson at the University of Nebraska at Lincoln, Nebr., to identify the hazards and bring manufacturers together to address them.

Safety standards established through efforts by Stetson and the manufacturers have essentially become international standards today, Chapman says.

By the 1970s, a few enterprising farmers and manufacturers were already adding remote controls and monitoring systems to their center pivots. Through radio signal or touch tone phones, an operator could "call" his center pivot from his home or pickup to start up or shut down the system, monitor whether it was running and determine the system's position in the field.

"I could be standing in London and be doing the same thing I'm doing right now," explained Grant, Nebr., farmer

Ron Patrick in an August, 21, 1976, Nebraska Farmer Magazine story, as he called one of his center pivots to give it commands over a telephone in his home office.

Center pivot controls have become increasingly sophisticated over the years. At the center pivot system's control panel, the operator can program the pivot operations for several weeks ahead. Such instructions can include different irrigation application rates among different sectors of the circle. Other operations, such as fertilizer and pesticide applications through the pivot system, can also be programmed into some of the latest control panels. And those functions can be accomplished through today's remote control/monitoring systems by phone or personal computer from the pickup or farm office. These controls can even "call" the irrigator in case of a malfunction.

Not only does such center pivot electronic gadgetry reduce farmers' time spent running back and forth to check on their center pivots, it allows them to go to bed at night without having to worry about an unscheduled shutdown during the night, which would interrupt irrigation until the malfunction is discovered the next morning.

Something called the "bow string truss," patented by Reinke Manufacturing in the 1960s, enhanced the center-pivot's suitability for irrigating rolling land and tall-growing crops such as sugarcane and even orchards. This trussing creates a stable structural support of the center pivot pipeline from the bottom up as opposed to suspending the pipeline from the tower, says Tim Goldhammer, vice president of marketing at Reinke Manufacturing.

Virtually all of the center pivot systems currently being manufactured are designed with this truss system. It permits up to 16 feet of clearance under the center pivot pipeline and provides strength and stability to the pipeline spans between towers. In some of the longer spans, water filling the pipeline in each span can weigh 2 tons or more.

Like assembling a giant erector set, manufacturers can build a center pivot with a combination of different span lengths (ranging from 150 feet to 200 feet or more) tailored to the topography of field where the center pivot is being installed. Center pivot systems can be designed to pass over terrain with slopes as steep as 30%. However, most center pivot manufacturers consider 15% to 20% slopes as approaching practical limits, especially when it comes to controlling irrigation water runoff.

In conjunction with longer, higher spans, center pivot manufacturers have engineered various couplings for connecting the spans to withstand the twisting and turning of the center pivot systems as they snake up and down hills in the course of completing their circular paths. However, center pivots are as popular today on level terrain as they are on hilly land. Many gravity irrigators are switching to these systems for reasons of labor-saving and precise control over the amount of water

applied. That's evidenced by how much the proportions of U.S. irrigated acreage under center pivot and gravity irrigation have changed in the past two decades.

Of the 50 million acres under irrigation in the U.S. in 1979, 62% was gravity irrigated and 17% was irrigated by center pivot/linear systems, with the remaining 21% irrigated by other methods, according to Irrigation Journal survey data cited in a Valmont Industries publication "Circles of Life."

By 2000, the survey information showed U.S. irrigated acreage at 63 million acres, with 33% under center pivot/linear systems and 45% under gravity irrigation, with the remaining acres watered by other irrigation methods.

While center pivot systems have been designed and refined to irrigate almost anywhere, they must do it on a circle, which

obviously doesn't conform to the way most fields are shaped. The standard 1,200- to 1,300-foot long center-pivot's approximate 130-acre circle within a ½-mile-square field leaves about 7.5 unirrigated acres in each corner, a total of 30 non-irrigated acres.

Since many of the first center pivots were placed on lower value rolling land with sandy soils, the unirrigated corners were generally not of utmost concern. Just being able to irrigate this type of land and produce bountiful crops from it was enough. The corners were simply left idle, used for feedlots, planted to dryland crops with hopes for the best, or put to such novel uses as growing Christmas trees. But it remained a problem to be solved, especially for center pivot installations on higher-value land. And center pivot manufacturers first rose to the challenge by adding high-volume end guns to their pivot systems.

An end gun placed at the outer end of the pivot pipeline, automatically activated as the outer end of the center pivot reaches the corner, sends a high volume stream of water into the corner. This is one solution, although not a complete one, because the end gun's pattern reaches only a portion of the corner and is subject to deflection by wind.

A more elaborate answer emerged in 1974, when

Valmont Industries introduced the corner system. This was a 250-foot extension of the center pivot pipeline with its own powered tower and controls. The corner-watering span is folded back and trailed from the end of the center pivot pipeline until it's automatically activated at the corners.

Moved by its own steerable, powered tower, the corner span steadily extends out into the corner, with sprinkler heads or nozzles coming on in sequence along the span's length as it continues to extend to its full length into the corner. Once the center pivot is past the corner, the corner system folds back to trail the center pivot pipeline until the next field corner is approached.

On a typical 130-acre pivot installation, the corner system can irrigate 15 to 20 of the approximate 30 acres in the corners. This innovation has come into use not only for reaching into corners but for accommodating such intrusions on the symmetry of the pivot circle as farmsteads and natural terrain features the pivot system can't otherwise negotiate. Corner systems are also adapted to irrigating irregular-shaped fields.

Corner watering systems, which all major center pivot manufacturers make for their center pivots, have undergone a number of refinements since

introduction in the 1970s. The first corner system was guided by radio telemetry from a buried wire laid out in a route for the corner system tower to follow. Programmable guidance systems and even global positioning systems (GPS) also guide corner systems through the corners and irregular boundaries of fields.

There are different ways to look at the economics of an investment in a corner system, which is most likely to be found on center pivots irrigating higher-value land. One thing corner systems can't do is irrigate long, rectangular fields. But once again, center pivot manufacturers answered the call with an adaptation of the center pivot sprinkler system, by designing the system to move laterally, giving rise to "lateral-move" or "linear" irrigation systems.

With the same sophisticated alignment systems that keep pivot towers aligned in a circular pattern, the towers in a lateral-move or linear system are kept in alignment as the system moves sideways along the length of a rectangular field.

The pivot point now becomes mobile rather than fixed at the center of the field, carrying its own power unit and guided along the length of the field by a guide wire or buried cable from which it receives signals for steering a straight path along the length of the field. Water is supplied by a hose dragged behind the unit or a supply ditch running parallel to the path of the end unit from which a pump on the end unit draws water from the ditch.

Although these lateral-move/linear systems suit a number of irrigators' needs, center pivots outnumber them by a huge margin.

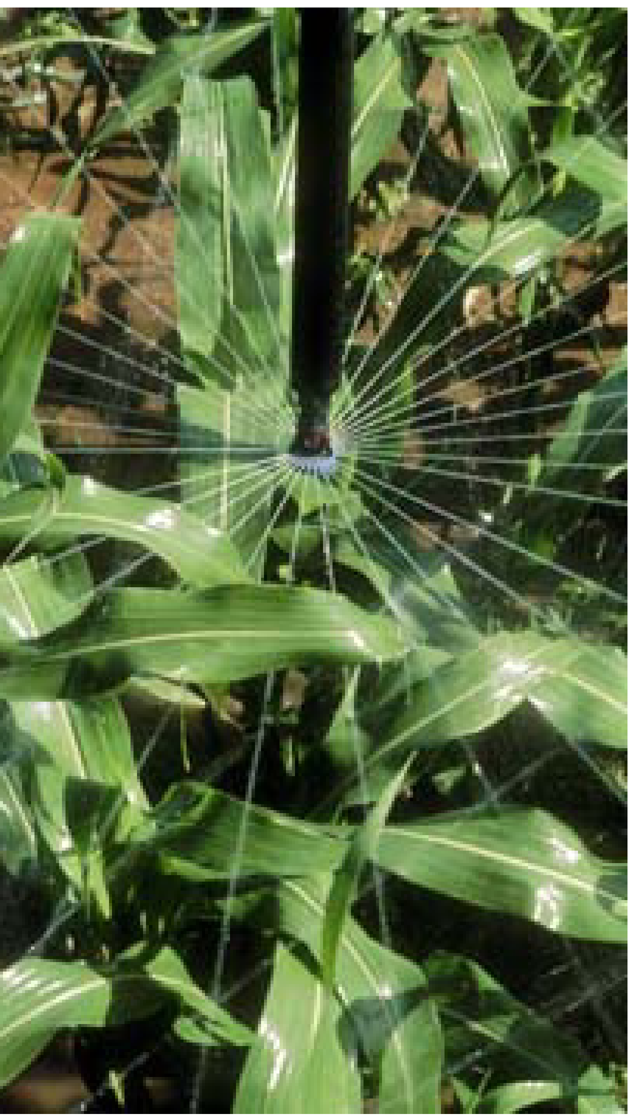
While irrigating through a pipeline revolving around a fixed point in a field affords automation, it presents what some refer to humorously as a "plumber's nightmare." Anyone who has ever played "crack the whip" can appreciate the challenges of distributing water uniformly through a center-pivot system. Things move very slowly at the inner part of the circle and much faster at the outer end. The outer tower of a quarter-mile long center pivot system must travel approximately 1.5 miles while the inner tower, 200 feet or less from the pivot point, travels only about ¼ mile—only 1/6th as far. While that first 200-foot span from the pivot is irrigating barely 3 acres, the outermost 200-foot span of the pivot system must irrigate approximately 40 acres.

Early center pivots had sprinkler heads located 32 feet apart along the pipeline, with the capacities of the sprinkler heads becoming progressively greater toward the outer end to compensate for the larger area and higher rate of water that must be applied there relative to the inner part of the circle.

Standard pivots in the 1970s and 1980s required 65 to 80 pounds per square inch (PSI) of pressure at the pivot point to deliver water at the necessary volume and pressure at the far end of the pivot.

Pressure requires power. And power requires energy, a fact that hit center-pivot irrigation hard when the energy crisis struck in the 1970s. A whole new train of engineering challenges was set in motion for center-pivot manufacturers by the arrival of energy shortages and high energy costs.

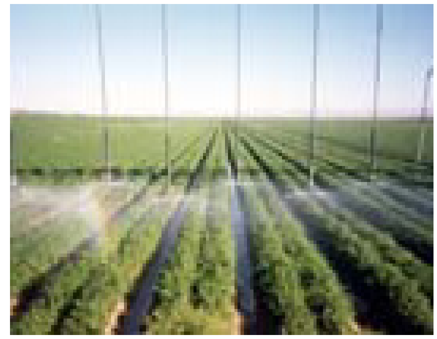
"While having the ability to control amounts of water applied within short periods (of time), center pivots require large amounts of energy to develop required pressures," University of Nebraska-Lincoln agricultural engineer James Gilley wrote in an article published in the April 1, 1978, issue of Nebraska Farmer Magazine. "One answer might be reduced-pressure center-pivot systems."



This was the beginning of the end for high-pressure center pivots. Now the industry was looking at low-pressure impact sprinkler heads and spray nozzles that required pressures as low as 20 to 30 PSI at the pivot to achieve energy savings of as much as 40%, in comparison with high-pressure center pivot systems.

But this posed a new problem, as agricultural engineer Gilley noted in his 1978 magazine article: "The application rate of low-pressure systems is higher than the application rate of conventional systems, because the same amount of water is being applied over a smaller area (covered by a low-pressure impact sprinkler head or spray nozzle)."

Applying water to soil too rapidly results in runoff, which can result in soil erosion and lack of uniform distribution of water on the field. Such outcomes offset many of the advantages irrigators sought from center-pivot irrigation.



Engineers at universities and at companies making center pivots and spray nozzles set to work on solutions.

They designed various kinds of spray nozzles and different ways of arranging the spray nozzles to increase the area they cover. Again, that demand for high volumes of water to cover large areas under the faster-moving outer spans of the pivot presented a challenge.

Some of the answers have come in special designs of spray nozzles—streams directed at deflector plates to enlarge the area over which the nozzle applies water and spinner nozzles to "throw" the water over a larger area are among the approaches taken. At Texas A & M in College, Station, Tex., agricultural engineers developed yet another approach involving a special nozzle in combination with tillage and planting practices. This system is called LEPA, an acronym for Low Energy Precision Application. LEPA uses drop tubes descending from the center pivot pipeline. At the end of each drop tube is a LEPA nozzle 15 to 20 inches above the soil surface. These nozzles lay down bubbled low-pressure streams of water between crop rows planted in a circle to conform to the circular route of the center pivot in the field. The LEPA system is combined with a tillage machine called the Dammer-Diker that gouges out small indentations in the soil surface to help trap irrigation water where it falls.

Center pivot manufacturers have turned their attention to various combinations of drop tubes, nozzles and nozzle spacings to irrigate with pressures at the pivot as low as 20 PSI.

Through computer software, center pivot manufacturers are designing different nozzle types and spacings tailored to the field's topography, soil type and capacity of the pumping plant supplying water to the center pivot. "Today, we offer nearly 40 different sprinkler packages," says Dave Thom at T-L irrigation. "It all goes into what I call the irrigation climate of that farm."

Another fact of physics enters the equation: Pressure in a pipeline changes with elevation. Application rate can vary dramatically along the length of a center pivot system operating on rolling land. Low pressure systems, especially, have little margin for changes in pressure along the center pivot pipeline on rolling land without upsetting the uniformity of water application. Just a 20-foot rise from the pivot point represents a pressure drop of 8 to 9 PSI at that elevation, a major factor for a low-pressure center pivot systems.

The answer to this dilemma has been pressure regulators and flow-rate spray nozzles that compensate for pressure changes that occur over the length of the pipeline as the center pivot travels over undulating terrain.

Refinements and advances in center pivot technology are continuing, particularly with growing pressure to utilize water resources more efficiently.

Some researchers are now exploring use of global positioning systems and geographic information systems (GIS) technology with center pivots to apply irrigation water at variable rates automatically according to GPS-mapped soil variations and other variable factors across the field.

Other possibilities include separate pesticide application systems attached to the center pivot, with pesticides applied at rates varied according to mapped variations in crop conditions and other production factors.

In viewing all the technological advances in center pivot irrigation, it's important to not overlook the role of the operator, emphasizes Dr. Dale Heermann at Colorado State University, Ft. Collins Colo.

This irrigation specialist, who has done extensive research on irrigation scheduling, says: "I have seen managers whose management style is to turn the system on and make sure it runs continuously. We've come a long way (in how irrigators manage center pivots to take advantage of those systems' capabilities). But it still doesn't mean we can't improve. Management can change the efficiency of anything."

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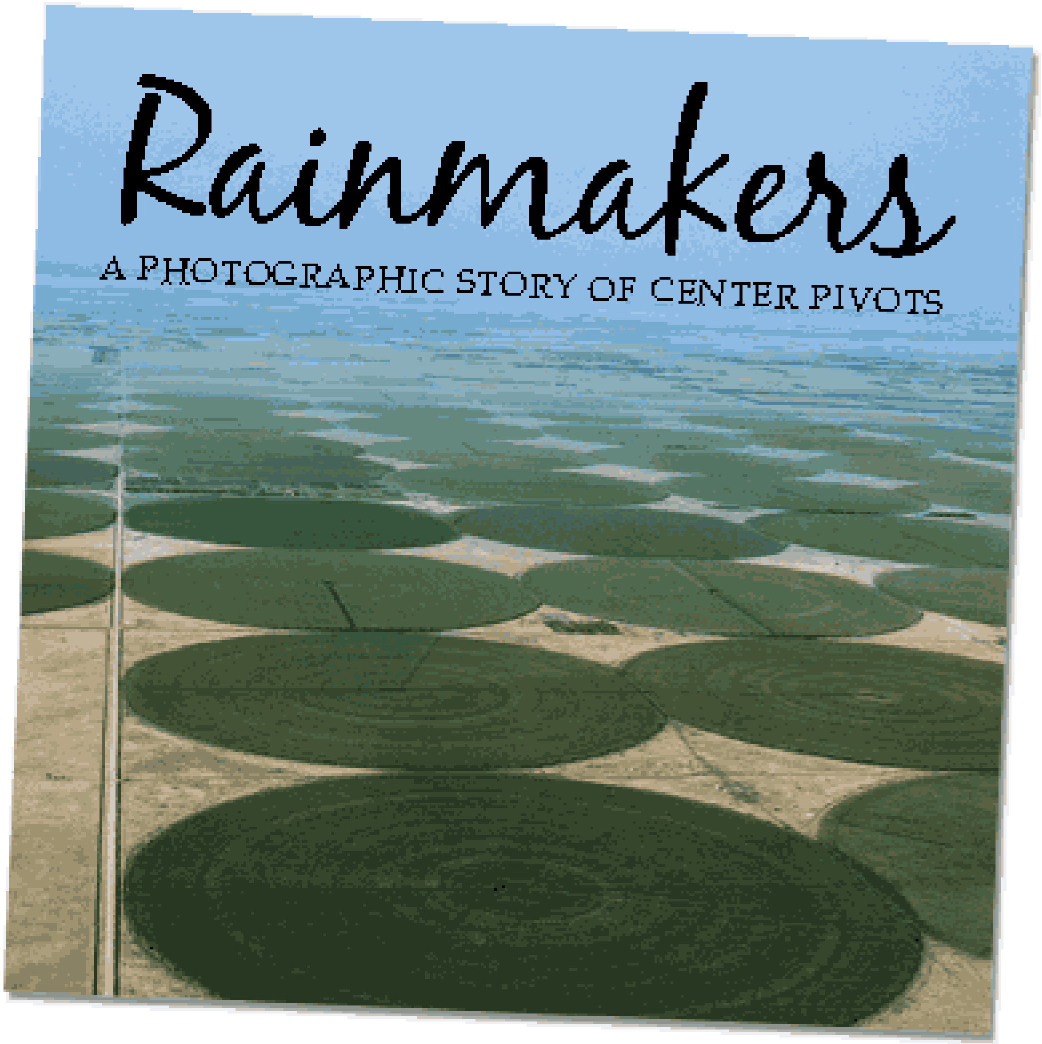

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