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GREAT CIRCLES ON THE GREAT PLAINS: THE CHANGING GEOMETRY OF AMERICAN AGRICULTURE*)

With 3 figures, 5 photos and 3 tables

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Zusammenfassung: Große Kreise auf den Great Plains: die sich wandelnde Geometrie der amerikanischen Landwirtschaft

Das in der ganzen Welt berühmte Bild der ausgeprägten Rechtwinkligkeit (75–80%) der Agrarlandschaft der USA wird in den letzten 20 Jahren zunehmend durch eine neue Form abgelöst. Große Kreisflächen legen sich exakt über die Rechtecke wie die runden Steine auf einem Damebrett. Diese Wandlung der landwirtschaftlichen Geometrie ist die Folge einer Entwicklung, die man die bedeutendste mechanische Neuerung in der Landwirtschaft seit der Einführung des Traktors genannt hat: die zentrierte Drehbewässerung (center pivot irrigation).

The farm landscape of the United States is famous throughout the world for its overwhelming rectangularity. More than three-fourths of the total national area was surveyed in systematic cadastral surveys that established a regular pattern of grid lines enclosing squares[1]). These surveys, most of which actually preceded settlement, set a pattern for property lines, transportation routes, and even field borders that is an enduring rectilinear legacy in the landscape.

Circling the Square

Within the past two decades, however, a new shape has begun to appear. Right-angled rectangular regularity is being modified by the closed curvature of circles. The North American agricultural landscape has often been likened to a gigantic checkerboard; increasingly great circular forms are being superimposed neatly upon the sqares, like checkers being placed on the board.

These great circles are simply large irrigated fields. However, the regularity of their patterns, the abruptness of their introduction, and the rapidity of their diffusion are clear indications that more as involved than a simple change in field shape. Indeed, this striking metamorphosis of agricultural geometry represents a development that has been called the most significant mechanical innovation in farming since the introduction of the tractor[2]).

The phenomenon is termed center pivot irrigation. Its design is simple in concept but complex in construction. In essence it involves a self-propelled, moving pipe (a "lateral" in irrigation parlance), dotted with sprinkler heads, mounted on wheels, and anchored at the center of the field (the pivot point). It moves in a circular arc, dispensing water in a regular pattern that is capable of almost infinite variation.

After a few years of trial-and-error experimentation, center pivot irrigation was introduced to the agricultural scene with little fanfare in the late 1950s

*) The writer was stimulated, encouraged, and instructed by Dr. LESLIE F. SHEFFIELD, Extension Co-ordinator for Irrigation of the University of Nebraska-Lincoln, who is probably the leading professional authority on center pivots, and by Dr. PHILIP VOEGEL of the University of Nebraska-Omaha, who is perhaps the geographer most knowledgeable about center pivots.

[1]) Major geographical studies of this phenomenon include WILLIAM D. PATTISON: Beginnings of the American Rectangular Land Survey System, 1784–1800, (Department of Geography Research Paper No. 50, University of Chicago, Chicago, 1964); NORMAN J. W. THROWER: Original Land Survey and Subdivision, (Monograph Series, Association of American Geographers, Rand McNally & Co., Chicago, 1966); and HILDEGARD BINDER JOHNSON: Order Upon the Land: The U.S. Rectangular Land Survey and the Upper Mississippi Country, (Oxford University Press, New York, 1976).

[2]) WILLIAM E. SPLINTER: "Center-Pivot Irrigation", Scientific American, Vol. 234 (June, 1976), p. 90.

in eastern Nebraska. It slowly caught the imagination of Great Plains farmers and began to spread north and south through the center of the nation. By the early 1970s there was a swelling tide of adoption in all states where irrigated farming was well established, with a few notable exceptions. Even in such relatively humid states as Minnesota and Florida center pivot irrigation has caught on. Indeed, at least a few center pivot systems are now operating in each of 39 states.

The story of this revolutionary change from rectilinear to curvilinear is a combination of the exotic and the commonplace, and despite the dynamism of its recent past, its future is still unclear.

A slow beginning

The chronicle of the early years of center pivot irrigation is quite unremarkable. It is similar to that of many other technological innovations — a man, partly stimulated by previous clumsy development, had an idea for a machine that could accomplish certain specific tasks. His prototypes had many defects, but he kept improving them; his attempts at small-scale manufacturing were unsatisfactory, so he licensed production rights to a corporation that had development capital; after a few struggling years, the machines began to sell, and then the market opened in spectacular fashion.

Frank Zybach was the inventor. A tenant wheat farmer near Strasburg, Colorado (25 miles east of Denver), Zybach developed his first so-called "Self-propelled Sprinkling Irrigation Apparatus" in 1949 and was finally granted a patent for the device in 1952[3]). By then he had moved to Columbus, Nebraska (80 miles west of Omaha), where he went into partnership with E. A. Trowbridge in a manufacturing enterprise that produced nineteen center pivot systems within a few months. In 1953, however, Zybach and Trowbridge licensed their patents, under a royalty agreement, to Valley Manufacturing Company of Valley, Nebraska (20 miles west of Omaha). Sales lagged for several years, but they began to increase in the early 1960s. With the expiration of the original patents in 1969, several dozen other manufacturers entered the field.

The first commercial installation of center pivots was in Holt County in north-central Nebraska, an area that has been a major focus of center pivot development ever since. Indeed, Holt County still has the greatest number of center pivot systems — more than 1,200 — of any county in the nation.

During the latter half of the 1950s center pivots were slowly adopted in sandy-soiled areas of central and southwestern Nebraska, as well as in eastern Colorado, several locales in Kansas, and even in western Oklahoma and the Texas Panhandle. In the other Great Plains states this innovation was not introduced until the early 1960s. By 1962, a decade after the invention was patented, only about 75,000 acres were under center pivot irrigation. The relatively slow acceptance of center pivots during the 1960s is reflected by the fact that the principal irrigation industry publication, then titled *World Irrigation,* neither specified center pivot as a type of irrigation in its annual state-by-state survey nor carried a feature article on them until 1969[4]).

It was not until the present decade, then, that center pivot systems began to proliferate spectacularly, apart from substantial late-1960s growth in Nebraska, Kansas, and Colorado. There were approximately 7,160 center pivots in operation in the Great Plains in 1970; this number grew by more than 300 percent

Table 1: Sequential proliferation of center pivot systems, Great Plains states

State	Number of Systems 1965	1970	1976	Percentage Increase, 1970–1976
Colorado*	400	1800	3800	111%
Kansas	700	2200	7000	218%
Montana*	na	na	230	na
Nebraska	1000	2000	11,700	485%
New Mexico*	0	40	600	1,400%
North Dakota	5	45	540	1,100%
Oklahoma	75	300	1100	267%
South Dakota	2	100	750	650%
Texas#	na	500	3500	600%
Wyoming*	15	175	550	214%
TOTAL	2197	7160	29,770	316%

* East of the Rocky Mts.

\# High Plains counties only.

(Note: All numbers are approximate. Data furnished by personal communication from irrigation authorities in the various states and from annual surveys published in *Irrigation Journal.)*

3) Leslie F. Sheffield: "Economics of Corn Production under Center-Pivot Irrigation in Southwest Nebraska, 1970", Paper Prepared for Irrigation Short Course, Nebraska Center for Continuing Education, Lincoln, Jan. 29–30, 1973, p. 163. According to Ringler, there had been several previous attempts to develop machines that irrigated crops by means of pipes suspended from moveable towers, some as early as the 1880's, but all had foundered on the problem of misalignment of the moving pipe; Zybach's major breakthrough was a successful alignment mechanism; see Don Ringler: "Inventor's Irrigation Systems Dot Nation with Grenn", Omaha World Herald, Sept. 16, 1972, p. 16.

4) Anonymous: "Center Pivot Sprinklers Open Great Plains Range", World Irrigation, Vol. 19 (March, 1969), pp. 16–23.

Table 2: Sequential proliferation of center pivot systems, other principal states

State	Number of Systems 1965	1970	1976	Percentage Increase, 1970–1976
Washington	3	90	1850	1,956%
Idaho	na	80	1600	1,900%
Oregon	0	104	1050	910%
Georgia	0	87	825	848%
Minnesota	20	100	760	660%
Florida	0	200	650	227%
Iowa	40	100	450	350%

(Note: All numbers are approximate. Data furnished by personal communication from irrigation authorities in the various states and from annual surveys published in *Irrigation Journal.)*

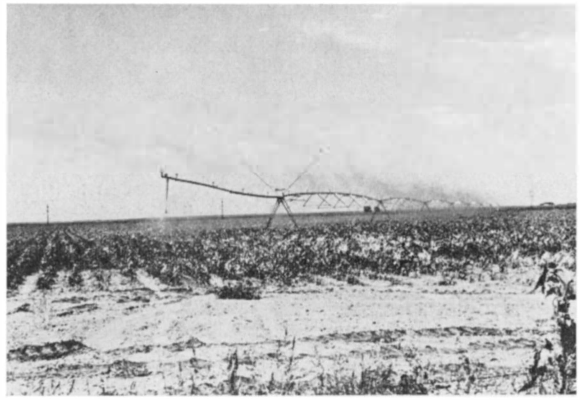

Photo 1: A typical center pivot system, in this case irrigating corn near Clovis in east-central New Mexico

during the next six years (Table 1). In most other parts of the country center pivots have been adopted in considerably smaller numbers, but the rapid proliferation of the early 1970s pertains in all states, with the peculiar exception of California, where center pivot acceptance has so far been minimal (Table 2).

Intricate precision of operation

Center pivot systems—like many other types of modern farm equipment—are intricate, complex, expensive machines. The basic element of the system is a length of pipe, normally of six-inch diameter, that is anchored at one end in the center of the area to be irrigated. The pipe is elevated from six to nine feet above the ground, where it is supported on mobile A-frame towers, each of which is mounted on a pair of wheels and powered by a self propulsion system[5]). Sprinkler heads or flooding nozzles are spaced at intervals along the pipe to dispense the water that is fed into the system from the pivot point (Photo 1).

The system revolves in a circular pattern about the field at a preset speed, with the perimeter tower as pace-setter. An alignment mechanism prevents lagging or acceleration by the intermediate towers, with each tower's movement being determined by the tower immediately outward from it in a smooth chain reaction of advances. The speed of the circular sweep is adjustable; a complete revolution can be accomplished in as little as twelve hours, but most systems are timed at a much slower pace, varying from three to seven days in duration. This flexibility permits adjustment to varying soil conditions; e.g., soil with poor infiltration or high runoff capability can be watered lightly at frequent intervals by cycling the system at higher speed.

Most systems are powered either by electricity or by hydraulic selfpropulsion in which small quantities of water are bled from the supply line at each tower to drive the pistons or gear trains that move the wheels. A few systems are propelled by oil or air-driven pistons.

The size of center pivot systems can be quite variable, but in the United States (where most of the world's center pivots are found) the vast majority—probably more than ninety percent—are designed to irrigate a quarter section (160 acres), with the length of the lateral being about 1,300 feet. The circular pattern omits the corners, of course, so on the average only about 133 acres are irrigated in each quarter section. Both smaller and larger systems are in use. Some have been designed to cover as little as 5 acres, and at the other extreme there are single systems for a full section (640 acres) of land. The larger systems tend to be unwieldy and uneconomical except in specialized situations.

The outer portions of the pipe must cover more ground and therefore move faster than the inner portions in any given circular revolution. In order to attain an even pattern of water distribution over the entire irrigated area, therefore, the water outlets must either be spaced closer together or be capable of larger discharges with increased distance from the pivot point (Photo 2). This provides an engineering challenge that is met in different ways by different manufacturers.

Most systems, once started, operate automatically and require little care unless there is a malfunction. They can be manipulated, however, to stop, back up, or even operate alternately forward and backward. This last capability is occasionally necessary where some obstruction, such as a gully or buildings, precludes the irrigation of a full circle, in which case a "slice" of the circular pie can be left unirrigated.

[5]) The initial Zybach invention had the pipe much closer to the ground, but the need to elevate the pipe to clear such tall-growing crops as corn soon persuaded the inventor to work only with raised pipes.

Photo 2: A center pivot system in operation in central Washington's Grant County. Note the more expansive discharges of water near the outer end of the lateral than near the pivot point (Courtesy of Valmont Industries, Inc.)

A device that solves many problems

There are some obvious flaws in shifting from rectangles to circles, and the establishment of any new and complex irrigation system is a matter of considerable expense. Consequently, center pivots must have notable perceived advantages to account for their rapid recent proliferation. Indeed, the center pivot phenomenon probably represents the most significant change in agricultural land use in the last quarter century. The reasons underlying such a conspicuous development are numerous and varied, but they can be summarized under a half dozen principal headings.

1. Savings in labor

Once a center pivot system is installed and set in motion it becomes virtually a push-button operation, which reduces the labor requirement to little more than maintenance. Various studies have demonstrated that center pivots have the lowest labor needs of any irrigation system, in some cases diminishing per-acre man-hour requirements by as much as ninety percent, thus allowing a single irrigator to handle up to ten times as much acreage as with conventional systems[6]).

2. Opening sandy land to irrigation

Irrigation traditionally has been either impractical or inefficient on sandy or other coarse-textured soils, due to their rapid absorption and poor retention of water. Center pivot systems, however, are capable of frequent, light, even applications of water which allow maintenance of enough moisture in the root zone to permit intensive cropping.

3. Opening undulating land to irrigation

Previous irrigation has been restricted to land that was virtually flat or that had to undergo extensive leveling or terracing to be made irrigable. By virtue of its flexible couplings at the support towers, however, center pivot systems are capable of marching uphill and down dale in remarkable displays of virtuosity. They can operate on slopes as steep as thirty percent, from which other types of farm machinery would literally fall. In practice they are not used on such extreme hills, but their slope capability makes it possible to irrigate much land that was previously unirrigable.

4. More efficient water use

The rate and frequency of water application can be very precisely controlled, allowing the irrigator to match the actual water requirements of the crop during all stages of its growth. Over-irrigation and under-irrigation can be avoided throughout the circle area. The Uniformity Coefficient (C_u), which is the industry's index of evaluation of uniformity of application, is normally above eighty percent for center pivots, even when the wind is blowing; for other types of irrigation the C_u is usually well below seventy percent, even on calm days[7]).

5. Savings in water

A well designed center pivot system wastes almost no water, Testimony indicates a saving of $^1/_3$ to $^1/_2$ in water use compared with gravity irrigation systems[8]).

6. Efficiency in fertigation and herbigation

Center pivot systems are particularly well adapted to easy and efficient spreading of some fertilizers, herbicides, and insecticides. These can simply be added to the water supply for uniform application to the crop at the proper time and in the requisite amounts.

[6]) See, for example, PETER W. BREUER: "Selecting a Sprinkler Irrigation System", (Circular AE-91, Extension Service, North Dakota State University, Fargo, 1973); LESLIE F. SHEFFIELD: "Irrigation and Crop Production in Nebraska", (Special Newspapers for International Minerals & Chemicals Corporation, Feb., 1976); DAVID L. GOSSETT and GAYLE S. WILLETT: "The Cost of Owning and Operating Sprinkler Irrigation Systems in the Columbia Basin", (Co-operative Extension Service, College of Agriculture, Washington State University, Pullman, Oct. 1976).

[7]) Anonymous: "Center Pivot Irrigation", World Irrigation, Vol. 20, (June, 1970), p. 8; DON RAZEE: "Center Pivot Comes to California", California Farmer, Vol. 245, (Oct. 16, 1976), p. 31.

[8]) STEPHEN F. HOESEL: The Impact of Center-Pivot Irrigation on the Sand Hills of Nebraska: Brown County, a Case Study (unpublished M.A. thesis, Department of Geography, University of Nebraska-Omaha, Omaha, 1973), p. 41; LESLIE F. SHEFFIELD: "Irrigation as it Relates to a Hungry World", (presentation as a panel participant at the Fourth Annual B. C. Christopher Agri-Business Conference for Institutional Investors, Kansas City, Sept. 20–21, 1976), p. 9.

The center pivot system thus fills a three-fold function—as irrigator, fertigator, and field sprayer—with the added advantage that no additional power and little extra labor are required.

The aggregate of these advantages is quite impressive. Per-arcre production is clearly enhanced, the risk of crop loss due to drought is minimized, and various production inputs are made more efficient and less expensive. Since center pivot irrigation has such admirable credentials, why would any Great Plains farmer hesitate to adopt it?

But what about the corners?

The initial reaction to center pivots by most laymen is one of keen interest in the unusual circular patterns. Almost invariably, however, this enthusiasm is promptly tempered by the sobering realization that the corners of rectangular fields are beyond the reach of the sprinklers and hence are left unirrigated by the center pivot system. "What about the wasted land in the corners?" is the universal puzzlement. "How can a farmer justify allowing that valuable land to lie idle?"

The query is clearly appropriate. A quarter-section center pivot system encompasses approximately 133 acres within its irrigated circle, leaving about seventeen percent of the rectangular field beyond the reach of its sprinklers. It this logical land use?

Most farmers who have adopted center pivots dismiss such questions as being largely irrelevant to their decision-making. Their basic contention is that the center pivot system is so efficient and productive on the 133 acres that it more than compensates for the lower productivity (or even idleness) of the 27 acres that the system does not reach. Moreover, in many (probably most) cases, center pivot systems have been established on land that was not previously irrigated; obviously irrigating 133 acres is a vast improvement over no irrigation at all.

The corner land need not be "wasted", of course. Some farmers have been quite imaginative in making use of the corners. Sometimes corners are irrigated with small gravity flow or hand-set systems. The corners can be planted to non-irrigated crops, or to pasture. Farm buildings can be clustered there, or livestock feedlots (Photo 3). Windbreaks can be planted, or even woodlots or Christmas trees. A fairly common cattle-and-corn cycle on the Great Plains finds the cattle being kept in the non-irrigated corners during the summer in a feedlot situation, then turned out to the circles in winter and spring to graze on the corn stubble. And if the corners of four adjacent quarter-section systems meet, a sizable area is available for the location of non-irrigated facilities.

It is possible to minimize the amount of "wasted" land in the corners by nesting adjacent circles (Photo 4). In practice, however, this is infrequently done, presumably because the American rectangular land survey system with its basic 640 acre units is so deeply ingrained into both landscape and thought patterns.

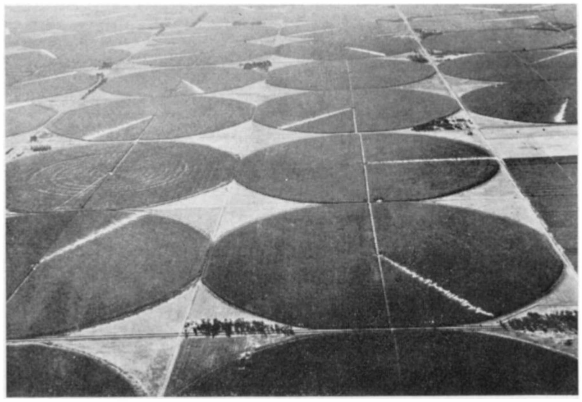

Photo 3: Lots of corners. This is a typical rank-and-file layout of irrigated circles. Most of the corners appear to be undeveloped, but some are conspicuously in use. The scene is in northeastern Nebraska's Antelope County (Courtesy of Valmont Industries, Inc.)

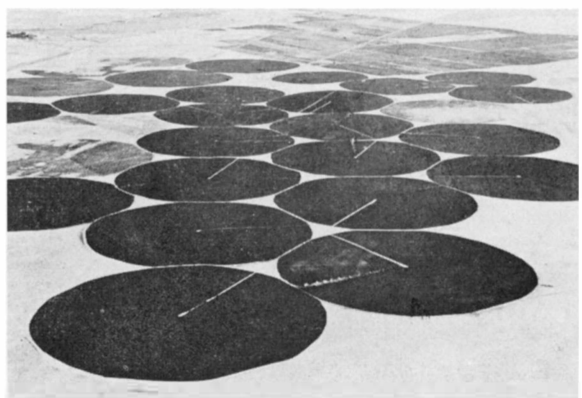

Photo 4: Nested circles result in less unirrigated land. This complex is situated near Moses Lake in central Washington (Courtesy of Valmont Industries, Inc.)

Center pivot manufacturers have addressed themselves to the problem of the corners in a variety of ways. Early efforts mostly involved the positioning of a "big gun" sprinkler at the outer end of the lateral to shoot water greater distances. Recent more intricate approaches have focussed on the attachment of a sweep arm onto the end the lateral; this development will be explored later in this paper.

And other problems

Most farmers, then, perceive the "corner problem" as no problem at all. There are, however, other disadvantages of center pivot irrigation which prevent it from becoming a universal panacea.

The initial problem is the capital investment. Center pivot operations are capital intensive. Barely more than a half-decade ago a quartersection system could be installed for $ 20,000; by 1978 the cost was more than three times that amount. Much of the capital for center pivot development has come from traditional farm financing sources in the form of loans to operating farmers, although in some cases the loans are of as long as 25 years duration for a piece of equipment that has an anticipated use span of only 10 to 20 years[9]). Such a capital outlay makes any potential center pivot user consider his options carefully, although a substantial amount of financing for center pivot development does come from investors outside the normal agricultural finance sector; it has become something of an investment novelty, particularly in the money markets of Omaha, Denver, and Chicago. This fact has far-flung social ramifications, which are beyond the scope of the present study.

A second cost disadvantage, which also has broader implications in this era of energy shortage, is the relatively large amount of fuel or electricity required to operate a center pivot. The water in the system is under pressure, and the energy required for pumping and pressurization is considerably greater than that needed for gravity irrigation. One report showed that an average center pivot system in Nebraska consumes about fifty gallons of diesel fuel per acre per year, which is "10 times the fuel needed to till, plant, cultivate and harvest a grop such as corn"[10]". Another study found a 53 gallon per acre per year consumption (also in Nebraska), in contrast to only 31 gallons per acre per year for most surface irrigation[11]). This energy problem is shared by other forms of sprinkler irrigation, but generally to a lesser degree than with center pivots.

There are also various technological difficulties that sometimes discourage center pivot usage. For example, attempts to use center pivots in areas of clay or adobe soils have sometimes resulted in their burying themselves so deeply that they became solid set systems on wheels. Indeed, it is often necessary to build up a slightly elevated right-of-way for the tower wheels to travel on as a precaution against their becoming mired, although some systems are specifically designed so that the water sprays only behind the lateral, thus assuring that the wheels will always be traveling over dry land. The water applications rate also presents a continuing challenge to center pivot designers. The outer part of the system travels a greater distance around the circle than the inner part, requiring a higher rate of application; if the water is applied faster than the soil can absorb it, there may be serious runoff and erosion problems.

The problem of over-development of water for use in center pivot systems is a legitimate worry, and it has no simple answer. These devices are heavy water users, and as their popularity burgeons, the demand for water must also increase. In many situations the result is not deleterious, for untapped aquifers underlying sandy lands that could not be irrigated by conventional methods provide water that would otherwise have been unused. However, the history of American irrigation is almost a continuum of water overuse, and already there are many places where center pivots are contributing to the general problem. Despite stringent safeguards in such states as Colorado and South Dakota, and despite the availability of almost-virgin aquifers in such places as the Nebraska Sand Hills, the pattern of overuse has already become apparent. Nevertheless, as noted earlier, center pivot systems are efficient water users. If irrigation is acceptable as a legitimate use of water, it is difficult to find fault with center pivot technology, although the enthusiasm of its adopters can certainly lead to abuses.

The agronomics of circles

Theoretically, any source of water can be used with center pivot systems. In practice, however, the vast majority of all Great Plains circles are supplied from groundwater wells. Estimates furnished by local specialists indicate that practically all water for center pivots in eastern Colorado, Oklahoma, and the Texas High Plains comes from wells. In other Great Plains states the proportions are not as overwhelming, but in every state except Montana more than three fourths of all circles are irrigated from wells. In the Pacific Northwest, on the other hand, more than 80 percent of all center pivots are supplied with river water, nearly all of it coming from the Columbia and Snake. Conditions are more variable elsewhere, but in each of the other principal center pivot states well over half the water is obtained from wells.

One of the interesting aspects of center pivot systems is the layout of plowed furrows. Should they be straight or circular, or should they follow the contour? All three patterns can be found, but the great majority are either straight or circular. Straight-line furrows are simplest, despite the interruption of the circular wheel tracks. The principal advantage of circular furrows is that they inhibit runoff by providing a ponding effect.

The center pivot phenomenon has spawned little in the way of "new" farming practices. Adoption of circular furrows is probably the most widespread

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[9]) *Irrigation Report Committee,* The Center for Rural Affairs: Wheels of Fortune: A Report on the Impact of Center Irrigation on the Ownership of Land in Nebraska, (The Center for Rural Affairs, Walthill, Nebraska, 1976), p. 94.

[10]) Splinter: op. cit., p. 94.

[11]) Randy Beam: "ERTS Satellite Carries New Hopes for Scientists", (Department of Agricultural Communications, University of Nebraska-Lincoln, Lincoln, 1974).

technique that might be called new. Minimum tillage and double cropping are frequently adopted, but these are not innovations peculiar to center pivots. Fertigation and herbigation by means of irrigation water distribution had already been developed in other types of sprinkler irrigation, although they have been considerably expanded and improved in center pivot systems. Certain specialized mechanical methods for controlling runoff, such as listing parallel to the wheel tracks and planting crops on top of the beds rather than in the furrows, have been developed, but these are slight modifications of existing practices. As previously suggested, it is often necessary to make specialized, if minor, earth moving adjustments to provide stable wheel tracks.

Almost all circles have a bee-line road leading from a point on the perimeter to the pivot point. This is a service road for attention to the well and pump, as well as a place for out-of-the-way storage of the sprinkler system during planting and harvesting periods.

The ownership pattern of center pivot systems is extremely diverse. There has, however, been a clear proliferation of corporate ownership. The most detailed study of ownership, made in Holt County, Nebraska, in 1975, showed that about 63 percent of the 1,000 systems in the county were owned by resident farmers, about 25 percent were in corporate ownership, and the remainder were varied[12]). The same study showed that more than 2/3 of the center pivot owners in the county owned only a single quarter-section system. Only seven owners had more than ten systems, with the largest owner (a corporation) controlling 127 systems. These statistics are probably fairly representative of center pivot ownership throughout the Great Plains. The largest single owner of systems may be an operation in southwestern Kansas that has more than 400 quarter-section systems.

The center pivot cropping pattern in the Great Plains is fairly predictable. Due to the high investment costs, center pivot users tend to concentrate on growing crops that will yield the greatest financial return per acre, although other factors may significantly influence their crop choice. By far the most widely grown irrigated crop in the Great Plains is alfalfa; however, it is only the second choice of center pivot irrigators. Corn is easily the leading crop grown on irrigated circles in the region, accounting for more than eighty percent of total center pivot acreage in the central plains (Nebraska and vicinity)[13]). Corn is outranked only in the northwestern part of the region (North Dakota–Montana–Wyoming), where it is second in center pivot acreage to alfalfa; and in the far south (Texas), where it ranks third behind wheat and grain sorghums. Other major center pivot crops in the Great Plains include small grains, potatoes, sugar beets, cotton (in Texas), soybeans, dry edible beans, and popcorn. Center pivot systems are seldom placed on pasture land, as the financial return is considered to be too low; however, in the central part of the region (Nebraska–Kansas–Colorado) as much as ten percent of total irrigated circle acreage is devoted to pasture. From a regional standpoint the only notable cropping trend related to the center pivot phenomenon is the great increase in corn acreage. A partial result is that more cattle raisers are able to provide their own feed grains (and silage), thus inducing them to keep their calves and yearlings at home, rather than ship them to the Midwest for fattening. This accelerates the already-changing stocker/feeder relationship between the Great Plains and the Corn Belt.

In other parts of the country the crops grown on irrigated circles are much more varied. In Washington and Oregon potatoes are the leader, followed by grains and alfalfa. In the principal center pivot states of the East, corn is the major crop grown on irrigated circles everywhere except Georgia (where peanuts is the leader, of course!) and Florida. Considerable center pivot acreage is devoted to potatoes and various vegetables in the eastern states, but there is so far surprisingly little circle irrigation of cotton or soybeans.

Mapping center pivots: A geographer's dream

The center pivot phenomenon is a veritable joy for geographical study for several reasons, not the least of which is its eminent mappability. The irrigated circles are large, conspicuous, and relatively permanent in the landscape. Moreover, they are nearly all of equivalent size, so that acreages can be estimated quickly and accurately simply from knowing how many circles there are.

Center pivots are easy to find on the ground because of the distinctive machinery which towers above any other farm equipment, although the circles themselves are difficult to distinguish at eye level. Ground reconnaissance, however, is a very slow way to count or map systems.

Aerial imagery, on the other hand, provides a simple, speedy, and relatively foolproof mechanism for mapping. The great circles are so conspicuously different from other elements of the landscape that they are often recognizable on even very high altitude space imagery. Indeed, the massive cluster of circles in Nebraska's Holt County served as a ground reference point for Skylab astronauts orbiting 270 miles above.

There is, however, no nationwide clearinghouse for keeping track of the sequential distribution of center pivots, and only a few states have produced distribution maps. The nearest approach to a national inven-

[12]) *Irrigation Report Committee*, op. cit., p. 22.

[13]) Information on cropping patterns was mostly obtained from mail questionnaires returned by irrigation specialists in the various states.

Table 3: Leading center pivot states 1976

Total Acreage under Center Pivot Irrigation		Ranking	Center Pivot Acreage as Percentage of All Irrigated Acreage	
1,762,856	Nebraska	1	North Dakota	54%
727,000	Kansas	2	Minnesota	53%
520,000	Texas	3	South Dakota	51%
500,000	Colorado	4	Illinois	51%
240,000	Washington	5	Iowa	45%
209,670	Idaho	6	Indiana	42%
150,000	New Mexico	7	Maryland	40%
150,000	South Dakota	8	Georgia	34%
141,275	Oklahoma	9	Michigan	34%
135,000	Oregon	10	Delaware	34%
104,000	Georgia	11	Wisconsin	33%
99,000	Minnesota	12	Nebraska	28%
85,000	Florida	13	Alabama	28%
78,300	Wyoming	14	Kansas	24%
59,000	Iowa	15	Colorado	16%
58,300	Wisconsin	16	Washington	15%
56,000	North Dakota	17	Oklahoma	15%
40,000	Nevada	18	Ohio	15%
39,000	Michigan	19	New Mexico	14%
33,100	Montana	20	Missouri	10%

Data Source: "1976 Irrigation Survey," *Irrigation Journal*, v. 26, Nov./Dec. 1976, pp. 23–29.

tory is the "Annual Survey of Irrigation", published each December by *Irrigation Journal*, in which the acreage under various types of irrigation is estimated by co-operating specialists in most states (Table 3). Acreage data can be converted into the number of systems per state by dividing by 130, which is the generally accepted but slightly conservative average acreage per center pivot system.

Based on these annual surveys and supplemented by data furnished by a mail questionnaire survey of irrigation specialists in all states, it is possible to inventory the contemporary distribution of circle irrigation throughout the nation, and to trace in general terms its sequential diffusion. County data, for the most part, are unobtainable, but a relatively accurate state-by-state picture can be produced (Fig. 1).

Approximately three-fourths of the United States' center pivot systems, covering nearly 3½ million acres, are located in the Great Plains. Circle irrigation is proportionately twice as important in this region as in the country as a whole; about eighteen percent of all Great Plains irrigated acreage is watered by center pivots. The four leading center pivot states – Nebraska, Kansas, Texas, and Colorado – are all in the region, their cumulative acreage amounting to two-thirds of the national total.

The Pacific Northwest is another area of considerable center pivot development, especially in central

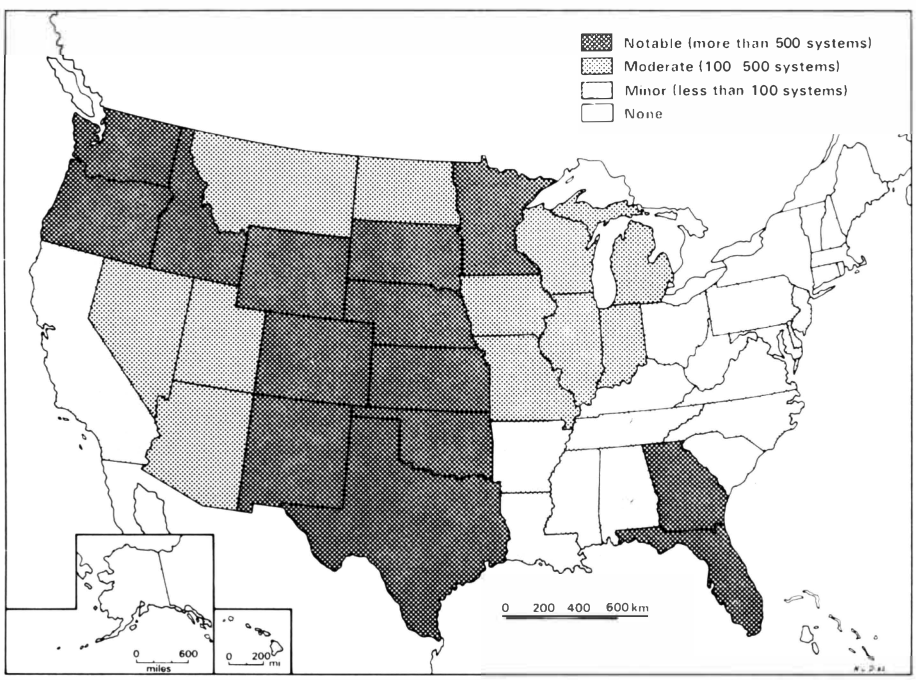

Figure 1: Approximate distribution of center pivot systems, by state, 1976. The prominence of the Great Plains is obvious (Based on data in "1976 Irrigation Survey", *Irrigation Journal*, Vol. 26, Nov./Dec., 1976, pp 23–29, and the writer's mail questionnaire survey)

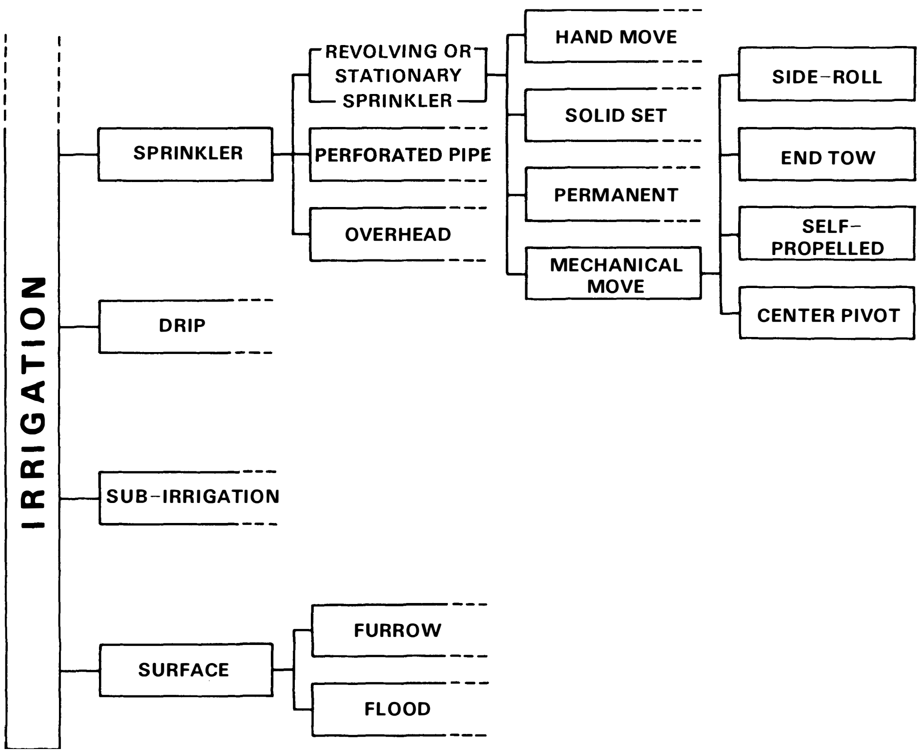

Figure 2

Washington, southern Idaho, and northcentral Oregon. In eastern United States there has been a rapid recent rate of center pivot adoption in states where previous irrigation techniques had been slow in catching on—particularly Georgia, Minnesota, Florida, Iowa, and Wisconsin. An interesting anomaly is the virtual absence of center pivots in California, the nation's leading irrigation state.

Center pivot in context

For many centuries irrigation has been a very important technique for improving crop yields, but its application required an immense input of hard labor and drudgery. Until about four decades ago "irrigation" invariably meant "surface irrigation", in which water was in some manner introduced onto relatively flat parcels of land where it stood for a while ("flooding") or was conducted leisurely down rows ("furrow irrigation")[14]). The invention of the rotating impulse sprinkler in the 1930s permitted the development of various types of "sprinkler" irrigation, opening the door to much greater flexibility and the possibility of diminished labor input. Since the end of World War II, when light-weight aluminum pipe became available at reasonable prices, sprinkler irrigation has been widely adopted. It appears in three basic modes: revolving or stationary sprinklers, overhead systems, and perforated pipe. Revolving sprinkler systems can be further subdivided into hand-move, solid-set, permanent, and mechanical move systems. Center pivot is a variety of the mechanical move fraction (Fig. 2).

In the United States most irrigation is still surface irrigation. Of the nearly 57 million acres under irrigation in 1976, about 72 percent were watered by flooding or furrow irrigation[15]). Some 35 percent of all sprinkler irrigated acreage is center pivot, which means that 9 percent of all irrigated acreage is in great circles, or approximatley $1^1/_2$ percent of all cropland in the nation. Clearly, then, circles have not yet transformed the American farming landscape. In most agricultural counties in the nation, there is not a circle to be seen.

In certain areas, however, circles are concentrated and prominent, and the shape of the fields is in fact significantly different from what it used to be. The Great Plains region provides the most conspicuous example (Photo 5). Almost every county in Nebraska, Kansas, and eastern Colorado contains at least one great circle, and in many cases, dozens or even hundreds, of them (Figure 3). Three-fourths of South

[14]) A very small proportion of land was irrigated by "sub-irrigation", in which the water table was manipulated at some predetermined level, usually by buried pipes in a sort of reverse drainage situation.

[15]) Based on data in the *Irrigation Journal* annual survey.

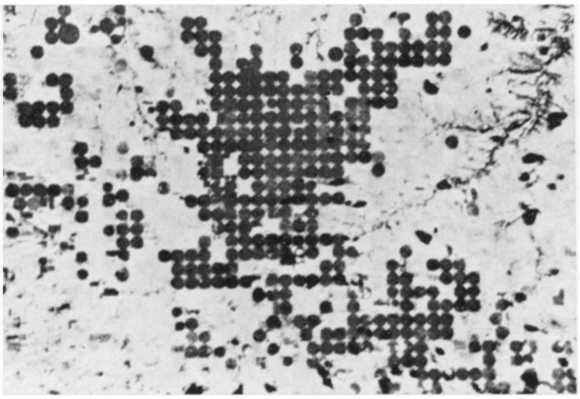

Photo 5: No county is as circularly conspicuous as Holt County. This is a Landsat image (Photo courtesy of Dr. Rex Peterson, Conservation and Survey Division, University of Nebraska-Lincoln)

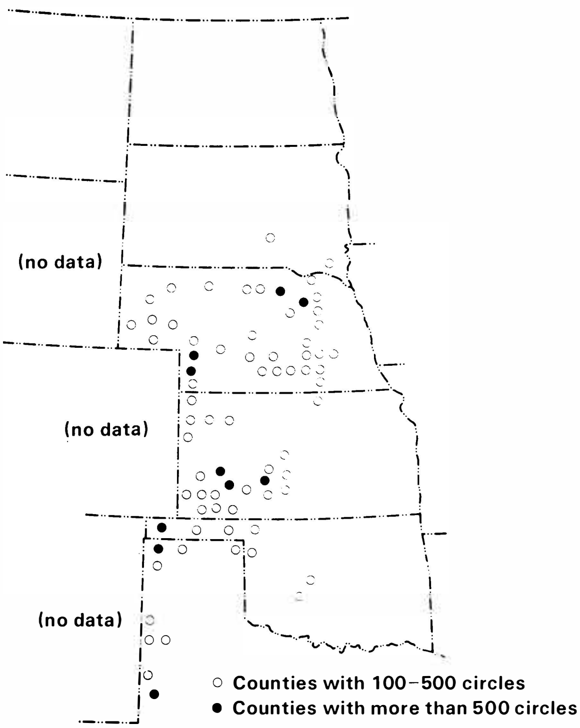

Figure 3: Principal concentrations of center pivot irrigation in portions of the Great Plains, by county, 1976. County data are unavailable for Wyoming, Colorado, and New Mexico. There are no counties with more than 99 circles in North Dakota or Montana. Survey data, which may be incomplete, indicate that outside the Great Plains Region there are four counties (3 in Washington, 1 in Oregon) with more than 500 circles each, and nine other counties with between 100 and 500 circles each (2 in Washington, 2 in Minnesota, 1 each in Oregon, Arizona, Florida, Georgia, Illinois)

Dakota's counties contain circles, as do more than half of the counties in North Dakota and Oklahoma.

Moreover, the increase in center pivot irrigation is much more rapid than that of any other form of irrigation. Total irrigated acreage in the United States is expanding at a rate of about three percent per year, whereas center pivot acreage is growing at about fifteen percent per year, and the trend lines continue to diverge.

Will circles soon be superseded?

Despite disclaimers previously presented, the relative uselessness of the unirrigated field corners remains a nagging perplexity. The usual attempt to get water onto the corners has been by means of a large volume sprinkler attached to the end of the circling lateral which is operated only as the corners are approached. Although this technique gets some water to the corners, it interrupts the regularity of application because pressure along the entire system is reduced whenever the "big gun" is in operation unless there is some means of temporarily pumping more water. The result is generally considered to be unsatisfactory.

The largest producer of center pivot systems, Valmont Industries of Valley, Nebraska, was the first manufacturer to attack this problem in a sophisticated manner[16]. Valmont's approach was to manufacture a system (called the Corner Catcher) that included a 250-foot sweep arm attached to the outer end of the lateral which can alternately trail behind unused or swing out into the corners tracking a low frequency signal from a buried cable. The Corner Catcher adds an additional 17 to 19 acres of irrigated land per quarter section, leaving only 2 to 2½ acres unirrigated in each corner. The sweep arm contributes great versatility to the system, since it can be programmed to irrigate a wide variety of field shapes, skipping obstructions along the way. It also increase the system's cost by about one-third. After extensive field trials, Valmont put the Corner Catcher on the market late in 1975. It is still too early to evaluate its acceptance, although it has been adopted in a number of states (proportionately most significantly in Oregon and Washington), and at least four other manufacturers are working on versions that will offer options of watering the corners.

Does this presage still another Euclidean change in the farm landscape — from circles to ellipses?

[16]) This was the original center pivot system manufacturer; its name was Valley Manufacturing Company before 1966.