Evaluation of center-pivot sprinkler systems

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Driven by water or electric motors, 1,300-foot-long center-pivot sprinklers can, in two days, irrigate 150-acre circles in one sweep. Nonuniformity of applied water can result from faulty design or maintenance.

Some causes of nonuniformity are correctable

Minimizing energy costs for pumping irrigation water requires growers to assess the performance of their irrigation systems. A system evaluation, which describes the performance characteristics such as application rate and uniformity of applied water, can help identify problems in both system design and management that might contribute to energy costs, crop yield reductions, or both.

We recently evaluated three center-pivot sprinkler systems of different design to determine their performance characteristics. Center pivots are machines that continuously revolve around a pivot point, and the revolution time is controlled by the speed of the outermost support tower. A unique design characteristic of these systems is that the water application rate must increase along the lateral to apply a uniform depth of water, since the area irrigated per unit length of lateral increases along the lateral. This rate can be increased by using (1) a constant sprinkler spacing with a progressively increasing nozzle orifice diameter, or (2) a constant nozzle diameter with a progressively decreasing sprinkler spacing. A large sprinkler, mounted at the end of the last lateral, called an end gun, is frequently used to increase the irrigated acreage.

The evaluations entailed measuring pressures, system and individual nozzle flow rates, travel speed, and depth and uniformity of applied water. Transects of catch cans extending radially from the pivot points provided data on depth and uniformity. We used both standard statistical methods (mean, standard deviation, and coefficient of uniformity [Christiansen]) and time/space series statistics to analyze the can data. The former give a
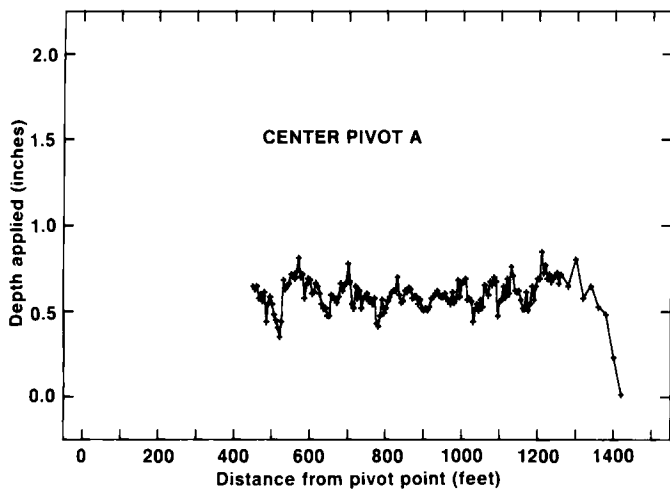
Fig. 1. Catch-can data beyond 400 feet along the sprinkler span showed slight valleys about every 130 to 140 feet.
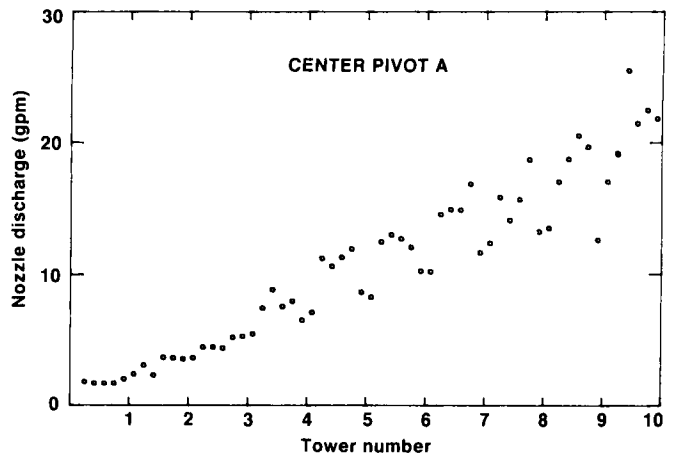

Fig. 2. Nozzle discharges increased appropriately along the lateral, but valleys occurred near each tower.
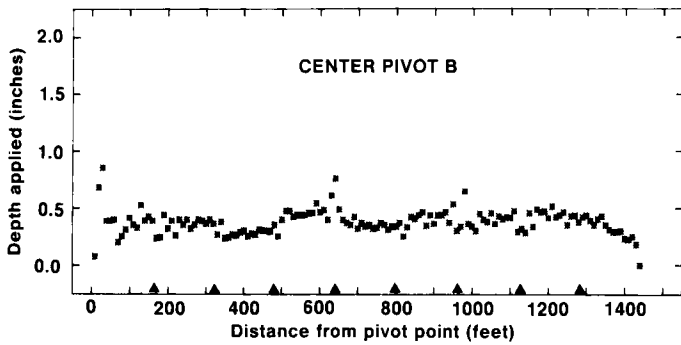

Fig. 3. Catch-can data along length of lateral showed no obvious trend in applied water. (Triangles show tower locations.)
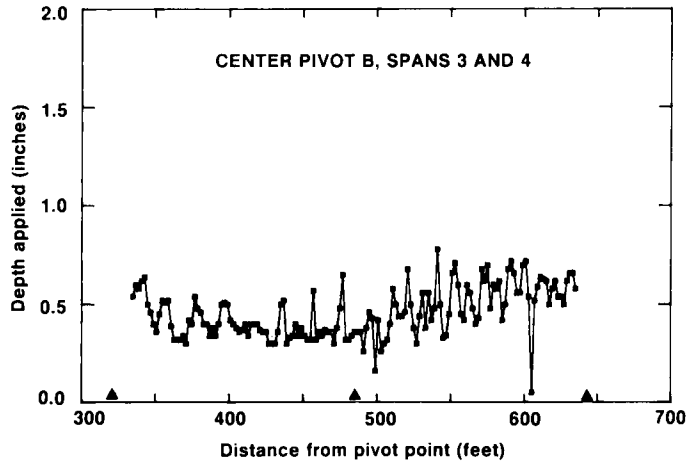

Fig. 4. Catch cans under third and fourth spans showed an average of 0.4 inch of applied water and a CU of 76 percent.
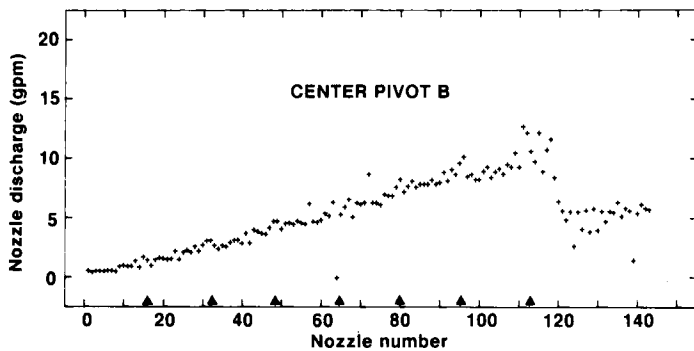

Fig. 5. Nozzle discharges increased until about the midpoint of span eight, after which they decreased.
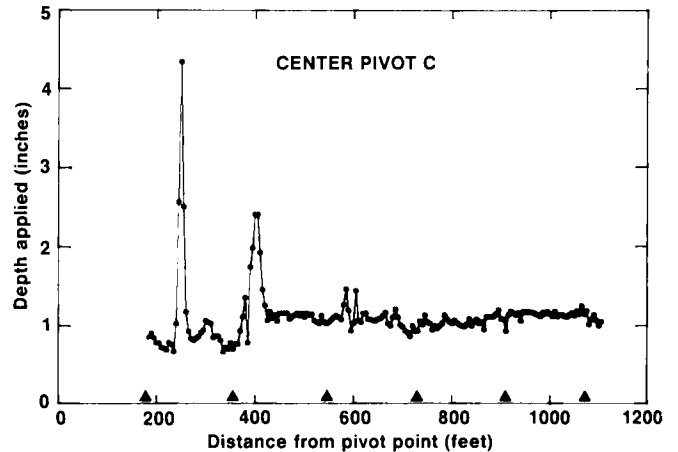

Fig. 6. Catch cans revealed two sources of variability: "spikes" and 24 percent less water applied for the first 360 feet.

measure of uniformity that can be related to a standard; time/space series statistics describe patterns of nonuniformity in the applied water.

Center pivot A

Center pivot A was a water-drive unit consisting of 10 spans, each 130 feet long. Lateral length was nearly 1,330 feet, including the overhang after the last tower. Impact sprinklers were spaced about 20 feet apart along the lateral. Area irrigated was nearly 136 acres. Travel speed of the last tower was 3 feet per minute, and the time for one revolution was 1.9 days. Catch cans spaced 5 feet apart along a radial transect caught 0.6 inch of water applied per revolution, and the coefficient of uniformity (Christiansen's CU) was 89 percent. (A value of 100 percent would indicate the same depth of water applied throughout the field.)

The catch can results show no well-defined patterns of the applied water (fig. 1). No obvious patterns appeared beyond 400 feet. A close examination of the data, however, shows slight valleys about every 130 to 140 feet. The applied water at the end of the lateral is the end-gun pattern.

The statistical analysis revealed a large periodicity, or repeating pattern, in the can data occurring every 130 to 140 feet, about one span length, which accounted for about 75 percent of the variability in the can data. A smaller periodicity occurred over a 20-foot interval.

The large periodicity was attributed to the grower's modification of the sprinkler system. To correct an underdesigned system, he had enlarged orifice diameters of all sprinklers except those adjacent to the water drives to increase the application rate. The system then applied less water near the towers than elsewhere, causing the periodicity. The smaller periodicity of every 20 feet was from the overlap of the sprinkler wetted patterns.

Our conclusion on the effect of the grower's modification was verified by the nozzle discharge data (fig. 2). Nozzle discharges increased along the lateral, as was necessary to maintain a constant depth of water throughout the field. Starting at the end of span four, however, valleys in the data occurred near each tower, the result of the unchanged orifice diameters near the water drive units. We recommended that the unchanged nozzles be enlarged to increase system uniformity.

Design criteria for a sprinkler system normally require that it apply water so that 80 percent of the irrigated area receives an amount at least equal to the peak evapotranspiration between irrigations. For this system, approximately 80 percent of the area received at least 0.53 inch per irrigation. Since the peak evapotranspiration per revolution was estimated at about 0.56 inch, the capacity of this system was just barely adequate under continuous operation.

Center pivot B

The second system, driven by electric motors, consisted of seven spans, each 160 feet long, with flow-regulating spray nozzles spaced every 10 feet, and an eighth span with a variable nozzle spacing. Lateral length was 1,312 feet, and the area irrigated was 150 acres. Travel speed of the last tower was 4.5 feet per minute, and the time for one revoluton was 1.3 days. The system was evaluated at pressures of 37 and 64 psi. The average depth applied was the same for both pressures.

We used two transects to evaluate the uniformity of applied water. One transect, with a can spacing of 10 feet, was used to detect any trend along the lateral, such as increasing or decreasing depth of applied water with distance. The other, with cans at 2-foot intervals under the third and fourth spans, indicated overlap of the closely spaced wetted patterns.

No obvious trend or periodicity in the applied water, verified by statistical analysis, was found in the first transect (fig. 3). Span three (336 to 504 feet) applied less water than elsewhere, the reasons for which are unknown. The average depth applied was nearly 0.4 inch and the coefficient of uniformity was 80 percent.

Depth applied and coefficient of uniformity of the transect over spans three and four were about 0.4 inch and 76 percent, respectively (fig. 4). Again, the depth applied under span three was less. The statistical analysis showed significant periodicity occurring every 20 feet under the third span and every 10 feet under the fourth. Overlap of the wetted patterns was the likely cause of this pattern. A followup evaluation found similar periodicity under other spans and about 24 percent more water applied directly under a nozzle than midway between nozzles.

The periodic behavior from the overlap caused much of the variability in the applied water. However, since this was a design problem, the grower could do little to improve the system.

Nozzle discharge data showed that the discharge increased with distance along the lateral until about the midpoint of span eight (fig. 5). Discharge and nozzle spacing thereafter decreased. Nozzle discharge over span three (no. 32 to 47) showed no reason for the relatively smaller depth of applied water found under that span. The statistical analysis showed no relationship between nonuniformity in the discharge data and nonuniformity of the first transect (fig. 3).

This system applied 0.4 inch of water every 1.3 days. For an 80 percent uniformity, 80 percent of the irrigated area received at least 0.32 inch per revolution. Since the peak evapotranspiration per revolution was about 0.38 inch, the crop was slightly underirrigated.

Center pivot C

The third system, also an electric drive, had seven spans, each 180 feet long, with impact sprinklers. Sprinkler spacing was variable along the lateral. Nozzle sizes were $5/32$ inch for the first two spans and $11/64$ inch for the remainder. Travel speed was 1.6 feet per minute, and the time for one revolution was 3.4 days. Average depth applied was 0.9 inch, and the coefficient of uniformity was 89 percent. The system irrigated 141 acres.

Catch can data showed some obvious sources of variability in the applied water (fig. 6). A large "spike" was found at about 250 feet and a smaller one at about 400 feet. The large spike was caused by a nonrotating sprinkler head. Reasons for the smaller spike were possibly a sprinkler head with no nozzle or a large-diameter orifice. Also, the average depth of applied water was about 24 percent less for the first 360 feet (excluding the spikes) than for the remainder of the lateral, the result of the smaller nozzles used on the first two spans.

A statistical analysis revealed no frequency-related patterns of nonuniformity in the catch can data. Repairing defective nozzles and increasing nozzle sizes over the first two spans would have slightly improved the system uniformity to only about 92 percent, because the area irrigated by the first two spans was small, about 9 acres, compared with the total acreage irrigated.

This system applied at least 0.8 inch of water over 80 percent of the land every 3.4 days. Peak evapotranspiration during this period was about 1 inch. The crop was thus underirrigated under continuous operation.

Conclusions

These evaluations showed several different causes of nonuniformity in these systems, varying from a grower modification to lack of maintenance to design problems. The first two causes are correctable. Problems with the system design, however, may be difficult and expensive to correct, and the benefits of any changes may not warrant the costs.

All three systems could use more capacity to meet peak evapotranspiration. Enlarging the nozzles of the impact sprinklers would increase the system capacity, but pump performance and lateral hydraulics characteristics would also affect the final flow rate. The flow-regulating spray nozzles on center pivot B would have to be replaced to increase system capacity.

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