EVALUATION OF CENTER PIVOT IRRIGATION SYSTEMS UNDER EGYPTIAN CONDITIONS

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Abstract

Four center pivot systems namely CPS1, CPS2, CPS3 and CPS4 were evaluated for improving water distribution uniformity during year (95/96). The selected systems covered areas ranged from 2 fed to 150 fed. Water distribution uniformity Cw, coefficient of uniformity of Charnes O12, Wilcox and Savele Owp, Bessani and More Opa, coefficient of variance CV and both of the application efficiency AE and system efficiency SE were studied. It was found that average value of uniformity coefficient Cw of O12, Owp and Opa can be considered as a suitable parameter to evaluate CP system under Egyptian conditions, in addition of coefficient of variation CV. Results indicated that the change of distribution uniformity Du ranged from 3% to 13% was due to operating the tested systems for two seasons. The change in the average uniformity coefficient Cw ranged from 0.7% to 8.9% resulting in the system efficiency changed from 9% to 13% depending on the amount of water applied (under 100% of setting speed). System maintenance specially after each season is essential to maintain high efficiency of the CP systems. Paper presented the most constrains which limited the expansion of CP system in Egypt.

INTRODUCTION

The center pivot system was introduced in some Egyptian desert areas in Saiheia, and West Nubaria since 1981. About more than 450 center pivots are still working until now. Several center pivots were replaced by other irrigation systems due to the problems facing center pivot operation under Egyptian conditions.

Current systems supply water, herbicides, insecticides and other chemicals in a manner that fits the timely need of the crops, reducing growing requirements for irrigation and chemicals application. The CP is considered a capable system to irrigate sandy soils, which was not previously considered feasible for agricultural pro-
Mechanical system such as the center pivot minimize problems concerning the variability of the soil intake and water holding capacity. Center pivot systems require efficient management to determine the operating pattern of the systems. The most important performance criterion for an irrigation system is the uniformity of application. Radi (1994) evaluated different types of irrigation systems in sandy soils. He found that Du and CU for CP systems in different locations in Noubaria, ranged from 51.8 to 76.5 for Du and ranged from 66.4 to 84.5 for CU.

The CU and DU uniformity parameters facilitate describing the actual distribution of the applied water. Mark et al., 1986, compared the coefficient of variance CV with the CU and recommended that CV is more appropriate for comparing the distribution for center pivot irrigation systems. Heerman et al., 1992 stated that in the most cases (60 CP systems tested) the normal distribution better describing the data. It has been recommended for analyzing the value of increasing irrigation system performance. They studied and investigated four distribution functions namely: normal, lognormal, uniformed and specialized power. They also concluded that CV is not an indicator of how well the data can be represented by a theoretical distribution. Heerman et al., (1992) reported that a level of CU and DU is generally selected for accepting a design and operation of the system. The manufacturers of center pivot system widely use the Christiansen uniformity coefficient to compare the irrigation uniformity. They also stated that the benefit of improving the center pivot system with lower CV values can be analyzed with the assumption of normal distribution.

Hill and Keller (1980) estimated the attainable irrigation uniformity and calculated the optimum amounts of water applied to maximize profit, for selected types of irrigation systems. The optimum application was influenced by the capital cost of the irrigation system, uniformity and efficiency of irrigation, expected impact of system type on crop yield, and value of crop. They added that results analysis showed that improvements in irrigation system uniformity should be mandatory to maintain profitable irrigation. Varlev (1976) analyzed the impact of irrigation uniformity on yield and the importance of considering the water-yield relation for over as well as under irrigation. Whenever irrigation supplied more than 60 to 80% of the total water it was impossible to attain the same yield with a nonuniform irrigation system by simply increasing the depth of application. Van Bormuth (1983) developed relationships between the coefficient of uniformity giving high economic return and the depth of applied water under a situation of deficit irrigation. He demonstrated that the greatest the depth of applied water (up to the plant water requirement) and
the greater the crop value, the higher the coefficient of uniformity that could be economically justified.

Improvement of uniformity under a center pivot system requires investment, either in capital outlay for system improvement or maintenance. Furthermore it is necessary to consider the concept of uniformity of water applied related to uniformity of yield. The objective of this paper is to study the improvement of uniformity of center pivot system and to identify the suitable parameters of uniformity for evaluation of CP system. Based on the performance study, the drawbacks which eliminated expansion of center pivot in Egypt could be specified.

FIELD PROCEDURES

Field data:

Four center pivot systems naming CPS1, CPS2, CPS3 and CPS4 were evaluated during summer season 95 and re-evaluated at the end of winter season 95/96. The CPS1 system was recently installed in the Experimental Farm of Faculty of Agriculture – Ain Shams – Univ. "Shalqam" Qalubia governorate (clay loam soil). The other three center pivot systems were already installed in Dina Farm, West Nubaria, in 1986-1992. Before evaluation, the systems were calibrated to determine the actual performance of each CP. The CPS1 received minor adjustment for a few number of nozzles. Other CP systems require adjustment and replacement of many nozzle sizes according to the catalog of each system. The relation between setting speed and both water uniformity parameters and system efficiency were studied (for the CPS1 only) to determine appropriate depths of application for scheduling center pivot irrigation. In the current paper setting speed was used to facilitate changing the system discharge. Table 1 shows the specifications of studied systems.

Table 1. Specifications of the studied center pivot systems:

<table>
<thead>
<tr>
<th>Specification</th>
<th>CPS 1</th>
<th>CPS 2</th>
<th>CPS 3</th>
<th>CPS 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length, m.</td>
<td>42</td>
<td>108</td>
<td>360</td>
<td>450</td>
</tr>
<tr>
<td>Actual irrigated area, fed.</td>
<td>2</td>
<td>50</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>Pressure at pivot, bar</td>
<td>2.5</td>
<td>2.5</td>
<td>3.0</td>
<td>5-6</td>
</tr>
<tr>
<td>Ave. system flow rate, m³/h</td>
<td>3.5</td>
<td>190</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Clearance, m</td>
<td>1.8</td>
<td>2.8</td>
<td>2.8</td>
<td>2.8</td>
</tr>
</tbody>
</table>
Procedures

Experiments were conducted in bare land (no crop) in the afternoon and the time at which the tests run were selected where wind speed was virtually calm. One radial line of catch cans was arranged for testing each system. For CPS1, CPS2 catch can spaced 2.6 m and 6 m respectively. The first can was positioned at 1.5 m and 4.5 m from the pivot respectively, while the last can was positioned beyond the end of the outermost head of the sprinkler head. For the CPS3 and CPS4 the can spacing was 9 m, with the first can at 4.5 m from the pivot, and last one was also beyond the reach of the outermost of the sprinkler head. The catch cans were weighted by multiplying the can position number by the water receiving depth, since receiving points represent progressively larger area as the distance from the pivot increases. Data of flow measurements and machine speed were recorded. For evaluating the system performance the following steps were taken.

Measures of uniformity:

1. Coefficient of uniformity

The field data was used to determine Christiansens uniformity \( CU_C \) (1942), Wilcox and Swales \( CU_W \) (1947) and Benani and Hore \( CU_B \) (1964) as follows:

\[
CU_C = \left(1 - \frac{\sum_{i=1}^{n} (X_i - \bar{X})}{\bar{X}}\right) \times 100
\]

Where

\( X_i \) = water depth in catch can number \( i \), cm.
\( \bar{X} \) = average water depth in can for number \( n \) of cans.

\[
CU_W = \left(1 - \frac{S}{\bar{X}}\right) \times 100
\]

Where: \( S = \) standard deviation.
\( \frac{S}{\bar{X}} = \) coefficient of variance.

\[
CU_B = \left[1 - (0.63 \times CV)\right] \times 100
\]

After the CP passes the position of the catch cans, the amount of water in cans were measured to determine the water depth. The quarter of the cans received the least amount of water considered for DU calculations.
2. The Soil Conservation Service 1982, uses a weighted procedure to determine distribution uniformity DU. The DU is defined as the ratio of the average water depth received by quarter of total number of cans which received the least amount of the water to average depth of the water by system catch multiplied by 100. The application efficiency AE (mean depth in catch cans divided by mean pumped depth), and system efficiency SE (AE * DU) were calculated. The CV has been recommended to be more appropriate than the CU in certain conditions (Solomon, 1984, Marek et al, 1988). Performance parameters were determined to facilitate specifying system adjustment for one year operation. All the recommendations of measurement are in accordance with the method used in this analysis.

According the calculation of DU, AE and SE were calculated as follows:

\[
DU = \frac{\text{average weighted low quarter catch}}{\text{Average weighted system catch}} \times 100
\]

\[
AE = \frac{\text{Average water depth system catch}}{\text{Average pumped water}} \times 100
\]

\[
SE = DU \times AE
\]

3. Finally the reasons of CP poor performance were recorded to identify the drawback related to center pivot operation maintenance, and management that limit the spread in using center pivot in Egypt.

RESULTS AND DISCUSSION

The preliminary calculations of CU showed the considered CUg and CUq for computing CU was better than the considered CUw. Consequently CUq was calculated as the average of CUg and CUq, while CUw was eliminated from calculations. The uniformity parameters CUg, DU and CV in addition to application efficiency AE and system efficiency SE were considered for performance evaluation of CP systems as shown in Table 2. Figs. 1-7 show the water depth catch can along the CP.

A function of the plots show the location of the improperly performing nozzles or malfunctioning sprinklers. Preliminary test was conducted to locate and adjust the malfunctioning nozzles of the tested systems before executing the evaluation. This means that, some sprinklers were replaced and others were repaired.
It is worth mentioning that the determination of system efficiency (SE) depending on DU and AE was a good indicator to express the performance of the CP system. It is also clear from Table 2, and Figures from 1 to 7a, there is a relation between the uniformity of water distribution around average catch can depth and the high value of SE. The determination of CV for evaluated systems during one year of operation is very useful. Results indicated that the difference between the lowest and highest CV values ranged between 0.06 to 0.13. These results indicated that the lower CV the higher SE value. Consequently, this CV was used as a parameter to pursue the changes in the calibrated system. The system efficiency was influenced by, the flow rate as a function of the system discharge, setting speed, and operating pressure. Comparing the changes in DU, CV, CUn, and SE for one year of operation, it may clearly be observed that the CUn is a good indicator to express the status of the system. Whereas the change of the coefficient of uniformity from 93% to 78% is equivalent to a decrease of 46% of the average of applied water as a function of system flow rate. It can be concluded that improving the coefficient of uniformity will improve the system efficiency which may reduce the operating costs. For Zea mays, each mm of water deficit was assumed to reduce grain yield by 19.8 kg/ha (Berrett and Slegersboe 1973). In conclusion, improvement of water uniformity is one of the most critical management decisions, the operator can make.

Table 2. The uniformity parameters, application efficiency (AE) and system efficiency (SE) for center pivot systems.

<table>
<thead>
<tr>
<th>System</th>
<th>Setting Speed, %</th>
<th>Ave. Catch Depth, cm</th>
<th>Ave. Pumped Depth, cm</th>
<th>CUn, %</th>
<th>CV, %</th>
<th>DU, %</th>
<th>AE, %</th>
<th>SE, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPS1</td>
<td>25a</td>
<td>0.93</td>
<td>0.96</td>
<td>93.0</td>
<td>0.11</td>
<td>83</td>
<td>97</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>25b</td>
<td>0.83</td>
<td>0.94</td>
<td>87.5</td>
<td>0.20</td>
<td>82</td>
<td>86</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>50a</td>
<td>0.75</td>
<td>0.76</td>
<td>90.9</td>
<td>0.14</td>
<td>84</td>
<td>99</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>50b</td>
<td>0.71</td>
<td>0.75</td>
<td>84.7</td>
<td>0.21</td>
<td>81</td>
<td>95</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>75a</td>
<td>0.68</td>
<td>0.61</td>
<td>87.9</td>
<td>0.17</td>
<td>82</td>
<td>95</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>75b</td>
<td>0.55</td>
<td>0.60</td>
<td>80.4</td>
<td>0.23</td>
<td>77</td>
<td>92</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>100a</td>
<td>0.47</td>
<td>0.49</td>
<td>83.9</td>
<td>0.22</td>
<td>77</td>
<td>96</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>100b</td>
<td>0.45</td>
<td>0.49</td>
<td>83.2</td>
<td>0.24</td>
<td>74</td>
<td>92</td>
<td>68</td>
</tr>
<tr>
<td>CPS2</td>
<td>100a</td>
<td>0.50</td>
<td>0.52</td>
<td>85.0</td>
<td>0.22</td>
<td>79</td>
<td>94</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>100b</td>
<td>0.50</td>
<td>0.52</td>
<td>77.8</td>
<td>0.32</td>
<td>65</td>
<td>94</td>
<td>61</td>
</tr>
<tr>
<td>CPS3</td>
<td>100a</td>
<td>0.44</td>
<td>0.50</td>
<td>91.6</td>
<td>0.13</td>
<td>86</td>
<td>88</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>100b</td>
<td>0.42</td>
<td>0.50</td>
<td>85.7</td>
<td>0.21</td>
<td>76</td>
<td>84</td>
<td>64</td>
</tr>
<tr>
<td>CPS4</td>
<td>100a</td>
<td>0.41</td>
<td>0.49</td>
<td>91.7</td>
<td>0.12</td>
<td>83</td>
<td>84</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>100b</td>
<td>0.40</td>
<td>0.48</td>
<td>82.8</td>
<td>0.25</td>
<td>73</td>
<td>83</td>
<td>61</td>
</tr>
</tbody>
</table>

Based on observations and the data of the field tests of center pivot systems for during two continuous seasons the following drawbacks were recorded:

1. Main spare parts of the CP system are not available.

2. Experienced persons for operation and maintenance of the center-pivot are not available.

3. High price cost of the center pivot.

4. The center pivot may become out of order when one of the front towers breaks down.

5. Accurate data about the optimum depth of applied water and irrigation scheduling of the center pivot system are not available.

**SUMMARY AND CONCLUSION**

Four types of center pivot system were evaluated for determining the uniformity of water distribution. From the field tests data it can be concluded that the average of CUC and CULg is considered as a good indicator for coefficient of uniformity. Meanwhile coefficient of variance CV is a good indicator to express the changes of CP systems status. Under Egyptian conditions it is necessary to carry out maintenance at the end of each season to maintain high efficiency of the system, and to improve the uniformity of water application. The main breakdown of center pivot systems under Egyptian conditions was determined by analyzing the field data and observations from system sites.
Fig. 1.a. Profile of catch water depth of CPS 1 for summer 95.

Fig. 1.b. Profile of catch water depth of CPS 1 after winter 95/96.
Fig. 2.a. Profile of catch water depth of CPS 1 for summer 95.

Fig. 2.b. Profile of catch water depth of CPS 1 after winter 95/96.
Fig. 3.a. Profile of catch water depth of CPS 1 for summer.

Fig. 3.b. Profile of catch water depth of CPS 1 for after winter.
Fig. 4.a. Profile of catch water depth of CPS 1 for summer.

Fig. 4.b. Profile of catch water depth of CPS 1 after winter.
Fig. 5.a. Profile of catch water depth of CPS 2 for summer 95.

Fig. 5.b. Profile of catch water depth of CPS 2 after winter 95/96.
Fig. 6.a. Profile of catch water depth of CPS 3 for summer 95.

Fig. 6.b. Profile of catch water depth of CPS 3 after winter 95/96.
Fig. 7.a. Profile of catch water depth of CPS 4 for summer 95.

Fig. 7.b. Profile of catch water depth of CPS 4 after winter 95/96.
REFERENCES


تقييم أجهزة الرى الحوري تحت الظروف المصرية

جمال حسن السيد و حافظ محمود محمد سلطان

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اجريت الدراسة الحالية لتقويم أربعة أجهزة للمؤسسة المصرية لمساحات 3 - 5 و 15 هكتار. وكان أحد هذه الأجهزة يعمل بالأراضي الطينية/ النمذجة بمنطقة صقلية - الشهيرة، والأنواع الأخرى تعمل بالأراضي المم看完 بمنطقة فرسا السويسية.

اعتمد التقييم على دلالات الانتقائية لكل من CV بالجدول CV ككل جهاز وكذلك كفاءة الجهاز كما تم تقدير كفاءة الانتقائية DU لكل جهاز من الأجهزة تحت الدراسة وجمع البيانات الخاصة أثناء موسم الزراعة الصيفي عام 1995 ونهاية موسم الشتاء 1996.

وقد أظهرت نتائج الدراسة أنه يمكن تحصين الانتقائية التوزيعي مع رفع كفاءة النظام بالإجراء الصيانة المبكرة في نهاية كل موسم زراعي.

كما أن استخدام معامل الاختلاف كمعدل التقييم في حالة النظام يعتبر مهما جداً بالإضافة إلى أن معامل الانتقائية التوزيعي الناجح من النشاط النموي لكل من CV يعتبر مناسبًا لتقويم نظام الرى الحوري تحت الظروف المصرية. كما تم تيسير المواعيد المؤثرة التي تحدد من استخدام الرى الحوري في مصر.