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Detecting the Performance of Centre Pivot Irrigation System Using DEPIVOT Simulation Model

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ABSTRACT
Design and evaluation of center pivot irrigation system (DEPIVOT) is a method for assessing the technical efficiency of center pivot sprinkler irrigation systems, such as operating speeds, for various requirements. Catch cans method was conducted to evaluate the distribution uniformity (DUlq) and Christiansen coefficient of uniformity (CU), catch cans method was used to evaluate two center pivot irrigation systems: CP1 (center pivot, 6'' diameter number of the nozzle orifice 17 attached with 10 L min^{-l} flow) and CP2 (center pivot, 8" diameter number of the nozzle orifice 25 attached with 20 L min^{-l} flow) under three speeds (50 %, 75 %, and 100 % of the system's normal speed, or 15 m h^{-1}, 22.5 m h^{-1}, and 30 m h^{-1}, respectively). All 18 can tests were entered into the DEPIVOT simulation model, which simulated the DUlq and CU for each test separately, allowing the DEPIVOT simulation model to be validated by statistically comparing the simulated and measured data in the field. The validation process using the DEPIOVT simulation model was found accurate, with a success rate over 95 %, making it a recommended method for validating the efficiency of center pivot irrigation systems.
Keywords: Simulation model, Validation, Center pivot, Distribution uniformity, Christiansen uniformity

1. Introduction

The irrigation process supplies water required for crop growth when rainfall is limited (Rockström et al., 2010). Agriculture already accounts for about 70 % of the freshwater withdrawals in the world and is usually considered as the main factor behind the increasing global scarcity of freshwater (Faurès et al., 2002). Agriculture is a cornerstone to food security and economic growth in developing countries. Therefore, irrigation water should be adequately applied to crops to avoid water waste (Noreldin et al., 2015). One possible approach to conserve the scarce resources of freshwater may be through improving the performance of the existing irrigation projects, meanwhile, there are different methods of irrigation water applications, such as center pivot sprinkler irrigation methods, which is one of the pressurized irrigation systems that take water from a source and spray it to the atmosphere as droplets by means of an enclosed system and under pressure. A sprinkler "throws" water through the air to simulate rainfall (Scherer, 2018). Irrigation uniformity is a concept that all areas within an irrigated field received the same amount of water (Kelley, 2004). DU is calculated by dividing the weighted average of the lowest 25% of the catch cans by the weighted average of the total catch cans. A value of 85% or greater is considered excellent, 80% is considered very good, 75% is considered good, 70% is considered fair, and 65% or less is considered unacceptable (Merriam and Keller, 1978). Evaluation of the water application efficiency (WAE) of low and mid-elevation spray application (LESA and MESA) using catch can test and drainage lysimeters, and develop governing equations based on the weather variables. Catch cans were used to collect the fraction of total irrigation water applied that reached the ground surface as WAE and drainage lysimeters to quantify the overall water loss (OAWL) and wind drift and evaporation losses (WDEL), where (WDEL = 100-WAE) (Sarwar et al., 2019). The model has two main components: A. the design of new systems and B. the evaluation of operating systems. The first component starts with the agronomic design aiming at the calculation of the system flow rate; this is followed by the hydraulic design: (a) computes friction head losses along the lateral; (b) the creation of the sprinkler chart; and (c) the validation of the sprinkler chart. The second component requires field data to calculate performance indicators, such as distribution uniformity (DU) and the coefficient of uniformity (CU) (Valín et al., 2011). The simulation model DEPIVOT has been developed to design new systems or to change systems during operation. The software concludes a simulation package developed in Visual Basic and database in Access. The user verifies if performance is within target values set at the start and may develop and compare alternative sprinkler packages until appropriate conditions are obtained (Valín et al., 2012).The center pivot evaluation and design software were used to simulate theoretical uniformity, and these simulations were tested against field observations of the coefficient of uniformity. Finally, we use the parameterized equations within the center pivot evaluation and design software to simulate the coefficient of uniformity for pivots with constant nozzle heights with a random distribution of nozzle heights, which simulate a dynamic elevation system (Al-agele et al., 2020). The performance evaluation was conducted on Mobile Drip Irrigation (MDI) for maize production, in comparison to common center-pivot nozzles (Low Elevation Spray Application (LESA) and Low Energy Precision Application (LEPA)). A center-pivot was retrofitted with MDI, LEPA and LESA. Irrigation capacities of 6.3, 3.1, and 1.6 mm/d were considered, there were no significant differences in water use efficiency between the application technologies ($p = 0.2352$), at 5% significance level, however, differences between irrigation capacities were significant ($p = 0.050$) (Oker et al., 2018). Distribution uniformity (DU) and coefficient of uniformity (CU) are commonly used irrigation performance measures of how evenly water is applied across a field during irrigation. The more DU or CU can be improved, the greater water will be conserved and the better the crop will perform. DU and CU are the most measured parameters for sprinkler irrigation using catch cans. Gross irrigation amounts are often increased to account for poor DU and CU by dividing the net irrigation required by the DU or CU as a decimal (Mohamed et al., 2019). The overall aim of this research study was to validate the DEPIVOT simulation model to evaluate existing center pivot irrigation systems.

2. Materials and methods

Two center pivot irrigation systems were tested at a private farm in Nubaria district, El-Beheira province, (latitude of 30̊ 37′ 28″ N and longitude of 30̊ 09′09″ E). The mechanical analysis of the experimental soil was measured (Table, 1), the experimental soil was classified as sandy according to (Klute, 1986).

Table 1
The mechanical analysis of the experimental soil at Nubaria region.

Soil depth, cm	Sand, %	Silt, %	Clay, %	Soil texture
0 – 20	78	5	17	Sandy
20 – 40	78	5.5	16.5	Sandy
40 – 60	76	5.5	18.5	Sandy

2.1. Center pivot irrigation system (CP) specifications

Two center pivot irrigation systems were evaluated; each system had 3 spans 6" diameter of 45 m long, 135 m in total for the whole system. The first center pivot (CP1) had 16 pieces have the number of the nozzle orifice 17 attached to each span after the pressure regulators (20 psi), low drift nozzle (LDN; 3 mm orifice diameter, 10 L min^{-l}), the nozzle height was 1.5 m from the soil surface . The second center pivot (CP2) had 3 spans of 8" diameter with 16 pieces have the number of the nozzle orifice 25 attached to each span after the pressure regulators (20 psi), low drift nozzle (LDN; 5 mm orifice diameter, 20 L min^{-l}), the height between the nozzle and the soil surface was 1.5 m.

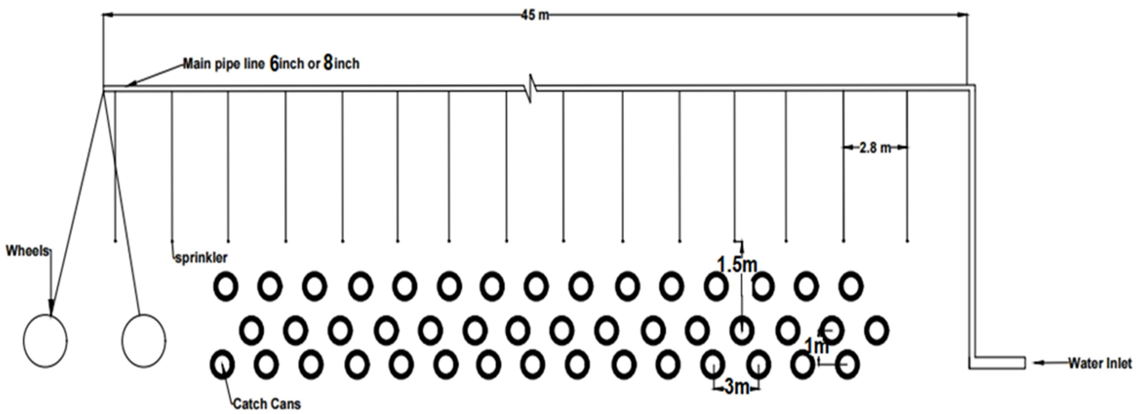

Fig. 1. Center pivot irrigation system dimensions and distribution of catch cans under the system during the performance evaluation process.

Fig. 2. Center pivot and catch cans distribution lines.

2.2. The performance evaluation test and calculations

The performance evaluation process was done under three system speeds (50%, 75% and 100%; 15, 22.5 and 30 m h^{-l}, respectively). Catch cans of 600 mm volume and 6.5 cm diameter were used; the catch cans were placed directly on the soil surface in 3 lines, 3 m between each other and 1 m between the lines. Figures (1) and (2) show the experimented CP irrigation systems and the distribution of catch cans during the test. System speed was fully automatic controlled using a control panel with a power timer. The low quarter distribution uniformity (DU) was determined as the ratio between the mean depth caught of one-fourth of the field receiving the least amount and the mean depth caught on the entire area according to Michael (1978) as shown in Equation (1).

$$\mathrm{DU}_{\mathrm{lq}} = \frac{\overline{V_{lq}}}{\overline{V_{tot}}} \qquad (1)$$

Where

$\overline{V_{lq}}$ is the average of the lowest one-fourth of catch cans measurements (mL).

$\overline{V_{tot}}$ is the average of the application overall catch cans measurements (mL).

The Christiansen Uniformity (CU) was calculated as in Eq. 2., (ASAE Standards, 2001).

$$\mathrm{CU} = 100 \times \left[1 - \frac{\sum_{i=1}^{n} \left| V_i - \overline{V} \right|}{\sum_{i=1}^{n} V_i} \right] \qquad (2)$$

Where

V_i is the individual catch cans measurement (mL).

$\overline{V}$ is the average volume of the application overall catch cans measurements (mL).

2.3. Validation of design and evaluation of center pivot simulation model (DEPIVOT)

DEPIVOT simulation model was used to calculate the simulated evaluation data of DUlq and CU under the above-mentioned experimental conditions of both tested center pivot irrigation systems to validate it to predict the center pivot's performance. Figure (3) shows the main screen of the simulation model which could be used to design a new center pivot irrigation system and/or evaluate the performance of an existing center pivot irrigation system, but in this study, the evaluation procedure was used only. Figure (4) shows the main inputs of the farm data, then the other inputs of the catch can diameter and depth, as well as the measured depths in the field, was put in the proper fields of the simulation model.

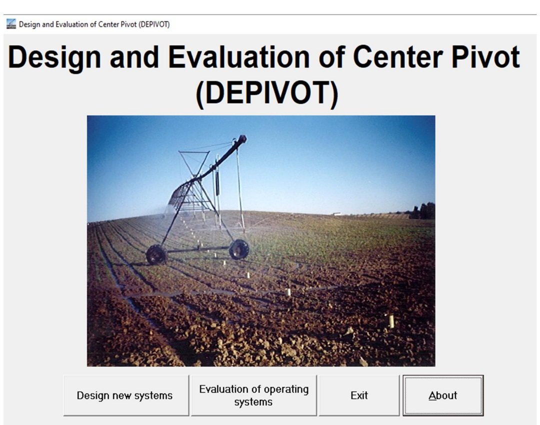

Fig. 3. The main window of the simulation model.

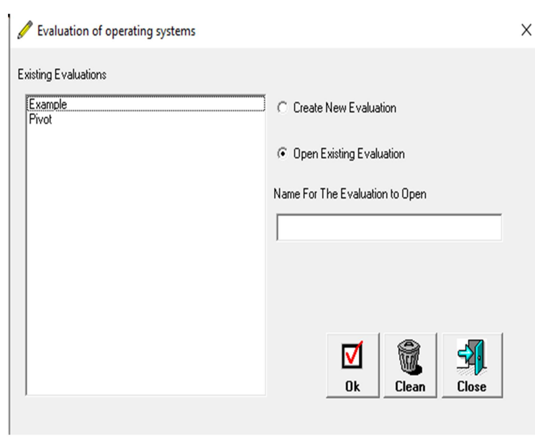

Fig. 4. The main input window of farm data.

2.4. Statistical analysis

The application depth of the water was determined by dividing the size of water caught in the catch cans by those cross-sectional areas, to collect water from sprinklers to study the effect of the experimental parameters on water coefficient uniformity (CU), and distribution uniformity (DU). The performance of the sprinkler irrigation system was evaluated three various times (early morning, noon, and night) which expressed as three replicates for the statistical analysis, (split-split plot design) according to Snedecor and Cochran (1990). It is recommended to use confidence intervals tests for the comparisons because these allow for objective decisions. So, the use of graphs and statistical confidence tests (t-test, and regression) is the most used approach for simulation model operational validity (Mehanna et al. 2015). Table (2) shows the acceptability of the regression analysis between the measured and the simulated DUlq and CU data.

Table 2

The acceptable, not acceptable range for comparing the measured and simulated values.

Parameter	Not acceptable	Acceptable
CU	Value < 75%	Value > 75%
DU	Value < 70%	Value > 70%

3. Results and discussion

3.1. Performance evaluation of center pivot irrigation system (CP)

CP1 and CP2 were evaluated at the Nubaria region under different parameters. A total of 18 capture can tests were performed under three varying system speeds (50 %, 75 %, and 100 % of the system's normal speed, respectively, or 15 m h^{-1}, 22.5 m h^{-1}, and 30 m h^{-1}). The collected water was measured using a graduated funnel after the irrigation system's maximum passing can lines to determine the low quarter distribution uniformity (DUlq) and the Christiansen uniformity coefficient(CU).Figures 5 and 6 display the relationship between system speed, DUlq, and CU for both tested systems, suggesting that increasing system speed from 15 m $h^{-1}$to 30 m h^{-1} increased DUlq and CU values for CP1, but the highest DUlq and CU values for CP2 were obtained using the mediate system speed (22.5 m h^{-1}). For this, CP1 is recommended for uniformly distributing irrigation water. The individual effects of the center pivot irrigation system and system speed on the measured DUlq and CU are presented in Tables 3 and 4, respectively. CP1 had the highest DUlq and CU values of 82.86 % and 77.87 %, respectively, which had no meaning when compared to CP2, which had the lowest DUlq and CU values (Table, 3). Table 4 shows the impact of machine speed on DUlq and CU showing that the maximum DUlq and CU values were obtained with the highest system speed (100 % of the standard irrigation system speed; 30 m h^{-1}), followed by the intermediate system speed (75 % of the standard irrigation system speed; 22.5 m h^{-1}), and the lowest values were recorded with the lowest system speed (50 % of the standard irrigation system speed; 15 m h^{-1}). The findings revealed that the pivot circular application uniformity is primarily determined by the transfer distance expressed as a percentage of the sprinklers' wetted radius. This, in turn, is determined by the percent timer configuration, the cycle time, and the speed at which the end tower travels. As a result, when opposed to low-speed devices, high-speed centre pivots had lower application uniformities, and sprinklers with larger wetted radii had greater uniformity. Higher uniformity coefficients were also achieved by reducing the cycle time. Based on these findings, the run time should be determined by the pivot end-tower travel speed and sprinkler wetted radius. Table 5 shows the relationship between the two experimental variables (irrigation systems and irrigation system speed). Fewer variations between the DUlq ways were noticed. For the CP1, the maximum values of DUlq and CU were obtained using 30 m h^{-1} system speed; 86 % with little difference as compared to the intermediate system speed (22.5 m h^{-1}); the same pattern was observed for CU. In general, the highest studied speed produced the highest DUlq and CU values. Furthermore, for standardized irrigation water delivery, CP1 and the highest system speed are the proper requirements. These results were consistent with the finding of Abedinpour (2017), who investigated the effect of different speeds produced CU values of 80.3, 82.7 and 86% for 40%, 60%, and 80% speed, respectively. Furthermore, DU standard value of 82% was obtained at 80% speed.

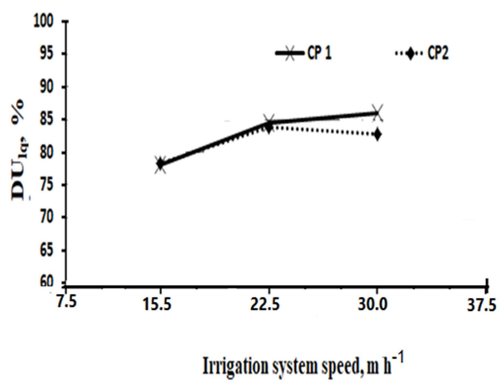

Fig. 5. The relationship between system speed, DUlq for center pivot 1 and center pivot 2.

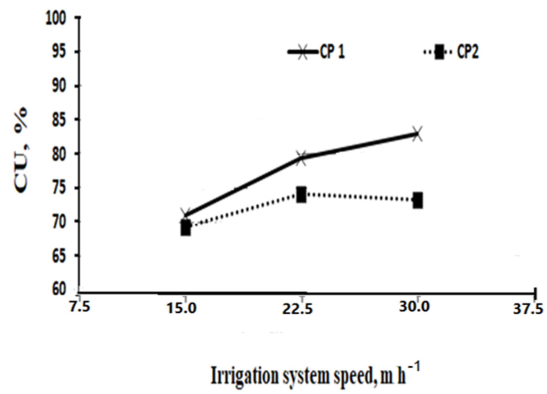

Fig. 6. The relationship between system speed and CU for center pivot 1 and center pivot 2.

Table 3
Uniformity and statistical analysis of catch can data for both tested center pivot irrigation systems.

Irrigation system	DU_{lq}, %	CU, %
CP1	82.86	77.87 [a]
CP2	81.63	72.27 [b]
L.S.D at 5% level	N.S.	4.325

Table 4
Uniformity and statistical analysis of catch cans data under different system speeds.

System speed, m h^{-1}	DU_{lq}, %	CU, %
15.0	78.13 [b]	70.27 [b]
22.5	84.18 [a]	76.80 [a]
30.0	84.42 [a]	78.15 [a]
L.S.D at 5% level	4.27	4.88

Table 5
Uniformity and statistical analysis of catch can data for both tested center pivot irrigation systems as affected by system speed.

Irrigation system	System speed, m h^{-1}	DU_{lq}, %	CU, %
Center pivot 1	15.0	77.98 [b]	71.12 [c]
	22.5	84.58 [a]	79.50 [ab]
	30.0	86.00 [a]	83.01 [a]
Center pivot 2	15.0	78.28 [b]	69.43 [c]
	22.5	83.77 [ab]	74.10 [bc]
	30.0	82.84 [ab]	73.30 [bc]
L.S.D at 5% level		2.36	N.S.

3.2.1. Inputs of DEPIVOT simulation model

3.2. Validation of DEPIVOT Simulation model under the studied center pivot irrigation system

DEPIVOT is a center-pivot design and measurement model that consists of five key sub-models, each of which estimates the desired uniformity performance indicators while in use. The user checks to see if the output is within the target values set at the start, and then develops and compares different sprinkler packages until the right conditions are identified. When the model is used to evaluate systems in practice using data obtained in farmers' fields, performance metrics are computed, and the model can be used to design improvements in current systems and enhance management in response to farmers' needs (Valín, et al., 2012). The Input observed data consist of the amount of water caught in each catch can (ml) (Fig. 7), so the model computes the respective water depths along a radius (Dj, mm), the average weighted system catches (Davg, mm), the average weighted low quarter catch DUlq (mm), and CU. All 18 can test were entered into the DEPIVOT simulation model to simulate the DUlq and CU for each test separately, to statistically compare the simulated data to validate the used simulation model under different experimental conditions (Table, 6).

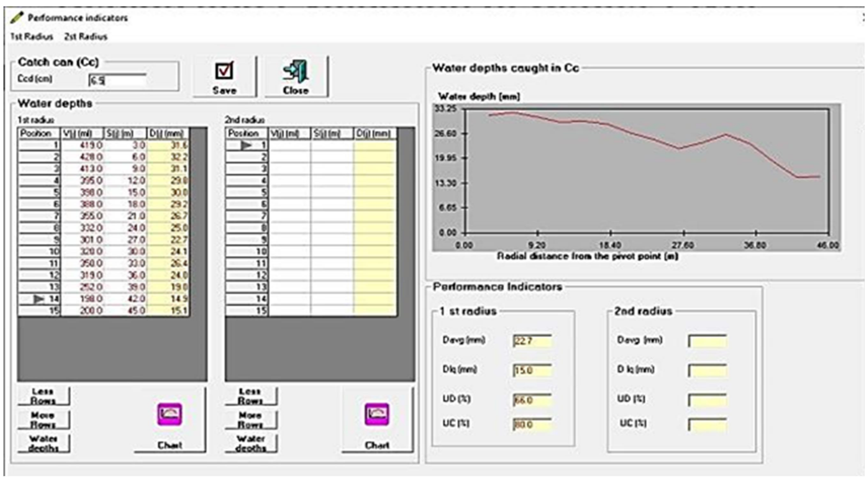

Fig. 7. Input widow of the collected field data and outputs of Dulq and CU window of the simulation model.

Table 6

Measured, simulated DU lq% and CU%.

Irrigation system	System speed, m h^{-1}	DU $_{lq}$, %		CU, %	
		Simulated	Measured	Simulated	Measured
Center Pivot 1 (CP 1)	15.0	83.20	77.95	85.50	70.85
		84.80	78.51	85.90	71.84
		82.20	77.50	83.90	70.67
	22.5	90.40	83.19	93.60	76.70
		83.10	88.98	92.20	86.96
		89.90	81.59	91.00	74.84
	30.0	88.60	84.83	90.90	80.84
		87.10	84.31	90.30	80.97
		92.10	88.88	92.60	87.22
Center Pivot 2 (CP 2)	15.0	66.00	79.09	80.00	66.00
		71.20	82.79	80.90	71.54
		67.90	72.96	82.50	70.75
	22.5	66.10	84.24	80.00	74.76
		64.90	83.15	79.10	73.44
		74.90	83.93	83.50	74.10
	30.0	73.30	82.26	82.80	72.13
		75.60	82.02	83.40	72.24
		76.40	84.26	84.80	75.53

3.2.2. Validation process

For the 18 DUlq experiments that were evaluated and simulated, a T-test and regression (R^2) analysis were performed (Fig. 8). The calculated and simulated DUlq data had a quadratic relationship with a strong regression coefficient (0.98). The same trend was obtained for the measured and simulated CU (Fig. 9) with a linear relationship and a high regression coefficient (0.98). Consequently, the DEPIVOT simulation model is acceptable to evaluate the center pivot irrigation system these data are in the same concern as Mehanna et al. (2015).

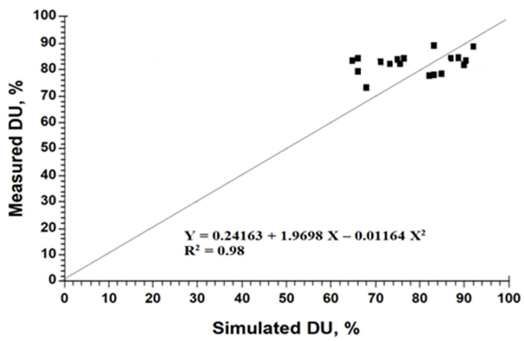

Fig. 8. Measured and simulated DUlq under the studied center pivot irrigations systems.

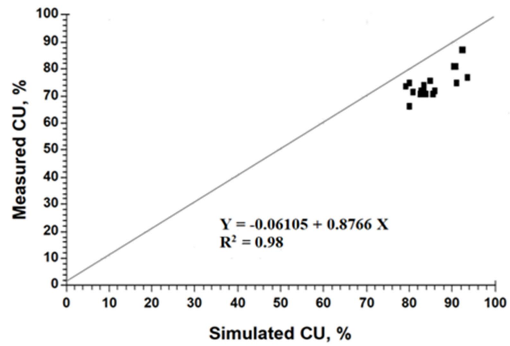

Fig. 9. Measured and simulated CU under the studied center pivot irrigations system.

4. Conclusion

To ensure proper water application and uniformity, the irrigation system must be evaluated. The DEPIVOT simulation model is an excellent tool for performing these calculations. The collected water was assessed using a graduated funnel after the irrigation system complete passed over the can's lines to determine the low quarter distribution uniformity (DUlq) and the Christiansen uniformity (CU). Experiments showed that DUlq (77.98 %, 84.58 %, 86.00 %) for CP1 and (78.28%, 83.77%, 82.84%) for CP2, as well as CU (71.12 %, 79.50 %, 83.01 %) for CP1 and (69.43 %, 74.10 %, 73.30 %) for CP2, under systems speed of 15, 22.5, and 30 m h^{-1}.The validation process using the DEPIOVT simulation model was very good, with a success rate of over 95 %, so it is recommended for validating the efficiency of center pivot irrigation systems. DEPIVOT's future work will involve using multi-criteria analysis to assist farmers in making the right decisions, considering economic and environmental considerations as well as productivity and runoff capacity.

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