CHARACTERIZATION OF WATER APPLICATION UNIFORMITY, RUNOFF AND WIND DRIFT EVAPORATION LOSSES UNDER CENTER PIVOT IRRIGATION SYSTEM

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ABSTRACT

The effect of water distribution uniformity (CU) on crop yield uniformity (CU yield) from a center pivot irrigation system operating under field conditions was analyzed. A field experiment was performed during two seasons (2015), located in Elmina, Alexandria and Ismailia (Egypt), in 31.3, 30.7 and 63ha. respectively plot irrigated with a center pivot system. The objectives of this paper are to study water application uniformity (CU) , run off and wind drift evaporation losses (WDEL) with two types of fixed spray plate sprinklers (FSPS): Senninger (LND-UP3-Inv. wobbler) and Nelson (D3000) both installed at the same height (1.5 m above the ground). Different predictive equations of WDEL were proposed for combinations of the two irrigation systems and the two operation times. Most equations use wind speed alone as an independent variable, although some use relative humidity or combinations of both variables plus air temperature. The results show that For two season, Senninger had higher values of CU (80–85%) than the nelson (75–80%). In sprinkler irrigation, a CU value of around 80% for each types of sprinklers can be sufficient to provide good crop yield uniformity, the mean value of run off 29% from water applied, WDEL were significantly higher with nelson (D3000) than with Senninger (LND-UP3-Inv. wobbler). The lowest WDEL values were registered with ranging from 14 to 19% under winter and summer operation conditions, respectively and mean yield for potato and sugar beet 32.7 and 91.2 ton/ha., respectively. These results were obtained for an average wind speed of 4.4 m/s at summer and 3.5 m/s during the winter and were normally below 5 m/s.

Key words: *Center pivot, distribution uniformity, runoff, wind drift evaporation losses.*

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1- INTRODUCTION

The center pivot irrigation is one of the modern irrigation methods introduced in North State because its capable to improve climate, increase productivity and decrease operation costs of irrigation by reduce the power used and this study aim to evaluate the efficiency of this modern method at different operation speeds (James, 1988).

In many areas of the world, 70-80 % of available fresh water is currently used in agriculture (Hoekstra & Chapagain, 2007). However, it is expected that as population and economy grow, a larger fraction of available water will be required for nonagricultural purposes, e.g., urban and industrial applications (Boserup, 2005). Also, climate change has already limited water resources for many regions of the world (Bandyopadhayay, Bhadra, Raghuwanshi, & Singh, 2009; Li et al. 2007; McVicar et al., 2007), which has a negative feedback to future agricultural sustainability and food security (Gheysari et al., 2015; Rockstrom et al., 2009).

Center pivot irrigation systems currently irrigate more than 12.5 million ha around the globe (Spears, 2003; Sadeghi & Peters, 2013), and they are steadily replacing traditional flood irrigation and other types of sprinkler irrigation. The key advantage of center pivots is their ability to apply water on a regular and consistent basis (Peters & Evett, 2007). In the last few decades, most modern sprinklers used in center pivots were designed to obtain mostly medium-sized drops (between 1.5 and 4mm mean diameter) and adequate dispersion (8–12 m, or more) by operating under low pressure (i.e. less than 200 kPa) (Allen et al., 2000; Tarjuelo,1999).

Water application uniformity with center pivots mainly depends on the sprinkler unit, the type or size of sprinklers and spacing along the lateral, the height above the ground or canopy, plot topography, and the speed of the machine in order to avoid run-off (Allen et al., 2000). An increase in sprinkler height usually produces better irrigation uniformity for a specific wind speed and direction, but it also increases EDLs (Faci et al., 2001; Montero et al., 2003). Installing the sprinkler at a lower height reduces the wetted area and increases the application rate, which can cause run-off problems with low infiltration soils (Faci et al., 2001; Keller and Bliesner, 1990).

Kincaid et al. (1996), analyzed the drop size distribution resulting from FSPS, and found that drop sizes tended to concentrate in a narrow range of diameters. A few years later, Faci et al. (2001), reported that the water application resulting from an isolated FSPS produces a wetted circular crown. This result is in agreement with the theory of ballistics applied to sprinkler irrigation (Fukui et al., 1980; Carrio´n et al., 2001), stating that for a given sprinkler set-up the horizontal distance separating the emitter from the landing point of a drop is a function of its diameter (among other variables). Therefore, if the range in drop diameters is small, all drops will land at approximately the same distance from the emitter. Performing simulated overlapping, Faci et al. (2001) reported problems with FSPS uniformity for large overlapping distances (over 5 m). These problems are related to the circular crown water application pattern, and are addressed in commercial irrigation machines by using narrow sprinkler spacings, typically of 2.74 m.

By the end of the 1990s, Senninger introduced the i-Wob standard angle TM, a different design for a RSPS. The rotation of the deflector plate is ensured by the eccentric rotation of the nine-groove deflector plate around a vertical axis. As a result, the rotation is much faster than for the Rotator Spray sprinklers, and the jets resulting from each groove change their vertical angle continuously.

Runoff control is an important factor in the successful design and operation of a center pivot irrigation system. Runoff is most likely to occur with high application rates, typical of popular developed low pressure systems, and where soils have a low intake rate. Estimation of potential runoff generally demands an iterative numerical calculation relating an infiltration function to a center pivot precipitation pattern. Some authors base their runoff models on the empirical Kostiakov infiltration equation (Kincaid et al., 1969), or on physically based infiltration functions such as the Green–Ampt equation (Slack, 1980; Von Bernuth, 1982). In current runoff approaches, mainly when integrated in irrigation conceptual models (Wilmes et al., 1993; Kincaid, 2001), many authors still utilize the referenced equations. As far as those equations and the Richards equation are in agreement, they assume that the infiltration capacity can be approximated as a simple function of cumulative infiltration regardless of the application rate versus time history (Skaggs et al., 1983). The Richards equation, for describing the one-dimensional vertical infiltration of water into soil, is a useful tool to provide a database for comparisons between runoff simulation models. Therefore, soil samples, many times presenting a large degree of spatial and temporal variability, are not needed.

Luz et al. (1998), developed a simple statistical method to estimate potential runoff based on the theoretical results derived by numerical solution of the Richards equation, for vertical water infiltration into soil. Soil hydraulic properties used as input data to the Richards equation were estimated using equations from (Rawls and Brakensiek, 1989).

During a sprinkler irrigation, a relevant part of the water discharged by the irrigation system does not reach the crop canopy. This unaccounted water is referred to as ‘‘wind drift and evaporation losses’’ (WDEL), and is expressed as a percentage of the gross volume of irrigation water. Several authors have identified irrigation system and meteorological variables influencing WDEL.

Among the system variables, the nozzle and drop diameter have a significant effect on WDEL. A large nozzle diameter results in large drop diameters (Keller and Bliesner, 1990). Large drops are more resistant to drift and present less area per unit of mass. As a consequence, they are less affected by WDEL. An increase in operating pressure results in a decrease in the resulting drop diameters (Montero et al., 2003), with an increase in WDEL.

Increasing nozzle elevation over the soil surface has been reported to increase WDEL, due to a longer drop trajectory and increased wind exposure (since the wind profile over a crop canopy is logarithmic). As a consequence, many new center pivot designs set the nozzles about 2 m lower than they used to be, and many existing center pivots have been modified to lower the nozzles (Dechmi et al., 2003b).

Despite all these practical developments, a decrease in WDEL with nozzle elevation has not yet been confirmed in experimental conditions, neither for solid-sets (Tarjuelo et al., 2000), nor for moving laterals (Faci et al., 2001; Playa´n et al., 2004).

The objectives of this work are to: (1) analyze the effect of CU and crop yield uniformity (CU yield) with a center pivot operating under field conditions, FSPS (Senninger and Nelson) were operated at 2m above the ground; (2) characterize WDEL under summer and winter operation conditions for center pivot irrigation system; and (3) evaluate the adequacy of some WDEL predictive equations found in the literature.

2- MATERIALS AND METHODS

Evaluations only refer to the process of water application performed by the system, without considering aspects of operation related to adequacy, such as time or amount of water application. When analyzing results, note that uniformity values obtained from calculations refer to concrete set times performed under specific conditions.

A field experiment was performed during summer and winter on 2015, located in Elmina, Alexandria and Ismailia in 31.3, 30.7 and 63ha respectively plot irrigated with a center pivot system, (latitude 28.08 ,30.05 and 30.6 N, and longitude 30.37,31.2 and 32.25E and mean altitude 40,19 and 13m above sea level) for EL-Minya, Alexandria and Ismailia respectively. The main field experiment characteristics of the center pivot are shown in table (1).

Table 1. The main field experiment characteristics of the center pivot

Feature	Locations		
	EL-Minya	**Alexandria**	**Ismailia**
Discharge (m^3h^{-1})	180	90	290
Pivot Pressure (kPa)	250	140	220
Lateral pipe diameter (mm)	152.4	142.87	162
The maximum revolution speed (ms^{-1})	2.2	1.2	3.2
Irrigation time (h)	14	16.5	16
No. of span	6	5	11
Pivot Length(m)	316	309	454
Type of sprinkler	Senninger (LDN-UP3)	Senninger (I. Wobbler)	Nelson (D3000GHP)
Sprinkler height above the ground (m)	1.5	1.5	1.5
Overhang (m)	4	4	4
Irrigated area (ha)	31.3	30.7	63

The soil samples were taken to make physical analysis of soil where the mechanical analysis was followed to find soil texture. The particles size distribution was determined according to the international method (Klute, 1986). The field capacity, permanent wilting point and total available water, were estimated using pressure plate device (Table 2). The intake rate for the soils were measured by using double ring infiltration meter, the reading was get constant after 2 hours and it were equal to 25.2, 30,4 and 15.2 mm/h for Elmina, Alexandria and Ismailia respectively.

Table 2. Soil textural classes, field capacity (θ_{FC}), wilting point (θ_{WP}) and total available water (TAW)

Location	Soil depth (m)	Sand (%)	Clay (%)	Silt (%)	θ_{FC} ($m^3\ m^{-3}$)	θ_{WP} ($m^3\ m^{-3}$)	TAW (mm m^{-1})
EL-Minya	1	86	6.5	7.5	0.30	0.135	16.4
Alexandri	0.8	96	1.7	2.3	0.331	0.785	20.2
Ismailia	0.8	81	9.5	9.5	0.272	0.13	11.4

2.1. Experimental design

The experiment was carried out using two crops (Potato and Sugar beet) that covered a fall of the area watered by the center pivot system. The meteorological variables were measured by an automated meteorological station located near from the plot and use evaporation pan to measure the evaporation from the catch cans.

2.2. General features of the system

The main spray devices characteristics of the center pivot are included in Table 3. Nozzle sizes of 1.59 and 7.54mm were used with operating pressures range from 100 to 130 kPa. Nozzle mounting heights of 1.6 to 2.1 m were used. The Nelson Spray I head (Nelson Irrigation Corp.) is an older style fixed-plate spray head. The Nelson D3000 (DHG) and Senninger i-wob sprinklers (Senninger Irrigation Inc.). These were mounted on 2-2.5m flexible-hose drops as recommended by the manufacturers. Three types of sprinklers were installed (FSPS): a) Senninger (LDN-UP3 and I. Wobbler) in EL-Minya and Alexandria, b) Nelson (D3000GHP) in Ismailia which were placed 2m above the ground using polythene flexible drop pipes with a diameter of 25mm (Fig. 1).

Table 3. The main characteristics of the center pivot spray devices.

Location	Sprinkler Type	Span	Distance from center pivot (m)	Plate color	Spacing between sprinklers (m)	Nozzle diameter (mm)	Flow (lph)
EL-Minya	Senninger (LDN-UP3)	1	0-66	Gold	2.5	2.38	223
				Lime		2.78	304
				Lavender		3.18	397
				Grey		3.57	504
		3	132-198	Turquoise	2.5	3.97	625
				Yellow		4.37	756
				Red		4.76	902
		5	264-330	Blue	2.5	5.75	1317
				Brown		5.95	1413
				Dark		6.75	1815
Alexandria	I.Wobbler	1	0-60	Gold	5	2.38	223
				Lime		2.78	304
				Lavender		3.18	397
				Grey		3.57	504
		3	120-180	Turquoise	4	3.97	625
				Yellow		4.37	756
				Red		4.76	902
				White		5.16	1058
		5	240-300	Orange	3	6.35	1608
				Purple		7.14	2035
				Green		6.75	1815
Ismailia	Nelson (D3000 GHP)	1	0-39	Beige	2	1.98	150
				Gold		2.38	256.2
				Lime		2.78	292.8
		5	195-234	Lime	2	2.78	292.8
				Lavender		3.2	388.2
				Black		5.2	1028.4
		7	312-351	White	2	5.56	1201.2
				Blue		7.54	2218.8
				Black		5.2	1028.4

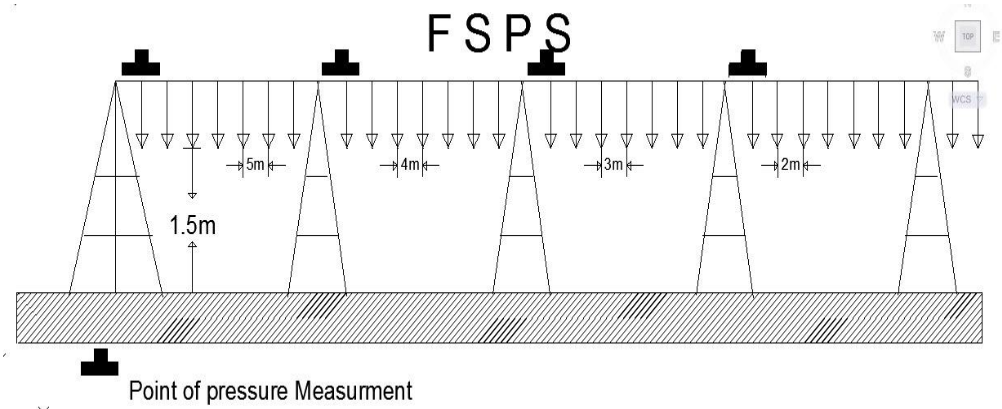


Fig.1. Diagram of the positioning of sprinklers on the center pivot system.

To obtain the required data, one rows of metal cans (100mm height × 95mm diameter) were placed next along radial making a 30 degrees angle at the pivot point; these cans were spaced 3m apart, starting with one at the position nearest the center pivot.

The center-pivot system was then allowed to pass completely over the row of catch cans. The water applied in each catch can was measured and recorded as soon as possible after the lateral passed. The speed timer was set at 100% at each test.

Part of water that collected in cans from each test was first adjusted for evaporation loss from the cans during recording. For this purpose, three catch cans each with measured amount of water in it, were placed outside the vicinity of the nozzle spray at the end of each test. Volumes in these cans were recorded about midway during the catch reading period and at the end of reading all the cans in the row. Losses obtained from the test cans were added to the can volumes of the row to compensate the losses during recording. The wind speed was measured at 2m above ground using a recording three cup anemometer shown in table (5).

2.3. Water application evaluation parameters

Eighteen evaluations were performed following the methodology proposed by Heermann (1990), Merrian and Keller (1978), and Merrian et al. (1980) as well as International ANSI/ASABE Standards S436.1 (2001) and ISO-11545 (2001). In field tests, plastic catch cans with 100 mm diameter openings and 95 mm in height were spaced 3m apart in the radius direction and placed above the ground. The water depth collected was calculated by dividing the volume caught by the open area of the catch can. In each evaluation, flow was measured at the entrance of the center pivot. For each evaluation of the system, the application uniformity is estimated using distribution uniformity (DU), Christiansen uniformity coefficient (CU), Application efficiency (Ea) and Potential Application Efficiency of Low Quarter (PELQ). The Christiansen uniformity coefficient is a parameter that is widely used to evaluate application uniformity which developed by (Christiansen, 1942) as follows:

$$DU = 100 \frac{\overline{X}_{LO}}{\overline{X}} \quad (1)$$

$\overline{X}_{LO}$: the average low-quarter amount caught or infiltrated (mm)

$\overline{X}$: the average amount caught or infiltrated (mm)

$$CU = 100(1.0 - \frac{\sum_{i=1}^{n} |z - m|}{\sum_{i=1}^{n} z}) \quad (2)$$

CU = Christiansen uniformity coefficient
z = individual depth of catch observations from uniformity test (mm)
m = mean depth of observations (mm) (Keller and Bliesner, 1990).
n = number of observations.

$$E_a = \frac{D_W}{D_g} * 100 \quad (3)$$

E_a = application efficiency (%)
D_W = the average weighted depth (mm)
D_g = the average gross depth (mm)

$$D_g = D_W + E_v \quad (4)$$

E_v = the average losses depth by wind and temperature (mm).

Potential Application Efficiency of Low Quarter (PELQ) is a measure of how well the system can apply water if management is optimal. PELQ is the ratio of the lowest 25% weighted average depth in the catch cans to the average applied rate that is obtained from the flow rate, revolution time, and wetted area.

PELQ should be determined in order to evaluate how effectively the system can utilize the water supply and what the total losses may be. It is, therefore, a measure of the best management practice and should bet thought of as the full potential of the system (sabah et al., 2011):

$$PELQ = DU * E_a = \frac{d_w}{D_g} * 100 \qquad (5)$$

PELQ = Potential Application Efficiency of Low Quarter

2.4. Water Losses

2.4.1. Runoff

The runoff statistical model, assuming non-crusting soil conditions, was developed with a step-wise technique. A multiple regression using the potential runoff (PR) data set from the numerical solution of Richards equation provided a first estimation of the parameters (Luz et all., 1998). Such equations presented an index, with parameters and respective coefficients established from attempts of the step-wise initial procedure. The index, X, was defined as:

$$X = \frac{(P_k * H)^{0.5}}{K_s} * D \qquad (6)$$

P_k = peak precipitation rate (cm/h),
D = water depth (cm),
H = initial soil water content (vol. %),
K_s = saturated hydraulic conductivity (cm/h).
PR = potential runoff (mm), were R_1 (% sand: 51–100)
PR = 2.8 X – 1.8 (7)

Runoff water was collected in all irrigation events. Three metallic rings will position approximately 18, 22 and 26m from the pivot. The rings, with a diameter of 50 cm and a height of 25cm, will buried at 5 cm in the soil. The rings will be used to collect the applied water that could not infiltrate into the soil area. The rings will maintain in the field throughout the period of the irrigation events, avoiding disturbance of the soil surface (Luiz, 2006).

2.4.2. Wind drift and evaporation losses (WDELs)

The experimental values of WDEL were related to meteorological variables recorded during the experiments in order to analyze the possible effects on losses and to determine a predictive equation. By calculating EDLs this way, one must consider that possible measurement errors of both flow and the water collected by the catch cans are being included, which could be estimated at no more than 3%. The meteorological variables used as independent variables were wind speed and direction, air temperature and relative humidity. These were measured by an automated meteorological station located near from the plot. The average value of the recorded data during the time the lateral sprinkler of the center pivot was moving across the line of catch cans was taken into account. The selected meteorological variables that can be related to WDEL were wind speed, relative humidity and temperature. Irrigation events were grouped according to their application time, both summer and winter irrigations grouped together.

2.4.3. WDELs predictive equations

The experimental values of WDEL were related to the meteorological variables recorded during the experiments, and correlations were performed. Eight predictive equations for WDEL were tested, and results were presented for both irrigation systems and summer/winter conditions. The predictive equations are presented in Table 4. These equations were derived using different sprinkler irrigation systems and parameters.

Table 4. The empirical equations used for WDEL estimation.

Reference	Empirical equations
Trimmer (1987)	$WEDL = [1 - (0.976 + 0.000117ET^2 + 0.0012U - IG(0.00043ET + 0.00018U + 0.000016ET * U))] * 100$ $IG = 0.032 * \frac{P^{1.3}}{D}$ IF IG ≤ 7 Then IG =7, IF IG≤17 Then IG =17
Keller and Bliesner (1990)	$WDEL = (1.98D^{-0.72} + 0.22(E_s - E_a)^{0.63} + 3.6 * 10^{-4} P^{1.16} + 0.4U^{0.7})^{4.2}$
Faci and Bercero (1991)	WDEL = 20.44 + 0.75U
Montero (1999)	$WDEL = 7.63\ (E_s - E_a)^{0.5} + 1.62U$
Tarjuelo et al. (2000)	$WDEL = 0.007P + 7.38(E_s - E_a)^{0.5} + 0.844U$
Faci et al. (2001)	WDEL = -0.74D + 2.58U + 0.47T
Dechmi et al. (2003a, b)	WDEL = 7.479 + 5.287U
Playa´n et al. (2004)	WDEL = 1.55 + 1.13U

The independent variables are: nozzle diameter (D, mm), vapor pressure deficit (E_s - E_a, kPa), operating pressure (P, kPa), wind speed (U, m s^{-1}), evapotranspiration (ET, mm day^{-1}) and air temperature (T, C^0).
The wind drift and evaporation losses (WDEL, %) produced during each irrigation event were computed from the irrigation depth applied by the sprinkler system (Dg, obtained from the sprinkler discharge and the water collected in both catch cans as averaged and recorded as the catch can irrigation depth, and expressed in mm) (Dechmi et all., 2003).

$$WDEL = \frac{D_g - D_w}{D_g} \times 100 \quad (8)$$

WDEL: The wind drift and evaporation losses (%).

2.5. Data recording

Water was controlled, deep percolation and runoff were assumed to be negligible. Water-use efficiency (WUE) and irrigation water-use efficiency (IWUE) values were calculated with Eqs. (4) and(5), respectively **(Howell et al., 1990)**.

$$\mathrm{WUE} = (\frac{E_y}{E_t}) \times 100 \quad (9)$$

Where WUE is the water use efficiency (t ha^{-1} mm^{-1}); E_y is the economical yield (t ha^{-1}); E_t is the plant water consumption, mm.

$$I\mathrm{WUE} = (\frac{\mathrm{E_y}}{\mathrm{I_r}}) \times 100 \quad (10)$$

Where IWUE is the irrigation water use efficiency (t ha^{-1} mm^{-1}), E_y is the economical yield (t ha^{-1}), I_r is the amount of applied irrigation water (mm).

2.6. Statistical analysis

An analysis of variance (ANOVA) was performed by considering the variables related with water distribution (CU, DU, E_a and PELQ), the variables related with potato and sugar beet yield to estimate the effect of sprinkler type and seasonal effect on water distribution uniformity. Fisher's least significant difference (LSD) test was used to determine the significant differences between average groups in the ANOVA.

3. Results and discussion

3.1. Irrigation uniformity

Irrigation uniformity values obtained in each irrigation locations and each season are also discussed. Analysis of the Heermann uniformity coefficient (CU, DU, Ea, PELQ and E) values shows that, in general, the irrigation events had good uniformity, with a significant difference ($p < 0.05$) The different water jet break-up and the consequent droplet size distribution, produced by the type of the sprinkler and seasonal effect are the main causes of these differences in the uniformity values.

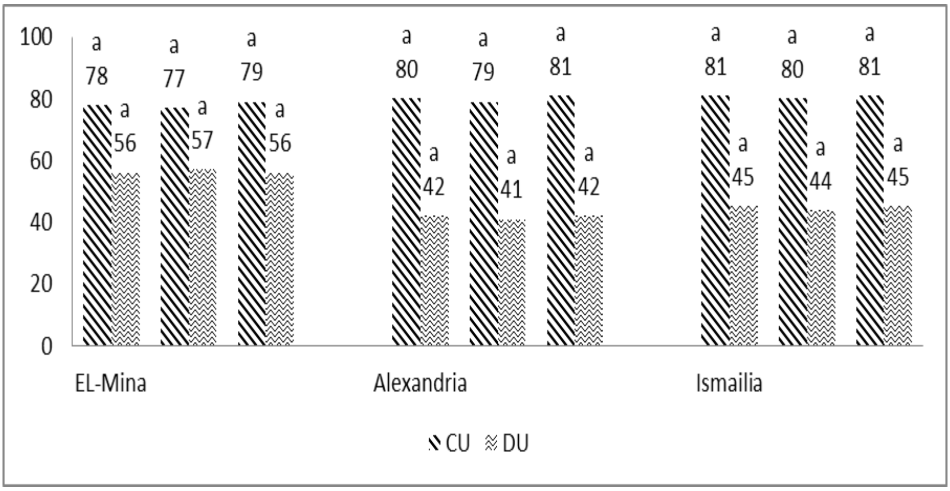
Table 5 shows the mean of wind speed, temperature and relative humidity obtained in the tests carried out during the summer and winter for the two experimental seasons.

Fig. (2, 3) show the average values of CU and DU corresponding to the three locations during the two seasons. a statistical analysis was carried out, no significantly differences in the CU and DU values on summer and winter were obtained between the two season in (summer and winter).

Table 5. Average results of climatic parameters during the tests.

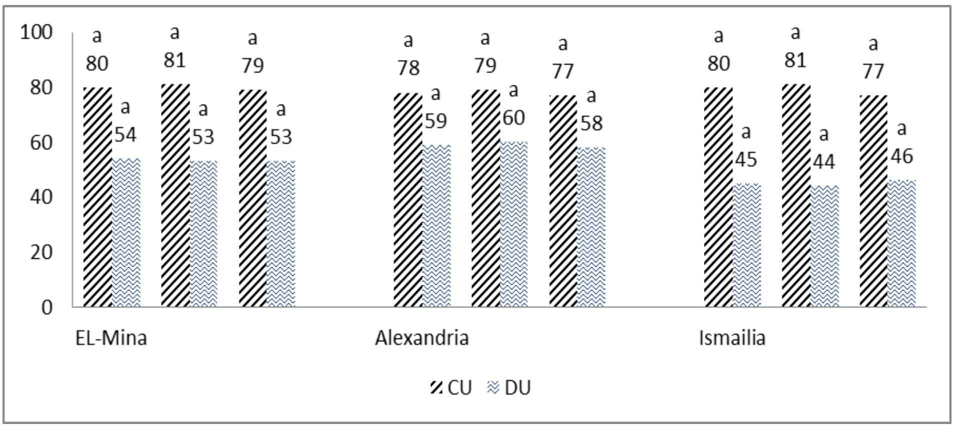
Seasonal Effect	Location	Wind speed (m/s)	Relative humidity (%)	Air temperature (C)
Summer	EL-Minya	6.8	24	38
	Alexandri	4.5	69	27
	Ismailia	2	71	29
Winter	EL-Minya	5	54	20
	Alexandri	4.4	71	17
	Ismailia	2.3	72	18

This result differs with the fact that in most of the sprinklers, for specific wind and temperature conditions, Water distribution uniformity increases in winter than summer because of in winter the wind speed and air temperature are lower than of the values in summer (Faci et al., 2001; Hills & Barragan 1998; Tarjuelo, 1999) and do not agree with the result of (Ortiz et al., 2010) that the significantly higher values in DU for FSPS at 2m height for summer season irrigation (Fig. 2 and 3), and higher wind speed during the summer, lead us to deduce that there was a positive effect from wind with this type of sprinkler, at least for the wind speeds tested ($2 - 6.8 ms^{-1}$). The reason for this improvement may be due to the wind dispersing the thin streams of water produced by the FSPS.



Bars shown with different letters are significantly different at the 0.05 probability level for CU, DU and least significant difference (LSD) for CU and DU equals 6.1 and 16.6respectivelly.

Fig. 2. Average CU and DU values in three locations in summer.



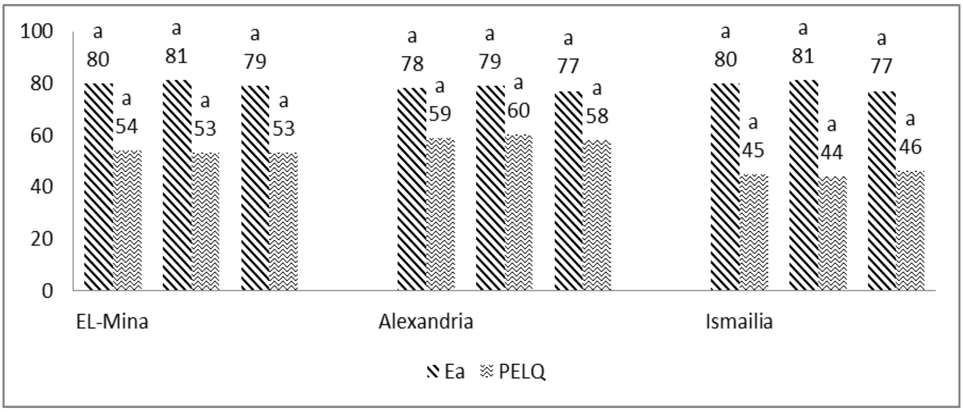
Bars shown with different letters are significantly different at the 0.05 probability level for CU, DU and least significant difference (LSD) for CU and DU equals 10.5 and 17.7respectivelly.

Fig. 3. Average CU and DU values in three locations in winter.

The values of Cu range from 77 to 81% in summer and winter season, which indicates that water distribution was reasonably good for all location. Under desert conditions for center pivot systems a value of Cu of less than 75% is unacceptable (Abo-Ghobar, 1992).

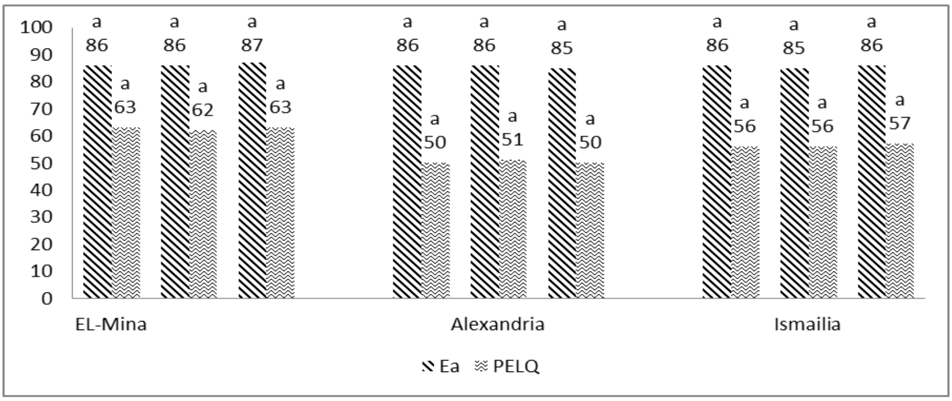
The DU values ranged from 41 to 57% in summer, 44% to 60% in winter (a value of less than 67% is generally considered unacceptable, from these values it can be concluded that some areas of these irrigated circles are receiving less than the average amount of water applied.

Fig. (4, 5) show the average values of E_a and PELQ corresponding to the three locations during the summer and winter season a statistical analysis was carried out, no significantly differences in the E_a and PELQ values were obtained between the two season in (summer and winter), because of the wind speed is not difference between summer and winter in three locations.



Bars shown with different letters are significantly different at the 0.05 probability level for E_a, PELQ and least significant difference (LSD) for E_a and PELQ equals 4.43 and 16.2 respectively.

Fig. 4. Average E_a and PELQ values in three locations in summer.

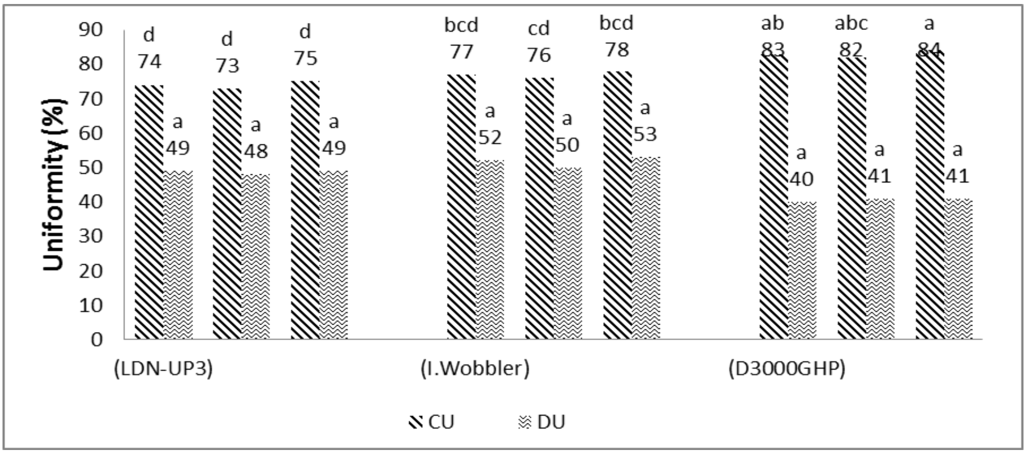


Bars shown with different letters are significantly different at the 0.05 probability level for Ea, PELQ and least significant difference (LSD) for Ea and PELQ equals 4.3 and 26.67respectivelly.

Fig. 5. Average E_a and PELQ values in three locations in winter.

The PELQ values are in the range from 44% to 60%in summer, 50 % to 63% in winter and the E_a values are in range from 74% to 88% in summer, 85% to 86% in winter. The value of PELQ is usually lower than the E_a value, and the difference between E_a and PELQ indicates the value

of evaporation losses. The values of PELQ obtained for the three locations are generally low (Abo-Ghobar, 1992).
In order to compare the FSPS (Sinnenger (LDN-UP3 and I. Wobbler) in EL-Minya, and Alexandria), Nelson in Ismailia), a statistical analysis was carried out, with significantly greater values of CU for sinnenger than for nelson for sprinklers located at 2m above ground and the same space between three types of sprinkler 2m, but greater values of DU for Nelson than for Sinnenger (Fig. 6).



Bars shown with different letters are significantly different at the 0.05 probability level, and least significant difference (LSD) for CU and DU equals 10.5 and 17.7respectivelly.

Fig. 6. Average CU and DU values of the three sprinkler types.

This may be due to the fact that the Sinnenger sprinkler streams of water with two output angles, whereas the Nelson have only one output angle, discharging to a single distance, which can lower the probability that water falls within the catch can and The LDN provides the largest area of instantaneous coverage at a lower pressure, The LDN produces uniform sized droplets along the wide range of nozzle flows found on center pivots, which helps center pivot irrigators fight wind-drift and evaporative loss. This results agree with (Ortiz et al., 2010).
At EL-Minya where the Senninger (LDN-UP3) was installed, whenever the nozzle diameter and operating pressure increases the values of CU increases in spans 1 and 2 excepting the span 3 the CU deceases with nozzle diameter increasing. Alexandria where Senninger (I. Wobbler) was

installed, whenever the nozzle diameter and operating pressure increases the values of CU increases, on the other hand on Ismailia where Nelson (D3000 GHP) was used, whenever the nozzle diameter and operating pressure increases the values of CU decreases in spans 1 and 2 and it increase in the outer span. The higher values of CU in Alexandria when used Senninger (I. Wobbler) and lower values of CU in Ismailia when install Nelson (D3000 GHP), but DU values didn't have the same trend in each center pivot system.

3.2. Water Losses

3.2.1. Runoff

During the 18 field experiments the wind speed ranged from 2 to 6.8 m s^{-1} (with an average of 4.4 m s^{-1}), the air temperature ranged from 27 to 43C^0 and the relative humidity ranged from 47 to 67%. The average WDEL were 20.17, 14.74 and14.62% for the EL-Minya, Alexandria and Ismailia location, respectively.

Table (7) shows the mean run off and evaporation values, wind speed, temperature and relative humidity obtained in the tests carried out during the summer and winter for the two experimental seasons. The average evaporation losses ranged from 9.6 to 13.1% of applied water for different location and sprinkler type.

The value of evaporation losses (E) in EL-Minya is higher than Alexandria and Ismailia because of the air temperature and wind speed higher in EL-Minya, the value of evaporation losses (E) summer is higher than winter because of the air temperature and wind speed higher in summer this result agree with (Abo-Ghobar,1992). The average run off ranged from 1.5 to 2.7mm of applied water for different location, run off is very related to soil type such as intake rate, hydraulic conductivity, water depth and water content therefor the value of run off is higher in EL-Minya due to sandy soil (Table 2).

The value of run off is greater in EL-Minya than Alexandria and Ismailia because of the water depth applied in EL-Minya 10mm but in Alexandria and Ismailia 4.1 and 4mm in summer season. The value of run off is greater in summer season than winter due to the amount of water applied.

Wind speed increases exponentially with height, therefore, the higher the nozzle from the ground surface or crop canopy the greater the pattern distortion, because of increasing wind speed. Increasing the height allows the wind to act on the spray due to longer travel time. The wind effect is more pronounced on smaller drops primarily due to greater drag (Bernuth, 1988). The average wind speeds were varied from $2 ms^{-1}$ to $6.8 ms^{-1}$. Although the range of these speeds is small, the evaporation losses increased with an increase in the wind speed.

Table 6. The main characteristics of the center pivot spray devices

Location	Sprinkler Type	Span	Nozzle diameter (mm)	Pressure (kPa)	CU (%)	DU (%)
EL-Minya	Senninger (LDN-UP3)	1	2.38-3.57	1.1- 1.2	80	50
		3	3.97-4.76	1.2- 1.3	85	47
		5	4.59-6.75	1.4- 1.67	67	63
Alexandria	Senninger (I. Wobbler)	1	2.38-3.57	1- 1.2	86	47
		3	3.97-5.16	1.2- 1.6	92	56
		5	6.35-6.75	1.85-2	92	51
Ismailia	Nelson (D3000 GHP)	1	1.98-2.78	1- 1.2	71	83
		5	2.78-5.2	1.4- 1.8	49	34
		7	5.56-7.54	2- 2.2	58	32

Table 7. The mean of irrigation depth, run off and evaporation values, wind speed, temperature and relative humidity.

Sessional effect	Location	irrigation depth (mm)	Runoff (mm)	Evaporation (mm/day)
Summer	EL-Minya	10a	2.6a	0.97a
	Alex.	8.5b	1.23ab	0.78b
	Ismailia	9b	2.55abc	0.82c
Winter	EL-Minya	6c	3.4bc	0.53c
	Alex.	5d	1.76c	0.45d
	Ismailia	6c	1.5c	0.46e
LSD		0.77	23.8	0.26

Different letters indicate statistically significant differences ($p < 0.05$) and least significant difference (LSD)

3.2.2. Wind drift and evaporation losses (WDELs)

The data presented in this paper call attention to center pivot system designers to the values of evaporation losses, and the effect of nozzle height on evaporation losses under summer and winter conditions especially in areas of limited water for irrigation.

In all the experiments the machine remained static and irrigated bare soil. These results indicate a 5% reduction of WDEL due to switching from summer to winter season. These values are similar to those obtained in this experiment.

Table (8) shows the percentage of WDEL reduction during the winter in comparison with WDEL obtained from summer season for all the equations during two seasons for the two experimental seasons. an increase in WDEL was expected when wind speed and air temperature increased because drops are longer in contact with the air.

The values obtained indicate a larger reduction of WDEL between summer and winter. Wind speed can be considered the best explanatory variable within the WDEL predictive equations. Nonetheless, there are other factors that also have an influence on the process of wind drift and evaporation, such as changes in wind speed and direction during the experiment, the proportion of small drops discharged by each type of sprinkler, or the inaccuracy of the measurement method. an increase in WDEL was expected when wind speed and air temperature increased because drops are longer in contact with the air.

The goal was to produce equations adapted to different irrigation systems and summer/winter operation, using independent meteorological variables which are easy to obtain equations based on wind speed, air temperature, operating pressure and nozzle diameter were proposed for all considered cases.

The values of WDEL ranged from 2.1% to 43% from water depth applied. The effect of wind speed on irrigation performance is not limited to WDEL, the values of WDEL increase due to increase in wind speed between different locations and different season (summer and winter). This results agree with (Montero et al., 2001; faci et al., 2001; Playa´n et al., 2004; Dechmi et al., 2003a, b; Montero, 1999; Faci and Bercero, 1991).

A summary of the experimental results is presented in Table 10. In each irrigation system the summer/winter fluctuations in catch can irrigation depth resulted in relevant differences in WDEL. the average values of WDEL (%) ranged from 20.47 to 13.23% through the two season with different locations.

Table 8. Predictive models of evaporation and drift losses (WDEL) for summer and winter.

Sessional effect	Location	WDEL (%)							
		Playa´n (2004)	Trimmer (1987)	Faci et al. (2001)	Keller and bliesner (1990)	Faci and Bercero (1991)	Dechmi et al. (2003a, b)	Montero (1999)	Tarjuelo et al. (2000)
Summer	EL-Min.	9.1a	86bc	19.8b	2.5a	25.2a	43.2a	33.1a	28.3a
	Alex.	6.5c	37c	0.87d	2.0c	23.4c	31.2c	24.2c	21.8c
	Isma.	3.7d	11c	16.5b	2.1b	22.5d	17.9f	21.1f	20.2d
Winter	EL-Min.	7.1b	39a	28.3a	2.1b	24.1b	33.1b	26.1b	22.5b
	Alex.	6.2c	31c	3.6c	2c	23.4c	30.4d	22.4d	16.7e
	Isma.	4.2e	9b	18.7b	2.1b	22.1e	19.3e	21.2e	15.9f
LSD		0.21	6.64	3.3	0.04	0.2	0.17	0.23	0.3

Different letters indicate statistically significant differences ($p < 0.05$) and least significant difference (LSD).

but the average values of WDEL (%) that obtained from the reference equation (Equ. 6) in center pivot experiments ranged from 17.3 to 7.7% through the two season with different locations (Table 9).

The WDEL based on others variable such as air temperature, operating pressure, vapor pressure deficit (E_s - E_a) and evapotranspiration, the increasing of this variable lead to increase in WDEL (Keller and Bliesner, 1990; Trimmer, 1987; Montero, 1999).

The largest values of WDEL (%) in EL-Minya in summer season due to the high wind speed and air temperature. the wind speed must always be considered when scheduling sprinkler irrigation. The effect of wind speed on irrigation performance is not limited to WDEL. Keller and Bliesner (1990) discussed its effect on irrigation uniformity. In the last decades, models have been developed to estimate the effect of wind speed on irrigation uniformity (Fukui et al., 1980; Carrio´n et al., 2001; Montero et al., 2001). Recently, Dechmi et al. (2004a, b) used such models to analyze wind effects on crop yield, through its effect on uniformity and WDEL.

3.3. Uniformity in crop yield

The results show that the final crop yield depends more on the total water applied than on water application uniformity with the different sprinkler type (Table 9).

The results show that it can be suitable to use FSPS systems, although they apply water with lower uniformity than RSPS. This result is very interesting from an economic point of view because FSPS are cheaper than RSPS and show greater durability because they lack rotating elements (Ortiz et al., 2010).

The characteristics of water use and yield showed significant differences between locations, except for water use (ET) and irrigation water use efficiency (IWUE). (Table 10).

The yield of potato ranged from 24 to 38.1 ton/ha. The yield of potato in El-Mina under senninger (LDN-UP3) equal 24ton/ha, In Alexandria under senninger (I. Wobbler) equal 38.1ton/ha and In Ismailia under nelson(D3000GHP) equal 36ton/ha.

Table 9. Average values and ranges (in parentheses) of catch can irrigation depth (mm), predictive WDEL (%) and measured WDEL (%) under field conditions.

Seasonal effect	Location	irrigation depth (mm)	Measured WDEL (%)	Predictive WDEL (%)
Summer	EL-Minya	10a	17.3a	33.7 (2.5- 86)
	Alexandria	8.5b	14.3b	20.4 (2- 87)
	Ismailia	9b	9.2c	17 (2.1- 22.5)
Winter	EL-Minya	6c	8c	25 (2.1- 39)
	Alexandria	5d	7.7c	17 (2- 31)
	Ismailia	6c	7.8c	16 (2.1- 21.2)
LSD		2.18	1.54	1.54

Different letters indicate statistically significant differences ($p < 0.05$)

Table 10. Total irrigation water amount (I), plant water consumption (ET), yield, irrigation water use efficiency (IWUE) and water use efficiency (WUE) of potato and sugar beet for different growing seasons and irrigation treatments.

Location	**Crop type**	**I (m^3 ha^{-1})**	**ET (m^3 ha^-**	**Yield (ton ha^{-1})**	**WUE (kg m^{-3})**	**IWUE (kg m^{-3})**
EL-Minya	Potato	13270a	9290a	24f	2.58c	1.81c
Alexandria		12440a	8710a	38.1d	4.37c	3.1c
Ismailia		13730a	9610a	36e	3.75c	2.62c
EL-Minya	Sugar beet	8140b	5700b	95b	16.67b	11.67b
Alexandria		5600c	3920b	71.5c	18.24b	12.76b
Ismailia		5150c	3550b	107a	30.14a	20.78a
LSD		2.2	2.17	1.54	2.15	2.2

Different letters indicate statistically significant differences ($p < 0.05$) and least significant difference (LSD)

The yield of sugar beet ranged from 71.5 to 107 ton/ha. The yield of sugar beet in El-Mina under senninger (LDN-UP3) equal 95ton/ha, In Alexandria under senninger (I. Wobbler) equal 71.5ton/ha and in Ismailia under nelson D3000GHP) equal 107ton/ha.

The WUE of potato is further improved by senninger (I. Wobbler) comparing with senninger (LDN-UP3) and nelson (D3000GHP).

The WUE of sugar beet is further improved by nelson (D3000GHP) comparing with senninger (I. Wobbler) and senninger (LDN-UP3).

4. CONCLUSIONS

The size of the catch cans used (100mm diameter) appears to be sufficient to evaluate irrigation with center pivot systems using senninger and nelson because of high variability in CU and DU values do not split from the catch cans.

With the senninger sprinkler, greater CU and DU values are obtained with sprinklers at 2m distance greater than at 4m distance using the same height sprinkler at 1.5 m above the ground.

In spite of the disadvantages that an experiment carried out under real field conditions has (the diameter of the nozzles used had to increase with their distance to the pivot end), this test has allowed us to determine important aspects of WDEL with this kind of equipment.

The type of sprinkler plays an important role in WDEL. They were approximately 27% lower in Nelson than in Senninger under summer season and 5% lower in Nelson than in Senninger under winter season.

Drop size is another important factor affecting WDEL. Thus, high WDEL using Nelson can be due to the proportion of small drops is produced with these sprinklers is higher than with Senninger, and these small drops are more sensitive to evaporation and wind drift.

Among the predictive equations of WDEL, wind speed was the best explanatory variable. However, there are other factors with considerable weight on the evaporation and wind drift process such as changes in both wind speed and direction throughout the experiment.

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الملخص العربي

توصيف كفاءة إضافة المياة،الجريان السطحى وفواقد البخر والرياح تحت نظام الرى بالرش المحورى

على مختار محمد*، محمد عبد الوهاب قاسم**، محمد السيد أبوعرب***

يهدف هذا البحث إلى دراسة كفاءة إضافة المياة، تقليل فوقد الجريان السطحى و تقليل فواقد البخر والرياح. ولتحقيق هذا الهدف تم إجراء تجربة حقلية، وقد تم تنفيذ التجربة الحقلية باستخدام ثلاثة انواع من الرشاشات الراذاذية Senninger (LDN) Senninger (I.Wobbler) and Nelson ، وقد تم إجراء التجربة الحقلية باستخدام المتغيرات الأتية؛ ٣ مواقع مختلفة (المنيا – الاسكندرية – الاسماعلية)و موسمين مختلفين (الصيف – الشتاء). ويمكن تلخيص أهم النتائج المتحصل عليها من هذه الدراسة كما يلي: كانت اعلى نتائج لمعامل انتظامية توزيع المياة (CU) وإنتظامية توزيع المياة (DU) عند استعمال الرشاش I.Wobbler (Senninger) فى الاسكندرية ٩٠%، ٥٣% على الترتيب، وكانت أعلى قيمة للجريان السطحى ٥٦% عند استعمال الرشاش (Nelson D3000GHP) ومتوسط اعلى قيم لفواقد البخر والرياح ٣٣.٧% فى موسم الصيف عند استعمال الرشاش (Nelson D3000GHP). أعلى انتاجية للبطاطس فى الاسكندرية ٣٨طن\الفدان عند استعمال الرشاش (Senninger I.Wobbler) وأعلى انتاجية لبنجر السكر ١٠٧طن\الفدان فى الاسماعلية عند استعمال الرشاش (Nelson D3000GHP).تم تطبيق التحليل الإحصائي على النتائج المتحصل عليها من التجارب الحقلية وذلك لمعرفة الفروق المعنوية بين متوسطات النتائج المتحصل عليه والحصول على اعلى انتظامية، اقل فواقد للجريان السطحى ،فواقد البخر والرياح واعلى انتاجية تحت اى نوع من الرشاشات المستخدمة.

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