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OVERALL WATER LOSSES DURING SPRINKLER IRRIGATION IN ARID AREA (CASE OF TOUGGOURT - ALGERIA)

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Abstract: **In recent years, the development of agriculture in Algeria Southeast grew rapidly, which increased demand for agricultural products. Since this region has difficult agro-climatic conditions, irrigation seems to be a necessary factor to ensure optimal development and higher agricultural production. Like many irrigation techniques that are widely used, the performance of sprinkler irrigation is significantly affected by these conditions (mainly evaporation) which cause colossal water losses. The purpose of this study is to evaluate, through the experimental approach, the global losses of water caused by evaporation and wind drift on two irrigated surfaces in the arid zone of Touggourt. Here we propose adequate predictive equations and explore the effect of irrigated area on overall water loss values. These are measured on two blocks (A and B) the rain gauge method. Block A contains four lateral lines while Block B has only two. For both, each lateral line has four sprinklers. The results showed that the overall water losses of block A are about 24.13 to 50.46%, while those of Block B range from 29.52 to 49.5 %.Two obtained models are adopted for both blocks which can be useful tools for determining overall water losses in environmental conditions (air temperature, relative humidity and wind speed).Noting that when the irrigated area was larger, the water losses will be lass.**

Keywords: **Sprinkler irrigation; evaporation; wind drift; environmental condition.**

I. Introduction

South-eastern Algeria is an important agricultural pole because it contributes strongly to national agricultural production. In 2018, irrigated areas in Biskra, EL Oued and Ouargla accounted for about 19.11% of the total national irrigated areas, which reached 1.33 million hectares [1].The main activity in these arid zones is date palm cultivation with an annual production of 755 079.7 tons of dates and 172 084.7 tons of fodder crops. Cereals were estimated by 109964.2tonsand vegetable crops by 1 240 395 tons. In Oued Righ valley, the weather conditions were very severe, especially the period between April and September. Indeed, the average daily temperature can exceed 40°C, with a relative humidity of air often less than 40% and a wind speed oscillates between 2 and 4 ms^{-1}. The water resources of this region come from two underground aquifers: the Terminal Complex and the Intercalary Continental with a total stream flow, intended for irrigation, estimated at 158.104 $m^3 \cdot s^{-1}$to 254 411 ha.Currently, the commonly used irrigation methods; surface irrigation (46%) followed by sprinkling (36%) and localized irrigation (18%). Small irrigated lands (less than five ha) represent 87.8% of the total regional farms [2].Sprinkler irrigation provides a better distribution of water at the soil surface and a homogeneous uniformity of moisture through the soil depth. All the way through, quantities of water evaporate during the path between the nozzle and the vegetation. Another quantity may be carried by the wind outside the weathered zone or intercepted by the vegetation. Then the remaining water enters through soil and reaches the ground [3]. However, the increased use of sprinkler technology, especially in sandy soils, requires serious studies of water losses. Therefore, the enormous exploitation of water resources for irrigation needs to be optimally managed by providing the necessary needs of crops, taking into account the value of the losses in order to achieve a high and stable yield. In fact, the lack of adequate calculation led many researchers to estimate water loss by spraying using established formulations in several regions of the world. Many authors showed that the sum of the overall losses caused by irrigation (sprinkling) depends on air temperature, wind speed and relative humidity of the air [4, 5, 6, 7, 8, 9].Among the sprinkler irrigation system variables, the nozzle and drop diameter have a significant effect on WDEL. The large of nozzle diameter will be significant by the droplet [10].In fact, large drops were more resistant to drifting and have less surface area per unit mass, and therefore they are less affected by WDEL.

Increasing in operating pressure results in a decrease of drop diameters [11, 12] with high WDEL.The increase in nozzle elevation of the ground surface causes high WDEL, due to a long fall path and big wind exposure [6]. Thus, day and night irrigation influences WDEL [8].

This study aims to measure the overall water losses caused by evaporation and wind drift (WDEL) in arid areas, propose adequate predictive equations adaptable of this area and explore the effect of irrigated area on overall water loss values.

II. Material and Methods

1. Study site

The experiment was conducted at the National Institute of Agricultural Research in Algeria (INRAA), experimental station of Touggourt (latitude: 33°.04.293' and longitude: 006°.05.788' E) which is located at 7km of Touggourt city to the Southeastern Oued-Righ valley (Fig .1). It is characterized by an arid climate, a relative humidity of 26 to 56% and a wind speed exceeds 3 $m \cdot s^{-1}$. During the irrigation period, the temperature varies between 11 and 34° C.

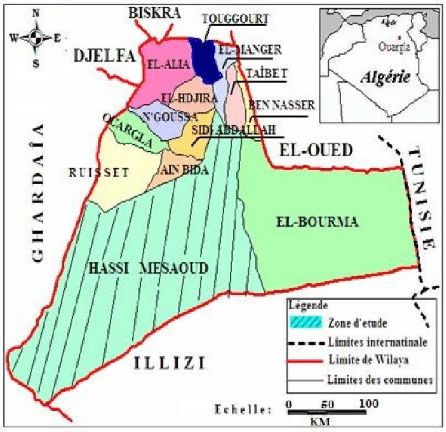

Fig.1. Location of Touggourt city [13].

The experimental site was equipped with a conventional sprinkler irrigation system (spaced by18 mx 18 m). The total surface contains two blocks: block A includes four lateral lines (Fig. 2) and block B comprised only two (Fig.3). Four sprinklersof RS130 type were installedfor each one.One single sprinkler was equipped with double nozzles (4.4 mm and 2.4 mm in diameter) and located at a height of 0.75 m from the ground. The water was pressurized by a vertical axis electric pump and the operating pressure wasmaintained constant (about 200 kPa) during the season. The experimental protocol consisted the determination of precipitation intensity. The distribution of water under the sprinklers was assessed by collecting the amounts of water using rain gauges that are arranged in a gridat 4 to 4.5 of spacing, according to ISO 11545 [14]. In order to estimate the precipitated water layer, 273 and 145 identical rain gauges (10 cm of diameter and 20 cm of height) were respectively used in blocks A and B. The measurements of these water layers were carried out just after each irrigation.

Climatic parameters were provided during the experiment period by a conventional meteorological station installed near the field. The windspeed was measured, at 2 m height, by an anemometer (Thies CLIMA), also, the air temperature was measured by a mercury thermometer (Schneider) as well as the relative humidity wasestimated by a psychrometric table (dry and wet thermometers).

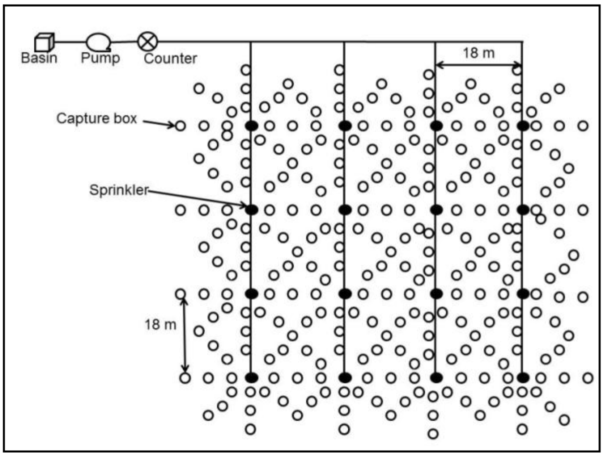

Fig.2. Experimental Schemeof Block A.

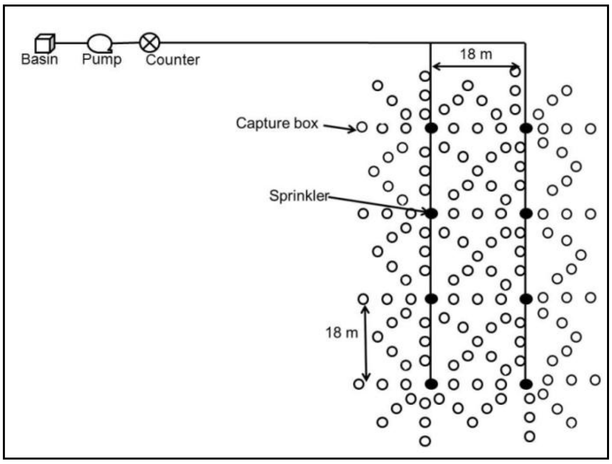

Fig.3.Experimental Scheme of Block B.

2. Determination of WDEL global loss parameters

2.1. Sprinkler water stream flow determination

The volume of irrigation water (sprinkler flow in cubic meters) was determined by means of a meter (installed at the beginning of the irrigation network). It was calculated by the following relation:

$$\boldsymbol{Q_a = \frac{V_f - V_i}{t}} \quad \dots\dots\dots(1)$$

Q_a = Total flow of sprinklers ($m^3 \cdot h^{-1}$)

V_f =Final counter reading (m^3)

V_i =Initial counter reading (m^3)

t =Irrigation time (h)

2.2. Determination of water stream flow average from rain gauges

Volumes collected in rain gauges were measured byusing graduated tube (250 ml) and directly presenting the values of precipitated water height (h).The average value of $\bar{h}$ represents the sum of all the heights divided by the number of rain gauge n:

$$\boldsymbol{hm = \frac{\sum_{i=1}^{n} h_i}{n}} \quad \text{……….} \ \mathbf{(2)}$$

The average flow of all rain gauges was calculated from the following formula:

$$\mathrm{Qp} = \frac{\mathrm{hm} \cdot \mathrm{S_a}}{1000 \cdot \mathrm{t}} \quad \text{……….} \ \mathbf{(3)}$$

h_{im} = average watering dose for all sprinklers (mm);

t = watering time (h);

S_a = area occupied by rain gauges; (m^2)

2.3. Determinations of overall WDEL losses

After irrigation, overall losses (losses by evaporation and wind drift (WDEL)) were estimated by the relation:

$$WDEL = \frac{Q_a - Q_P}{Q_a} \cdot 100 \quad \text{……….} \ \mathbf{(4)}$$

WDEL=percentage of watering rate (%)

Q_a = sprinkler water stream flow ($m^3 \cdot h^{-1}$);

Q_P = water stream flow average from rain gauges ($m^3 \cdot h^{-1}$)

3. Relationship between total losses and meteorological parameters

There are many formulas for calculating overall water losses during sprinkler irrigation, some of themwere widely used in arid regions, presenting:

- YAZAR formula

The formula of YAZAR [4] was established, in the region of Nebraska (USA), by the following form:

$$\boldsymbol{WDEL = 0.003exp\,(0.2W)(es - ea)^{0.59}\,T^{0.23}P^{0.76} + 0.27W^{2.15}} \quad \text{… … … ..} \ \mathbf{(5)}$$

Where:

$WDEL$ −Pertes globales (%)

T- Air temperature (°C);

H -Air humidity (%)

W -wind speed ($m \cdot s^{-1}$)

$(es - ea)$= water vapor pressure deficit (kPa), calculated by the following relation [12]:

$$\left(e_S - e_a\right) = e_S\left[1 - \frac{H}{100}\right] = 0.611 \cdot \exp\left(\frac{17.2 \cdot T}{237.3 + T}\right)\left(1 - \frac{H}{100}\right) \quad \text{……….} \ \mathbf{(6)}$$

e_S and e_a = are respectively the saturating water vapor pressure and the water vapor pressure in the air (kPa);

P=service pressure (kPa)

- SAPUNKOV formula

The formula of SAPUNKOV [5] was widely used in the Stavropol region (ex USSR).It was used depending on the type of spraying technique, in particular:

Large-bore sprinkler

$$\boldsymbol{WDEL} = \mathbf{8.75}\ \phi^{0.22} \quad \text{.......... (7)}$$

SAPUNKOV's relation involves a parameter, called a complex indicator of climatic intensity (ϕ) which is defined by KHABAROV in [16], it is given by the following relation:

$$\phi = \boldsymbol{T}\,(\boldsymbol{W} + \mathbf{1})\,(\mathbf{1} - \mathbf{0.01}.\boldsymbol{H}) \quad \text{.......... (8)}$$

In order to model the data obtained through the field analysis tests, the general model was used to estimate the evaporation and drag losses by performing the multiple regression process.

4. Model performance evaluation criteria

The WDEL obtained from the data-driven model and previous studies were evaluated using three performance end points: coefficient of determination (R^2) (Equation (09)), root mean square error (RMSE) (Equation (10)) and mean absolute error (MAE) (Equation (11)), [17] these criteria can be presented as:

$$\mathbf{R}^2 = \frac{\left(\sum_{i=1}^{n}(\boldsymbol{Oi}-\ddot{O})(\boldsymbol{Pi}-\acute{P})\right)^2}{\sum_{i=1}^{n}(\boldsymbol{Oi}-\ddot{O})^2 \cdot \sum_{i=1}^{n}(\boldsymbol{Pi}-\acute{P})^2} \quad \text{.......... (9)}$$

$$\mathbf{RMAE} = \sqrt{\frac{\sum_{i=1}^{n}(\boldsymbol{O}_i-\boldsymbol{P}_i)^2}{\boldsymbol{n}}} \quad \text{.......... (10)}$$

$$\mathbf{MAE} \left|\frac{\sum_{i=1}^{i=n}(\boldsymbol{O}_i-\boldsymbol{P}_i)}{\boldsymbol{n}}\right| \quad \text{..........(11)}$$

Where:

O = observed value;$\ddot{O}$= averaged observed value:Pi = estimated value;$\acute{P}$= averaged estimated value: n = number of observations

Coefficient of determination, R^2 assesses the level of relationship between observed and estimated values, with values close to 1.0 showing good execution of the model[18]. RMSE has the advantage of expressing error in the same units as the variable, thus providing more information on the efficiency of the model [18]. When the RMSE is low, the prediction is accurate. MAE Measures the average magnitude of errors in a set of forecasts, regardless of their direction. MAE ranges from 0 to infinite, and lower values were better [19].

5. Statistical analyses

In order to compare between predicted values of two blocks at 5%, T- test and Mann-Whitney test was applied by using SPSS version 20 software.

III. Results and Discussions

The measurements of total losses and climatic parameters (air temperature, air humidity and wind speed) of block A are presented in Table 1.

Table 1. Global total values and climatic parameters of block A.

Day	T (°C)	H (%)	W ($m \cdot s^{-1}$)	WDEL (%)
09.11.2017	15.86	38.33	1.24	29.41
22.11.2017	12.53	53	0.9	27.5
27.11.2017	14.4	49	0.77	29.62
05.12.2017	9.8	53.66	0.81	24.13
12.12.2017	14.66	42.33	1	24.78
19.12.2017	9.86	52.66	0.72	25.09
24.12.2017	11.46	55.33	0.71	24.09
02.01.2018	16.33	37.33	0.74	30.92
18.01.2018	14.33	41.33	1.73	26.89
21.01.2018	15.33	49.33	0.7	26.52
28.01.2018	13	45.33	2.18	24.58
12.02.2018	11.66	45.66	1.77	28.08
08.03.2018	20.26	43.16	1.43	27.11
12.03.2018	19.8	37.33	1.07	28.29
20.03.2018	20.2	28.66	2.6	34.38
27.03.2018	16.2	42	2.14	36.35
17.04.2018	23	36.3	3.29	43.89
25.04.2018	31.4	28.17	3.68	50.46
30.04.2018	28.5	33.5	2.51	43.90
07.05.2018	28	38.33	2.5	38.46
14.05.2018	25.6	42	2.73	38.36
21.05.2018	27.83	43.5	2.73	38.71
25.07.2018	36	33.33	2.49	40.86
30.07.2018	38.5	31	1.48	46.75
01.08.2018	36.66	32	2.73	37.64

Table 2 shows the measurements of the overall losses and climatic parameters (air temperature, air humidity, wind speed) of block B.

Table 2. Values of total losses and climatic parameters of block B

Day	T (°C)	H(%)	W ($m \cdot s^{-1}$)	WDEL (%)
19.11.2017	14.03	49.5	0.4	34.57
21.11.2017	13.5	50.66	0.46	34.89
26.11.2017	16	39.66	0.78	34.4
28.11.2017	17.33	46.5	1.58	35.04
03.12.2017	10.2	48.66	0.56	31.88
10.12.2017	12.6	54	1.17	32.85
17.12.2017	11.66	52.53	0.86	29.52
25.12.2017	9.46	62.66	0.41	31.53
03.01.2018	14.66	48.33	0.64	32

09.01.2018	13.13	50.46	0.89	32.77
17.01.2018	14	41	1.17	34.16
24.01.2018	14.33	57.33	1.22	31.67
13.02.2018	15.66	39	1.09	33.51
14.03.2018	20.66	42.5	1.87	35.2
26.03.2018	15.33	43.66	3.02	38.59
18.04.2018	20.2	44.3	2.86	35.62
23.04.2018	29.26	30	2.43	49.5
03.05.2018	21.2	26.5	2.96	40.72
09.05.2018	25.4	46.5	2.57	43.97
14.05.2018	28.33	42.33	1.87	36.63
23.05.2018	36.66	30.66	2.17	45.69
09.07.2018	37.66	31.33	1.6	47.27

Figures 4, 5 and 6 illustrate the effect of individual climate parameters on WDEL. In blocks A and B, air temperature was the most explanatory variable followed by wind speed and relative humidity respectively. It is clear that air temperature and wind speed were directly proportional to WDELs. Unlike, the latter is inversely proportional to the humidity of the air.

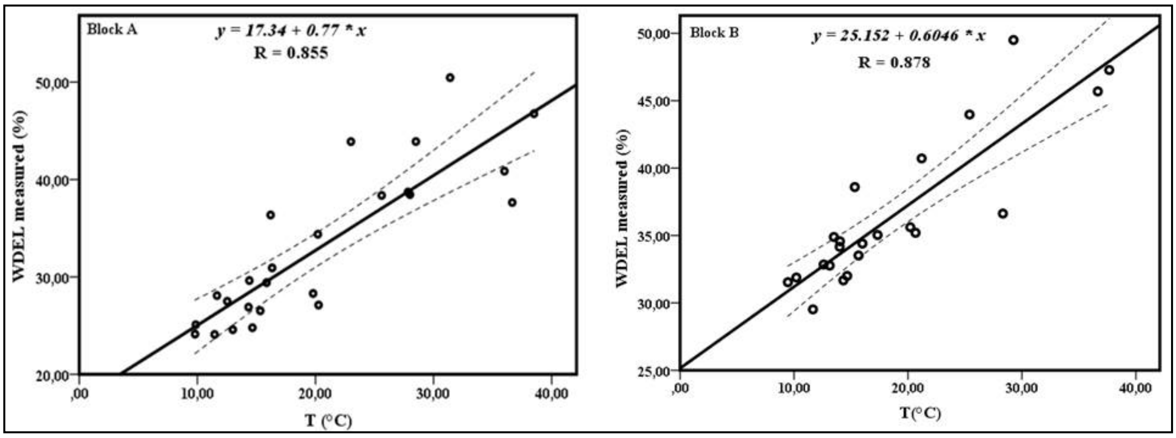

Fig.4. WDEL variation according to temperature.

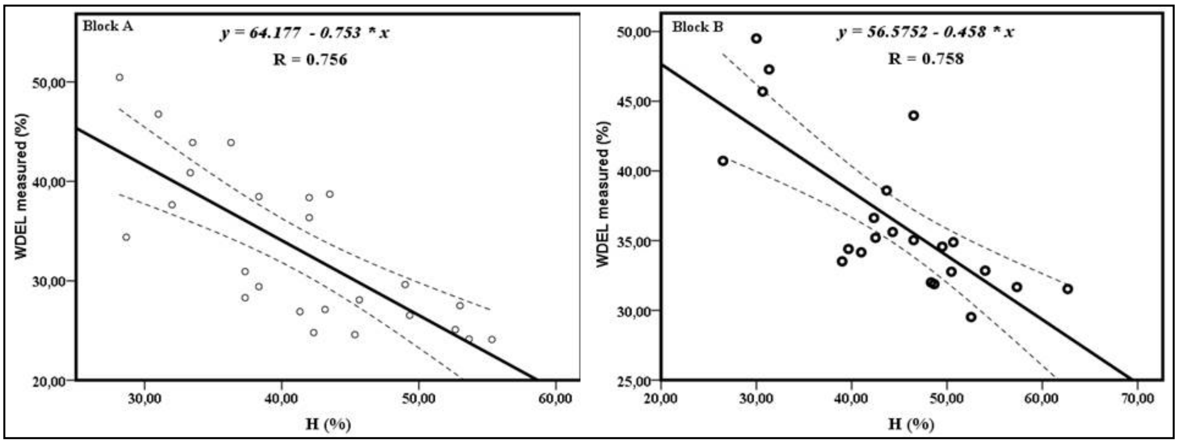

Fig.5. WDEL variation according to airhumidity.

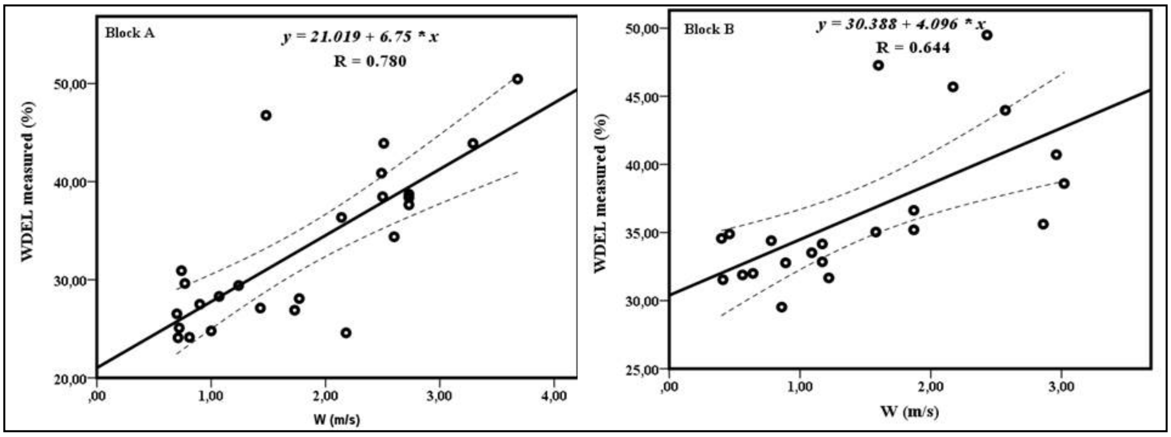

Fig.6. WDEL variation according to wind speed.

1. Global loss modelling (WDEL)

The regression analysis between overall losses and climatic parameters allowed us proposing the following models:

- For block A:

$$\boldsymbol{WDEL}\,(\%) \;=\; \mathbf{0.543}\cdot\boldsymbol{T} \;+\; \mathbf{3.323}\cdot\boldsymbol{W} \;+\mathbf{16.04} \quad \ldots\ldots\ldots\ (12)$$

- For block B:

$$\boldsymbol{WDEL}\,(\%) \;=\; \mathbf{0.521}\cdot\boldsymbol{T} \;+\; \mathbf{1.356}\cdot\boldsymbol{W} \;+\mathbf{24.708} \quad \ldots\ldots\ldots\ (13)$$

Air temperature and wind speed were the most determining parameters in the overall water loss for the two blocks (Tables 3 and 4).

Table 3. Statistical parameters of block A regressions.

Model		Coefficient	SE	Beta	t	sig
Block A	T	0.543	0.109	0.604	4.981	0.000
	W	3.323	1.049	0.384	3.167	0.004
	Constant	16.04	1.871		8.572	0.000

Table 4. Statistical parameters of block B regressions.

Model		Coefficient	SE	Beta	t	sig
Block A	T	0.521	0.086	0.756	6.079	0.000
	W	1.356	0.791	0.213	1.714	0.003
	Constant	24.708	1.451		17.027	0.000

The values of the overall losses measured were compared to the values calculated by the models of YAZAR, SAPUNCOV and the models proposed for blocks A and B in Figures 7 and 8 respectively.

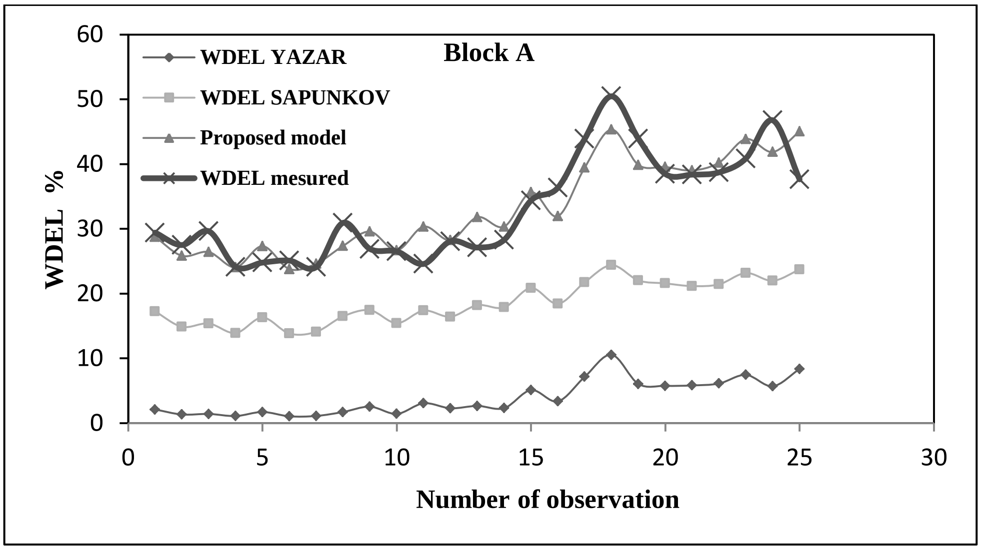

Fig.7. Comparison between the measured and calculated overall losses values (block A).

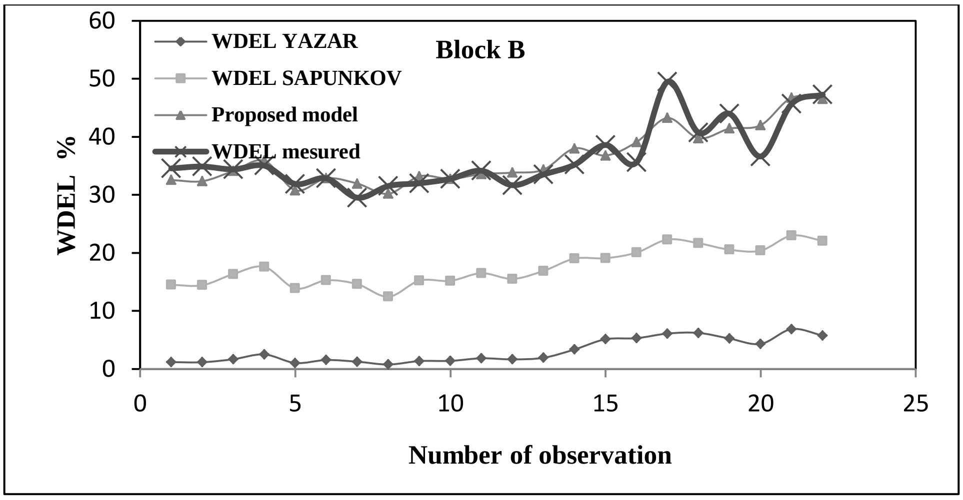

Fig.8. Comparison between the measured and calculated overall losses values (block B).

2. Evaluation of proposed and existing model's performance

To define the performance evaluation of the proposed and existing models, the following criteria were used: coefficient of determination (R^2), root mean square error (RMSE) and mean absolute error (MAE). The results of the evaluation criteria by R^2, RMSE, MAE (for the two blocks A and B were illustrated respectively in tables 5 and 6.

Table 5. Performance evaluation of proposed and existing models (Block A).

Model	**Test**		
	R^2	RMSE (%)	MAE(%)
Yazar	0.811	29.69	29.18
Sapuncov	0.804	15.31	14.46
Proposed model	0.815	3.32	0.002

Table 6. Performance evaluation of proposed and existing models (Block B).

Model	**Test**		
	R^2	RMSE (%)	MAE(%)
Yazae	0.761	33.58	33 .37
Sapuncov	0.755	19.13	18.87
Proposed model	0.805	2.41	0.0016

The performance criteria used (R^2, RMSE and MAE) of the two proposed models (12) and (13) were better compared to the performance criteria of the models of YAZAR and SAPUNCOV even as the latter has a high coefficient of determination.

The comparison between the values of the overall measured WDEL losses, modeled, calculated and the formulas of YAZAR and SAPUNCOV for blocks A and B were presented in Figures 9 and 10 respectively.

These last figures clearly showed that the values of the overall losses modeled by relations (12) and (13) were very close to the measured values.

Figures 9 and 10 show the measured values of the overall WDEL losses which were compared to those predicted and estimated where the regression line was nearly identical to the first bisector, confirming the accuracy of the current study models in both blocks.

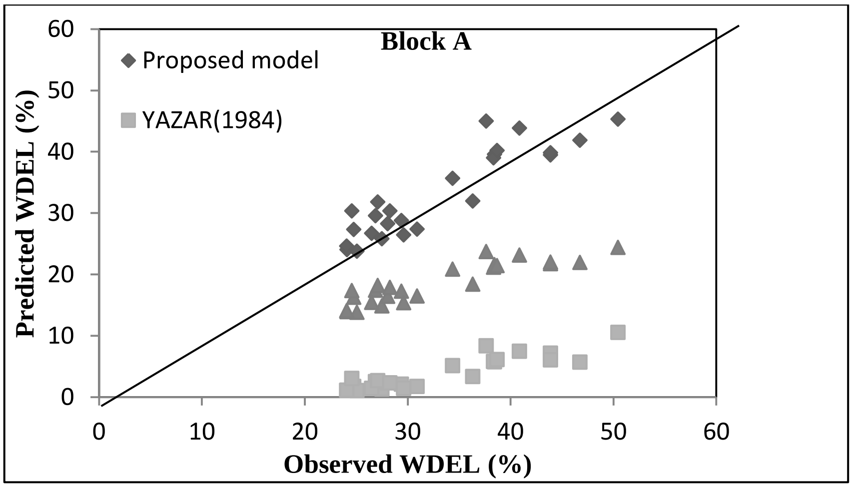

Fig .9. Comparison between values of the overall measured WDEL losses, modeled calculated and the formulas of YAZAR and SAPUNCOV for the blocks A.

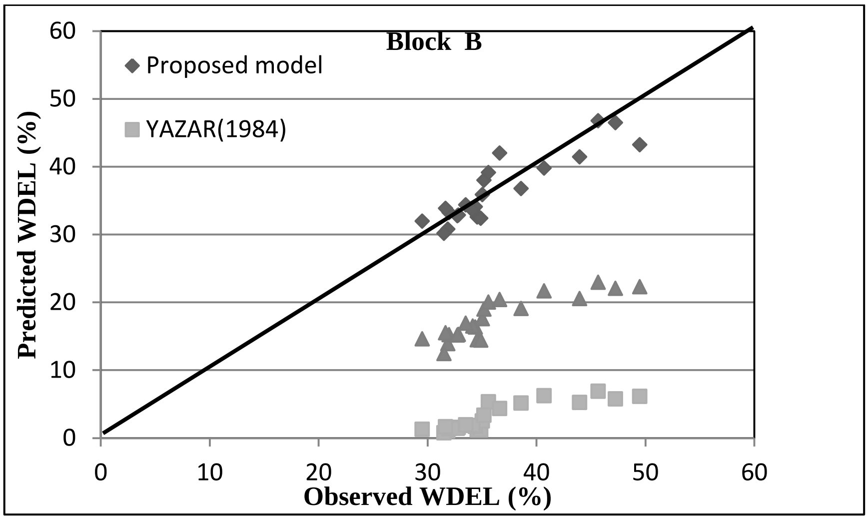

Fig.10. Comparison between values of the overall measured WDEL losses, modeled calculated and the formulas of YAZAR and SAPUNCOV for the blocks B.

3. Comparison between overall losses of the two blocks (blocks A and B)

In this study phase we try to verify the influence of an increase in the irrigated area on the overall losses (evaporation and wind drift losses). The verification was based on Shapiro-Wilk normality test. For a sample size of (N = 47 < 50), the significant values of Shapiro-Wilk was equal to 0.002, 0.001 for blocks A and B respectively. (Table 7).

Table 7. Normality test.

G		**Shapiro-Wilk**		
		Statistical	ddl	signification
WDEL	A	0.911	47	0.002
	B	0.896	47	0.001

The values presented in Table 7 clearly showed that the two blocks (A and B) didn't follow a normal distribution at a confidence interval of 95%. In this case, Mann-Whitney nonparametric test was used in the comparison [20]. This test indicated that Sig Asymp's significance level value of 0.000 was less than 0.05, indicating that there was a highly significant difference between the two blocks. The mean values of overall losses (WDEL) of blocks A and B were 32.16 ± 6.82% and 37.16 ± 5.22%, respectively. The relative difference between the means of the two blocks is of the order of 13.46%, which means that the increase in the irrigated area contributed to the decrease in WDEL by about 13.46% (Figure 11).

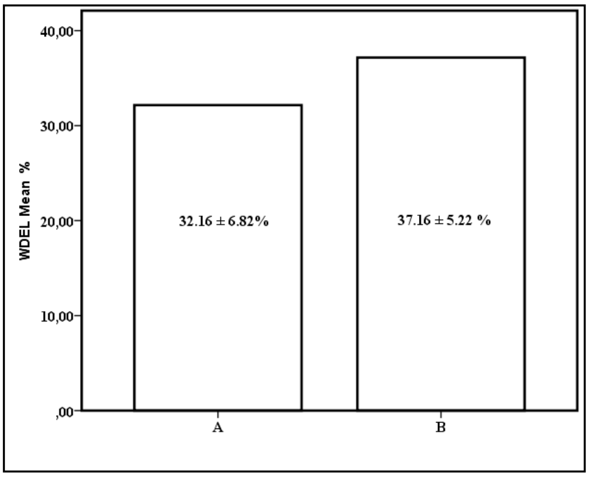

Fig.11. Bar chart of WDEL of block A and block B.

Conclusion

Touggourt was characterized by an arid climate. The agro-climatic conditions favour the rapid development of the sprinkler irrigation technique in this area, which poses enormous problems of losses by evaporation and wind drift. The experiment showed that overall water losses are mainly affected by meteorological factors such as air temperature and wind speed. The obtained formulae for calculating water losses, adapted to arid regions, provide underestimated values. The later doesn't suit the arid climate of Algeria. Correlation analysis between overall water losses and both studied meteorological elements allowed to establish empirical models between these characteristics. The water loss values calculated by the established models don't differ significantly from the measured values. Besides, the obtained results showed that the increase in irrigated area is an obvious determining factor for the decrease of water losses, by evaporation and wind drift from the cloud drops of approximately 13.46%.

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