Journal of Soil Sciences and Agricultural Engineering

Evaluation of Surface Renewal VS. Eddy Covariance Methods to Estimate Cereal Crops Evapotranspiration

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ABSTRACT

This study aims at evaluating the application of using the surface renewal "SR" method against Eddy Covariance "EC" method, for direct estimation of crops evapotranspiration "ETc" of wheat and rice crops, cultivated under the agro-climatic conditions of the old lands in the Nile Delta region in Egypt. Two field experiments were conducted at Qalubia governorate, in 15 feddan experimental field. The assessments were conducted for rice and wheat crops during the agricultural seasons of 2016. During the two seasons, the surface energy fluxes were recorded each 30 min, including net radiation, soil heat fluxes, sensible heat fluxes by EC method, and sensible heat fluxes by SR method. The SR method was calibrated against the EC method, and the determined latent heat fluxes "LE" of the both methods show high correlation with R^2 around 0.98 for both crops. The comparison between ETc-SR and ETc-EC showed statistically good performance, with NRMSE of 11% for rice, and 16% for wheat. The rice results showed that the widely used ETc-FAO was a slight higher than ETc-SR and ETc-EC, by 5% and 0.7%, respectively. Wheat results showed that the ETc-FAO was higher than ETc-SR and ETc-EC by 30% and 32%, respectively. The results of rice and wheat could be promising for further improvement in using the SR method as reliable, accurate, and cost-effective method to estimate ETc for field crops, while more validation is still needed to cover different types of agricultural practices.

Keywords: rice; wheat, water requirements; Energy balance approach.

INTRODUCTION

In irrigated agricultural systems in arid regions, the precision estimation of the crops evapotranspiration "ET" is critical consideration to ensure efficient and sustainable irrigation management. Crop evapotranspiration "ETc" should be determined using direct or indirect methods. The most common indirect method is often approximated ETc values as the product of reference evapotranspiration "ETo" and a crop coefficient "Kc" factor. ETo is adjusting ETc for variations in weather parameters, and the Kc referring to biological, eco-physiological, and agronomic characterizing the stages of crop growth and production. "ETo" is commonly estimated using weather data as a function of several models such as Penman-Monteth equation. Allen *et al.* (2011) highlighted some direct field-scale methods for "ETc" measurements, which include methods related to the energy balance (e.g., Bowen ratio or residual of the energy balance, and Eddy covariance "EC"), and methods related to mass balance (e.g., lysimeters).

Shapland *et al.* (2012) simplified the energy balance context, as "ETc" can be obtained from actual measured components of the "energy balance equation" (Rn=G+H+LE). This equation considers that the net radiation "Rn" must be in balance with the ground heat flux density "G", sensible heat flux density "H", and latent heat flux density "LE", and other less significant energy terms for simplification proposes (e.g. photosynthesis and biomass energy storage). Based on the energy balance

equation, "ETc" can be estimated by measuring "Rn", "G", and "H" and then calculate "LE" using the residual of the energy balance equation:

$$LE= Rn-G-H \qquad (1)$$

"LE" can then be divided by the latent heat of evaporation "L" to obtain the mass flux density of water vapor, and the mass flux density of water can be converted to hourly and daily ETc (Equation 2).

$$ETc =LE/L \qquad (2)$$

The eddy covariance "EC" method (Anandakumar, 1999; Baldocchi, 2003; Simmons *et al.*, 2007) is one of the most common technique for field-scale "ETc" measurements. The "EC" method involves simultaneous high-frequency measurements of vertical air velocity and scalar concentration, with three dimensional sonic anemometer over a time interval (Lee *et al.*, 2004), followed by computation of their covariance which represents the vertical flux of the measured scalar (water vapor, temperature, etc..). The "EC" method could be highly accurate for research purposes, whereas its applicability at the farm level is limited, mainly because of the high cost of the sensors, complexity of their operation, and the intensive data analysis (Rosa and Tanny, 2015).

The surface renewal "SR" method is another energy balance method to estimate "ETc" at field scale, using more simple and lower cost high frequency temperature sensor. It is based on the dynamics of sweeps and ejections of air parcels that occur near the canopy surface; it is assumed that this renewal mechanism is responsible for the exchange of sensible heat between the

crop and the atmosphere (Paw U *et al.*, 1995). Using high frequency air temperature measurements, the renewal of sweeps and ejections is modeled as temperature ramps through a "structure function" analysis. Ramps amplitude and frequency enable estimating the sensible heat "H" exchange between the canopy and the atmosphere (Snyder *et al.*, 1996). The practical use of the SR method could be reliable after a calibration process, aiming to safely use the method for estimating the sensible heat flux of a similar crop under similar agro-technical and climatic conditions (Snyder *et al.*, 2008; Rosa and Tanny, 2015).

The current study is aiming to introduce an evaluation of the application of using "Surface Renewal (SR)" and "Eddy Covariance (EC)" methods, for estimating crop-evapotranspiration of wheat and rice crops, cultivated under the agro-climatic conditions of the old lands in the Nile Delta region in Egypt.

MATERIALS AND METHODS

The field assessment

The field assessment was carried out in the "agricultural production sector farm" (30.39° N, 31.25° E, 27 m)- belongs to the Ministry of agricultural and land reclamation of Egypt- located at Moshtouhor district, Qalubia governorate, which is located in the southern part of the Nile Delta region. In this farm, the data was collected from experimental field of a total area 15 feddan (6.3 ha).

At the beginning of the field experiments, soil texture and soil-water relationship parameters were determined from laboratory tests, by collecting random soil samples taken from two layers, at depths 0-40 cm and 40-70 cm. As shown in Table (1) the soil texture was clay.

The field assessment was conducted in two consecutive agricultural seasons. The first one was the summer season, of rice crop that was cultivated by transplanting, at 27th May 2016. The Rice cultivar was "Giza 179", that was fully flooded by water at depths 7 to 10 cm, and the water was drained and recycled every three days. The irrigation was cut-off and water totally drained at 22 days before the harvesting, which was *carried out at 27th September 2016 (123 days).*

Table 1. Physical properties of soil, and soil-water relationships at Moshtouhor- Qalubia, Egypt

	Physical properties				soil-water relationships		
Depth	Sand [%]	Silt [%]	Clay [%]	Textural class	F.C. [%]	P.W.P [%]	B.D [g/cm³]
0-40	22.2	27.9	49.9	Clay	33.5	16.0	1.10
40-70	23.2	28.2	48.6	Clay	38.5	18.5	1.15

F.C.: Field capacity [%]; P.W.P: Permanent wilting point [%] ; B.D: Bulk Density [g/cm³]

The second season of the field assessment was the winter season of wheat crop, using "Giza 168" cultivar, that was cultivated at raised beds (60 cm width ×20 cm height), with a seeding rate of 70 kg/feddan, at 15th November, 2016. The crop was irrigated seven times per season using surface furrow irrigation system. The irrigation was cut-off at 25 days before the harvesting of the wheat crop, which was carried out at 1st May 2017 (167 days).

The applied on-farm practices for the two crops were following the recommendations of the Ministry of the Agriculture and Land Reclamation. And, from the records of the pump station, the overall applied irrigation was 692 mm/ season for wheat, and 1385 mm/season for rice.

Measurement devices setup

For the field assessment, one station of surface fluxes was installed in the middle of the experimental field. This station had a Campbell Scientific (USA) CR3000 data logger, and the NR LITE2 net radiometer from Kipp & Zonen (Delft, Netherlands) was used to measure net radiation. The station had two groups of soil heat flux "G" sensors, each group consisted of one HFT3 Campbell Scientific heat flux plate sensor inserted at 0.15 m depth below the soil surface, and two TCAV Campbell Scientific soil thermistors placed at 0.05 m depths above and under the installed heat flux plates. The first soil group was installed under the plants row, and the other group was inserted between the plants rows. In order to estimate the sensible heat fluxes "H_{EC}" by "EC" method, the station had RM Young three-dimensional sonic anemometer (Model 81000RE), collecting high-frequency wind velocities in three orthogonal directions. Moreover, the station had a Campbell Scientific fine wire thermocouple (FW3), of Chromel-Constantan 76.2-μm diameter, that used to measure the high-frequency temperature data to estimate the sensible heat fluxes "H_{SR}" by "SR" method. The fine-wire thermocouple data and sonic anemometer data were collected at a sampling rate of 10 Hz, and mounted at 2 m height, whereas the other variables were sampled once per minute and was recorded each thirty minutes.

Furthermore, ET_o system station (Dacom, Netherlands) was installed near to the surface fluxes station, aiming to estimate the daily reference evapotranspiration (ET_o) using the FAO-Penman (FPM) method (Allen *et al.*, 1998).

Data analysis methods

The full description of the theoretical basics and the calculation model of the "SR" and "EC" methods, can be found in Paw U *et al.* (1995 and 2005), Snyder *et al.* (1996), Spano *et al.* (1997), and Shapland *et al.* (2013). In this study, both "EC" and "SR" methods were used for estimating "H" and "LE" based on the residual of the energy balance "REB" approach, that shown in Equation (1). The "H_{EC}" is determined from high frequency measurements of scalars of air temperature and the vertical component of wind speed measured by 3D sonic anemometer as described by Lee *et al.* (2004):

$$H_{EC} = \rho\, C_p\, (\overline{w\, T_S}) \qquad (3)$$

Where

ρ = air density [g m⁻³]; C_p = specific heat of air at constant pressure [J g⁻¹ K⁻¹], w=the vertical wind velocity [ms⁻¹], T_S = the sonic temperature [K], and the overbar denotes the time- averaged interval.

Then the latent heat flux "LE_{EC}" is derive from the following energy balance equation:

$$LE_{EC}= Rn- G- H_{Ec} \qquad (4)$$

in which all the fluxes in the equation was measured and estimated in W·m⁻².

The SR sensible heat flux "H_{SR}" is calculated from the average heating of the air parcel and the number of times the air parcel is renewed at the canopy surface over

30-min intervals, measured by high-sensitivity temperature sensor, as shown in Equation (5):

$$H_{SR} = \alpha\, H' = \alpha\left[z\,\rho\,C_p\left(\frac{a}{t_r}\right)\right] \quad (5)$$

Where

α = calibration factor; z = sensor measurement height [m]; and a = average ramp amplitude [K], which corresponds to the temperature enhancement of the air parcel. "t_r" is the mean air parcel renewal time over the sampling period (Paw U *et al.*, 1995). The ramp amplitude "a" and duration "t_r" are determined using the Van Atta ramp model (Van Atta 1977),

which uses half-hour means of the second, third, and fifth moments of the air temperature structure function "$S^n(r)$" (Equation 6):

$$S^n(r) = \frac{1}{m-j}\sum_{i=1+j}^{m}(T_i - T_{i-j})^n \quad (6)$$

Where

m = number of data points in the half-hour interval measured at frequency "f"; n = order of the structure function (second, third, and fifth moments); j = sample lag between data points corresponding to a time lag "r j/f"; and T_i =the temperature sample number i [K].

In this research, the second, third, and fifth moments were calculated and recorded for both r = 0.25 s and r = 0.50 s, and the structure function were used to estimate "a" by solving the third order equation for real roots of the amplitude (a):

$$a^3 + pa + q = 0 \quad (7)$$

Where:

$p = 10\, S^2(r) - \frac{S^3(r)}{S^5(r)}$ & $q = 10\, S^3(r)$

Then the inverse ramp frequency is calculated as:

$$l + s = \frac{a^3 r}{S^3(r)} \quad (8)$$

From solving the previous equations, the sensible heat flux density is first estimated, without a correction for unequal heating "H'", as following:

$$H' = z\,\rho\,C_p\left(\frac{a}{l+s}\right) \quad (9)$$

The "α" value for unequal heating is determined by calculating a linear regression between "H_{EC}" and "H'". Then "H_{SR}" is estimated as:

$$H_{SR} = \alpha\, H' = \alpha\left[z\,\rho\,C_p\left(\frac{a}{l+s}\right)\right] \quad (10)$$

Using Equation (1) and similar to Equation (4) the latent heat flux density "LE_{SR}" could be determined using the "H_{SR}". Subsequently, the actual evapotranspiration can be determined for the two methods of "EC" and "SR", by dividing the "LE" values [MJ·m^{-2}·d^{-1}] by L=2.45 MJ·kg^{-1} (Equation 2), to obtain the "ETc" in kg·m^{-2}·d^{-1}, which is equivalent to mm·d^{-1}.

The data collection campaigns were conducted during the active period of the growing seasons that include the irrigation events. Thus the data collection campaign of rice started at 10 June 2016 (after the full germination of the plants), ended at 6 September 2016 (after irrigation cut-off by one day), and it encompassed 4224 record for half-hourly data along 89 days. The wheat campaign started at 25 November 2016 (after the full germination), ended at 8 April 2017, and included 6432 half-hourly record along 135 days.

The determined "ETc" daily values from REB methods "ETc-SR" and "ETc-EC", were compared to "ETc-FAO" values calculated using the widely-used FAO method (ETo from FAO-Penman multiplied by the "Kc" for each crop. The daily "ETo" data was acquired from the Dacom ETo station. The FAO "Kc" values (Allen *et al.*,

1998) were used as 0.6, 1.2 and 1.03 for rice crop, at initial, mid-season and late-season growth stages, respectively. Likewise, the "Kc" values for wheat crop were 0.3, 1.15 and 0.25, at initial, mid-season and late-season growth stages, respectively. The start and the end of each growth stage was defined according to the morphological parameters of crop, and with help from field-crops experts.

The "coefficient of determination" (R^2) was used as a statistical indicator to evaluate the quality of relationship between the "H_{EC}" and "LE_{EC}" half-hourly data before using it in the calibration process of the SR method, and then it used to evaluate the quality of the calibration, by comparing the "LE_{SR}" by "LE_{EC}". Additional to R^2, Root Mean Square Error (RMSE) and Normalized Root Mean Square Error (NRMSE) were used as well to evaluate the half-hourly "LE_{SR}" *vs.* "LE_{EC}". The RMSE and NRMSE were used also to evaluate the statistical differences between the daily values of the "ETc-SR" vs. "ETc-EC", "ETc-SR" vs. "ETc-FAO", and "ETc-EC" vs. "ETc-FAO". The general approach of calculating the RMSE is using the following equation:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Y-X)^2}{n}} \quad (11)$$

And the NRMSE:

$$NRMSE = \frac{RMSE}{\bar{X}} \quad (12)$$

Where:

"Y" and "X" denoting the two factors under the comparison, "n" is the number of the compared records, "$\bar{X}$" is the average of the "X" factor records.

The relationship between "Y" and "X" can be considered excellent if the "NRMSE" is less than 10%, good for 10-20%, average quality is 20-30%, and bad if the error value greater than 30%. Both "RMSE" and "NRMSE" are widely used for the statistical evaluation of numerical analysis and modeling for environmental systems, as explained by Willmott (1982) and Kobayashi and Salam (2000).

RESULTS AND DISCUSSION

Quality assurance of EC data and calibration of the SR

The "SR" method have to be calibrated before using it to estimate the "ETc" for any given crop. The calibration process is usually carried out by comparing the "H_{SR}" measurements against any other "REB" method, in order to determine the linear bias of the "H_{SR}" values. Snyder *et al.* (1996) and Spano *et al.* (2000) explained the possible physical sources of the linear bias. It's likely occurred as a result of the vertical heterogeneity of energy exchange within the canopy and air, that under medium-to-high weather factors fluctuations (unstable atmospheric conditions), cool air parcels move instantly downward and then travel horizontally over the canopy surface, and then the cool air swept into the canopy will gradually warm from heat transfer from canopy surface to air parcel, which create the positive amplitude ramps. Whereas, under stable-to-low weather factors fluctuations (stable atmospheric conditions), the temperature of the air parcel would cool as warm air swept into the canopy, transfers heat from the air to the canopy surface, resulting in a slow temperature drop and uneven heating of the air parcel, and create negative amplitude ramps.

Besides the heterogeneity of energy exchange, Snyder *et al.* (1996) and Spano *et al.* (2000) mentioned the non-uniformity in parcels sizes and heights as another sources of the occurrence of linear bias of the H_{SR} values.

In this study, the determined "H_{SR}" values has been calibrated for wheat and rice crops, against the "H_{EC}". As a first step in this calibration process, the accuracy of the "EC" data was evaluated. Shapland *et al.* (2012) and Rosa and Tanny (2015) recommended the "energy balance closure analysis" as a tool for examining the quality of the fluxes measured by the "EC" method. This analysis is based on the energy balance equation (Equation 1), that assumes that the [Rn – G] fluxes is almost equal to the turbulent fluxes estimated by "EC" [H_{EC} + LE_{EC}], as shown in Equation (13):

$$H_{EC} + LE_{EC} = b\,(Rn\text{ - }G) \qquad (13)$$

In which, "b" represents the slope of a linear regression between the two sides of the equation. The full equalization between the two sides of the equation is rarely obtained in flux measurement studies (Wilson *et al.* 2002), since the energy balance is not fully closed. Figure (1) shows the application of Equation (13) using the data of rice and wheat crops,

using the half-hourly fluxes data, which shows very good slops for the examined crops, equaled to 0.98 for rice and 0.86 for wheat, with corresponding high R^2 of 0.988 and 0.985, respectively.
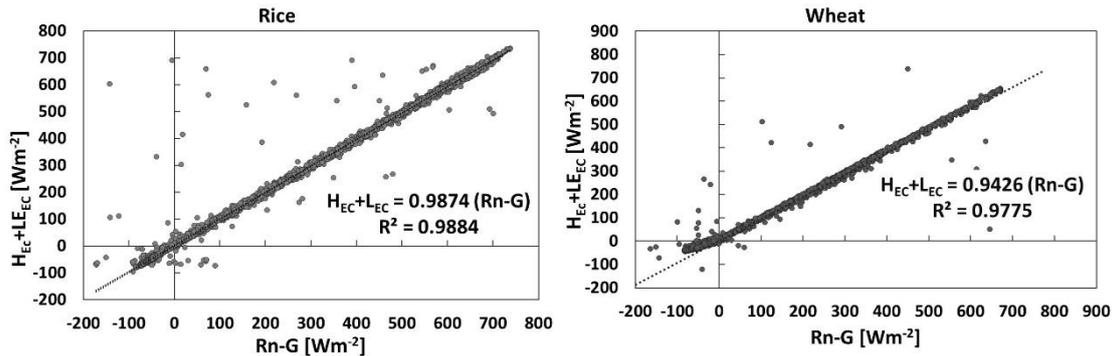

Figure 1. "Energy balance closure analysis" for evaluating the quality of the fluxes determined by EC method, using half-hourly data for rice and wheat crops.

After the evaluation of "EC" data, the calibration of the "SR" method has been done by plotting the uncliberated "SR" half-hourly values of the sensible heat flux density "H'", against the estimated corresponding values of "H_{EC}". Then, the slope of the regression line through "H'" vs. "H_{EC}" was calculated to determine the calibration factor "α" under both stable and unstable atmospheric conditions separately (Shapland *et al.* 2012). The results of the calibration are shown in Figure (2). For rice crop, "α" values were 0.7578 and 0.7287, for negative and positive "H'", respectively. Likewise, "α" values for wheat crop were 1.1831 and 1.1478, for negative and positive "H'", respectively.
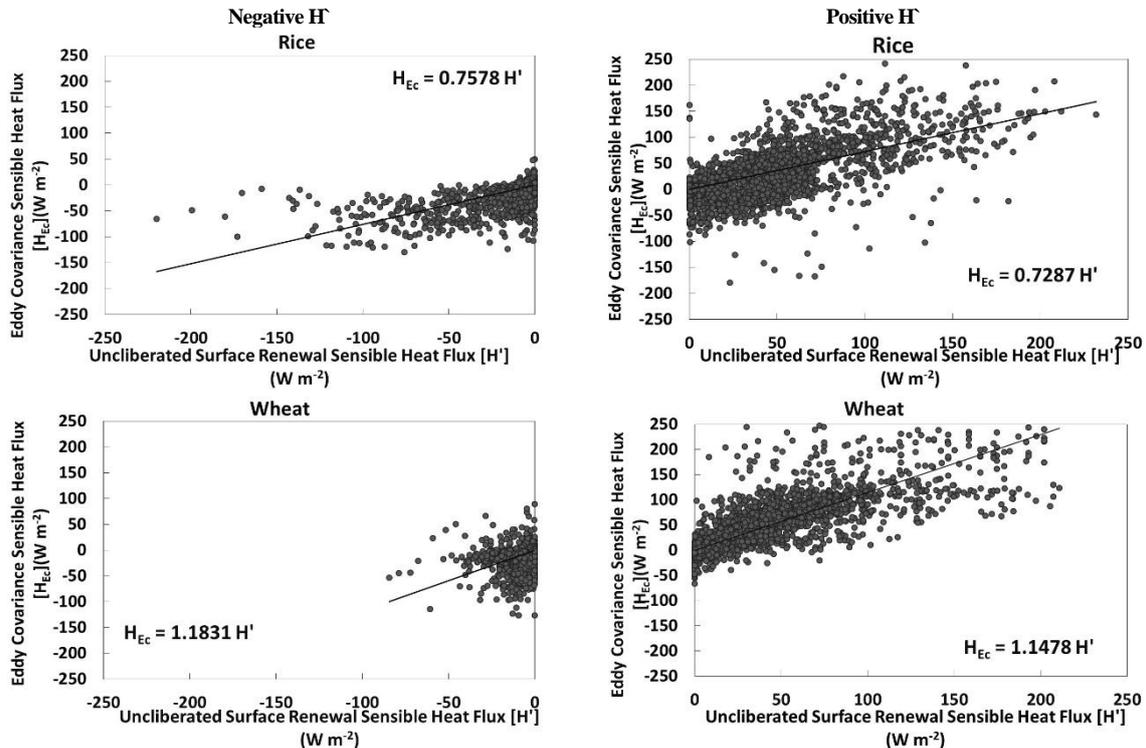

Figure 2. Half-hourly "H_{EC}" *vs* uncalibrated positive and negative "H'" from "SR" method, for rice and wheat crops.

Based on the previous calibration, the "H_{SR}" values were calculated using the determined "α" values, as mentioned in Equation (10). The calibrated "H_{SR}" and "H_{EC}" half-hourly values were used to calculate the latent heat fluxes of "SR" and "EC" methods (LE_{SR} and LE_{EC}), using Equation (4) with the same "Rn" and "G" values. Figure (3) shows the high correlation between the "LE_{SR}" and "LE_{EC}", with R^2 around 0.98 for both crops, "RMSE"

24.77 Wm^{-2} and 21.40 Wm^{-2}, and good "NRMSE" of 18.38% and 17.92% for rice and wheat, respectively. Hu *et al*. (2018) listed several examples of studies concluded that the calibrated SR technique is a good independent method for estimating surface fluxes, and can be reliable to estimate "LE" with good accuracy.
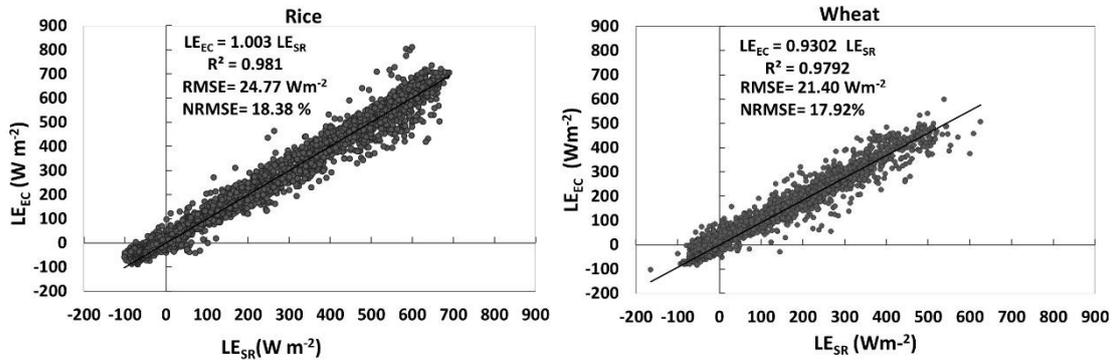

Figure 3. Half-hourly "LE_{SR}" vs "LE_{EC}" for rice and wheat crops, as an evaluation for "SR" calibration process.

Crop water requirements "ETc" results

The actual evapotranspiration determined by "REB" methods (ETc-SR and ETc-EC) of rice and wheat crops were calculated using the daily determined "LE_{SR}" and "LE_{EC}", using Equation (2). Figure (4) shows the daily values of the "ETc-SR" and "ETc-EC" for rice and wheat crops. Those values were compared to the determined "ETc-FAO" values of the crops under investigation.

For rice crop, the daily average "ETc" was 5.06 and 4.67 mm/day for "EC" and "SR" methods, respectively.

Whereas the determined "ETc-FAO" average value was 4.96 mm/day, corresponding to average "ETo" of 4.76 mm/day. For the whole season, the difference between the "ETc-SR" and "ETc-EC" was small with a "RMSE" of 0.52 mm/day and good "NRMSE" of 11%. The difference between the two methods varied along the different growth stages of the crop, gave an excellent "NRMSE" of 9.32 and 4.40 % at initial and late-season growing stages, and gave good "NRMSE" of 12.87% during mid-season growing stage.
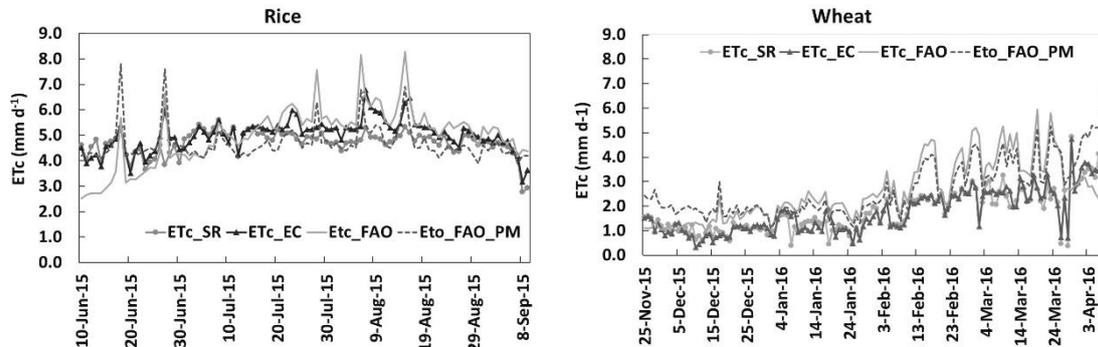
Figure 4. The daily evapotranspiration estimated by "EC", "SR" and FAO methods, for rice and wheat experiments.

For the same season of rice crop, the "ETc-FAO" values were higher than "ETc-SR" by "NRMSE" for the whole season equal to 1.07 mm/day and "NRMSE" of 22.6%. Regarding the growth stages, "ETc-SR" values were higher than "ETc-FAO" at the initial stage with a "RMSE" of 1.06 mm/day and 22.71% "NRMSE". Then, "ETc-FAO" values become higher than "ETc-SR" during mid-season and late-season growth stages, by "RMSE" values equal to 1.17 and 0.45 mm/day and "NRMSE" values equal to 24.18% and 9.79% for each season, respectively. The difference between "ETc-FAO" and "ETc-EC" had almost the same previous trend, that the "NRMSE" for the whole season was 0.78 mm/day and "NRMSE" of 15.39%. Similar to "ETc-SR" at the initial stage, the "ETc-EC" was higher than "ETc-FAO", with "RMSE" of 0.88 mm/day and 18.68% "NRMSE", then the "ETc-EC" values become

lower than the "ETc-FAO" during mid-season and late-season growth stages, by "RMSE" values equal to 0.74 and 0.35 mm/day and "NRMSE" values equal to 13.82% and 7.33% for each season, respectively. Montazar *et al*. (2017) explained the observed high values of the "ETc" determined by "REB" methods, at the beginning of the flooded rice season, as a result to the small canopy cover proportional to the water surface in the flooded field, that in this case the surface area of the water exposed to the weather conditions are higher than the area of the plants canopy, which produce higher "LE". As the size of rice canopy increases, it covers the water surface, and avoid the effect of the water surface in the "LE" values.

The overall "ETc" values of the rice crop were 447, 423 and 450 mm/season for "ETc-SR", "ETc-EC" and "ETc-FAO" methods, respectively. The seasonal records

from the three methods were close, that the "REB" methods detected a slight lower seasonal "ETc" rather than the "ETc-FAO", by 5% lower for "ETc-SR", and 0.7% lower for "ETc-EC".

For wheat crop, the daily average "ETc" values were 2.04, 2.06, 2.60 mm/day for "ETc-SR", "ETc-EC" and "ETc-FAO" methods respectively, with a corresponding average of "ETo" equal to 2.69 mm/day. Along the whole season, there were small differences between "ETc-SR" and "ETc-EC" values, resulting 0.33 mm/day "RMSE" and 16.25 % "NRMSE". This trend of the differences was almost the same when the data analyzed for initial, mid-season, and late-season growth stages separately. "ETc-FAO" values were remarkably higher than the "ETc-SR" and "ETc-EC" during the whole season and growth stages, with an overall "NRMSE" of about 72% for "ETc-SR", and 70% for "ETc-EC".

The total "ETc" values determined by "REB" methods of the wheat season were 247 and 240 mm/season for "ETc-SR" and "ETc-EC", respectively, which were 30% and 32% less than the total from "ETc-FAO" (354 mm/season).

The acquired results could be explained and accepted by understanding the basic assumptions of each method, that "ETc-FAO" is based on an approximate method, have several sources of uncertainty, such as using a static "Kc" values without considering the dynamic variables affected by the cultivar of the crop, the on-farm management practices, and the environmental conditions (English *et al.* 2008). Whilst the "REB" methods are direct measurements methods, can be used to accurately to measure site-specific sensible heat flux "H", and represent the dynamic energy balance between the plant canopy and the surrounding environment at the field scale. Perry *et al.* (2019) stated that due to the difficulty conduct accurate measurements to dynamic biometeorological factors on "ETc-FAO", a direct measurement of "ETc" with relatively low-cost methods is desirable.

Simmons *et al.* (2007) and Allan *et al.* (2011) referenced the "EC" method as the most reliable method to estimate the "ETc" from plants canopies. However, "EC" set up is expensive, and its measurements of the sonic signals are direct to distortion due to rainfall, fog, insects, and dirt (Castellvi *et al.*, 2008). Recently, the "SR" method has been considered as technical simple with high reliability and feasibility method to determine the "ETc", compared to the "EC" method. Hu *et al.* (2018) listed several examples of studies that compared the two methods, and showed favorable agreement against the "EC" method. Some of those studies concluded that the "SR" method can determine the "ETc" with good performance for surfaces with dense canopies such as field crops (e.g. Shapland *et al.* (2013)). Moreover, other studies showed that "SR" method compared to "EC" Method provided better agreement under the more arid conditions (Hu *et al.*, 2018).

CONCLUSION

High reliable estimation of the actual crop-water requirements is essential to design and conclude on-farm irrigation management guidelines, that can efficiently improve the water productivity under the aridity and limited water resources. In this study, the performance of the "SR" method to determine the "ETc" of rice and wheat, was studied and evaluated against the corresponding values determined by "EC" and "ETc-FAO" methods, and the following can be concluded:

- Considering the high reliability of the "EC" method to estimate "ETc", the results showed statistically good performance in estimates of "ETc", with NRMSE of 11% for rice, and 16% for wheat.
- The results of the total "ETc" of the rice showed that the "ETc-FAO" was a slight higher than "ETc-SR" and "ETc-EC", by 5% and 0.7%, respectively. Those differences increased in the case of wheat, that the "ETc-FAO" was higher than "ETc-SR" and "ETc-EC" by 30% and 32%, respectively. Noting that The "ETc-FAO", represent the widely used method for planning and practicing irrigation management at the national level
- The current results for rice and wheat could be promising for further improvement in using the "SR" method as reliable, accurate, and cost-effective method to estimate crop water requirements for field crops.
- The calibration process of the "SR" method is very important to ensure the good performance of this method. Under the current study, the calibrated "SR" showed high correlation between the determined "LE_{SR}" towards the corresponding "LE_{EC}" with R^2 around 0.98.
- More validation is needed for the "SR" method calibration at different management systems and field conditions of rice and wheat crops, which could lead to updating the current information and guidelines about irrigation management of the investigated crops. In general perspective, the application of "REB" methods can lead to major changes in the default guidelines of crop-water management at the field scale for different types of crops.

ACKNOWLEDGEMENTS

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تقييم طريقتي "Surface renewal" و "Eddy covariance" لتقدير بخر-نتح محاصيل الحبوب

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هدفت هذه الدراسة إلى تقييم استخدام طريقة "Surface renewal (SR) مقابل طريقة "Eddy Covariance (EC) ، لتقدير البخر-نتح المحصولى "ETc" لمحاصيل القمح والأرز المزروعة تحت الظروف المناخية بالأراضى القديمة في منطقة دلتا النيل في مصر. أجريت تجربتان حقليتان بمحافظة القليوبية في حقل تجريبي بمساحة 15 فداناً حيث تم إجراء التقييم الأول لمحصول الأرز خلال موسم صيف 2015 ، تلا محصول القمح خلال فصل الشتاء 2016/2015. خلال الموسمين تم تسجيل تدفقات الطاقة السطحية كل 30 دقيقة ، بما في ذلك صافي الإشعاع الشمسى، وتدفق حرارة التربة، وتدفق الحرارة المحسوسة بطريقة "EC" ، وتدفق الحرارة المحسوسة بطريقة "SR". تمت معايرة طريقة "SR" مقابل طريقة "EC" حيث أبدت التدفقات الحرارية الكامنة "LE" للطريقتين بعد المعايرة ارتباطاً كبيرًا بمعامل R2 حوالي 0.98 لكلا المحصولين. أظهرت المقارنة بين "ETc-SR" و "ETc-EC" أداءً إحصائيًا جيدًا، حيث بلغت قيمة "NRMSE" 11% للأرز و 16% للقمح. أظهرت نتائج الأرز أن "ETc-FAO" المستخدم على نطاق واسع، كان أعلى قليلاً من "ETc-SR" و "ETc-EC" ، بنسبة 5٪ و 0.7 على التوالي. و أظهرت نتائج القمح أن "ETc-FAO" كان أعلى من "ETc-SR" و "ETc- EC"بنسبة 30٪ و 32٪ على التوالي. و من ثم يمكن اعتبار النتائج الحالية للأرز والقمح واعدة لإجراء مزيد من التحسين في استخدام طريقة "SR" كطريقة موثوقة ودقيقة وفعالة من حيث التكلفة لتقدير "ETc" للمحاصيل الحقلية، بينما لا تزال هناك حاجة لمزيد من الدراسات لتغطية أنواع مختلفة من الممارسات الزراعية.