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Application of Bowen Ratio Energy Balance for estimating the water requirement of Chulsar Rice Crop in Cambodia

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Abstract: *The water requirement for the Chulsar Rice Crop is becoming a more and more common practice in Cambodia research, as it secures productivity and ensures constant the amount of water use. Effective water planning and management require accurate determination of crop water requirement so it plays an important role for irrigation practice. Consumptive water requirement is the amount of water potentially required meeting the evapotranspiration needs of the paddy rice so that the rice does not suffer in its growth through short supply of water and it is the depth of irrigation water, exclusive of precipitation, stored moisture, or groundwater, which is required to meet evapotranspiration during the crop period. We have been preformed a sensitivity analysis by using and comparing the different technological methods where we employ Lysimeter method (direct method), Bowen Ratio Instrument is using two different equations: Bowen Ratio Energy Balance (BREB) & ASCE Short, and CROPWAT model which is indirect method. By the way, the observation was undertaken in a small experimental paddy field located in Cambodia Agriculture Research and Development Institute (CARDI), which have an area of 2650 meter square, particularly with Chulsar for 100 days and we found out that the amount of crop water requirement of BREB is 571 millimetres. Totally, compared to the other method we are apparently coincided get 15 percentages different, for overall, the result can be used to assist the user in order to obtain the products qualifiedly and much more than that previously in deflicit irrigation.*

Keywords: Crop water requirements; Effective water planning; Deflicit irrigation; Direct and Indirect methods; Evapotranspiration; Precipitation; Moisture; Groudwater; Bowen Ration Energy Balance; ASCE Short; CROPWAT.

1. INTRODUCTION

Irrigated agriculture has taken an important role in the world agricultural landscape. Indeed, 17% of the world total cultivated farmland surfaces allow 40% of the food and fibre production (Fereres and Evans, 2006). However, water scarcity issues nowadays will definitely impact on irrigation activities, forcing us to manage water in a more efficient and productive way.

As looking for award to our country, Cambodia has undergone a dramatic economic transformation, with an impressive GDP growth rate of 9.8 precent in 2000 to 2008, exceeding most countries in the region. The rapid growth is accompanied by remarkable performance in the agricultural sector, which grows at 5.6 precent per year over the same period. Nevertheless, Cambodia's economy is still highly dependent on agriculture, which contributes close to one-third of national GDP and employs more than half of the total labour forces (Bingxin Yu & Xinshen Diao, 2011).

The quantity of water needed to compensate the evapotranspiration loss form the crop field is termed as crop water requirement. The value of crop water requirement is identical to evapotranspiration (ET). Crop water requirement varies with time and space, as the evapotranspirative demand varies with local climate and crop condition. Crop water requirement represents the evapotranspiration under ideal crop growth condition. The ET from a crop with insect and pest-affected condition and low population, crop density, will be different from that of a well-established and well-grown crop.

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Crop water requirements encompass the total amount of water used in evapotranspiration. FAO (1984) defined crop water requirements as the depth of water needed to meet the water loss through evapotranspiration of a crop, being disease-free, growing in large fields under non restricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment. Crop water requirements are dependent on crop type and climatic conditions to raise a successful in a given period. The climatic conditions strongly influence the crop's evapotranspiration rate (ET_C), which is made up of evaporation from the soil surface and transpiration from the crop. As for most crops the evapotranspiration varies with the growth stage of the crop (Ali, 2010).

The aim of this study is to explore the technical approached potentialities to drive rice yard irrigation. We will first study rice yield in order to evaluated how irrigation may offer a better water productivity and to which extent. Then we will tackle introductory sensitivity analysis that targets climatic parameters on the Bowen Equations. Methods and results obtained by the experimental equipments which installed in the CARDI's field for finding the other meteorological parametres. The last section will summarize the encountered limits of calculation, and the proposition made to overcome.

2. METHODOLOGY

2.1. Study Area

This project is under the framework of the title of « Improved Irrigation Water Management to Increase Rice Productivity in Cambodia » supported by Australia Centre of International Agricultural Research (ACIAR). The project is conducted to improve rice productivity in Cambodia since this country is abundant in water resources and good climatic condition. However, the existing irrigation system in the country has been used precious water improperly.

The study was taken in a small experimental field, which locates in Cambodian Agricultural Research and Development Institute (CARDI) and the purchase of $70\ hectares$ of land, at the Prateah Lang Commune, Dangkor District, and 20km south of Phnom Penh. The field has an area of $2650\ m^2$ with long of $55.5\ m$ and $47.7\ m$ wide, and $10\ m$ above the sea level.

2.2. Instrument of Bowen Ratio

Bowen ratio instrument is considered the micro climatic measurement object to gain the number of meteorological data to compute, for instance, the Evapotranspiration (ETo) as well. Plus, called a completed Bowen ratio, some parameters with their instruments participate fundamentally in building this object such Air Temperature, Wind-speed, Net Radiation, Soil heat flux measurements as shown in *Figure 1*.

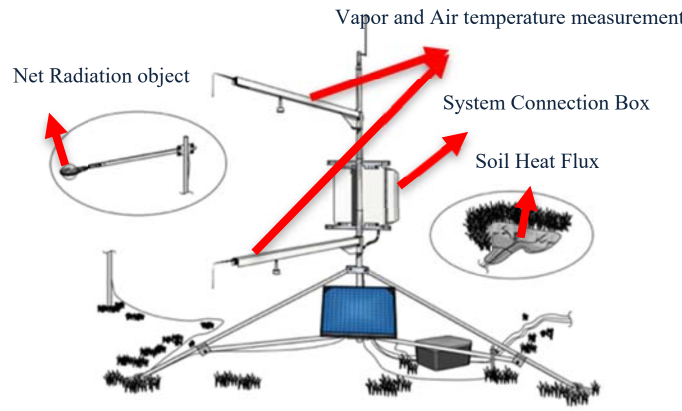

Fig.1. CSI Bowen Ratio system

The Bowen Ratio Energy Balance (BREB) method estimates latent heat flux from a surface using measurements of air temperature and humidity gradients, net radiation, and soil heat flux (Fritschen and Simpson, 1989). It is an indirect method, compared to methods such as eddy covariance, which directly measures turbulent fluxes, or weighing Lysimeter, which measure the mass change of an isolated soil volume and the plants growing in it. Its advantages include straightforward, simple measurements; it requires no information about the aerodynamic characteristics of the surface of interest; it can integrate latent heat fluxes over large areas (hundreds to thousands of square meters); it can estimate fluxes on fine time scales (less than an hour); and it can provide continuous, unattended measurements. Disadvantages include sensitivity to the biases of instruments which measure gradients and energy balance terms; the possibility of discontinuous data when the Bowen ratio approaches -1, and the requirement, common to micrometeorological methods, of adequate fetch to ensure adherence to the assumptions of the method.

2.2.1. Water Vapour Measurement

It is common practice in Bowen ratio measurements to measure wet bulb depression to develop the water vapour gradient. The position of the two psychrometers is periodically reversed to cancel systematic sensors errors.

Every 2 minutes the air drawn through the cooled mirror is switched from one height to the other with the valve. Forty seconds is allowed for the mirror to stabilize on the new dew-point temperature and 1 minute and 20 seconds worth of measurements for an individual level are obtained for each 2 minutes cycle.

The dew-point temperature is measured every second and the vapour pressure is calculate by the data logger using the equation describe by Lwe (1976). The average vapour pressure at each height is calculated every 20 minutes (Bowen Ratio Instrument Manual Book).

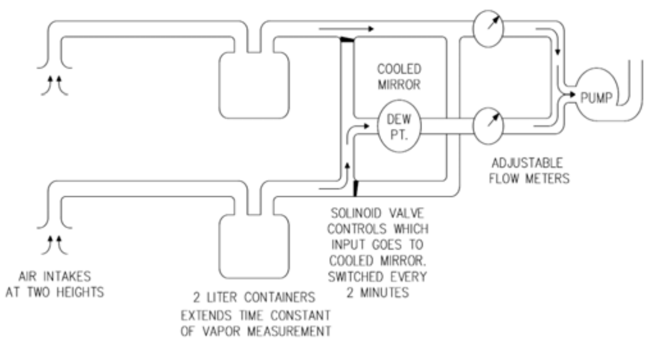

Fig.2. Water vapour measurement

2.2.2. Air Temperature Measurement

Air temperature is measured at two heights with chromel-constantan thermocouples wired. The differential voltage is due to the difference in temperature between T_1 and T_2 and has no inherent sensor offset error. The data logger resolution is $0.006\ °C$ with $0.1\ \mu V$ rms noise. The thermocouples are not aspirated. Attempts to aspirate the TCs with the air from the vapour measurement system were not successful.

Testing less than $1000\ Wm^2$ solar radiation, with several radiation shield designs and aspiration rates of up to $80\ cm/s$, showed a significant increase in temperature due to radiation from the shield/ducting minutes (Bowen Ratio Instrument Manual Book).

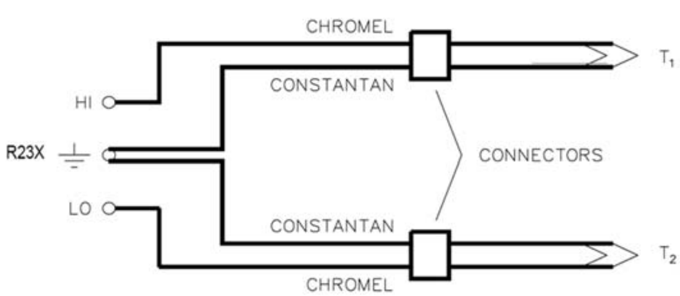

Fig.3. Air temperature measurement

2.2.3. Soil Heat Flux and Net Radiation Measurement

Net radiation and soil heat flux are averaged over the same time as the vapour pressure and temperature differences. To measure soil heat flux, heat flux plates are buried in the soil at a fixed depth of between $5\ to\ 10\ cm$ reduce errors due to vapour transport of heat. Typically the plates are buried at a depth of $8\ cm$.

The average temperature of the soil layer above the plate is measured using 4 parallel thermocouples. The heat flux at the surface is then calculated by adding the heat flux flux measured by plate to the energy stored in the soil layer. The storage term is calculated by multiplying the change in soil temperature over the averaging period by the soil heat capacity.

2.2.4. Instrument Installation of Laten Heat Flux

The net radiometer is mounted on a separate stake (not provided by Campbell Scientific) so that the tripod is not a significant portion of its field of view. It should be positioned so that it is never shaded by the tripod or mounting arms and should be mounted so that it points south.

Figure 4 shows the typical Bowen ratio installation on the CM10 tripod. The 023A enclosure, mounting arms, and SP20R solar panel all mount to the tripod mast (1 or 1/4 in. pipe, inside diameter) with U-bolts. The mounting arms should be oriented due south to avoid partial shading of the thermocouples.

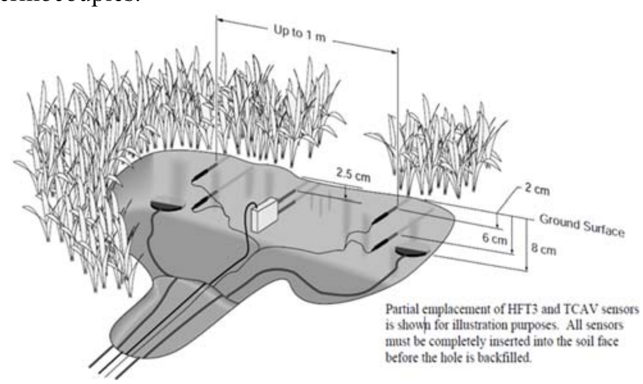

Fig.4. Criterion of soil flux installation

2.3. Calculation Procedure

Important equations and condition for calculation BREB

- The latent heat flux for evaporation

$$\boldsymbol{Le = \lambda \times E = \frac{R_n - G}{1+\beta}} \qquad (Eq.\ 1)$$

- The Bowen Ratio (β)

When the Bowen ratio approaches -1, the calculated fluxes approach infinity. Fortunately, this situation usually occurs only at night when there is little available energy, Rn-G. In practice, when β is close to -1 (e.g., -1.25 < β < -0.75), Le and H are assumed to be negligible and are not calculated. Ohmuna (1982) describes an objective method for rejecting erroneous Bowen ratio data.

$$\boldsymbol{\beta} = \boldsymbol{\gamma} \times \frac{T_2 - T_1}{e_2 - e_1} \quad (Eq.\ 2)$$

- The actual vapour pressure

Actual vapour pressure is used to represent the water content (humidity) of the air at the weather site. The actual vapour pressure can be measured or it can be calculated from various humidity data, such as measured dew point temperature, wet-bulb and dry-bulb temperature, or relative humidity and air temperature data.

The dew point temperature (**T_{dew}**) is the temperature to which the air must cool to reach a state of saturation. For daily calculation time steps, average dew point temperature can be computed by averaging over hourly periods or, for purposes of estimating **ET_{sz}**, it can be determined by an early morning measurement (generally at 07:00 or 08:00 hours). The value for **e_a** is calculated by substituting **T_{dew}**.

$$e_a(T) = e^o \times \frac{RH}{100} \quad (Eq.\ 3)$$

- The saturation vapour pressure

$$e^o(T) = 0.6108 \exp\left(\frac{17.27 \times T}{T + 237.3}\right) \quad (Eq.\ 4)$$

- Psychometric constant (γ)

$$\gamma = \frac{C_p \times P}{\varepsilon \times \lambda} = 0.665 \times 10^{-3} \times P \quad (Eq.\ 5)$$

- Atmospheric pressure (P)

$$P = 101.3 \times \left(\frac{293 - 0.0065 \times Z}{293}\right)^{5.26} \quad (Eq.\ 6)$$

- Reference evapotranspiration (ETo)

$$ET_o = \frac{\lambda \times E}{2.45} \quad (Eq.\ 7)$$

- Data treatment technique comprehension

The data gathered from Bowen ratio instrument to determine ETo have been sometime troublesome due to lack of checking their instrument, which cause them stop working, and then make data complicatedly to deal with.

Normally, Air temperatures, Wind-speed and Net Radiation have been getting to mal-situation to cope with, yet they can be going to be normal by adjusting them through their hourly working before and after getting to average, if not all, the final result is considered logically to use.

3. RESULTS AND ANALYSIS

The Bowen Ratio instrument consists of a number of parameters such air temperature at two heights, relative humidity at two height, net solar radiation, soil heat flux, average wind speed, maximum winds-speed, wind direction, battery life recorded every 30 minutes; yet Bowen Ratio method and ASCE short method require standardly air temperature, relative humidity, net radiation and soil heat flux to estimate ETo, that some data were been absent in participating.

Table 1. Parameters of Bowen Ratio's instruments in decade of each month

Month		Temperature (ºC)	Relative Humidity (%)	Net Radiation (MJ/m^2*h)	Soil Heat Flux (W/s^2)	Wind - speed (m/s)
Feb.	1	26.11	71.77	23.65	-317.26	2.06
	2	27.15	70.19	24.86	-330.23	2.21
	3	26.99	69.22	25.55	-494.39	2.17
Mar.	1	27.86	69.58	26.14	-181.53	2.24
	2	29.46	65.04	26.41	-238.3	2.13
	3	29.61	67.28	24.45	12.55	1.99
Apr.	1	28.97	74.11	25.31	-200.8	1.83
	2	28.38	79.25	25.15	-75.34	1.36
	3	29.79	75.23	35.57	58.03	1.42
May	1	29.61	78.34	30.72	149.51	1.33

These data above in the *Table 1*, from 1 February 2014 to 10 May 2012, are used to represent the data at CARDI and have been download from our sensor in our field from Bowen Instrument. The temperature hovers around 26.1°C and 29.8°C respectively for the daily temperature while the average relative humidity varies from 65% to 79.3%.

In addition, the daily wind speed is about 1.8 m/s, and the sun is 0 to 5.4 hours per day. The daily pan evaporation is 4 mm/day to 5 mm/day, while rainfall occurs often from May to November is the rainy season. The total rainfall for this period is 1535 mm.

3.1. Bowen Ratio Equation Balance Result

Table 2. BREB's result accord with each stage

Stage	BREB		Cumulative	
	ETo	ETc	ETo	ETc
Initial	35	37	35	37
	41	45	76	82
Develop	42	49	118	131
	50	58	168	189
	51	59	219	249
Mid	54	65	273	314
	60	72	334	386
	53	63	386	449
Late	51	59	437	508
	54	62	491	571

The *Table 2* illustrates the values of ETo and ETc shows separately the stages and its cumulative to identify the crop water requirement of Chulsar rice in dry-season (1 February to 11 May 2014). To ease the values of cumulative in table above, the line graph was illustrated to clarify the lower value to the higher one (i.e. the total cumulative of ETc until the last late stage is 571 mm) and to certify the variable point of line.

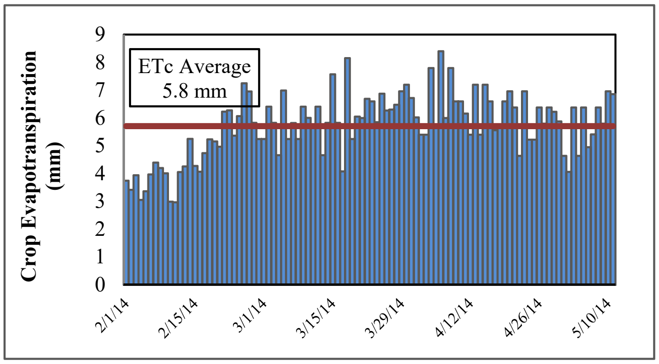

Fig. 5. Crop evapotranspiration ETc in daily of Chulsar rice in dry season 2014

Moreover, crop water requirement value daily (ETc) calculated by BRBE method to see the differences from the starting point to ending and compared with its means being equal to 5.8 mm with the minimum of 3 mm and the maximum of 8 mm as shown in *Figure 5*.

3.2. Comparison of Four Methods Result

In the research is involving in calculating crop water requirement by using four different methods to lean on the processing of estimation, in the Table3.3. belows finalizes the result of ETc calculated from those methods and compared the differences. The value of Bowen Ratio and ASCE Short methods are most similar, while the results from the CROPWAT and Lysimeter (result from thesis, SIV Vatana, BUN Saret, 2014) computation are acceptable for the calculation of crop water use (recommend by FAO ETc 450-700 mm); and irrigation scheduling and scheme can also be estimates by the model as the result in the *Table 3*.

Table 3. The ETc in stage and its cumulative in 2014

Month	Stage	Cumulative of ETc in decade of each stage			
		BREB	ASCE	Lysimeter	CROPWAT
February	Init.	37	47	48	36
		82	99	94	73
	Dev.	131	147	148	110
March		189	205	205	163
		249	269	267	222
	Mid.	314	329	340	293
April		386	392	401	349
		449	447	467	402
	Late	508	513	541	462
May		571	580	604	512

To characterize the water loss in stage and totally, the two charts above described the ETc in decade and the cumulative totally aiming to compare the results gained from each approaches and to finalize the results comparing.

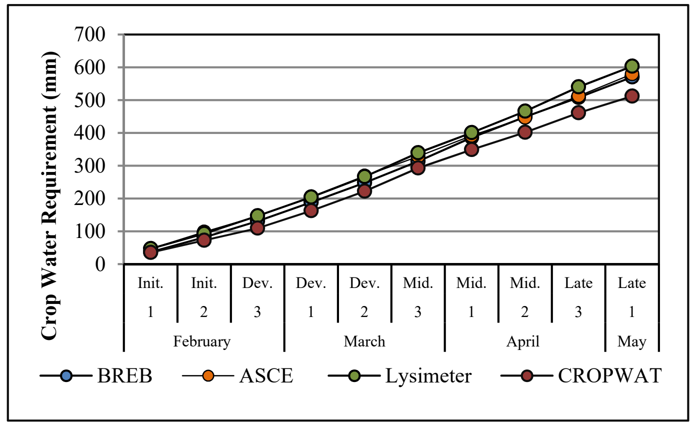

Fig. 6. Crop water requirement for four methods of each stages

In *Figure 6.* is the line the four methods to figure out which one differently turns away, yet all of lines are apparently coincided with differentiating of total cumulative of BREB, ASCE, Lysimeter and CropWat is equal to 571 mm, 580 mm, 604 mm and 512mm respectively.

Moreover in the *Figure 7.* shows the column of the values of ETc in decade, which the results obtained, are approximately similar.

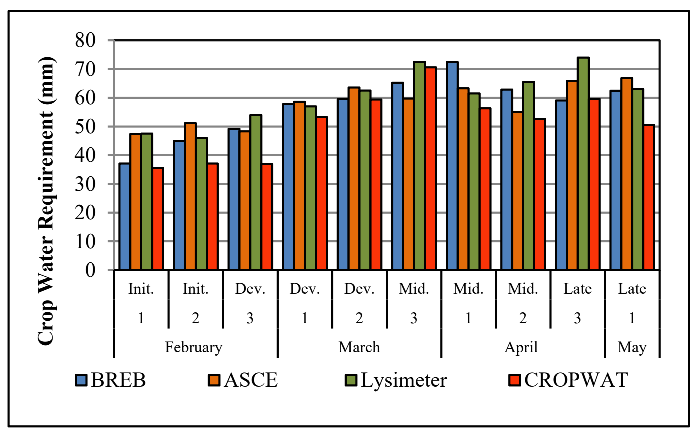

Fig. 7. Cumulative comparasion of crop water requirement

Table 4. shows the deviation value in percentage (%) of ETc from ASCE short, Lysimeter, CROPWAT to BREB method. In the other hand, the minus values meant that it is smaller than that of BREB and the positive is higher.

Table 4. Deviation percentage of each methods to BREB

Month	Decade	Stage	Deviation from all method to BREB in percentage		
			ASCE	Lysimeter	CROPWAT
February	1	Init.	27.03	29.73	-2.70
	2		13.33	2.22	-17.78
	3	Dev.	-2.04	10.20	-24.49
March	1		1.72	-1.72	-8.62
	2		8.47	6.78	0.00
	3	Mid.	-7.69	12.31	9.23
April	1		-12.50	-13.89	-22.22
	2		-12.70	4.76	-15.87
	3	Late	11.86	25.42	1.69
May	1		8.06	1.61	-17.74

4. CONCLUSIONS

This project focuses on the study of paddy rice water requirement and irrigation water requirement, which is an important component toward efficient management of water resource for rice productivity. To study this, experimental field need to be selected in order that paddy rice is grown with sufficient water supply. In this study, the experimental field is located in CARDI and covers the surface of about $2585\ m^2$, which started from sowing date 01 February 2014 to 11 May 2014. Bowen Ratio Energy Balance result: $ETo = 491\ mm$ & $ETc = 560\ mm$. Dealing directly with this project, we obtain many experiences concerning research and it is a hard work to control all experimental process perfectly at field as done at the laboratory. Following is some key recommendation to contribute to next study:

- The experimental field operation should be done more carefully and all phenomena occurring to the field should be recorded clearly in order to easy to control and collect field data.
- All equipment's installation should be done carefully, respect manual of each instruments in a good position and make sure that all equipment work well.
- The cooperation among field operators should be encouraged so that we can obtain a reliable field operation record.
- For Bowen Ratio instrument, frequent maintenance is needed because this system is easy to get destroyed from some condition such as bird dropping, dust cover sensor, spider web contamination on the aspirated-thermocouple etc.
- The meteorological data for CROPWAT model should be recorded within CARDI boundary to obtain more accurate estimation of crop water requirement.
- Be careful in the rain season, the water could submerge the pan. The submerging could cause some missing data, so the field has to have an evacuation drain to avoid submerging when the water level rises by the rainfall.
- Growing should conduct the technical standard that is providing the high product of rice and insure that vegetation height and density between inside and outside the pan are the same.

Good management in irrigation is very crucial. Providing water to the crop in adequate amount, and timely irrigation enhances the crop yields and productivity. Moreover, the water will be saved and be not wasted. Since the water is well managed, irrigation system will be extended, and when an extension is implemented, more and more job opportunities simultaneously happen. This will lead to poverty reduction.

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