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Estimating Rice Water Use using Water Balance Approach: Case study in Cambodia

Saret Bun[1*], Chantha Oeurng[1] Vandy Lim[2], John Hornbuckle[3]

1. *Department of Rural Engineering, Institute of Technology of Cambodia,*
2. *Cambodian Agricultural Research and Development Institute (CARDI)*
3. *CSIRO, Irrigation Agriculture Flagship Research, Australia*

Abstract: *To improve water management for increasing rice productivity, the study of crop water demand is very important. This study aims to estimate the water requirement of rice by using direct measurement method (water balance conception method). The observation was undertaken in a small experimental paddy field, which has an area of 2650m^2, located in Cambodian Agricultural Research and Development Institute (CARDI) in Cambodia. For Phka Rumduol variety (120 days) in the rainy season (August 1 to November 27, 2013), the total rice water requirement is about 651mm which lost 448mm (69%) by evaporation, 165mm (25%) by transpiration and 38mm (6%) by percolation. For Chul'sa variety (100 days) in the dry season (February 1 to May 11 2014), the total rice water requirement is 604mm which lost 406mm (67%) by evaporation, 146mm (24%) by transpiration and 52mm (9%) by percolation.*

Keywords: Water balance; Lysimeter; Rice water use; Crop water requirement; Evaporation; Transpiration; Percolation

1. INTRODUCTION

Cambodia's economic, agricultural activities remain the main source of income for many people living in rural areas. Agricultural water management, particularly irrigation is promoted by the Royal Government of Cambodia as a major component of its poverty reduction and economic development plans (IWMI, 2013) and the most important agricultural commodity is rice, the central to agricultural sector: not only do the majority of Cambodia's farmers depend directly and indirectly on the success of the rice crop each year, but also being the main food staple (CDRI, 2011). Agriculture is the main water user in Cambodia, MOWRAM estimated these to be 95 percent. In the dry season, when there is a lack of water, accessing water for agriculture is time-consuming and expensive (CDRI, 2011). Thus the study to identify the rice water use was researched and it is importance of increased rice productivity.

Water balance conception method is an accounting of the inputs and outputs of water system (Inthavong et al., 2010) and the changes in internal water storage must also be considered. Both the spatial and temporal boundaries of a water balance must be clearly defined in order to compute and to discuss a water balance (Fig.1). A complete water balance is not limited to only irrigation water or rainwater or groundwater, etc., but includes all water that enters and leaves the spatial boundaries (ITRC, 1999). The field water balance is an account of all quantities of water added to, subtracted from, and stored within a given volume of soil during a given period of time in a given field. The water balance is merely a detailed statement of the law of conservation of matter, which states simply that matter can neither be created nor

[*] Coresponding authors:
E-mail: saret_bun@yahoo.com

destroyed but can only be changed from one state or location to another. It is a mass balance of the flow and storage of water in surface soil (for a particular depth) per unit area basis, using the hydrologic equation:

$$Inflow - Outflow = Change\ in\ storage \qquad \text{(Eq.1.)}$$

In the presence of the surface water and rice, water is basically consumed in four different ways (i.e. evaporation, transpiration, percolation and drainage). Drainage is controllable, so it is not the water loss in the natural process. Thus, we can ignore this element. And since evaporation and transpiration cannot be measured separately, both of them are combined as evapotranspiration. Now we have two elements of daily water requirement, evapotranspiration and percolation.

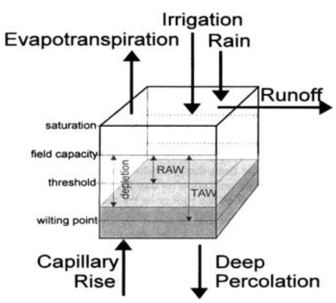

Figure 4. Inflow and outflow of the water balance conception.

Lysimeter experiments were conducted for a rainy season (July-October 1994) at Karnal, India, N.K. Tyagi et al., (1999) the average weekly ET of rice varied from < 3mm per day in the early growing period to > 6.6mm per day at miking stage. The peak ET_C was 6.61mm per day and it occurred 11 weeks after transplanting at reproductive stage. The improvement of the lysimeter data processing to eliminate bad data and minimize the effect of random variations in the measurements. Grass evapotranspiration rates (ETo) were compared with evapotranspiration rates predicted from data taken at a nearby weather station that is part of the California Irrigation Management Information System (CIMIS), P.J. Vaughan (2006), daily CIMIS ETo predictions were in good agreement with daily lysimeter ETo measurements for ETo < 6mm d^{-1} but tended to be smaller when ETo > 6mm d^{-1}.

2. METHODOLOGY

The study was conducted in the experiment farm at the research field of Cambodian Agricultural Research and Development Institute (CARDI) *(Fig.2)* where is located in National Road No.3, Prateah Lang Commune, Dangkord District, Phnom Penh, Kingdom of Cambodia (20 kilometres south of Phnom Penh) with an elevation of 15m (MSL), latitude of 11º28'N and longitude of 104º48'E with dimensioned 55.5m and 47.7m.

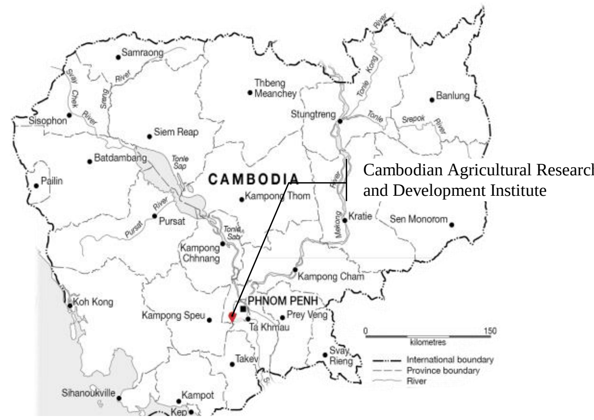

Figure 5. Study area, CARDI.

The materials which were used for this study are water balance equipment and water level sensors and were installed in the experimental farm at CARDI.

2.1 Water balance equipment (lysimeter)

Lysimeter has a surface of 0.64 m^2 (0.8 m x 0.8 m) with a depth of 0.8 m for pan ET and pan P, and 0.25 m^2 (0.5 m x 0.5 m) with a depth of 0.5 m for pan E. In general, a lysimeter consists of the soil-filled inner container and retaining walls. The two sets of lysimeter as lysimeter I and lysimeter II (Fig.2) were installed in two different locations of an experimental field with three different function pans of each: evaporation pan (Pan E), evapotranspiration pan (Pan ET), and evapotranspiration and percolation pan (Pan P). In pan E, it contains only the water (soil-filled at the pan bottom) during pan ET and pan P contain a water and rice crop (Fig.3).

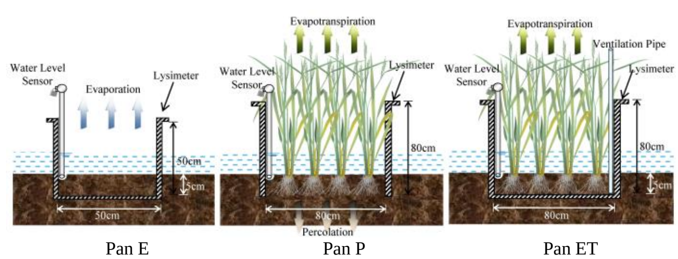

Figure 3. Water balance equipment and conception.

2.2 Water level sensors

Water level sensor (WLS) was used for detect water level of this study that provides highly accurate water level measurements for a variety of applications, including those in severe environments. It has a dynamic temperature compensation system, enabling high accuracy measurements over a wide temperature range. WLS has a molded-on waterproof cable. The pressure sensor in it is protected by a stainless steel micro-screen cap, which makes fouling with silt, mud, or sludge virtually impossible (IRB, 2014).

- Calculation concept:

The pressure sensor run as a water level sensor may also be used to calculate the level of a water (fluid). This technique is commonly employed to measure the depth of a submerged body (such as a diver or submarine), or level of contents in a tank (such as in a pan). For most practical purposes, water level is directly proportional to pressure *(Fig.4)*. In the case of fresh water where the contents are under atmospheric pressure, 1psi = 27.7 in H_20/ 1Pa = 9.81 mmH_20.

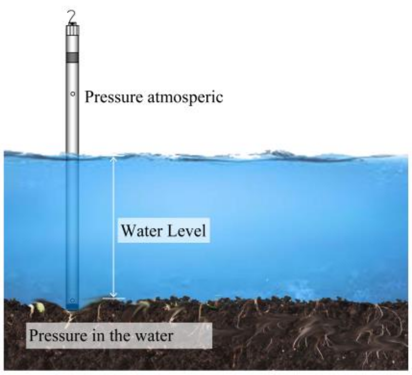

Figure 4. The concept of a sensor detect.

The basic equation for such a measurement:

$$P = \rho g h \quad \text{(Eq.2.)}$$

Where P is pressure, ρ is density of the fluid, g is standard gravity, h is height of water column above pressure sensor.

- Configuration and installation:

A water level sensor is a device designed to read the level of water in a pan and useful if you must ensure a minimum amount of water, such as in a cooling tank. WLS must be mounted with a bracket to the container, that is suspended in the water with an automatically detects and reports the water level in the pan and paddy field. OmniLog Data Management Program was used to configure the WLS on the first time to start the season with the sample period one hour and 60 seconds of the averaging sub interval. There are eight sensors, E1 - E2 - ET1 - ET2 - P1 - P2 - W1 - W2, were used in the experimental farm that four of it, installed with lysimeter I and other installed with lysimeter II. E1 and E2 were installed in Pan E1&E2, operated at lysimeter I&II and used to detect amount of water loss by evaporation. ET1 and ET2 were installed in Pan ET for detecting amount of water loss by evapotranspiration. Last, P1 and P2 also were installed in Pan P for detecting amount of water loss by evapotran-spiration and percolation. Not too different, W1 and W2 were operated in the farm and used for measuring the water level in the farm next to experimental pans.

- Data collection:

Data from an experimental field is very important to identify each water balance components for estimating the crop water requirement, especially the eight sensors installed in the field. Data collections such as: water level sensor was downloaded every field visit by using Omnilog with time step one hour to identify water balance components as evaporation, transpiration, percolation. Then land prepara-tion, rice sowing, fertilizer operation, farm/pan irrigate water, drainage, rice harvesting, and other operation at the on-farm level were note. For farm irrigate water was pumped from the irrigation canal and recode the flow rate as linear method. From this operation, water irrigation, water drainage were calculated during rainfall data was record by CARDI regularly.

Last, water balance components such as evaporation, transpiration, percolation, water irrigation, water drainage, and rainfall were known for estimate rice water use.

- Data processing

The water balance components *(Fig.5.)* will be defined by the subtraction of water level change in each pan. Using the concept of field water balance, we can determine each water component.

$$(I+R)–(T+E+P+D)=Storage\ change \quad \text{(Eq.3.)}$$

where I: irrigation, R: rainfall, T: transpiration,
E: evaporation, P: percolation, and D: drainage

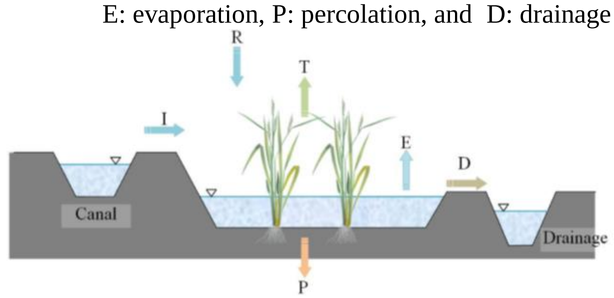

Figure 5. Water balance conception.

Here is the process of calculation the water level data from sensors:

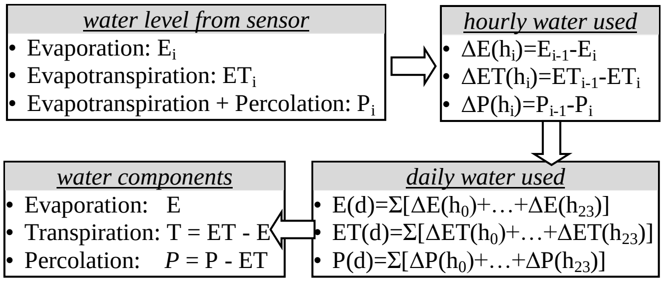

Fig.6. Water level calculation process.

Where E_i, ET_i, P_i are water level data of pan E, ET, and P. $\Delta E(h_i)$, $\Delta ET(h_i)$, $\Delta P(h_i)$ are hourly water change during time (i-1) to time i of pan E, ET, and P. E(d), ET(d), P(d) are daily water change of pan E, ET, and P. E, T, P are water loss of each water component of Evaporation, Transpiration, and Percolation.

3. RESULTS AND DISCUSSION

3.1 Rainy season (August 1 to November 27, 2013)

Field visiting was set up every two times per month in order to follow up the continuously water level data for preventing the error that cause by sensor and for maintaining the water balance equipment. Moreover, field visit was practiced for observing and note the operation at the on-farm level such as irrigation water apply, rainfall data, and other noted event.

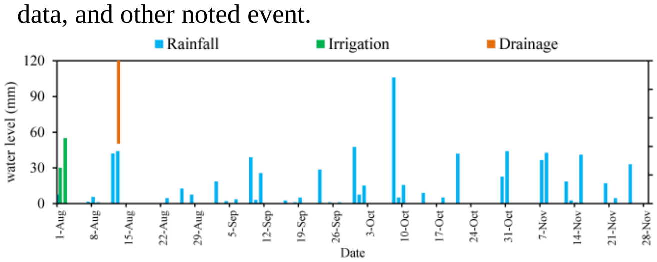

Figure 7. Water operation in paddy field, rainy season 2013.

Rainfall intensity, irrigation and drainage were recorded and counted as the water operation in the experimental paddy field to understand the amount of water input.

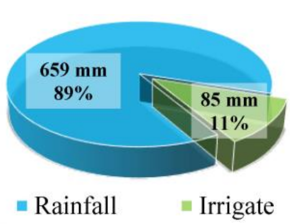

Figure 8. Diagram of water applied.

According to the noted event, there was twice irrigated water in the field during the land preparation. It was observed and recorded from August 1, 2013 to November 27, 2013 (Fig.7). We noticed that during the observed period, rainfall was 128mm in August, 179mm in September, 272mm in October and 197mm November. Due to the heavy rain at the initial stage in August, 116mm of water was drained from the field. The main water source was rainfall which presented 89% (659mm) of the water input and irrigated water was only 11% or 85mm (Fig.8).

Since the first decade of August, the rice plant was in the initial stage, water applied into the pan and paddy field were controlled in low depth till second decade of the August. With the healthy rice plant and its resistance to the water, from second decade of August, amount of water was irrigated to the paddy field and each pan rigorously to maintain water level of approximately 150mm (Fig.9).

Figure 9 showed the water level sensor signals recorded by sensor of lysimeter I and II.

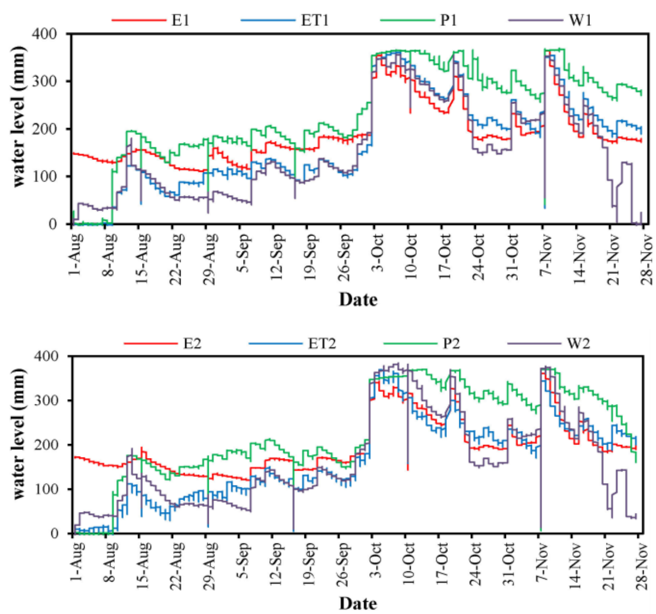

Figure 9. Raw water level of Lysimeter I&II.

- Daily water loss:

The result presented all in Figure 10 has been converted and corrected from the hourly database of all sensors to daily basis during the monitoring period. The average numbers of E, ET, P and W is 3.7mm, 5.1mm, 5.4mm and 5.2mm respectively were plotted to show that the result is unquestioning logic that E < ET < P ≈ W. The water monitoring in the pans and in the paddy field.

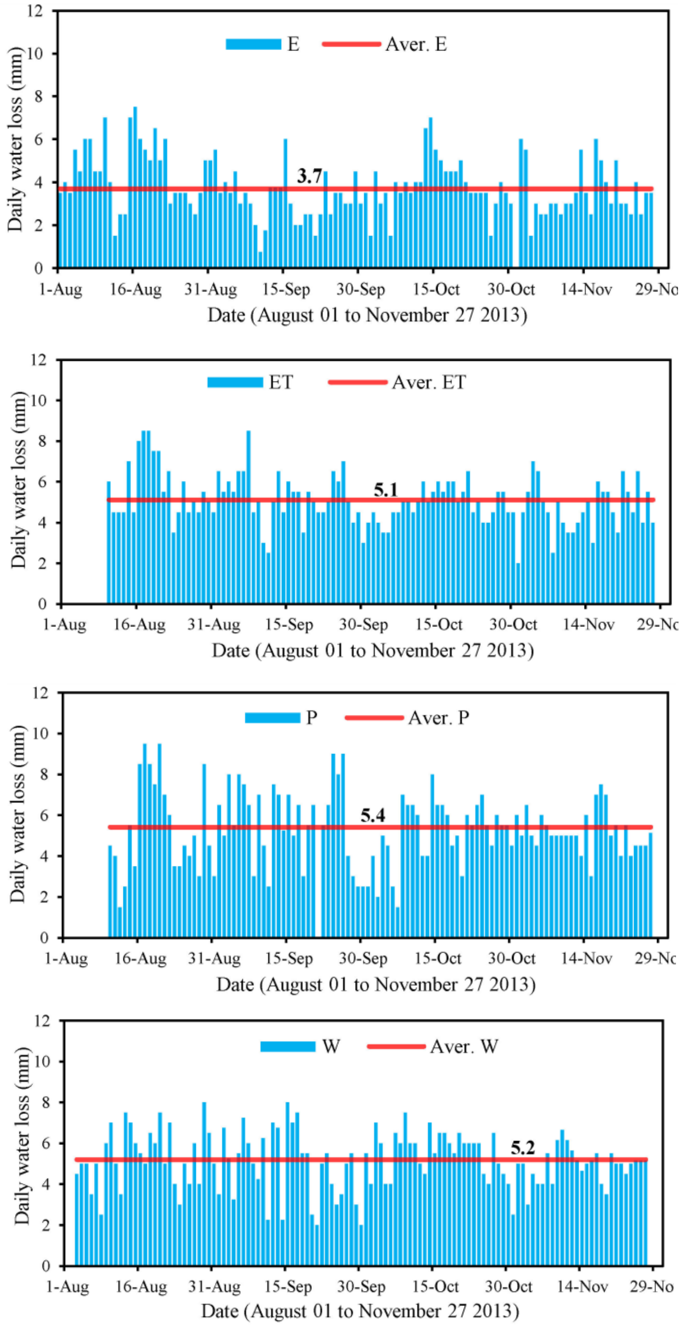

Figure 10. Daily water loss of each pan and field

- Water consumption by decade:

Water balance consumption can be summed by decade in order to resume to the water requirement for each water balance components. Table 1. shows the water consumptive use correspondence to the decade of each month and stage. In the case of Phka Rumduol rice, there is 20 days of initial stage, 40 days of development stage, 30 days of mid-season stage and 40 days of late season stage and totally 120 days.

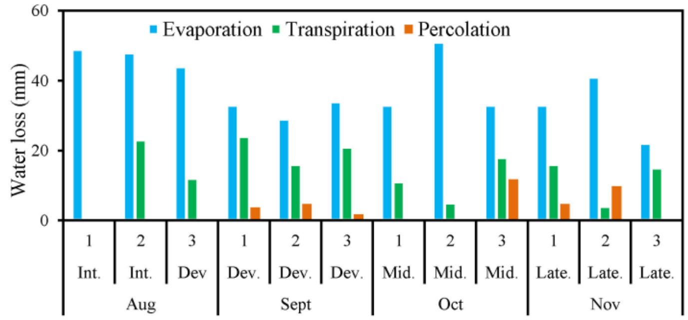

Figure 11-a. Water loss of each decade

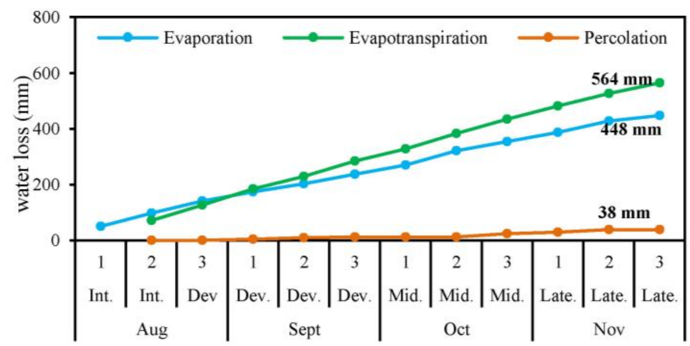

Figure 11-b. Water consumption of each decade.

Figure 11 is the multiple bars graph which illustrated the water consumption by decade. In the first decade, we supposed there was only evaporation because water requirement for evapotranspiration is too low, so that the water level in the paddy and the pan could not recorded by sensors and also showed that peak for crop water requirement is in the mid-season stage.

Table 3. Water consumption by decade of each water components, rainy season

Month	Stage	Decade	Evap. (mm)	Trans. (mm)	Perco. (mm)
	Int.	1	49	-	-
Aug	Int.	2	48	23	0
	Dev.	3	44	12	0
	Dev.	1	33	24	4
Sept	Dev.	2	29	16	5
	Dev.	3	34	21	2
	Mid.	1	33	11	0
Oct	Mid.	2	51	5	0
	Mid.	3	33	18	12
	Late.	1	33	16	5
Nov	Late.	2	41	4	10
	Late.	3	22	15	0
Total		120 days	448	165	38

The water component have been sum up by cumulative values and by decade as presented all in Figure 11 to see how much water consumption increases from the beginning to the end of rice water use monitoring.

The water balance component was taken as the average value in the Figure 12. As the result on the chart, 448 mm or 69% of water use was transfer by evaporation to atmosphere while only 165mm or 25% could use by the plant through transpiration. The deep percolation for loamy sand soil was 38 mm or 6% of the water use.

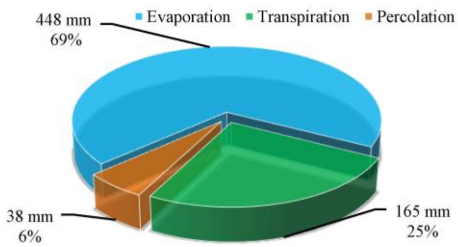

Figure 12. Water component during rainy season.

3.2 Dry season (February 1 to May 11, 2014)

Rainfall event was observed and recorded from February 1 to May 11, 2014 *(Fig.14)*. We noticed that during the observed period, rainfall was very little compare to the previous season.

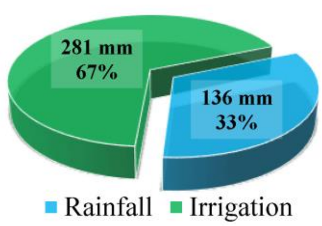

Figure 13. Water applied during dry season, 2014.

The water irrigation is more than rainfall (67% and 33%). Other more, there is no water drainage from the paddy field during this season. For the main water source for rice growing is the same with the previous season, rainfall presented only 136 mm of the water input during water irrigation was operated until 281 mm (Fig. 13).

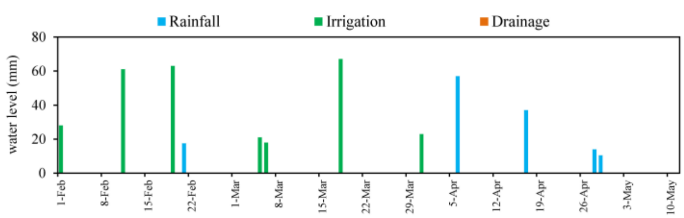

Figure 14. Water operation in paddy field, dry season 2014.

- Daily water loss and water consumption by decade:

The average numbers of E, ET and P is 4.1mm, 5.7mm, 6.3mm respectively were plotted to show that the result is unquestioning logic that E < ET < P. Water balance consumption can be summed by decade in order to resume to the water requirement for each water balance components.

In table below shows the water consumptive use correspondence to the decade of each month and stage. In the case of Chul'sa rice, there is 20 days of initial stage, 30 days of development stage, 30 days of mid-season stage and 20 days of late season stage and totally 100 days.

Table 4. Water consumption by decade of each water components, dry season.

Month	Stage	Decade	Evap. (mm)	Trans. (mm)	Perc. (mm)
Feb.	Int.	1	48	0	0
	Int.	2	45	0	1
	Dev.	3	32	13	10
Mar.	Dev.	1	43	12	3
	Dev.	2	41	13	10
	Mid.	3	51	14	9
Apr.	Mid.	1	38	22	3
	Mid.	2	34	27	6
	Late.	3	40	27	8
May	Late.	1	37	22	5
Total		100 days	406	146	52

The multiple bars graph below illustrated the water consumption by decade. In the first 2 decades, we supposed there was only evaporation because water requirement for evapotranspiration is too low, so that the water level in the paddy and the pan could not recorded by sensors and also showed that peak for crop water requirement is in the mid-season stage.

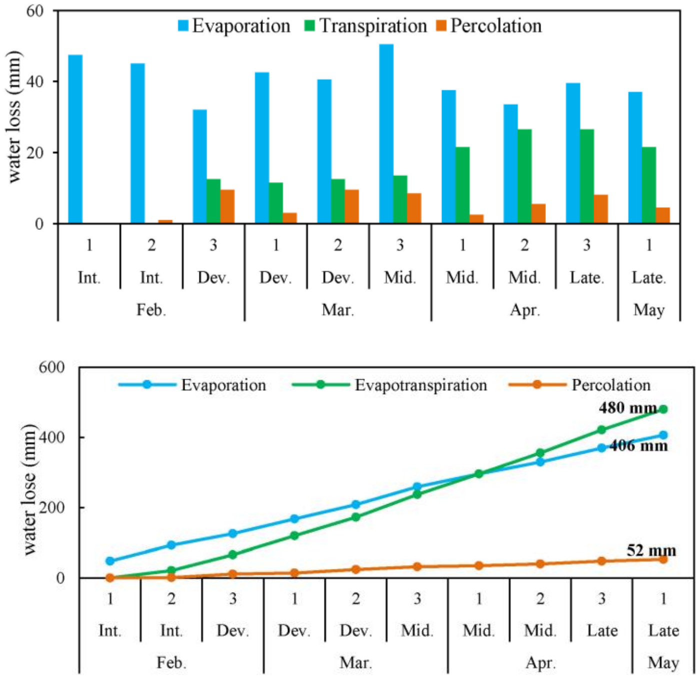

Figure 15. Water balance of each decade.

The daily values of each water component have been sum up by cumulative values and by decade as presented all in Figure 15. This graph will enable to see how much water consumption increases from the beginning to the harvesting of rice water use monitoring.

As what we can notice in the Figure 15 first two decade of the February, the plant was in the initial stage, so that the amount of water requirement is too low that we had to control the water level in low level because the sensor cannot record. And then in this two decade we assume that there was no water loss for the transpiration and percolation.

The results presented above demonstrate that, in the study of rice water use in case of Chul'sa rice on loamy sand at CARDI can be summed up.

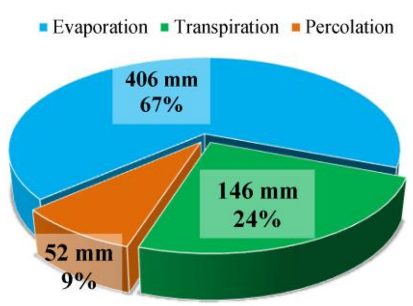

Figure 16. Water component during dry season.

As the result on the chart, 406 mm or 67% of water use was transfer by evaporation to atmosphere while only 146mm or 24% could use by the plant through transpiration. The deep percolation for loamy sand soil was 52 mm or 9% of the water use.

After the study on both season, we got the result of water use and water balance component in the experimental paddy field at CARDI which is shown in figure below:

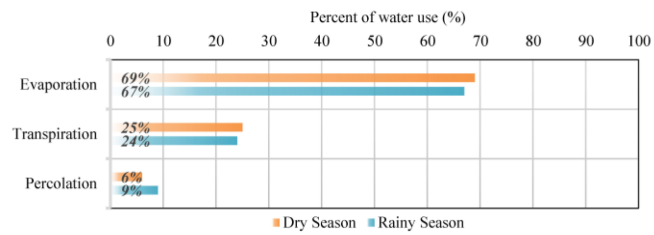

Figure 17. Percentage of water use in both seasons.

4. CONCLUSIONS

Water balance component shows that Phka Rumduol rice, which has the period of grow 120 days, in rainy season (August 1 to November 27, 2013) requires totally 651 mm (6510 m^3/ha) which is 448 mm for evaporation, 165 mm for transpiration and 38 mm for percolation and for dry season, the Chul'sa rice which has the period of grow 100 days, during the dry season (February 1, to May 11, 2014) the total rice water requirement is 604mm (6040 m^3/ha) which loss 406 mm by evaporation, 146 mm by transpiration and 52 mm by percolation.

This study research for improvement of irrigation water management to increase rice productivity show that the used method provides reliable and acceptable results according to direct measurement of water loss in the experimental pans by using WLS which installed in the experimental paddy field.

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