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Evapotranspiration observation and data analysis in reed swamp wetlands

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Abstract Water is very important to wetlands. The state of water in a wetland determines the state of the ecosystem within it. In order to understand the water loss and water balance in wetlands, the evaporation from the water surface (E_w) and transpiration from vegetation (T_r) should be observed and calculated accurately. Taking Baiyangdian wetland in northern China as the experimental base, this study develops an on site monitoring system for evaporation and transpiration called the compensation Evapotranspiration Observation System (CETOS). The system includes two compensation cylinders and several observation cylinders set in the reed swamp wetlands. The compensation calculation of the observed data of the cylinders can reveal the amount of evaporation from the water surface, and the amounts of transpiration of reeds with different density. Using this method for the on-site experiment in Baiyangdian wetland, established that the accumulated evaporation from the water surface (E_w) was 442.2 mm in 2008, while the evapotranspiration from the reed belt (ET) was 2.85 times of E_w. In 2009, the corresponding amounts were 544.4 mm and 2.67 times, respectively. The data have been successfully used in the study of water resources plan of Baiyangdian wetland.

Key words evapotranspiration; observation; compensation; wetlands; Baiyangdian wetland, China

INTRODUCTION

Water is one of the basic elements of a wetland ecological environment, and the state of water in a wetland determines the state of the ecosystem within it. In order to maintain wetlands in their proper state and study the water resources management of wetlands, the amount and the processes of water loss from wetlands are key factors. Especially in reed wetlands, the evapotranspiration from the water surface and reeds is a major component of water loss. It is important to quantify it.

The evapotranspiration of wetlands is affected by several factors such as the hydrometeorological factors of radiation, wind speed, temperature and humidity, as well as the ecosystem factors of plants, overlay rate, and the growing state. The plants in wetlands with large stalks, such as reeds, cover the water surface so limit the direct evaporation from it, but water is lost through plants transpiration. In the different plant growth periods, there are different states of these two processes. There are already some methods for determining the evaporation from the water surface in wetlands, such as the monitoring method by setting an evaporation dish on the water surface in wetlands, or calculation by a well established formula. But it is still a difficult problem to accurately determine the evapotranspiration from the water surface with reeds or other kinds of plants, and especially on-site in wetlands.

Nowadays, there are numerous studies of ET assessment, and the most represented methods are direct measurement methods and modelling approaches (Rana & Katerji, 2000; Paw *et al.*, 2004; Verstraeten *et al.*, 2008). According to the modelling approaches, actual ET can be estimated by using crop coefficients to adjust reference ET obtained from different kinds of models using measured microclimatological and underlying surface information. However, there are some limits in the modelling approaches: differences among the evapotranspiration characteristics of different plant species can not be indicated from microclimatological data (Pauliukonis & Schneider, 2001); several calibrations and validations of evapotranspiration models can not be carried out owing to observed data deficiencies.

The direct measurement methods include the lysimeter and the evaporation pan methods. Chen *et al.* (1996) set evaporation pans in the natural environment of Sanjiang wetland, China, and planted hydrophytic vegetations in the pans. They got the evapotranspiration data by measuring the change of water level in the pans. Mitsch *et al.* (1977), Heimburg (1984) and Ewel & Smith

(1992) observed the change of water level of wetlands directly to make water resources evaluation. For transpiration measurement, the methods of stomata meter and eddy correlation measurement are used. Herbst & Kappen (1999) observed the stomata conductance of reeds in the Bornhoved Lake, Germany, with stomata meters. Sánchez-Carrillo (2001) used a portable stomata meter, LI-1600, to observe the transpiration of reed, cattail and sedge in a Spanish wetland. German (2000) used the method of eddy correlation measurement to observe the evapotranspiration in a wetland in America. In fact, the direct measurement methods are not widely used because of the high cost and operational difficulties.

This study takes a wetland in northern China as the experiment base, and develops an on-site system for direct measurement of evaporation and transpiration; it is called the compensation evapotranspiration observation system (CETOS). It can easily measure the evaporation and transpiration of a wetland with hydrophytes like reed and cattail, at the same time.

METHOD

Observation principle

The vertical water losses from wetlands include evaporation from the water surface, transpiration from emergent hydrophytic vegetation and leakage through the bottom. The difficulty of monitoring the evapotranspiration of reed wetlands directly is that it is not easy to separate these three items. In order to solve this problem, two assumptions are made. One is that the water leakage through an earth level below a certain depth for a part of a wetland is the same. The other is that the change of the water leakage driven by small differences of water level can be ignored. In fact, as almost all wetlands have a watertight bottom which maintains the wet conditions for long periods, these two assumptions are naturally easy to meet. Then, by applying the compensation principle and investigating the vertical water loss of a wetland under the two assumptions, every component of the vertical water losses can be obtained. For this purpose, a compensation evapotranspiration observation system (CETOS) has been developed (Xu & Wang, 2005a,b,c).

Figure 1 shows a sketch of the compensation evapotranspiration observation system (CETOS) with three cylinders. The system is composed of three open cylinders with ultrasonic water level recording equipment.

In order to establish the compensation evapotranspiration observation condition, three open-ended cylinders should be set into the underlying soil in a part of the wetland with similar geographical and hydrological conditions, which meets the assumptions mentioned above. The three cylinders should be put into soil over the plants to avoid harming their growing conditions. The plants in the three cylinders should be treated as three different states. The first cylinder should keep the plants in their usual natural state; plants in the second cylinder should be cut above the water surface to keep the same water surface area as the first; and in the third cylinder the plants should be cut above water surface and the cylinder fitted with a water tight cover, as

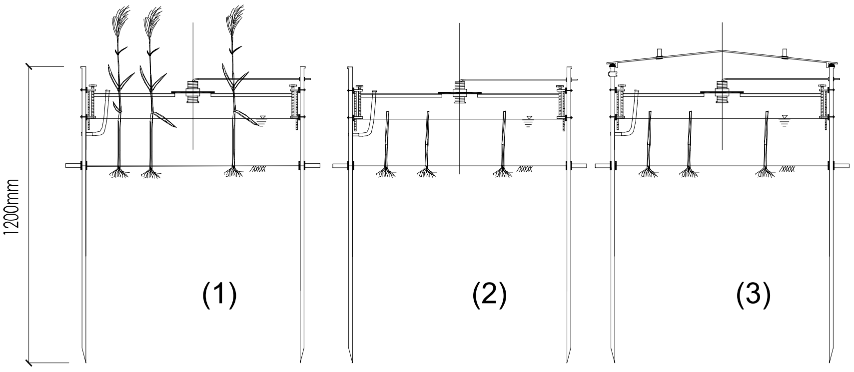

Fig. 1 Sketch of the cylinders of the compensatory evapotranspiration observation system.

shown in Fig. 1. The other working condition of the CETOS is to keep the air pressure in the three cylinders identical and to keep the water surface in and out of the three cylinders at the same level at the start point of the compensation observation period.

By monitoring the water level changes in each cylinder for a compensation period, for example one day, the water losses in the three cylinders can be observed by the ultrasonic water level sensors. It is known that the water loss, measured by the change of water level, in the third cylinder is the amount of water leakage through the lower open end of the cylinder. The other two cylinders have the same amount of water loss through their lower ends as from the third one. Then, based on the compensation principle, the amount of evaporation and transpiration can be computed from the sets of observation data from the three cylinders:

(a) The evaporation from the water surface (E_w) equals the observed water level change in cylinder (2) minus that of cylinder (3).
(b) The evapotranspiration from reed belt (ET) equals the observed water level change in cylinder (1) minus that of cylinder (3).
(c) The transpiration from reed belt (T_r) equals the observed water level change in cylinder (1) minus that of the cylinder (2).

Observation equipment

Based on the measurement principles mentioned above, a multi-cylinder evapotranspiration observation system was developed; it consists of a data processing system, connecting water pipes and monitoring cylinders. Each monitoring cylinder is made of steel plate and is 1200 mm in height and 618 mm in diameter. Figure 2 shows a diagrammatic representation of a multi-cylinder evapotranspiration observation system. The area of every cylinder is the same as for an E-601 pan, with an area of approximately 0.3 m^2. Three are the basic monitoring cylinders which are an ET monitoring cylinder, an E_w monitoring cylinder and a compensation cylinder. Other cylinders (up to 7) can be used for monitoring the ET of plots with different densities of reed or other kinds of emergent hydrophytic vegetation.

The observation system is designed to be set in a natural wetland environment. All monitoring cylinders are pushed into the wetland soil and down to about 600 mm, so that the cylinder can encircle the root zone of the emergent hydrophytic vegetation. The water depth in the monitoring cylinders is 100 to 500 mm. Water pipes connect the monitoring cylinders and measurement pipes.

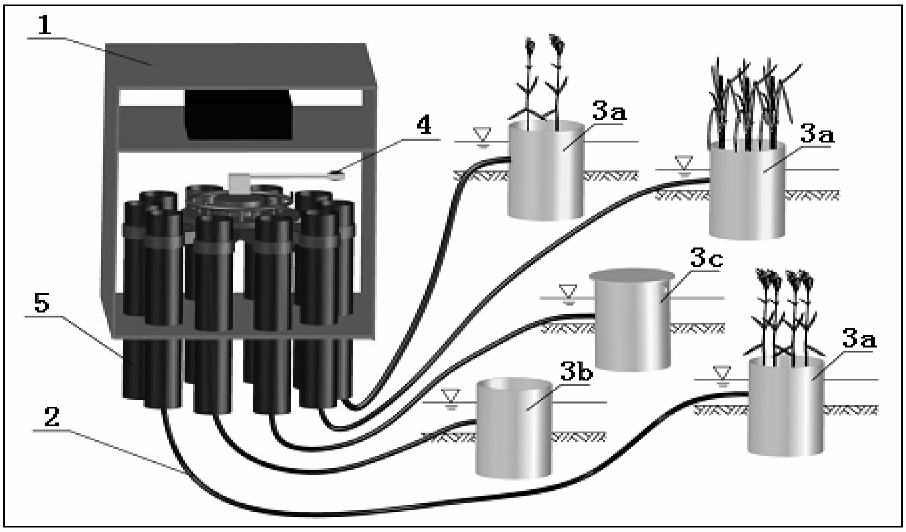

Fig. 2 Diagrammatic representation of a multi-cylinder evapotranspiration observation system. (1) data processing system; (2) water pipes; (3) monitoring cylinders, including ET monitoring cylinders (3a), E_w monitoring cylinder (3b) and a compensatory cylinder (3c); (4) ultrasonic sensor; and (5) measurement pipes.

An ultrasonic sensor can read the water levels of all cylinders together in an artificially set sampling time. The data processing system saves the data in a data logger which can be visited and downloaded anywhere via the internet (Xu *et al.*, 2009).

OBSERVATION DATA

One of the study sites is located in the Baiyangdian wetland (116°01′E, 38°53′N, 4.4 m a.s.l., 366 km^2), which is the biggest freshwater wetland in North China. The Baiyangdian wetland is in the warm semi-humid continental monsoon zone with an annual mean temperature of 12.1°C, annual mean precipitation of 524.9 mm and annual mean evaporation of 1369.0 mm. There are four distinguishing seasons, with a dry and cold winter and a high temperature summer.

The vegetation of Baiyangdian wetland is dominated by reed. In order to study the difference of evapotranspiration from reed of different density, three ET observation cylinders were used. The stalk densities are 42, 55 and 76 reeds per square metre. The observation was carried out from 2007 to 2009. Figure 3 compares ET, E_w and P of a wetland plot with a stalk density of 55 reeds per square metre. The results indicate that precipitation behaves as a strong inhibitory effect on ET rates.

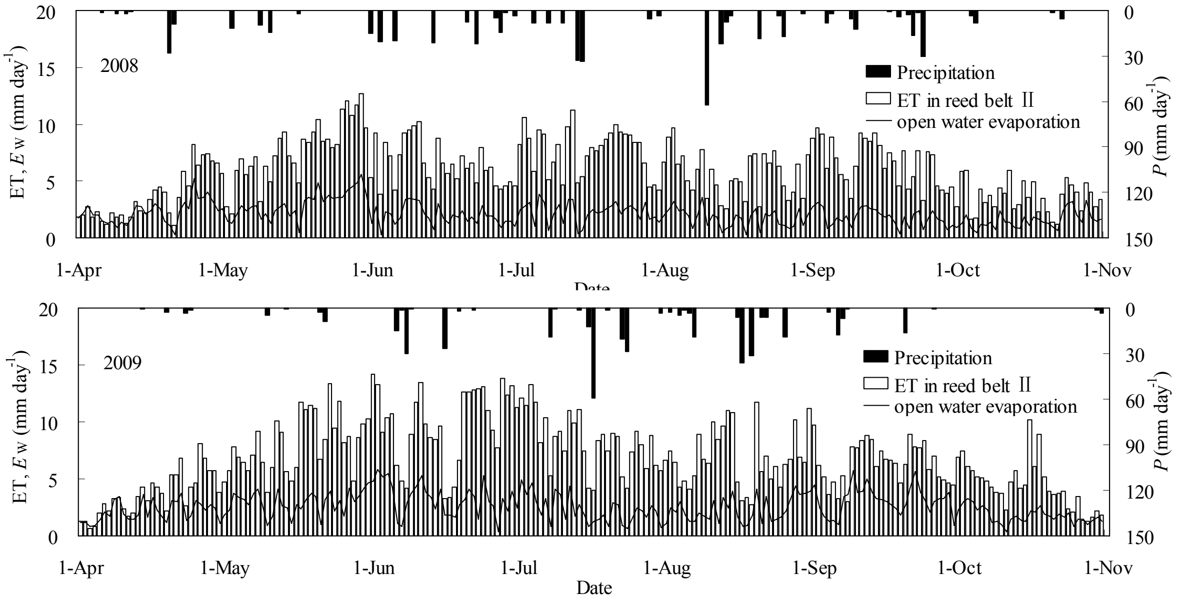

Fig. 3 Measured daily sums of evapotranspiration (ET), open water evaporation (E_w) and precipitation (P).

DATA ANALYSIS

Considering the association of reed density and the ET rates, the Leaf Area Index (LAI; the ratio of the area of all leaf to the area of land surface) is introduced to the study. The LAI of three reed plots are 4.1, 5.2 and 8.7, respectively, in 2009. Based on the hourly monitoring data, the monthly value of evapotranspiration, open water evaporation and precipitation were calculated and are shown in Table 1.

Table 1 shows that strong evapotranspiration occurred from mid-May to mid-July when the reed grows fast and the LAI approached their maximal values. After late-August, there were obvious downward trends in the ET rates. From then until late-October, the reeds almost lost their transpiration abilities as the wilting period was entered.

Table 1 Monthly value of precipitation (*P*), open water evaporation (E_w) and evapotranspiration (ET) of three plots with variable LAI.

Year	Month	*P* (mm)	E_w (mm)	ET (mm): LAI (1)	LAI (2)	LAI (3)
2008	Apr	43.0	68.4	78.8	106.3	140.0
	May	37.4	91.6	187.8	239.0	342.2
	Jun	127.3	58.6	144.6	196.3	290.4
	Jul	103.9	69.1	169.2	235.5	322.8
	Aug	135.7	53.6	128.1	174.4	268.1
	Sep	84.1	53.5	169.9	199.4	258.3
	Oct	18.9	47.4	91.2	110.5	137.1
	Total	550.3	442.2	969.6	1261.4	1758.9
2009	Apr	8.4	63.9	82.3	108.7	136.9
	May	17.1	90.4	199.0	251.3	351.5
	Jun	76.0	98.4	236.7	292.5	432.1
	Jul	146.9	71.0	185.0	260.0	398.4
	Aug	137.0	71.5	139.3	212.4	299.7
	Sep	44.7	94.0	163.4	191.2	247.8
	Oct	4.4	55.2	111.2	136.3	168.4
	Total	434.5	544.4	1116.9	1452.4	2034.8

In 2008, the maximum daily ET for the three reed densities (42, 55 and 76 stalks/m^2) was 10.7, 12.7 and 18.2 mm, respectively. The accumulated ET in the vegetation growth period for the three reed densities were 969.6, 1261.4 and 1758.9 mm, respectively. The accumulated E_w in the same period was 442.2 mm, and the ratios of ET/E_w were 2.19, 2.85 and 3.98, respectively, for the three plots. In 2009, the ratios of ET/E_w in the vegetation growth period were 2.05, 2.67 and 3.74, respectively. It is obvious that the maximum monthly ET occurred in June 2009. In contrast, in 2008 the maximum monthly ET was found in May. The reason was that reeds grew much faster during May and June in 2008 than during the same period in 2009. Correspondingly, LAI increased more rapidly from May to June in 2008 than 2009. It can be concluded that the temporal patterns of ET can be influenced significantly by the growing state of the vegetation.

The evapotranspiration observation by CETOS was also utilized in the Zhalong reed swamp wetlands in 2004 and 2005. A similar varying tendency of the ratios of ET/E_w was observed (Xu & Wang, 2007), and the results have been used in a study of water resources management planning.

DISCUSSION AND CONCLUSION

The paper introduced a prototype observation method for wetland evapotranspiration. Two assumptions of the method are: (1) the water leakage through the soil below a certain depth around a part of a wetland is similar, and (2) the change of the water leakage driven by a small difference of water level can be ignored. Then, the compensation evapotranspiration observation system (CETOS) was established. The application of it in Baiyandian and Zhalong wetlands, China, has been successful. It can provide observations of the evaporation from the water surface and transpiration from vegetation separately on site. From the analysis of observed data, it is known that, apart from ecological factors, temporal patterns of ET were influenced by meteorological factors. The results also indicate that the ET/E_w ratio is positively correlated with aboveground biomass. The larger the LAI and stand density are, the bigger the ET/E_w ratio. In addition, the ET/E_w ratio is connected with weather conditions. Comparing ET with E_w from open water demonstrates that the vegetation can be significantly influenced by daily mean temperature and net radiation.

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