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EVAPOTRANSPIRATION OF LOW-LYING PRAIRIE WETLAND IN MIDDLE REACHES OF HEIHE RIVER IN NORTHWEST CHINA

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ABSTRACT: Low-lying prairie wetland, which has characteristics of both grassland and wetland, has irreplaceable ecological functions in inland river basins of Northwest China. Owing to its small-scale distribution, so far, the observation and research on it are rare. The estimation of evapotranspiration is significant to ecological and environmental construction, scientific management of pasture and protection of wetland. For studying the evapotranspiration (ET) of low-lying prairie wetland in the middle reaches of the Heihe River, an inland river, in Northwest China, the automatic weather station in Linze Ecological Experimental Station of Lanzhou University (39°15′3″N, 100°03′52″E), Linze, Gansu Province, was selected as a case study. Based on meteorological data collected, Bowen-Ratio Energy Balance (BREB) method was used to calculate the evapotranspiration (ET) of low-lying prairie wetland. The analysis results showed that in a whole year (September 2003-August 2004), the total ET was 611.5mm and mean daily 1.67mm/d. The ET varied with different growing stages. In non-growing stage (NGS), initial growing stage (IGS), middle growing stage (MGS) and end growing stage (EGS), the ET was 0.57, 2.01, 3.82 and 1.49mm/d, with a percentage of total ET of 18.26%, 9.20%, 61.83% and 10.71% respectively. In March, ET began to increase. But in April, the ET increased most. After that, it increased gradually and got the maximal value in July. From then on, the ET decreased gradually. In September, the ET decreased rapidly. With the ending of growing and the freezing of soil, the ET stopped from the middle of November to February in next year. Hourly ET analysis showed that at 8:00 a.m. (during MGS at 7:00 a.m.), the evapotranspiration began, at 13:00 p.m. got its maximal value and at 19:00 p.m. (during MGS at 20:00 p.m.), the evapotranspiration stopped. The intensity of ET in sunny day was much larger than that in cloudy day in the same growing stage.
KEY WORDS: evapotranspiration; low-lying prairie wetland; inland river basin

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1 INTRODUCTION

Water balance and interactions are foundation to utilize water resources rationally in arid inland river basins in China (WU *et al*., 2005). Water availability in those areas may be the main constraint to poverty alleviation, public health, economic development and environmental improvement (JEWITT *et al*., 2004). Evapotranspiration is one of the principal elements of the hydrological cycle. Two-thirds of the precipitation is returned to the atmosphere as evapo ration and transpiration (WARD and ROBINSON, 2000). This percentage may be higher in arid regions (WANG *et al*., 2003). Research on evapotranspiration is mainly focused on crops and mature methods of estimating are obtained (JENSEN *et al*., 1990; RANA and KATERJI, 2000). As many characteristics of evapotranspiration between crop field and grassland are in common, therefore, the methods can be referenced on the study of grassland (ZHAO *et al*., 2003). Some scholars have done some research on the evapotranspiration of grassland in different areas (NAGAKAWA, 1984; SONG, 1995; SONG *et al*., 2004), but it is still weak and not yet systemic in arid and semi-arid areas of China (KANG *et al*., 2004).

Low-lying prairie wetlands usually develop near the banks of the rivers or lakes, or the lower land where

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groundwater outcrops or the water level is high. Because of ample water supply, those grasslands flourish and have high vegetation. So, generally speaking, they are good pastures (CHEN and QU, 1992). With the increase of irrigation water, over exploitation of groundwater and improvement of water conservancy facilities, the decrease of runoff in the riverbed and the decline of groundwater level result in the shrink of the low-lying prairie wetlands (HE and ZHANG, 2001). Some of them come into dry land and turn into farmland (WANG and YANG, 2001). The area of low-lying prairie wetland is reducing. Because of strong evaporation and reduction of water supply, the degree of salinization in wetlands increases (SONG *et al*., 2000). As a result, the productivity of this kind of grassland decreases. The degradation of low-lying prairie wetland also occurs in other countries and has been paid much attention to (CRITCHLEY *et al*., 2003; VERHOEVEN, 2001). Prairie wetlands concurrently contain dual functions of grasslands and wetlands. As they exist in a very fragile and sensitive ecosystem, it is hard to recover if destroyed. Thus it is necessary and significant to study and protect those grasslands for a rational and sustainable use. The estimation of the evapotranspiration (ET) of low-lying prairie wetland may be significant to ecological and environmental construction, scientific management of pasture and protection of wetland. Also, it will offer some data on establishing climatic, hydrological and environmental models in inland river basins.

For studying the evapotranspiration (ET) of low-lying prairie wetland in the middle reaches of the Heihe River, an inland river, in Northwest China, the automatic weather station in Linze Ecological Experimental Station of Lanzhou University (39°15′3″N, 100°03′52″E), Linze, Gansu Province, was selected as a case study. The experimental area is 1375m above sea level. The mean precipitation, about 60% of it occurs during the period from July to September, is 121.5mm. The potential evaporation is over 2340mm. The mean temperature is 7.1℃, and 168 days are frost-free. The main wind direction in this area is NW and with a mean wind speed of 3.2m/s. Dry and windy are main climatic characteristics in this area. Most of the grassland is dominated by two densely vegetation communities, i.e., *Aneurolepidium dasystachys* and *Phragmites communis*. *Achnatherum beauv*, *Kalidium foliatum* and *Nitraria tangutorum* inset among them. The vegetation cover is 80% or so. The soil in experimental area is a salinized meadow soil. The experimental area lies at the bitter end of the tilt alluvial-diluvial plain in front of Qilian Mountain. It is the drainage area of groundwater, which recharged by fissure water in mountainous area and groundwater from the infiltration of surface water in plain. The water level is 0.2–2.0m. In spring and autumn, the groundwater outcrops. As there is no irrigation and little precipitation here, the evapotranspiration of prairie wetland mainly depends on groundwater.

2 DATA AND METHOD

2.1 Data

A Vaisala MAWS301 automatic weather station was set up in a 10m×10m experiment plot. The experiment began on August 22, 2003 and ended on November 24, 2004. The data used for this analysis were obtained from September 1, 2003 to August 31, 2004.

Parameters measured included air temperature, relative air humidity, wind speed and direction, long wave and short wave radiation, air pressure, precipitation, etc. at three levels (1.2m, 4.1m and 10.68m). The equipments and their range, accuracy are shown in Table 1. The interval for data collecting was 10min. The raw data were stored in datalogger and picked up by computer.

Table 1 Range and accuracy of instruments in automatic weather station

Parameter	Equipment	Range	Accuracy	Producer
Wind speed	WS425 ultrasonic wind sensor	0–65m/s	±0.135m/s	Vaisala, Finland
Air temperature	HMP45D temperature probes	−40℃–+60℃	±0.2℃	Vaisala, Finland
Relative humidity	HMP45D relative humidity probes	0–100%	±1%	Vaisala, Finland
Radiation	CNR1 radiometer	0–1000 W/m²	±10%	Kipp and Zonen, Netherlands
Air pressure	PMT16A pressure meter	600–1100hPa	±0.3hPa	Vaisala, Finland

2.2 Method

As mentioned above, there exist many methods to estimate the evapotranspiration (ET). Among those methods, Bowen-Ratio Energy Balance (BREB) method has been widely studied in a variety of field conditions and it has been proven to be a standard and very accurate method in semi-arid environments (RANA and KATERJI, 2000; TODD *et al*., 2000). Though some scholars thought the use of this method was restrictive in arid area (SONG, 1993), HUANG Miao-fen (2001) analyzed its applicability from a view of climatology in the oasis-desert zone. In order to improve the accuracy of this estimation, we considered the length of the wind wave and the homogeneousness of the ground maturely to be close to the assuming conditions of the BREB.

Based on the law of the conservation of energy and the gradient diffusion equation, surface energy balance can be expressed in the following equations:

$$R_n=LE+H+G \quad (1)$$

$$H=\rho c_p K_h \Delta t/\Delta z \quad (2)$$

$$LE=(1/\gamma)\rho c_p K_w \Delta e/\Delta z \quad (3)$$

where R_n is the net radiation (W/m^2); H and LE are the sensible and latent heat fluxes respectively (W/m^2); G is the soil heat flux (W/m^2); ρ is air density; c_p is the specific heat capacity of air; γ is the psychometric constant; K_h and K_w are the eddy diffusivities for heat and for water vapor respectively; and Δt, Δe and Δz are the gradients of temperature, vapor pressure and height respectively.

If we assume $K_h=K_w$, the Bowen Ratio (β) can be defined as follows:

$$\beta=\frac{H}{LE}=\gamma\frac{t_1-t_2}{e_1-e_2}=\gamma\frac{\Delta t}{\Delta e} \quad (4)$$

and LE can be expressed as:

$$LE=\frac{R_n-G}{1+\beta} \quad (5)$$

In equations (4) and (5),

$$\gamma=0.665\times10^{-3}P \quad (6)$$

$$P=101.3\left(\frac{293-0.0065z}{293}\right)^{5.26} \quad (7)$$

where P is air pressure (kPa); z is the altitude (m).

And e can be defined as:

$$e=e(T)\frac{RH}{100} \quad (8)$$

$$e(T)=0.6108\exp\left(\frac{17.27T}{T+237.3}\right) \quad (9)$$

where e is actual water vapor pressure (kPa); RH is relative humidity; $e(T)$ is saturate vapor pressure at a given air temperature (kPa); T is air temperature (℃).

G is given by the following equation:

$$G=-\lambda\frac{\Delta T}{\Delta Z} \quad (10)$$

where Z is the depth of soil, T is soil temperature, and λ is soil heat conductivity.

R_n can be gotten by the balance of energy of long wave and short wave.

3 RESULTS AND ANALYSES

3.1 Variation of *ET* in Different Growing Stages

The characteristic values of climatic factors and ET of the low-lying wet grassland were listed in Table 2. As we can see, the total ET in experimental plot was 611.5mm in a complete year and the mean daily value was 1.67mm/d. The ET varied sharply in different growing stages. In non-growing stage (2003-10-15 to 2004-04-26), due to small radiation, low air temperature and high relative humidity, the mean daily ET was only 0.57mm/d. Though this stage lasted for 195 days, the ET during this period only occupied less than 20% of the total ET. When entering into the initial growing stage (2004-04-27 to 2004-05-24), with a higher temperature, a stronger radiation and wind speed, the ET of the grassland increased sharply. Mean daily ET reached 2.01mm/d. For this stage only lasted for 28 days, the ET shared a small percentage of the total ET. In the middle growing stage (2004-05-25 to 2004-08-31), with a highest temperature and net radiation, a stronger wind speed and a lower relative humidity, the evaporation got to a highest level. At the same time, the growth of the pasture turned into the peak season, the transpiration also reached strongest. So, mean daily ET reached 2.01mm/d and came to a peak. The ET in this period took up over 60% of the total ET though its lasting time only took up 27% of the whole year. With a lower air temperature, a weaker radiation and a higher relative humidity, the ET decreased markedly in end growing stages (2003-09-01 to 2003-10-14). The mean daily ET was 1.49mm/d.

3.2 Monthly and Daily Variation of ET

Fig. 1 and Fig. 2 showed the daily and monthly variation of evapotranspiration (ET) of the low-lying wet grassland respectively. Table 3 list the monthly ET. From the mid-November 2003 to February 2004 (i.e.

Table 2 Characteristic values of climatic factors and *ET* of grassland during different growing stages

Growing stage	Period	Day (d)	Of the total days (%)	Air temperature (℃)	Relative humidity (%)	Wind speed (m/s)	Net radiation (W/m^2·d)	*ET*		
								Mean (mm/d)	Total (mm)	Of the total *ET* (%)
Non-growing	2003-10-15–2004-04-26	195	53.3	–0.8	53	1.5	27.4	0.57	111.7	18.26
Initial	2004-04-27–2004-05-24	28	7.7	15.0	40	2.2	105.5	2.01	56.3	9.20
Middle	2004-05-25–2004-08-31	99	27.0	20.8	51	1.7	133.4	3.82	378.1	61.83
End	2003-09-01–2003-10-14	44	12.0	13.6	57	1.1	59.3	1.49	65.5	10.71
Total		366	100.0	–	–	–	–	1.67	611.5	100.00

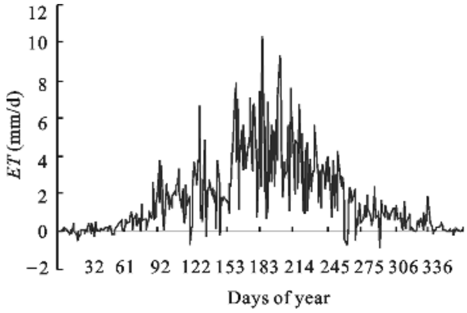

Fig. 1 Daily variation of evapotranspiration (ET)

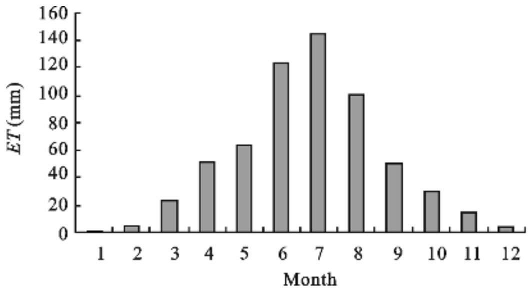

Fig. 2 Monthly variations of evapotranspiration (ET)

DOY315–DOY365, DOY1–DOY61), the ET maintained in a very low level nearly 0mm/d. At the early of March (from DOY62), with the rising of air temperature and the melting of frozen soil, the increase of evaporation led to the increase of evapotranspiration. The ET got to 0.73mm/d in March. In April, the soil melted completely, the ET increased sharply. The herding grass started growing in May, the ET also rose. In June, the grass began to enter into the middle growing stage; the ET increased rapidly and came to the top value, 4.64mm/d, in July. In September, with the coming of the end growing stage, the ET decreased sharply and dropped to 1.69mm/d. Henceforth, along with the stop of grass growth and freezing of soil, the ET decreased gradually and stopped in mid-November.

3.3 Hourly Variation of ET

Four representative days were chosen to discuss the hourly variation of ET in a day in different growing stages and different weather conditions. In Fig. 3, 2004-07-09 and 2004-07-22 represented fine and cloudy days in the middle growing stage (MGS). 2003-09-14 and 2003-09-18 are fine and cloudy days in the end growing stage (EGS).

We could draw some conclusions from Fig. 3. In the middle growing stage, the ET began at 7:00 a.m. After that, it increased sharply and got to the highest value at 13:00 p.m. In the afternoon, the ET reduced gradually

Table 3 Monthly ET of grassland in a year

Month	Mean daily *ET* (mm/d)	Monthly *ET* (mm)	Of the total *ET* (%)
1	0.04	1.1	0.18
2	0.15	4.4	0.71
3	0.73	22.7	3.71
4	1.73	51.8	8.46
5	2.07	64.1	10.48
6	4.11	123.3	20.16
7	4.64	144.0	23.55
8	3.24	100.3	16.40
9	1.69	50.6	8.27
10	0.97	30.1	4.92
11	0.50	15.0	2.45
12	0.09	2.9	0.47
Total	1.67	611.5	100.00

and sharply. With a sudden drop of air temperature and aggrandizement of the humidity, the ET came to the minimum at 20:00 p.m. In fact, condensed water appeared. After 20:00 p. m., the ET put up a tiny increase and maintained in a low level. In fine days, the increasing rate of ET in the morning was nearly in accordance with the dropping rate of ET in the afternoon. The curve of the ET showed symmetrical shape. In cloudy days, the variation of the ET was more complicated. In the end growing stage, the variation trend of the ET in a day was just as same as it in the middle growing stage. The difference existed in time that ET lasted and intensity of the ET. The ET began 1h later and stopped 1h earlier in EGS than in MGS. Also as we could see from Fig. 3, the intensity of the ET was much weaker in EGS than in MGS in the same weather condition.

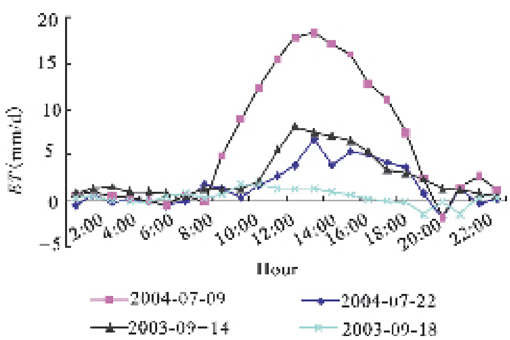

Fig. 3 Hourly variations of evapotranspiration (ET) in typical days in different growing periods

4 CONCLUSIONS

(1) Bowen-Ratio Energy Balance (BREB) method was applied to estimating the evapotranspiration of low-lying grassland in the middle reaches of the Heihe River

in Northwest China. In a whole year, the evapotranpiration was 611.5mm and a daily mean 1.67mm/d.

(2) In different growing stages of grassland, the ET varied sharply. In non-growing period (NGP), initial growing period (IGP), middle growing period (MGP) and the end growing period (EGP), the ETs were 0.57, 2.01, 3.82 and 1.49mm/d, and with a percentage of total ET of 18.26%, 9.20%, 61.83% and 10.71% respectively.

(3) The ET of the grassland had an obvious monthly and daily variety. From the mid-November of 2003 to February of 2004, the ET maintained in a very low level. In March, with the increase of evaporation, the ET also rose. A significant increment of ET occurred in April. After entering into the middle growing stage, the ET increased sharply and came to its maximum value in July. In September, with the coming of the end growing stage, the ET decreased sharply. Henceforth, along with the stop of grass growth and freezing of soil, the ET decreased gradually and stopped in mid-November.

(4) The analysis of hourly variation of the ET showed that ET began at 7:00 (in MGS) or 8:00 (in EGS) a.m., and came to its maximum value at 13:00 p.m. or so. At 19:00 p.m. (in EGS) or 20:00 (in MGS) p.m., the ET stopped and maintained a low level in nighttime. The intensity of ET in fine days was much larger than that in cloudy days in the same growing stage.

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