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Relationship Between Land Use and Evapotranspiration-A Case Study of the Wudaogou Area in Huaihe River basin

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Abstract

Land use has critical influence on evapotranspiration (ET). Winter wheat and bare land are selected to analyze ET in the Wudaogou area in the Huaihe River basin. Firstly Penman-Monteith formula combining crop coefficient was used to calculate the actual evapotranspiration of winter wheat, and a modified Penman Equation was applied to calculate the actual evapotranspiration of bare land. Then the impact of temperature and precipitation on evapotranspiration was evaluated. The results show that maximum monthly mean evapotranspiration of bare land appears different from that of winter wheat. But the monthly mean evapotranspiration of bare land has a similar trend with the winter wheat during the growth period. Based on regression analysis of data, correlation functions between evapotraspiration and temperature, and precipitation have been respectively established for winter wheat and bare land to seek the influence mechanism of evapotranspiration under different land use types.

Keywords: Land use; Evapotranspiration; Winter wheat; Bare land; Regression analysis

1. Introduction

Hydrologic cycle is the important link between subsystems of the earth, biology and atmosphere. Evapotranspiration is an important component of the hydrologic cycle and the main item of water budget and heat balance. Furthermore, evapotranspiration is closely related to the physiological activities of plant and the formation of the biological yield. Therefore, understanding of evapotranspiration has great

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significance. In addition, different land use patterns will cause different evapotranspiration and affect runoff, infiltration and other hydrologic processes. Thus water balance and water environment evolution are also affected. So studying the relationship between land use and evapotranspiration is also very important to water regulation and water resources assessment.

The Huaihe River basin is one of the areas where water resources are more sensitive to climate change and more vulnerable in China. The Wudaogou Hydrological Experimental Station in the north plain of the Huaihe River basin, has a representativeness to the basin. So this paper has taken the Wudaogou area as an example to study the relationship between land use and evapotranspiration.

2. Study area

The Huaihe River Basin is located between 30°55'~36°36'N and 111°55'~121°25'E, with an area of 270,000km^2. The climate of the area belongs to a semi-humid monsoon. The annual average temperature is 11~16℃ increasing gradually from north to south. The long-term annual average precipitation is around 888mm, generally diminishing from south to north. Precipitation is higher in mountains than plains, and higher in coastal areas than inland. The long-term average annual runoff depth is 230mm. The annual average water surface evaporation is 900~1500mm.

The Wudaogou Hydrological Experimental Station (117°21'E, 33°9'N) locates in the north plain of the Huaihe River Basin. The climate of the area is north subtropical and warm temperate semi-humid monsoon one. The average temperature is 14.6℃ here. It has abundant sunlight and annual average sunshine hours are 2085h. The annual average frostless period lasts 212 days. The annual average precipitation here is 840mm and precipitation in flood season (from June to September) accounts to about 63% of the annual total. The annual average pan evapotranspiration is l181.3mm. And the groundwater depth is shallow [1].

3. Research methods

Different land use types determine different water permeability, water aquosity and other characteristics of the underlying surface, thus affecting the evaporation and recharge of river basins, affecting the recharge, drainage, runoff, and conversion between "four waters" (surface water, soil water, shallow groundwater, and deep groundwater). Therefore, combined with the actual situation of the study area and the existing meteorological and hydrologic data of the Wudaogou Hydrological Experimental Station in 2005, this paper selected bare land and winter wheat to calculate the evapotranspiration separately, using month as calculation interval, and to contrast and analyze the law and the influence mechanism of evapotranspiration under different land use types.

3.1. Calculation of the reference crop evapotranspiration

The Penman-Monteith formula is a physically based model with high accuracy and well stability, and easy to adapt for various regions by using conventional meteorological data. So the monthly reference crop evapotranspiration was calculated by the Penman-Monteith formula. Then based on the growth status of the actual crop, the calculation results above were multiplied by the monthly crop coefficient of winter wheat for revisions to obtain the actual evapotranspiration of winter wheat. The Penman-Monteith formula is described as [2]

$$E_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{1}$$

where E_0 is the reference crop evapotranspiration; Δ is the gradient of saturated vapor pressure to temperature; R_n is the net radiation; γ is the psychrometric constant; T is the mean temperature; u_2 is the wind speed at 2m altitude; e_s is the saturation vapour pressure; e_a is the actual water vapor pressure; G is the soil heat flux.

Detailed values of the parameters in Eq. (1) derive from the literatures [3-5].

3.2. Calculation of the actual crop evapotranspiration

$$E_{ti} = K_i \times E_{oi} \tag{2}$$

where E_{ti} is the monthly actual evapotranspiration of crop; K_i is the monthly crop coefficient during the growth period of winter wheat and uses the monthly crop coefficient of winter wheat in northern area of Jiangsu province of China [6] (presented in Table 1), according to the "similarity principle"; E_{oi} is the monthly reference crop evapotranspiration calculated by Eq. (1); i is the month.

Table 1. Values of the monthly crop coefficient of winter wheat K_i

Month	1	2	3	4	5	6	7	8	9	10	11	12
K_i	0.35	0.92	1.06	1.41	1.30	0.63				0.71	0.94	0.89

3.3. Calculation of bare land evapotranspiration

The soil surface evaporation depends on not only the meteorological factors, but also the soil water content, soil water potential and soil hydraulic conductivity [7], so according to the existing meteorological and hydrologic data in 2005 and soil moisture data, the following modified Penman equation (Eq. (3)) combined with the following soil wetness function (Eq. (4)) is derived to compute the actual bare land evapotranspiration [8-12].

$$E_s = \frac{(R_n - G)\Delta + \rho_a C_P (e_s - e_a)/r_a}{\lambda(\Delta + \gamma/\beta)} \tag{3}$$

where ρ_a is the air density; C_P is the specific heat of air at constant pressure; r_a is the aerodynamic resistance to transport of water vapour from the canopy to a plane 2 m above it; λ is the latent heat of vaporisation of water; β is the soil wetness function and the other notations are same as above mentioned.

$$\beta = \begin{cases} 0 & \theta \le \theta_m \\ \frac{1}{4}\left\{1-\cos\left[\frac{\pi(\theta-\theta_m)}{(\theta_{fc}-\theta_m)}\right]\right\}^2 & \theta_m < \theta < \theta_{fc} \\ 1 & \theta \ge \theta_{fc} \end{cases} \tag{4}$$

where θ is the volumetric water content of surface soil; θ_{fc} is the field moisture capacity of the top soil layer; θ_m is the volumetric soil water content correspondent to the mono-molecular suction (pF4.2 ~ 7.0).

The field capacity of the top soil layer can be obtained by the soil properties of lime concretion black soil in the Wudaogou area and the existing experimental data, that is θ_{fc} =24.6%. Then combined with the distribution schematic diagram of soil moisture and suction force (Fig. 1(a)) and soil moisture characteristic curve (Fig. 1(b)), because the soil moisture correspondent to the mono-molecular suction (pF4.2~7.0) is the hygroscopic water and the swelling water, the soil attracts the moisture so strongly that plants can not use the moisture. And the strong adsorption between the surface molecules of the soil particles and the moisture makes the hygroscopic water not move, even though the swelling water can move, the movement way is moving from the soil particles with rather thick water films to the thinner ones in humid way, and its moving speed is very slow [13]. So its contribution to calculation of the bare land evaporation is negligible. Thus the final values are taken as θ_m =10%, θ_{fc} =24.6%.

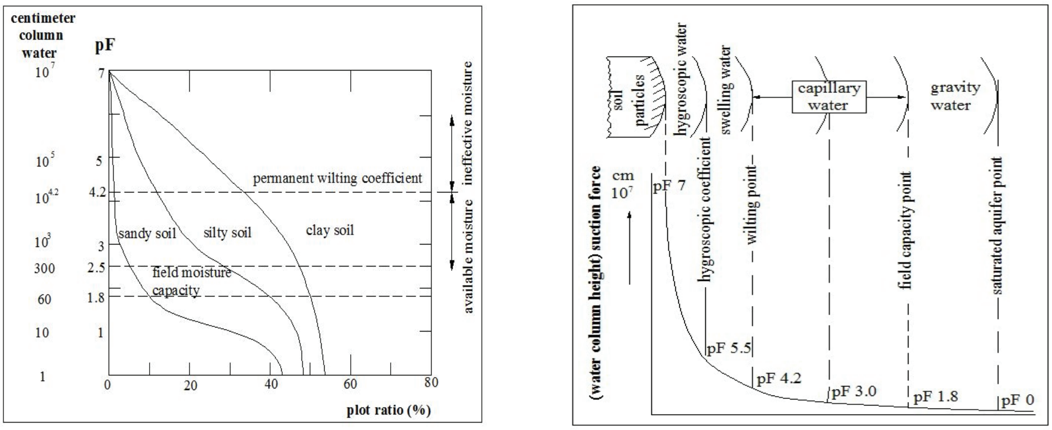

Fig. 1. (a) the distribution schematic diagram of soil moisture and suction force [14]; (b) soil moisture characteristic curve

4. Analysis of results

The monthly average evapotranspiration and the total amount of the monthly evapotranspiration of bare land and winter wheat and the corresponding evapotranspiration of bare land during the growth period of winter wheat calculated in the third part are as follows:

Table 2. The monthly average evapotranspiration of winter wheat and bare land (mm/d)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Winter wheat（E_{ti}）	0.16	0.48	1.25	2.56	2.65	1.93				0.97	0.95	0.70
Bare land（E_{si}）	0.16	0.19	0.35	1.01	1.47	2.06	0.99	1.63	1.44	0.93	0.29	0.23

Table 3. The total amount of the monthly evapotranspiration of winter wheat and bare land (mm)

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total amount
Winter wheat（E_t）	4.82	13.56	38.70	76.89	82.17	57.82				30.06	28.58	21.85	354.45
Bare land（E_s）	5.01	5.31	10.84	30.40	45.58	61.89	30.62	50.65	43.22	28.91	8.62	7.20	328.25

Table 4. The corresponding total amount of the monthly evapotranspiration of bare land during the growth period of winter wheat (mm)

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total amount
E_s	5.01	5.31	10.84	30.40	45.58	61.89				28.91	8.62	7.20	203.76

Comparing Tables 3 and 4, it shows that the evapotranspiration is impacted by different land use types and different from each other. The quantitative difference between the total amount of the evapotranspiration of winter wheat and the corresponding total amount of bare land is 150.69mm during the growth period of winter wheat.

4.1. Comparison and analysis of the evapotranspiration of winter wheat and bare land

The curves of the monthly mean evapotranspiration of winter wheat and bare land were drawn separately in Fig. 2. Combined with the growth law of winter wheat, it can be seen from Fig. 2 that the evapotranspiration decreases slowly after sowing in October, and it reaches its minimum value of 0.16mm/d in the wintering period in January, while it rises gradually at returning green stage namely in mid-March, and its rate of increase is the fastest at jointing stage in early April. Then the evapotranspiration is the highest in its heading filling period during the end of April to May, later the evapotranspiration declines rapidly at mature stage in June.

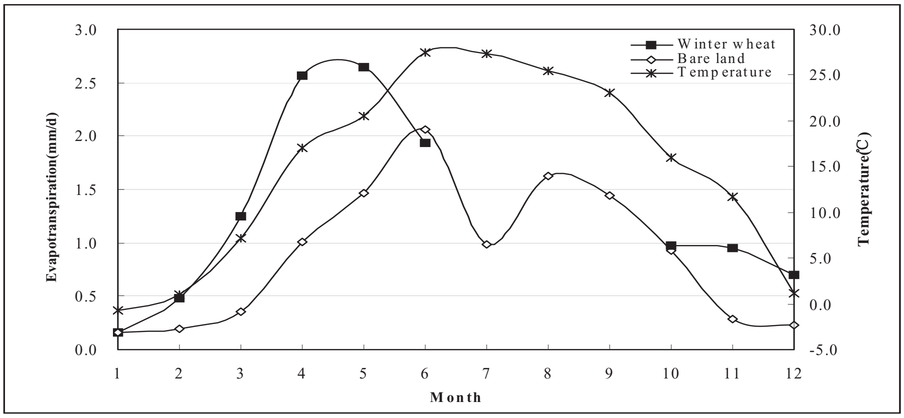

Fig. 2. the monthly mean evapotranspiration of winter wheat and bare land and the monthly mean temperature in 2005

The monthly mean evapotranspiration of bare land has the similar trend to that of winter wheat, but the maximum monthly mean evapotranspiration of bare land appears in June, one month later than winter wheat. In addition, the monthly mean evapotranspiration of bare land gives two peaks in June and August successively, and is also the lowest in January. During the whole growth period of winter wheat, the monthly mean evapotranspiration of winter wheat is all higher than that of bare land in other months, except in June, and almost the same in January. When winter wheat matures in June, its evapotranspiration decreases rapidly, while the evapotranspiration of bare land is up to the annual maximum which is higher than that of winter wheat.

4.2. The relationship between evapotraspiration and temperature

The monthly mean temperature in 2005 is plotted in Fig. 2 as well. It can be found that the temperature also has the minimum in January. The monthly mean evapotranspiration rises constantly as the temperature rises during February to May. Then the temperature continues to increase rapidly, while winter wheat matures and its evapotranspiration decreases rapidly, but the evapotranspiration of bare land continues to increase during May to June. The temperature begins to decline gradually in June to December, while the evapotranspiration of bare land decreases rapidly during June to July and begins to increase rapidly during July to August, and decreases with the reduction of the temperature in September and October. The temperature decreases rapidly during November to December, but the corresponding evapotranspiration decreases slowly. Taking a wide view of the year, the temperature has some influences on evapotranspiration and plays a controlling role during January to June.

Through regression analysis of data, correlation functions of winter wheat and bare land between evapotraspiration and temperature have been respectively established as $E_t = f_t\left(T\right)$、 $E_s = f_s\left(T\right)$. The results show that the polynomial regression analysis which analyzed the relationship between the monthly mean evapotraspiration of winter wheat and the monthly mean temperature is the best, while the index regression analysis produces the best results for bare land, and the R^2 values are both the highest (0.84 for winter wheat and 0.9 for bare land). The corresponding fitting function of winter wheat is as follows:

$$E_t = f_t\left(T\right) = -4\times10^{-6}T^5 + 1\times10^{-4}T^4 + 8\times10^{-5}T^3 - 3.44\times10^{-2}T^2 + 3.13\times10^{-1}T + 3.4\times10^{-1} \qquad (5)$$

The fitting function of bare land is as follows:

$$E_s = f_s(T) = 0.1855e^{0.08387T} \qquad (6)$$

4.3. The relationship between evapotraspiration and precipitation

The total amount of the monthly evapotranspiration of winter wheat and bare land and the total amount of the monthly precipitation in 2005 are plotted respectively in Fig. 3. It is clear to see that the minimum precipitation appears in October, the precipitation rises rapidly in June and July, while the corresponding evapotranspiration of bare land declines quickly, and the precipitation decreases rapidly in July and August, while the evapotranspiration of bare land increases quickly. Moreover, combined with the mean temperature curve, it can be analyzed that the evapotranspiration of winter wheat and bare land is mainly controlled by the temperature during January to June and August to October and has a positive correlation with the temperature. During June to August the evapotranspiration of winter wheat and bare land is mainly affected by the precipitation, and the evapotranspiration declines slowly under the combined effects of the temperature and the precipitation during October to December.

This phenomenon can be explained that the precipitation affects the soil moisture condition, though the crop evapotranspiration increases with increasing soil moisture within a certain range, when the soil moisture content is close to or exceeds the field capacity for a long time, the crop evapotranspiration will decrease with the increase of soil moisture [6], so the evapotranspiration has a reverse change trend to precipitation during July to August.

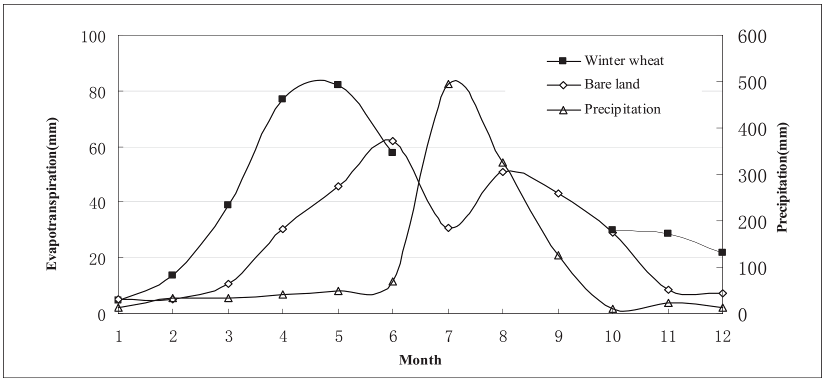

Fig. 3. the total amount of the monthly evapotranspiration of winter wheat and bare land and the total amount of the monthly precipitation in 2005

Likewise, correlation functions of winter wheat and bare land between evapotraspiration and precipitation have been respectively established as $E_t = f_t\left(P\right)$、$E_s = f_s\left(P\right)$. The results have shown that the polynomial regression analyses both produce the best results for winter wheat and bare land, and the R^2 values are both the highest (0.81 for winter wheat and 0.88 for bare land). The corresponding fitting function of winter wheat is as follows:

$$E_t = f_t(P) = 1\times10^{-5}P^5 - 1.9\times10^{-3}P^4 + 1.3\times10^{-1}P^3 - 4.01P^2 + 54.94P - 247.3 \tag{7}$$

The fitting function of bare land is as follows:

$$E_s = f_s(P) = -4\times10^{-9}P^5 + 4\times10^{-6}P^4 - 1.1\times10^{-3}P^3 + 1.25\times10^{-1}P^2 - 3.95P + 44.637 \tag{8}$$

5. Conclusion

In this paper, winter wheat and bare land were selected to calculate the evapotranspiration. The impact of temperature and precipitation on evapotranspiration has been quantified and the mutual relationship between land use and evapotranspiration has also been explored. The results have shown that the evapotranspiration in various land use is different; maximum monthly mean evapotranspiration of bare land appears different from that of winter wheat land. However, the monthly mean evapotranspiration of bare land has the similar change trend to that of winter wheat during the same period; Through regression analysis of data, except that the index regression analysis which analyzed the relationship between evapotraspiration of bare land and the temperature produces the best results, other correlation functions established by the polynomial regression analysis are acceptable; The evapotranspirations of winter wheat and bare land are dominated by the temperature during January to June and August to October in a year with a positive correlation relationship; The evapotranspiration of bare land is mainly affected by the precipitation during June to August, and has a reverse change trend to the precipitation; The evapotranspiration declines slowly under the combined action of the temperature, the precipitation, solar radiation and other kinds of factors during October to December.

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