

Evaluation of three reference crop water requirements algorithm in north China*

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Penman-Monteith equation is widely used to calculate the reference crop water requirements, which is composed of two parts: the first part is the radiation part and the second part is the aerodynamics item. Penman-Monteith equation requires more meteorological factors compared with the Hargreaves formula and Priestley Taylor formula, but it is still unknown about the calculation accuracy of the Hargreaves formula calculation and the Priestley Taylor formula calculation. This research demonstrates that the Hargreaves formula calculation results and the Priestley Taylor formula calculation results have a linear relationship with the Penman-Monteith formula calculation results, the correlation coefficient are separately 0.9461 and 0.9222, the coincidence degree are 0.97585 and 0.971501. It is helpful to use the Hargreaves formula and the Priestley Taylor formula to calculate the reference crop water requirements in North China instead of the Penman-Monteith equation, and the the Hargreaves formula calculation results have a greater accuracy compared with the Priestley Taylor formula calculation results.

Keywords: the reference crop water requirements; Penman-Monteithequation(PT); Hargreaves formula(HA); Priestley Taylor formula(PT).

1. Introduction

Reference crop evapotranspiration (ET_0) is an essential indicator for the calculation of crop water consumption and the planning for the irrigation area.

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The reference crop water requirement is calculated according to the Penman-Monteith formula (PM formula) proposed by the FAO in 1998 (Allen, 1998). Sufficient meteorological data (maximum temperature, minimum temperature, average temperature, radiation or sunshine duration, relative humidity, wind speed) are needed when using the PM formula, which has a great effect on the area where the meteorological data are missing or the meteorological data are incomplete. Hence it is a good idea to calculate the reference crop water requirement with less meteorological data. Hargreaves formula (HA formula) (Hargreaves, 1985) is a good choice to calculate the reference crop water requirement based on the temperature data, which is simple and easier and less dependent on the meteorological data. Researches (Vanderlinden, 2004; Razinei, 2013; Berti, 2014; Luo, 2014) on the HA formula calculation have been reported widely, some reports illustrate that it has a large variation compared with the PM formula calculation (Martínez-Cob, 2004; Gavilán, 2006; Martí, 2015). Priestley Taylor formula (PT formula) (Priestley, 1972) is a widely used way to calculate the reference crop water requirement based on the radiation data proposed by the FAO (Utset, 2004; Sumner, 2005; Ding, 2013; Szilagy, 2014; Baik, 2015). However, few researches on the accuracy of the two formula calculations (HA formula and PT formula) have been reported. This research mainly focuses on the evaluation and accuracy of the two formula calculation compared with the PM formula calculation in the North China.

2. Materials and Methods

2.1. Site characteristic

Farmland Irrigation Research Institute (35°19'N, 113°53'E, 73.2m) is located in Xinxiang City of Henan province. The annual mean rainfall is 610mm, the annual mean air temperature is 13.5°C, annual accumulated temperature above 0°C is 5070.2°C, annual sunshine duration 2497h, frost-free period 220 days. The meteorological data include the annual hourly average temperature, maximum temperature, minimum temperature, relative humidity, sunshine hours, 2m height wind speed from 1951 to 1998 in this research institute.

2.2. Three evapotranspiration models

Penman–Monteith model

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

Hargreaves model

$$ET_h = 0.0023(T_{\max} - T_{\min})^{0.5} \left(\frac{T_{\max} + T_{\min}}{2} + 17.8 \right) \frac{R_a}{\lambda \rho_w} \quad (2)$$

Priestley Taylor model

$$ET_p = \alpha \frac{\Delta}{\Delta + \gamma} \times (R_n - G) \quad (3)$$

2.3. Simulation Evaluation Index

In this paper, mean, mean deviation error (MBE), root mean square error (RMSE), the relative error and relative root mean square error are included.

The mean deviation error (MBE) and relative mean deviation error (RBE) are:

$$MBE = \frac{1}{N} \sum_{i=1}^N (O_i - P_i) \quad (4)$$

$$RBE = \frac{MBE}{\bar{O}} \times 100 \quad (5)$$

In the equation, N is number of determination, O_i is measured value and P_i is predicted value, overline stands for mean.

Root mean square error (RMSE) and relative root mean square error (RSE) are:

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (O_i - P_i)^2}{N - 1}} \quad (6)$$

$$RSE = \frac{RMSE}{\bar{O}} \times 100\% \quad (7)$$

Fitting degree IA:

$$IA = 1 - \left[\frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (|O_i - \bar{O}| + |P_i - \bar{P}|)^2} \right] \quad (8)$$

3. Results and Discussion

3.1. Trend of the reference crop water requirements in Xinxiang

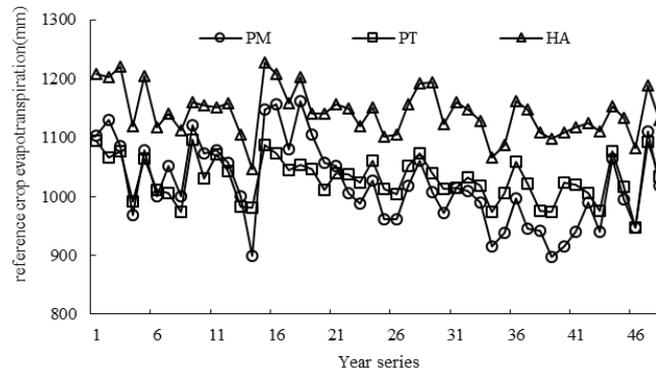


Fig. 1. Comparison of annual variation of reference evapotranspiration.

As it can be seen from the Figure 1 that the reference crop water requirements were in a decreasing trend with the increase of time. The maximum of the reference crop water requirement is 1200mm, while the minimum value is 900mm. If the crop coefficient does not change, the reference crop water requirements were in a decreasing trend with the increase of temperature, so it could be concluded that the evaporation paradox phenomenon also exists in the North China. The figure also shows that the value of HA formula calculation was close to that of the PM formula calculation, while the value of the PT formula calculation had a large degree of variation compared with that of the PM formula calculation, initially illustrating that HA formula calculation has higher accuracy than the PT formula calculation.

3.2. Variation of the monthly average

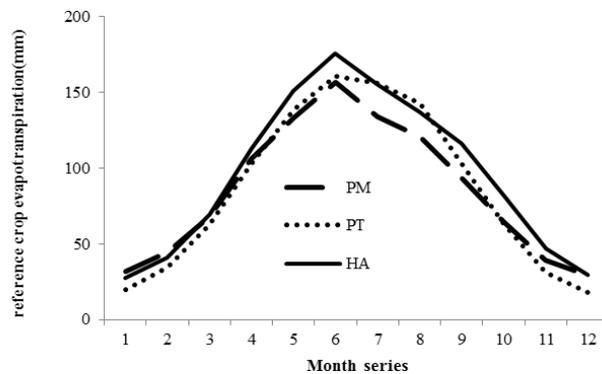


Fig. 2. Multi-year monthly average of ET_0 .

The above Figure 2 shows the yearly average of the reference crop water demand calculated by three equations (PM, HA, PT). It shows that the radiation raised with the increase of temperature since January, and the reference crop water storage capacity also increased from the 20mm (the minimum) to the 180mm (the maximum) in July, and then falling down. The overall trend was the “V” type.

3.3. Relationship analysis

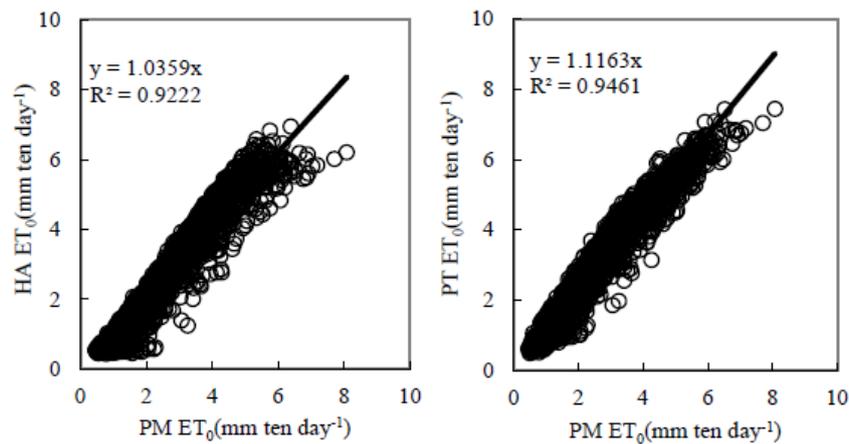


Fig. 3. Scatter plots of PM ET_0 versus HA ET_0 and PT ET_0 .

The above two Figure 3 imply that the reference crop water requirement calculated by the PM formula is higher than that of the HA formula and PT formula, whose correlation coefficient were separately 0.9461 and 0.9222. In general, it has a linear relationship, and according to the value of the correlation coefficient, the sequence of the reference crop water requirement calculation accuracy was PM formula, HA formula and PT formula.

3.4. Error Analysis

Take the crop water requirements calculated by the PM formula as the standard, conclusions could be obtained through the comparison of the HA and PT formula calculation results and PM formula calculation results (Table 1): ① The average deviation and the relative average deviation of HA formula calculation were -0.02mm and -0.93%; while those of PT formula calculation were -0.34mm and -12.06%; ② The average crop water requirements calculated by the PM formula, HA formula and PT formula were 2.84mm, 2.86mm and 3.18mm. It shows that the results of HA formula is more close to the PM formula results; ③ The root-mean-square error and the relative root-mean-square error of HA

formula calculation were 0.517mm and 18.2412%, while those of the PT formula calculation were 0.553959mm and 19.5452%. It indicates that the root-mean-square error of the PT formula calculation is larger; ④The soil surface temperature was simulated by the HA formula calculation and PT formula calculation, and the coincidence degree were 0.98 and 0.97. Overall, HA formula calculation of the reference crop water requirement has more accurate degree than that of the PT formula calculation.

Table 1. Error analysis of ET_0 by three PM HA and PT.

evaluating indicator	Penman-Monteith	Hargreaves	Priestley Taylor
Average	2.835582	2.861947	3.177285
Standard Error	0.037227	0.043449	0.042176
Median	2.682316	2.703088	3.119804
standard deviation	1.547055	1.805615	1.75273
variance	2.393378	3.260246	3.072061
kurtosis	-0.87493	-1.34901	-1.25622
skewness	0.368878	0.219789	0.156969
area	7.618614	6.513	6.938513
min	0.458363	0.436093	0.496919
max	8.076977	6.949092	7.435433
sum	4897.05	4942.583	5487.171
maximum	8.076977	6.949092	7.435433
minimum	0.458363	0.436093	0.496919
confidence (95.0%)	0.073015	0.085218	0.082722
average deviation	0	-0.02635	-0.34172
the relative average deviation	0	-0.93%	-12.06%
root-mean-square error	0	0.517	0.553959
relative root-mean-square error	0	0.182412	0.195452
coincidence degree	1	0.97585	0.971501

4. Conclusion

The results of this study indicate that if enough meteorological factors (maximum temperature, minimum temperature, average temperature, wind speed, humidity, sunshine duration) could be obtained, Penman-Monteith formula would be the first choice to calculate the reference crop water demand in North China; otherwise Hargreaves formula would be used firstly followed by the Priestley Taylor formula.

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