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**Abstract:** Soil evaporation (*Es*) and crop transpiration (*Tc*) are important components of water balance in cropping systems. Comparing the accurate calculation by crop models of *Es* and *Tc* to the measured evaporation and transpiration has significant advances to the optimal configuration of water resource and evaluation of the accuracy of crop models in estimating water consumption. To evaluate the adaptation of APSIM (Agricultural Production Systems simulator) in calculating the *Es* and *Tc* in Nanjing, APSIM model parameters, including the meteorological and soil parameters, were measured from a two-year field experiment. The results showed that: (1) The simulated evaporation was basically consistent with the measured *Es*, and the regulated model can effectively present the field evaporation in the whole maize growth period ( $R^2 = 0.85$ , D = 0.96, p < 0.001); and (2) The trend of the simulated *Tc* can present the actual *Tc* variation, but the accuracy was not as high as the evaporation ( $R^2 = 0.74$ , D = 0.87, p < 0.001), therefore, the simulation of water balance process by APSIM will be helpful in calculating *Es* and *Tc* in a humid area of Nanjing, and its application also could predict the production of maize fields in Nanjing.

Keywords: soil evaporation; crop transpiration; APSIM model; summer maize

# 1. Introduction

Composed of soil evaporation (Es) and crop transpiration (Tc), evapotranspiration (ET) is the only factor in both surface energy balance and water balance [1]. The accurate estimation of ET is not only of great practical significance to the efficient management of farmland water use, the optimal allocation of regional water resources and the development of water-saving agriculture, but also provides a reliable scientific basis for the study of global climate change and water resources management [2,3]. ET calculations are also used for irrigation scheduling and can also be used as a reference technique to compare other irrigation scheduling methods for example [4]. As a part of ET, either Es or Tc is an important component in crop system water balance [5]. Although Es has no direct benefits on crop production, it may have an indirect effect on crop growth and yield formation through influencing canopy atmospheric humidity and temperature [6]. Soil moisture influences ground temperature, which affects the vertical air temperature profile, soil surface water loss and surface energy balance. Through these direct and indirect effects, Es can reduce the water lost as Tc without affecting ET. Es is usually measured using micro-lysimeters [7–9]. This measurement is one of the important methods for the direct determination of evaporation in the shallow layer of soil. Owing to its excellence for handiness, flexibility and accuracy [10], it is widely used in Es beneath crop and crown canopies [11,12]. However, the method is time-consuming and cannot be operated during rainfall, so researchers seek to use models to simulate Es. As a consequence, there have been developed several approaches, among which the Penman-Monteith model, proposed by H.L. Penman and modified by Monteith, is the most well-known one to



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**Copyright:** © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). calculate evaporation capacity (evaporation from water surface) [13], but a large amount of meteorological data input is a chief drawback of its extensive application [14]. The Ritchie formula, which requires minimal data input, is simplified from the Penman-Monteith and now, the simplified formula is widely used in complex crop models, including APSIM and DSSAT [5]. While based on the equilibrium evaporation theory, the Priestley-Taylor formula, which applied in the APSIM model for ET calculation, is also a simplified form of the Penman-Monteith model [15,16]. The major difference between the Priestley-Taylor formula and the Penman-Monteith model is that the latter considers the aerodynamic term, but the former does not, so the latter is convenient to calculate for less meteorological data input. Moreover, according to Li et al. [17], the hourly imitative effect of Priestley-Taylor is better than Penman-Monteith, day-to-day scale, and the daily imitative effect Priestley-Taylor and Penman-Monteith model fitting effect is basically the same, and the goodness of fit between the two and observed values is high. In comparing conventional meteorological data-based models (Hargreaves, Priestley-Taylor and Penman-Monteith) and meteorological gradient data-based models (Bowen-ratio energy balance, Gradient-based method, and ecosystem process simulation), the results showed that the simulation results of Hargreaves, Priestley-Taylor and FAO-Penman-Monteith are nearly consistent, among which the Priestley-Taylor simulation results are optimal [18]. Some of these formulas are nested within some crop models to simulate crop growth. Evaluating the performance of Priestley-Taylor and FAO-Penman-Monteith, respectively, nested within CERES-Wheat, the results showed that the CERES-Wheat model (Crop Environment Resource Synthesis for Wheat, Ritchie et al., East Lansing, MI, USA) based on Priestley-Taylor and Penman-Monteith, respectively, can accurately simulate the evapotranspiration of winter wheat in arid-semi-arid regions in China. [19–21]. Certainly, in terms of the Tc simulation, APSIM (Agricultural Production System Simulator) selected Penman-Monteith [22], as well as this paper. At present, a number of researches showed that the APSIM model has been validated and applied in several countries and regions. A study on the simulations of crop yield, water use and water use efficiency (WUE) with different precipitation years and different irrigation conditions showed that a calibrated and validated APSIM wheat-corn model can accurately simulate the response of crop growth and yield to different water treatments in the Haihe River plain [23]. In addition, some scholars assessed the suitability of the APSIM-Maize model (CSRIO and University of Queensland, Brisbane, Queensland, Australia), as well as analyzed the spatiotemporal characteristics of spring maize, rain-fed yield during 1961–2010 in the southwest of China with the model. The results showed that the APSIM model had better simulation effect on six common maize varieties in this area [24]. Later, combined with field trials, APSIM was applied to analyze the influence factors of spring maize yield in different precipitation and nitrogen application rates. The results demonstrated that the APSIM model has high precision for spring wheat yield simulation [25]. In addition, a simulation of the evaporation of soil water beneath a wheat crop canopy in Punjab, India showed that the simulated values and observed values were relatively good with a high goodness of fit [5].

Different from others, APSIM combined the Ritchie and Penman-Monteith models to calculate *Es* and *Tc*, respectively. Based on the data from an agro-meteorological station, the purpose of this study is to learn about the *ET* variation trend, meanwhile simulate *Es* and *Tc* beneath a maize crop canopy and make an assessment of the models' adaptability in Nanjing, so as to provide a quotative value for field water management.

#### 2. Materials and Methods

#### 2.1. Measurement Field

The field experiment was conducted over 3 maize seasons (2016–2018) on the experimental farm of the agro-meteorological station (32.16° N, 118.86° E, Figure 1), which is located in Nanjing, Jiangsu province, China. The region is characterized by a subtropical monsoon humid climate. With obvious seasonal variation of precipitation, it has an average annual rainfall of 1102 mm of which most is received in summer. Characterized with 4 distinctive seasons, it is hot and rainy in summer, and mild and humid in winter. The annual average relative humidity is 76%, and the annual average temperature is 15.4 °C. More than 200 days in the whole year are frost-free.



Figure 1. Location of experimental farm in Nanjing, Jiangsu province of China.

The experimental soil was "Magan soil" (mainly distributed in the Jianghuai hilly area and the south bank of the Yangtze River in Jiangsu province, China) [26], which belongs to anthropo-hydrogenic paddy soil. The plough layer is loam clay, which has a clay content of 26.1%, soil bulk density of 1.57 g/cm<sup>3</sup> and a soil pH (H<sub>2</sub>O) value of 6.3. The total carbon and nitrogen contents are 19.95 g/kg and 1.19 g/kg, respectively, and the maize variety was "Jundan 66". Basic soil characteristics and parameters of the experimental site are shown in Table 1, where it can be seen that all of the characteristics of the soil increased layer-by-layer, but DUL, LL15 and SAT of the soil from the ground surface to the depth of 40 cm have little changes among the 4 soil layers. However, the Airdry changed a lot with the soil layers varied (Table 1).

Soil Depth (cm)	Air Dry (mm/mm)	DUL (mm/mm)	LL15 (mm/mm)	SAT (mm/mm)
0~5	0.038	0.221	0/119	0.300
5~15	0.136	0.250	0.136	0.300
15~25	0.150	0.268	0.160	0.322
25~40	0.158	0.274	0.167	0.311

Table 1. Soil hydraulic characteristics of experimental site.

Notes: Air dry: air dry for each soil layer; DUL: drainage upper limit (0.33 bar) for each soil layer; LL15: lower limit (15 bar) for each soil layer; SAT: saturation (0 bar) for each soil layer.

#### 2.2. Measurements and Variations of Meteorological Factors in Maize Growing Periods

The meteorological data required for 2016–2018 (daily maximum temperature, minimum temperature, precipitation and sunshine hours) were determined by the automatic meteorograph HOBO U30-NCR (Bourne, Onset, MA, USA). The parameters of corn, soil and field management during the crop growth period were derived from the field observations.

The detailed incoming radiation ( $R_n$ ), maximum temperature/low temperature, rainfall, wind speed (at 2 m height above the land surface) and relative humidity (RH) in the whole corn growth period are shown in Figure 2a–c, respectively. It is worth noting that as a source of energy for crop evapotranspiration [16], the  $R_n$  has the highest correlation coefficient to transpiration among all of the related factors [27]. As shown in Figure 2a, the radiation was relatively large and its value fluctuated obviously during the whole

3 growth periods, with the highest value of  $26.82 \text{ MJ/m}^2/d$  on 15 June 2018, and the lowest value of  $1.96 \text{ MJ/m}^2/\text{d}$  on 15 September 2016. In addition, the values on sunny days were larger than those of rainy weather. Meanwhile, the wind speed was basically stable and relatively small during the 3 growth periods, values of it were generally below 1.5 m/s, but its maximum value reached 2.4 m/s, which appeared on 26 August 2016. As can be seen from Figure 2b, during the 3 growth periods, the daily maximum temperature had larger fluctuations annually; however, the daily minimum temperature had larger fluctuations in 2016, and smaller fluctuations in 2017 and 2018. The lowest value was 5.08 °C, which appeared on 21 June 2016, and the highest was 30.12 °C, which appeared on 28 July 2017. In terms of the whole 3 growth periods, the diurnal temperature range in 2016 was relatively larger than that of the other years. As we can see from Figure 2c, the total rainfall in 2016 was less and concentrated in the final days of June and early days of July, and the concentrating period of precipitation in 2017 and 2018 was August. The maximum rainfall reached 182.4 on 15 August 2018, and the secondary peak appeared with a value of 82.7 on 11 July 2018. It can be seen that the annual variation of *RH* had little change, but its diurnal variation was very large and fluctuated greatly with a highest value of 99.7% and a lowest level of 47.1% during the 3 years. The fluctuation of RH was related to the fluctuation of rainfall and radiation. When the rainfall was large at the beginning and the radiation was low, the relative humidity was relatively large accordingly. Whereas at the end of August and the beginning of September in 2016, the precipitation was basically zero, so the relative humidity was relatively low.

#### 2.3. APSIM Model

Developed by the Australian Agricultural Production Systems Research Group (AP-SRU), the APSIM (Agricultural Production System Simulator) is an agricultural model to simulate biophysical processes in complex agricultural production systems. In a narrow sense, it is just a mechanism model of systematic agricultural farming. However, a generalized APSIM can simulate systematic processes comprising soil, crop, tree, pasture, grassland and livestock. Being flexible to integrate non-biophysical agricultural resources, such as water storages and agricultural machinery [28], it also contains a series of interconnected biophysical and management models that are used together in simulation analyses. Currently APSIMs have been used in many respects, including horticultural crop system simulation, resource application and its efficiency assessment, climate change and adaptability analysis and analysis of yield variance [29].

The major functional modules can be divided into program management, environment, biology and economy. The management module includes judgment, management and reporting. Some environmental modules include illumination, soil moisture and soil nitrogen. The biological module includes various crops, grasslands and surface residues. All of these modules are interconnected through the "central engine". Any module can be "plugged in, unplugged". Among them, the soil module in the environmental module is the core of the APSIM crop model. The Ritchie model is for soil evaporation simulation and the Penman-Monteith water demand is for potential transpiration calculation.



**Figure 2.** Radiation and wind speed (**a**), maximum/low temperatures (**b**), rain and relative humidity (*RH*) (**c**) during maize growth during 2016–2018.

#### 2.3.1. Es Model in APSIM

Applied to calculate *Es* in the APSIM, the Ritchie model divides the process of evaporation into two stages [30]. The evaporation rate of stage 1 equals the rate of potential evaporation until a specified amount of water has evaporated (*U* or *CONA*, the upper limit of evaporate rate in stage 1 cumulative evaporation). The evaporation of soil in stage 2 is a function, which is proportional to the square root of time, and its rate is lower than the rate of potential evaporation. The formulas for stage 1 and 2 are as follows:

$$\sum E_{s1} = \sum_{t=0}^{t_1} E_{s0} = U, \ t < t_1 \tag{1}$$

$$\sum E_{s2} = \alpha \sqrt{(t-t_1)}, \ t > t_1 \tag{2}$$

$$E_{so} = [\Delta/(2.45(\Delta+\gamma))]R_{ns}$$
(3)

$$R_{ns} = R_{no}e^{-0.4Lai} \tag{4}$$

$$R_{no} = R_s (1 - \epsilon) \tag{5}$$

$$\epsilon = \epsilon_s + 0.25(0.23 - \epsilon_s)Lai \tag{6}$$

where,  $\sum E_{s1}$  and  $\sum E_{s2}$  are the cumulative values of *Es* in stage 1 and 2, respectively, *t* is the total number of *Es* days after the wetting date,  $E_{s0}$  is the amount of potential soil evaporation (replaced with observed evaporation here) each day during stage 1,  $t_1$  is the total number of *Es* days in stage 1, and  $\alpha$  (mm/d<sup>0.5</sup>) is the coefficient in stage 2, and it is assumed to be a constant value for particular soil and mainly depends on soil hydraulic characteristic,  $\Delta$  (kPa/°C) is the slope of saturated water vapor pressure,  $\gamma$  (kPa/°C) is the psychrometer constant,  $R_{ns}$  (MJ/m<sup>2</sup>/d) is the average net radiation at the soil surface,  $R_{no}$  (MJ/m<sup>2</sup>/d) is the average net radiation at canopy,  $R_s$  (MJ/m<sup>2</sup>/d) is the solar radiation,  $\epsilon_s$  is the albedo for bare soil with a value of 0.1 here [31],  $\epsilon$  is the developing canopy albedo varying with Lai, which is the leaf area index. What is noteworthy is that different soils have different *U* values. According to the Ritchie experiment, *U* values of clay, loam and sandy soil are 12 mm, 9 mm and 6 mm, respectively.

#### 2.3.2. Tc Model in APSIM

Based on energy balance and water vapor diffusion, the *Tc* model in the APSIM is the Penman-Monteith water demand, which is derived from the energy balance equation of crop canopy (evapotranspiration surface). The water demand is caused by two parts: radiation-driven term (*PETr*) and aerodynamically-driven term (*PETa*). *Tc* is the sum of the *PETr* and *PETa*. Details are as follows [22,32,33]:

$$PETr = \frac{\varepsilon R_n}{1 + \varepsilon + \frac{G_a}{G_c}} \frac{1000}{\lambda \rho_{water}}$$
(7)

$$PETa = \frac{\rho_{air} DG_a}{1 + \varepsilon + \frac{G_a}{G_c}} \frac{1000N}{\rho_{water}\lambda}$$
(8)

where, *N* (*s*) is the day length,  $R_n$  (MJ/m<sup>2</sup>/d) is energy available for evapotranspiration,  $\lambda$  (J/kg) is the latent heat of vaporization,  $\rho_{air}$  and  $\rho_{water}$  (kg/m<sup>3</sup>) represent the density of air and water, *D* (kPa) is the specific vapor pressure deficit, and  $G_a$  and  $G_c$  are the (bulk) aerodynamic and surface resistances. Most of the factors can be calculated by the formulas in FAO Irrigation and Drainage Paper No. 56 [34]. In addition, this formula involves the slope of the vapor saturation-temperature curve  $\Delta$  (kPa/°C), the calculation in the model code are as follows:

$$\Delta = \frac{28.0\lambda}{29.0c_p P_{air}} \frac{de_{sat}(T)}{dT}$$
(9)

$$\frac{de_{sat}(T)}{dT} = \frac{4098.2e_{sat}(T)}{\left(T + T_{abc}\right)^2} \tag{10}$$

$$e_{sat}(T) = 6.106 \exp(\frac{17.27T}{T + 237.3})$$
(11)

where,  $c_p$  (J/kg) is the specific heat of air at constant temperature,  $P_{air}$  is the air pressure,  $\frac{de_{sat}(T)}{dT}$  is the slope of sat. vapor pressure-temperature, *T* is the average daily temperature,  $T_{abs}$  is 273.16, and  $e_{sat}(T)$  is the saturated vapor pressure.

# 2.4. Methods for Parameters Tuning and Model Evaluation

## 2.4.1. Parameters Calibration of *Es*

As mentioned earlier, it can be validated that the accuracy of the APSIM simulated *Es* is mainly related to the *CONA* value and the  $\alpha$  value, therefore we firstly modified the two coefficients with some of the data measured before. In this study, the stage 1 constant *CONA* (11 mm) was determined from field observations of daily *E*<sub>0</sub> in the early growth periods when *E*<sub>s</sub>/*E*<sub>0</sub> remained > 0.9. As mentioned before, "Magan soil" belongs to loam clay, so it can be concluded that the CONA varies from 9 to 12, and trial and error was the first choice. The *E*<sub>0</sub> is calculated as follows [35]:

$$E_o = \left[\frac{\Delta}{\gamma}R_{no} + 0.262(1 + 0.0061u)(e_{sat} - e_a)\right] \left(\frac{\Delta}{\gamma} + 1\right)^{-1}$$
(12)

where,  $e_{sat}$  (mb) is the saturated vapor pressure at mean air temperature,  $e_a$  (mb) is the vapor pressure at mean air temperature,  $R_{no}$  (MJ/m<sup>2</sup>/d) is the average net radiation at canopy (1 mm/d is equivalent to an energy flux of 2.5 MJ/m<sup>2</sup>/d), and u (km/d) is the wind speed at a height of 2 m.

The stage 2 coefficient was calculated with Equation (2) when the stage 1 was finished in a precipitation process (from a rain occurring to another rain occurring). The  $\alpha$  (4.83 mm/d<sup>0.5</sup>) was the average slope of 4 precipitation cycles in the 2 years.

#### 2.4.2. Determination of Stemflow

Plant stemflow meters can measure the instantaneous runoff density of the plant, which can continuously observe the liquid flow of the plant for a long time, which is conducive to studying the law of water exchange between the plants and the atmosphere. Taking this as an observation means to monitor the impact of the forest ecosystem on environmental changes for a long time, as it has important theoretical guidance significance and application value for afforestation, forest management and forestry management. This study installed the packaged, stem sap flow gauge Flow32A-1K onto the maize stems, which have good growth and no damage in the middle stage of the growth. Before installation, we removed the aging leaves at the bottom of the corn, and the sensors were installed at the stem base of the corn, approximately 10 cm from the soil surface, to monitor the stemflow velocity of plants so as to test the simulation results. In order to prevent the sensors' damage by water absorption of external wrapped foam and avoid the measuring error caused by the growth of maize adventitious root, the sensors were removed after heavy rain, and installed back to the original positions after they dried.

#### 2.4.3. Methods of Model Evaluation

The performance of the crop models is often evaluated by using linear regression by least squares. However, the coefficient of determination ( $R^2$ ) alone, in general, is often inappropriate and has deficiencies when used to compare predicted and observed values. Therefore, an index of agreement (D), as well as the systematic root mean square error (RMSE<sub>s</sub>) and unsystematic error (RMSE<sub>u</sub>), were suggested to use for comparisons of model-predicted and observed variables [36–39].

$$R^{2} = \left(\frac{\sum_{i=1}^{n} (X_{i} - \overline{X}) \times (Y_{i} - \overline{Y})}{\sum_{i=1}^{n} \sqrt{(X_{i} - \overline{X})^{2}} \times \sum_{i=1}^{n} \sqrt{(Y_{i} - \overline{Y})^{2}}}\right)^{2}$$
(13)

$$D = 1 - \left[\frac{\sum_{i=1}^{n} (Y_i - X_i)^2}{\sum_{i=1}^{n} (|Y_i - \overline{X}| + |X_i - \overline{X}|)^2}\right]$$
(14)

$$RMSE_{s} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\hat{Y}_{i} - X_{i})^{2}}$$
(15)

$$RMSE_{u} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (Y_{i} - \hat{Y}_{i})^{2}}$$
(16)

where, the coefficient  $R^2$  and D, ranged from 0 to 1, represents the consistency between the simulated and measured values. The closer that the value is to 1, the higher the fitting degree is. Herein,  $X_i$  and  $Y_i$  are measured and simulated values, respectively,  $\overline{X}$  and  $\overline{Y}$  are the average of measured and simulated values, respectively,  $\hat{Y}_i$  is the regression estimate for the observation, and n is the number of observations. The smaller the RMSE value is, the better the fitting effect.

#### 3. Results

#### 3.1. Simulated and Observed Es from Maize

#### 3.1.1. Es Variation in the Maize Growth Periods

As shown in Figure 3, the simulated and observed *Es* both in 2016 and 2017 fluctuated greatly and remained at a high level in early growth periods and gradually declined with fluctuation during the late stages of growth. In addition, it was lower with a stable tendency separately during the late stages of maize development. The variation trends of the simulated *Es* both in the two years were broadly in line with the observed values. In addition, the highest simulated *Es* in 2016 was 5.74 mm/d and appeared on 26 June, and the lowest one was 0.16 mm/d, which appeared on 14 July. The highest observed *Es* in 2016 was 5.95 mm/d and occurred on 26 June, and the lowest one was 0.24 mm/d, which appeared on 14 September. In 2017, the simulated *Es* reached a peak of 4.42 mm/d on 23 June, and reached the valley value of 0.08 mm on 4 September. The observed *Es* peaked on 10 July at 3.91mm/d, and touched bottom on 21 August at 0.10 mm/d. In general, the *Es* in 2016 was higher than in 2017. It should be noted that there are some missing observed data because we did not have the means to collect data on rainy or other bad weather days, and the data collection started after maize emergence in 2017.



**Figure 3.** Comparison of APSIM simulated and field observed daily evaporation in 2016 and 2017. The observed data was obtained by weighing micro-lysimeter every day, and calculating differences between two successive days.

## 3.1.2. Comparison of Simulated and Observed Es

It can be seen that the APSIM-simulated and the field-measured values had the same trends both in the 2016 and 2017 maize growth periods. The determination coefficient  $R^2 = 0.85$  (p < 0.01), the adjusted determination coefficient  $R^2 = 0.85$  and the index of

agreement D = 0.96 (Figure 4, Table 2), which means the relationship between the simulated and the measured values reaches an extremely significant level. The RMSEs = 0.0783 mm/d, RMSEu = 0.4435 mm/d (Table 2), and the fitted slope was 0.9647 (Figure 4), which means the ratio of the simulated value to the measured value was close to 1:1 and the model had a small regression error. The variation curves of the simulated value in the two years were basically consistent with the responsive measured values, except that the simulated value was obviously higher than the measured value in August 2016 (Figure 3). The *Es* was in stage 2, and the simulated values were the potential evaporation; however, the soil moisture was not sufficient to support theoretical amounts for there was little rain during this period. Individually, the fitting degree in 2016 ( $R^2 = 0.81$ ) was better than that in 2017 ( $R^2 = 0.80$ ), and yet there was no remarkable difference between the two. However, compared with the total fitting degree, both the two fitting degrees in 2016 and 2017 were significantly lower than the total one.



**Figure 4.** The linear regression between simulated and observed evaporation values during maize growth in 2016 and 2017.

Table 2. Regression statistics for simulated versus observed *Es* and *Tc* both in 2016 and 2017.

Sub-Models	$R^2$	D	<i>p</i> -Value	RMSEs (mm/d)	RMSEu (mm/d)
Es	0.85	0.96	0.000	0.0783	0.4435
Tc	0.74	0.88	0.000	1.2261	1.4197

3.2. Simulated and Observed Tc from Maize

3.2.1. Tc Variation in the Maize Growth Periods

As shown in Figure 5, the simulated *Tc* both in 2016 and 2017 fluctuated greatly. It was lower in early growth periods, then rose rapidly and remained at a high level in middle growth periods and gradually declined with fluctuation during the late stages of growth. The installation of equipment was in the middle periods of the crop growth, and equipment should be dismantled on rainy days. However, even without enough time to disassemble the equipment on occasion, the maintenance and repair must be undertaken a long time after raining. Therefore, there was no complete observed data, but it showed that the simulated *Tc* values were basically consistent with the observed values. In 2016, the simulated *Tc* reached a peak of 12.15 mm/d on 24 July. In 2017, the highest simulated value was 13.07 mm/d and appeared on 19 July. The simulated *Tc* in 2016 was higher than in 2017 on the whole.



Figure 5. Comparison of simulated and observed crop transpiration in 2016 and 2017.

3.2.2. Comparison of Simulated and Observed Tc

From Figure 6, it can be seen that there was a correlation between the simulated and observed *Tc* values. However, the fitting degree between the simulated and observed *Tc* was not very good, which was reflected in the determination coefficient  $R^2 = 0.74$  (p < 0.001) (Figure 6). The RMSEs = 1.2261 mm/d and the RMSEu = 1.4197 mm/d (Table 2) means that the predicted ratings slightly deviated from the true ones. However, the simulated and observed *Tc* had good agreement, connoted by the index agreement D = 0.82. and the fitted slope was 0.8553 (Figure 6), all of which meant that the fitting degree between the simulated and observed *Tc* was not "high" but statistically significant. Compared with the observed *Tc*, it was shown that the trends of fluctuation in the two growth periods of 2016 and 2017 were basically consistent (Figure 6). The fluctuation frequencies of the simulated *Tc* were higher than the observed.



**Figure 6.** The linear regression between simulated and observed transpiration values during partial maize growth in 2016 and 2017.

#### 4. Discussions

As global warming has intensified, the contradiction between the water supply and demand has become increasingly obvious. Accurate predictions of *Es* and *Tc* have become increasingly important, since both of them are of great importance in water balance calculation. The APSIM water balance model can simulate the *Es* and presented good adaptability in Nanjing area, the same as in Southwestern, Ningxia, Gansu and Northeast of China [24,36,40,41]. However, different areas have different fitting degrees. Ma et al. [42] showed that the simulated and measured soil moisture content have a significant positive correlation (the value of  $R^2$  was between 0.959~0.973). Li et al. [43] showed that

the relationship was found between predicted and observed soil storage water (R > 0.7) with a variation of  $\pm 20\%$ . As inferred, the method of model parameter optimization and experimental observations in different tests are different, which could affect the results and fitting degrees. The validation water balance process of the APSIM model gives a convenient method to simulate the *Es* and *Tc* by crop growing models. After calibrating the parameters needed in the simulation, the water consumption of the maize field would be predicted under both climate change and crop growth variation. Moreover, the APSIM helps simulate the production of the maize field.

The simulation of Tc in the APSIM uses the Penman-Monteith water demand. With improved Penman-Monteith, most researchers showed good fitting results. Lu (2008) showed that the error between the simulated and the measured Tc was -1.2% [44], and Gao et al. [45] showed that the simulated and the observed values fit well ( $R^2 = 0.70$ ). Moreover, Li et al. and Yan et al. [46,47] demonstrated that the simulated and measured values of Tc had good agreement. In similarity with the above, the result of the simulated Tc in this paper was also good ( $R^2 = 0.74$ ). The reason may be the APSIM model separated ET into *Es* and *Tc*, which improves the *Es* and *Tc* simulation, respectively. In addition, it is worthless that there are not unified standards for the calculation of some parameters needed in the Penman-Monteith. Different formulas for parameters calculation may influence the estimation values. As well, the Penman-Monteith neglected the energy consumption of inner dissipation and photosynthesis and did not take the airflow exchange and the atmospheric stratification into account [32]. Moreover, the Penman-Monteith water demand in the APSIM amplifies the effects of the VPD (vapor pressure deficit), which may lead to errors. Therefore, the applicability of the Penman-Monteith model and the method of parameters determination are still controversial [48].

## 5. Conclusions

In order to evaluate the performance and the adaptability of evaporation and transpiration simulating by the APSIM in a humid area in Nanjing, China, this paper compares two simulations of *Es* and *Tc* by APSIM with the measured *Es* and *Tc*. Analysis over the study area revealed that the systematic root mean square error RMSEs and unsystematic root mean square error RMSEu of Es were 0.08 and 0.44 mm/d, respectively. The determination coefficient  $R^2$  and adjusted  $R^2$  was 0.85, (p < 0.001) and the index agreement D was 0.96, which connoted that the correlation degree reached a significant level. Based on the results, it was concluded that the calibrated Ritchie model in the APSIM can simulate the Es during maize growth periods in Nanjing. From the results that the RMSEs and RMSEu were 1.22 and 1.42 mm/d, respectively, the  $R^2$  was 0.74 and the index agreement D was 0.88 in the simulation of *Tc*, it can be concluded that compared with the *Es* simulation, the *Tc* simulation error of the APSIM should be further reduced and the performance of the model should be further improved in Nanjing. However, it also has a good agreement with the observed values. The results of this project may be beneficial to further research on field moisture. Both of the *Es* and *Tc* simulations can provide a reference for water-saving irrigation.

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