Supplementary Material

2.3.2 Calculation of the actual evaporation transpiration ET_a'

Combining the actual growth of rice (plant height, leaf area, etc.) and the actual meteorological data of the experimental station, the modified Penman Monteith (PM) formula [1] is used to calculate the actual evaporation transpiration ET_a' of rice. the equations are as follows:

$$ET_a' = \frac{\Delta(R_n - G) + \rho_a c_p (e_s - e_a)/r_a}{\left[\Delta + \gamma(1 + \frac{r_s}{r_a})\right]\lambda} \tag{S-1}$$

Where, ET_a' are the actual evaporation transpiration of rice，mm d^{-1};

Δ are the slope of the air pressure curve of saturated water，kPa °C^{-1};

R_n are the net radiation from the crop surface，MJ m^{-2} d^{-1};

G are the soil heat flux, when the day is the time step, can be ignored，MJ m^{-2} d^{-1};

γ are the dry wet table constant，kPa °C^{-1};

$e_s - e_a$ are the difference between saturated vapor pressure and actual vapor pressure，kPa;

ρ_a are the average air density，kg m^{-3};

c_p are the specific heat of air，1.013×10^{-3}，MJ kg^{-1}°C^{-1};

r_a are the aerodynamic impedance，s m^{-1};

r_s are the surface impedance，s m^{-1};

λ are the enthalpy of vaporization，MJ kg^{-1}.

The calculation process is as follows:

Step（1） Δ

$$\Delta = \frac{4098 \times [0.6108 \times \exp(\frac{17.27T}{T + 237.3})]}{(T + 237.3)^2} \tag{S-2}$$

Δ are the slope of the saturation water pressure at air temperature, kPa °C^{-1}. Note: In this paper, daily mean temperature is selected, ℃.

Step（2） γ

$$\gamma = \frac{C_p P}{\varepsilon\lambda} = \frac{0.00163P}{\lambda}$$

(S-3)

$$\lambda = 2.501 - 2.361 \times 10^{-3} T$$

(S-4)

Where, C_p are air pressure specific heat, 1.013×10^{-3} MJ kg^{-1}°C^{-1}；ε are the specific gravity of water vapor and dry air molecules, 0.622；λ are the latent heat for vaporization, MJ kg^{-1}；P are atmospheric pressure, kPa，the measured values of photosynthetic apparatus were used in this study.

Step（3） ρ_a

$$\rho_a = 1.293 \cdot \left(\frac{P}{101.3}\right) \cdot \frac{273.16}{273.16 + T}$$

(S-5)

Step（4） R_n

$$R_n = R_{ns} - R_{nl} \quad \text{(S-6)}$$

$$R_{ns} = (1-\alpha) R_s \quad \text{(S-7)}$$

$$R_{nl} = \sigma \left[\frac{T_{max,K}^4 + T_{min,K}^4}{2} \right] \left(0.34 - 0.14\sqrt{e_a}\right) \left(1.35 \frac{R_s}{R_{so}} - 0.35\right) \quad \text{(S-8)}$$

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \quad \text{(S-9)}$$

$$N = \frac{24}{\pi} w_s \quad \text{(S-10)}$$

$$w_s = arccos\left[-tan(\varphi) tan(\delta)\right] \quad \text{(S-11)}$$

$$\delta = 0.408\, sin\left(\frac{2\pi}{365} J - 1.39\right) \quad \text{(S-12)}$$

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r \left[w_s\, sin(\varphi) sin(\delta) + cos(\varphi) cos(\delta) sin(w_s) \right] \quad \text{(S-13)}$$

$$d_r = 1 + 0.033\, cos\left(\frac{2\pi}{365} J\right) \quad \text{(S-14)}$$

$$T_{max,K} = T_{max} + 273.16 \quad \text{(S-15)}$$

$$T_{min,K} = T_{min} + 273.16 \quad \text{(S-16)}$$

$$e_s = \frac{e(T_{max}) + e(T_{min})}{2} \tag{S-17}$$

$$e(T) = 0.6108 \times \exp\left(\frac{17.27T}{T + 237.3}\right) \tag{S-18}$$

$$R_{so} = (a_s + b_s) R_a \tag{S-19}$$

Where, R_{ns} are the net short-wave radiation, MJ m^{-2} d^{-1}; R_{nl} are the net long wave radiation, MJ m^{-2} d^{-1}; σ are the Stephen-Ludwig Boltzmann constant, 4.903×10^{-9} MK K^{-4} m^{-2} d^{-1}; α are the reflectivity. According to Yang Changming et al. [2], 0.175 for jointing heading stage and 0.168 for filling maturity stage were selected for reflectivity; $T_{max,K}$ and $T_{min,K}$ are the highest and lowest absolute temperatures, respectively, K; T_{max} and T_{min} are the lowest and highest temperatures respectively, ℃, e_a are actual water vapor pressure, kPa; R_s are the solar radiation, MJ m^{-2} d^{-1}; R_a are radiation outside the earth, MJ m^{-2} d^{-1}; a_s 、b_s are the regression coefficient, $a_s = 0.25$ 、$b_s = 0.50$; n and N are the actual sunshine hours and the theoretical possible sunshine hours, h; d_r are the average distance between the earth and the Sun; J are daily order, the values range from 1 to 365 or 366, and the order of January 1st is 1; φ are latitude, rad; w_s are the angle of sunrise, rad; δ is the magnetic declination of the sun rad; G_{sc} is the solar constant, 0.0820 MJ m^{-2} min^{-1}.

Step（5） r_a

$$r_a = \frac{\ln\left[\frac{z_m - d}{z_{om}}\right] \ln\left[\frac{z_h - d}{z_{oh}}\right]}{k^2 u_z} \tag{S-20}$$

$$d = 2/3H \tag{S-21}$$

$$z_{om} = 0.123H \tag{S-22}$$

$$z_{oh} = 0.1z_{om} \tag{S-23}$$

$$r_s = \frac{r_l}{0.5LAI} \tag{S-24}$$

Where, H are the plant height, m (see table S-1), at waterlogging stress stage, the plant height is the height above the water surface; z_m are wind speed measurement, this study was 2 m; z_{om} are the length of roughness that controls momentum transfer, m; z_h is the measure height for humidity, this study was 1.5 m; z_{oh} is the coarse length that controls the transfer of heat and water vapor, m; u_z are the measured wind speed, m s^{-1}; k is the von Kaman constant, 0.41; d is the zero plane displacement height, m; r_l are the stomatal resistance that fully irradiates the blade, s m^{-1}; LAI are leaf area index (see table S -2) , at stage waterlogging , LAI are the leaf area index above the water surface.

Step (6) T_a'

ET'_a actually includes crop leaf transpiration strength T_a' and tree evaporation E_s, where es can be calculated by the following as Ritchie [3].

$$T_a' = ET'_a - E_s \tag{S-25}$$

$$E_s = \begin{cases} ET'_a \times (1 - 0.43 \times LAI) & LAI \leq 1 \\ ET'_a \times \exp(-0.4 \times LAI)/1.1 & LAI > 1 \end{cases} \tag{S-26}$$

Where E_s is the evaporation between plants, mm d^{-1}, and mmd-1; LAI is the leaf area index of rice.

Figure S1

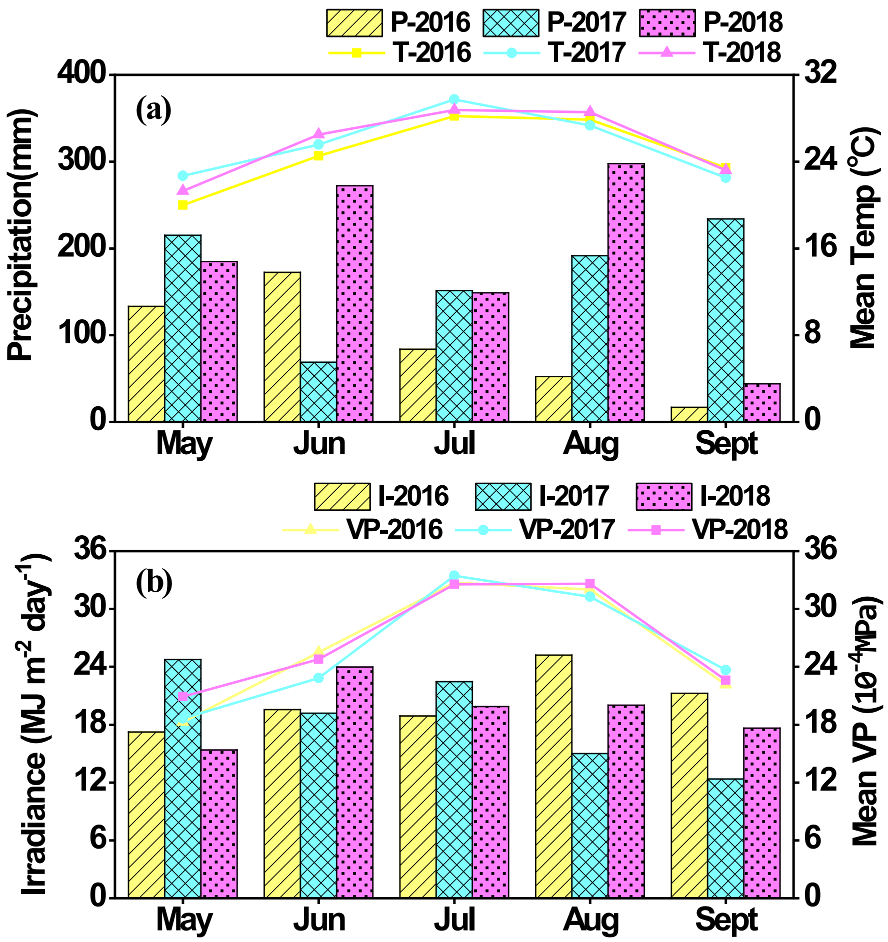

Figure S1. (a) Monthly precipitation (P) and mean air temperature (T), (b) irradiance (I) and mean vapor pressure (VP) at the Xinmaqiao Comprehensive Experiment Station of Irrigation and Drainage, Bengbu, China (117°21′34″E, 33°08′56″N) during the rice growing season (May to September) in 2016–2018.

Table S1 The fitting formula of rice plant height (H) with time in 2016–2018 under different treatments.

2016	The fitting formula	R^2	2017	The fitting formula	R^2	2018	The fitting formula	R^2
Normal Control	H=58.193ln(t)-108.81	0.9686	Normal Control	H=57.655ln(t)-114.01	0.9434	Normal Control	H=56.199ln(t)-111.70	0.9915
RSDW1	H=46.065ln(t)-71.44	0.9671	RSDW4	H=54.012ln(t)-99.02	0.9736	RSDW7	H=58.326ln(t)-112.26	0.9313
SD1	H=38.231ln(t)-48.22	0.8729	SD4	H=58.870ln(t)-117.76	0.9472	SD7	H=48.200ln(t)-76.266	0.9021
SW1	H=59.206ln(t)-114.78	0.9843	SW4	H=64.087ln(t)-136.03	0.9191	sw7	H=56.894ln(t)-104.01	0.9716
RSDW2	H=37.477ln(t)-44.99	0.9398	RSDW5	H=44.418ln(t)-69.10	0.9423	RSDW8	H=50.825ln(t)-83.091	0.9218
SD2	H=38.746ln(t)-47.46	0.9336	SD5	H=59.419ln(t)-119.99	0.9827	SD8	H=51.391ln(t)-91.456	0.9297
SW2	H=55.160ln(t)-99.29	0.9689	SW5	H=63.454ln(t)-134.03	0.9262	SW8	H=59.171ln(t)-114.67	0.9835
RSDW3	H=31.762ln(t)-23.33	0.9154	RSDW 6	H=57.055ln(t)-113.47	0.9850	RSDW9	H=53.337ln(t)-93.134	0.9541
SD3	H=31.252ln(t)-20.83	0.8955	SD6	H=55.095ln(t)-103.44	0.9364	SD9	H=39.833ln(t)-51.42	0.8822
SW3	H=56.384ln(t)-104.48	0.9570	SW6	H=65.356ln(t)-140.47	0.9160	SW9	H=60.053ln(t)-110.43	0.9699

Note: H is the plant height of rice cm; t are the days after transplantation, d. RSDW represents the rapid shift between drought and waterlogging treatment groups, SD for the single drought treatment group, SW for the single waterlogging treatment group, and Control for the normal moisture treatment group.

Table S2 The fitting formula of rice leaf area index (LAI) with time in 2016–2018 under different treatments.

2016	The LAI fitting formula	R2	2017	The LAI fitting formula	R2	2018	The LAI fitting formula	R2
Normal Control	LAI=-0.0037t2+0.4187t-6.0076	0.9828	Normal Control	LAI=-0.0028t2+0.3285t-3.8217	0.8948	Normal Control	LAI=-0.0026t2+0.3102t-3.4305	0.9599
RSDW1	LAI=-0.0041t2+0.4409t-6.7326	0.7212	RSDW4	LAI=-0.0027t2+0.3304t-4.2093	0.9044	RSDW7	LAI=-0.0036t2+0.4181t-5.9090	0.7821
SD1	LAI=-0.0030t2+0.3444t-4.7470	0.7810	SD4	LAI=-0.0027t2+0.3270t-4.0467	0.9313	SD7	LAI=-0.0020t2+0.2584t-2.6140	0.9277
SW1	LAI=-0.0036t2+0.3739t-4.6400	0.8274	SW4	LAI=-0.0033t2+0.3916t-5.4764	0.9856	sw7	LAI=-0.0036t2+0.4036t-5.4012	0.9793
RSDW2	LAI=-0.0024t2+0.2973t-3.8875	0.8038	RSDW5	LAI=-0.0025t2+0.2987t-3.4676	0.9342	RSDW8	LAI=-0.0024t2+0.3131t-4.1129	0.7411
SD2	LAI=-0.0023t2+0.2740t-3.1797	0.8577	SD5	LAI=-0.0031t2+0.3557t-4.7202	0.9294	SD8	LAI=-0.0031t2+0.3667t-5.0485	0.7756
SW2	LAI=-0.0024t2+0.3048t-3.7047	0.9711	SW5	LAI=-0.0033t2+0.4064t-6.0147	0.9527	SW8	LAI=-0.0027t2+0.3191t-3.6580	0.9269
RSDW3	LAI=-0.0022t2+0.2637t-2.9038	0.7818	RSDW 6	LAI=-0.0025t2+0.3018t-3.6761	0.8536	RSDW9	LAI=-0.0017t2+0.2266t-2.3169	0.8351
SD3	LAI=-0.0028t2+0.3189t-4.1789	0.8352	SD6	LAI=-0.0028t2+0.3259t-4.0905	0.9186	SD9	LAI=-0.0023t2+0.2963t-3.8341	0.8164
SW3	LAI=-0.0020t2+0.2697t-2.9464	0.9611	SW6	LAI=-0.0041t2+0.4675t-7.0892	0.9603	SW9	LAI=-0.0023t2+0.2977t-3.4052	0.9887

Note: LAI is the leaf area index of rice cm; t are the days after transplantation, d. RSDW represents the rapid shift between drought and waterlogging treatment groups, SD for the single drought treatment group, SW for the single waterlogging treatment group, and Control for the normal moisture treatment group.

References

[1] Allan R G , Pereira L S , Raes D ,et al.Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56[J].Fao, 1998.DOI:doi:http://dx.doi.org/.

[2] Changming Y , Linzhang Y , Chao-Ling W ,et al.Canopy spectral characteristics of different rice varieties[J].Chinese Journal of Applied Ecology, 2002.

[3] Ritches J T. Specification of the ideal model for predicting crop yields. In: R.C. Muchow and J.A. Bellamy (Eds). Climatic risk in crop production: model and management for semiarid tropics subtropics. CAB international, Wallinford [J]. 1991.