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Supplementary information

Processing tomato production is expected to decrease by 2050 due to the projected increase in temperature

In the format provided by the authors and unedited

We applied the non-parametric Mann-Kendall test[1,2,3] to detect the monotonic trend of yield changes in future climate scenarios. A monotonic trend refers to a statistically consistent upward or downward trend (linear or non-linear) of a variable over time. The Man-Kendall test first determines the sign of the difference between each data point of a time series (x) at timestep (i) to the rest of data points measured at later timesteps ($x_j \; where \; j > i$):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \quad \& \quad sgn(x_j - x_i) = \begin{cases} +1 & if \; x_j - x_i > 0 \\ 0 & if \; x_j - x_i = 0 \\ -1 & if \; x_j - x_i < 0 \end{cases}$$

where n is the number of data points, and sgn is the sign function. The method then computes the variance of S as:

$$Var(s) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p-1}^{g} t_p(t_p - 1)(2t_p + 5)\right]$$

where g is the number of tied groups (i.e., group of equals values) and t_p is the number of observations in the p^{th} group. The method then computes the test statistic as:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(s)}} & if \; S > 0 \\ 0 & if \; S = 0 \\ \dfrac{S+1}{\sqrt{Var(s)}} & if \; S < 0 \end{cases}$$

A positive (negative) Z value signifies that the data trend increases (decreases) monotonically. For all trend evaluations, we considered a significance level of α = 0.05. Additionally, we employed the Thiel-Sen estimator method to quantify the magnitude of yield change. Thiel-Sen estimator is a non-parametric approach that applies the following equation to quantify the slope (β) in a time series:

$$\beta = median\left(\frac{x_j - x_i}{j - i}\right), j > i$$

We applied the Man-Kendal test to statistically assess the trends in yield and temperature changes during future scenarios (i.e., 2010-2100) and used Thiel-Sen estimator to quantify the magnitudes of the changes. These statistical approaches were applied spatially to consider both temporal and spatial changes in tomatoes yield.

Supplemental Table 1. Crop coefficients calibrated using field experiment data. Foggia is missing because the results are published and publicly available from another study[4].

Locations	EM-FL	SD-PM	FL-LF	LFMAX	SLAVR	SIZLF	XFRT	WTPSD	SFDUR	SDPDV	PODUR	THRSH	TRIFL
California	37	29	25	2.9	400	400	0.85	0.004	26	300	55	8.5	0.95
Inner Mongolia + Gansu	30	50	52	1.36	290	100	1.9	0.008	25	300	59	9.5	0.45
Emilia	67	25	17	1.96	500	400	1.1	0.008	30	400	50	8.5	0.45
Xinjiang	30	45	52	1.36	290	100	1.9	0.008	25	300	59	9.5	0.45

TRILF: Rate of appearance of leaves on the mainstem (leaves per thermal day)

EM-FL: Time between plant emergence and flower appearance (R1)

SD-PM: Time between first seed (R5) and end of leaf expansion (photothermal days)

FL-LF: Time between first flower (R1) and end of leaf expansion (photothermal days)

LFMAX: Maximum leaf photosynthesis rate at 30 C, 350 vpm CO2, and high light (mg CO2/m2-s)

SLAVR: Specific leaf area of cultivar under standard growth conditions (cm2/g)

SIZLF: Maximum size of full leaf (three leaflets) (cm2)

XFRT: Maximum fraction of daily growth that is partitioned to seed + shell

WTPSD: Maximum weight per seed (g)

SFDUR: Seed filling duration for pod cohort at standard growth conditions (photothermal days)

SDPDV: Average seed per pod under standard growing conditions (#/pod)

PODUR: Time required for cultivar to reach final pod load under optimal conditions (photothermal days)

THRSH: Threshing percentage. The maximum ratio of (seed/(seed+shell)) at maturity. Causes seed to stop growing as their dry weight increases until the shells are filled in a cohort.

Supplemental Table 2. Bias-adjusted[5] climate models used in this study. Equilibrium climate sensitivity (ECS) represents the global surface air temperature increase in an equilibrium state after doubling pre-industrial atmospheric carbon dioxide concentrations [CO2]. Transient climate response (TCR) represents the global surface air temperature warming by the time pre-industrial [CO2] is reached under a scenario in which there is a 1% per year increase in [CO2][6].

Global Climate Model	**Equilibrium Climate Sensitivity (℃)**	**Transient Climate Response (℃)**
1. GFDL-ESM4	2.6	1.6
2. IPSL-CM6A-LR	4.6	2.3
3. MPI-ESM1-2-HR	3.0	1.7
4. MRI-ESM2-0	3.2	1.6
5. UKESM1-0	5.3	2.8

Supplemental Table 3. statistical details of the Man-Kendall test and Thein-Slope estimator for the U.S. (California) considering each model and future scenario

GCM	Scenario	Mean air temperature					Yield					Yield vs. mean air temperature				
		P_{value}	Z*	Ƭ**	Slope***	trend	P_{value}	Z	Ƭ	slope	trend	P_{value}	Z	Ƭ	slope	trend
GCM1	SSP1-2.6	**0.137**	**-1.490**	**-0.090**	**-0.006**	**no trend**	**0.14**	**-1.49**	**-0.090**	**-0.006**	**no trend**	**0.14**	**-1.49**	**-0.090**	**-0.006**	**no trend**
	SSP3-7.0	**0.011**	**-2.530**	**-0.160**	**-0.013**	**decreasing**	**0.01**	**-2.53**	**-0.160**	**-0.013**	**decreasing**	**0.01**	**-2.53**	**-0.160**	**-0.013**	**decreasing**
	SSP5-8.5	**< 0.001**	**-3.770**	**-0.230**	**-0.019**	**decreasing**	**< 0.001**	**-3.77**	**-0.230**	**-0.019**	**decreasing**	**< 0.001**	**-3.77**	**-0.230**	**-0.019**	**decreasing**
GCM2	SSP1-2.6	**0.010**	**-2.580**	**-0.160**	**-0.009**	**decreasing**	**0.01**	**-2.58**	**-0.160**	**-0.009**	**decreasing**	**0.01**	**-2.58**	**-0.160**	**-0.009**	**decreasing**
	SSP3-7.0	**< 0.001**	**-6.420**	**-0.400**	**-0.028**	**decreasing**	**< 0.001**	**-6.42**	**-0.400**	**-0.028**	**decreasing**	**< 0.001**	**-6.42**	**-0.400**	**-0.028**	**decreasing**
	SSP5-8.5	**< 0.001**	**-7.680**	**-0.470**	**-0.048**	**decreasing**	**< 0.001**	**-7.68**	**-0.470**	**-0.048**	**decreasing**	**< 0.001**	**-7.68**	**-0.470**	**-0.048**	**decreasing**
GCM3	SSP1-2.6	**0.194**	**-1.300**	**-0.080**	**-0.005**	**no trend**	**0.19**	**-1.30**	**-0.080**	**-0.005**	**no trend**	**0.19**	**-1.30**	**-0.080**	**-0.005**	**no trend**
	SSP3-7.0	**0.254**	**-1.140**	**-0.070**	**-0.005**	**no trend**	**0.25**	**-1.14**	**-0.070**	**-0.005**	**no trend**	**0.25**	**-1.14**	**-0.070**	**-0.005**	**no trend**
	SSP5-8.5	**< 0.001**	**-5.220**	**-0.320**	**-0.030**	**decreasing**	**< 0.001**	**-5.22**	**-0.320**	**-0.030**	**decreasing**	**< 0.001**	**-5.22**	**-0.320**	**-0.03**	**decreasing**
GCM4	SSP1-2.6	**0.548**	**-0.600**	**-0.040**	**-0.002**	**no trend**	**0.55**	**-0.60**	**-0.040**	**-0.002**	**no trend**	**0.55**	**-0.60**	**-0.040**	**-0.002**	**no trend**
	SSP3-7.0	**0.006**	**-2.770**	**-0.170**	**-0.014**	**decreasing**	**0.01**	**-2.77**	**-0.170**	**-0.014**	**decreasing**	**0.01**	**-2.77**	**-0.170**	**-0.014**	**decreasing**
	SSP5-8.5	**< 0.001**	**-4.050**	**-0.250**	**-0.021**	**decreasing**	**< 0.001**	**-4.05**	**-0.250**	**-0.021**	**decreasing**	**< 0.001**	**-4.05**	**-0.250**	**-0.021**	**decreasing**
GCM5	SSP1-2.6	**< 0.001**	**-6.130**	**-0.380**	**-0.030**	**decreasing**	**< 0.001**	**-6.13**	**-0.380**	**-0.03**	**decreasing**	**< 0.001**	**-6.13**	**-0.380**	**-0.03**	**decreasing**
	SSP3-7.0	**< 0.001**	**-10.700**	**-0.660**	**-0.068**	**decreasing**	**< 0.001**	**-10.70**	**-0.660**	**-0.068**	**decreasing**	**< 0.001**	**-10.70**	**-0.660**	**-0.068**	**decreasing**
	SSP5-8.5	**< 0.001**	**-10.570**	**-0.650**	**-0.075**	**decreasing**	**< 0.001**	**-10.57**	**-0.650**	**-0.075**	**decreasing**	**< 0.001**	**-10.57**	**-0.650**	**-0.075**	**decreasing**

* Z represents the Man-Kendall test statistic result

** Ƭ is the rank correlation coefficient that shows the monotony of the slope

*** The unit for the mean temperature slope is (^{o}C/year), yield is (t DM/ha/year), and yield vs. mean air temperature is (t DM/ha/^{o}C)

Supplemental Table 4. statistical details of the Man-Kendall test and Thein-Slope estimator for Italy (Emilia) considering each model and future scenario

GCM	Scenario	Mean air temperature					Yield					Yield vs. mean air temperature				
		P_{value}	Z*	Ƭ**	Slope***	trend	P_{value}	Z	Ƭ	slope	trend	P_{value}	Z	Ƭ	slope	trend
GCM1	SSP1-2.6	**0.991**	**0.010**	**0.001**	**0.001**	**no trend**	**0.99**	**0.01**	**0.001**	**0.001**	**no trend**	**0.99**	**0.01**	**0.001**	**0.001**	**no trend**
	SSP3-7.0	**< 0.001**	**-3.290**	**-0.200**	**-0.013**	**decreasing**	**< 0.001**	**-3.29**	**-0.200**	**-0.013**	**decreasing**	**< 0.001**	**-3.29**	**-0.200**	**-0.013**	**decreasing**
	SSP5-8.5	**< 0.001**	**-4.430**	**-0.270**	**-0.018**	**decreasing**	**< 0.001**	**-4.43**	**-0.270**	**-0.018**	**decreasing**	**< 0.001**	**-4.43**	**-0.270**	**-0.018**	**decreasing**
GCM2	SSP1-2.6	**< 0.001**	**-5.060**	**-0.310**	**-0.010**	**decreasing**	**< 0.001**	**-5.06**	**-0.310**	**-0.010**	**decreasing**	**< 0.001**	**-5.06**	**-0.310**	**-0.010**	**decreasing**
	SSP3-7.0	**< 0.001**	**-8.010**	**-0.490**	**-0.032**	**decreasing**	**< 0.001**	**-8.01**	**-0.490**	**-0.032**	**decreasing**	**< 0.001**	**-8.01**	**-0.490**	**-0.032**	**decreasing**
	SSP5-8.5	**< 0.001**	**-10.330**	**-0.640**	**-0.065**	**decreasing**	**< 0.001**	**-10.33**	**-0.640**	**-0.065**	**decreasing**	**< 0.001**	**-10.33**	**-0.640**	**-0.065**	**decreasing**
GCM3	SSP1-2.6	**0.897**	**0.130**	**0.010**	**0.000**	**no trend**	**0.90**	**0.13**	**0.010**	**0.000**	**no trend**	**0.90**	**0.13**	**0.010**	**0.001**	**no trend**
	SSP3-7.0	**< 0.001**	**-4.340**	**-0.270**	**-0.013**	**decreasing**	**< 0.001**	**-4.34**	**-0.270**	**-0.013**	**decreasing**	**< 0.001**	**-4.34**	**-0.270**	**-0.013**	**decreasing**
	SSP5-8.5	**< 0.001**	**-6.980**	**-0.430**	**-0.030**	**decreasing**	**< 0.001**	**-6.98**	**-0.430**	**-0.030**	**decreasing**	**< 0.001**	**-6.98**	**-0.430**	**-0.03**	**decreasing**
GCM4	SSP1-2.6	**0.046**	**-2.000**	**-0.120**	**-0.004**	**decreasing**	**0.05**	**-2.00**	**-0.120**	**-0.004**	**decreasing**	**0.05**	**-2.00**	**-0.120**	**-0.004**	**decreasing**
	SSP3-7.0	**0.011**	**-2.540**	**-0.160**	**-0.006**	**decreasing**	**0.01**	**-2.54**	**-0.160**	**-0.006**	**decreasing**	**0.01**	**-2.54**	**-0.160**	**-0.006**	**decreasing**
	SSP5-8.5	**< 0.001**	**-7.800**	**-0.480**	**-0.026**	**decreasing**	**< 0.001**	**-7.80**	**-0.480**	**-0.026**	**decreasing**	**< 0.001**	**-7.80**	**-0.480**	**-0.026**	**decreasing**
GCM5	SSP1-2.6	**< 0.001**	**-6.330**	**-0.390**	**-0.014**	**decreasing**	**< 0.001**	**-6.33**	**-0.390**	**-0.014**	**decreasing**	**< 0.001**	**-6.33**	**-0.390**	**-0.014**	**decreasing**
	SSP3-7.0	**< 0.001**	**-11.000**	**-0.680**	**-0.067**	**decreasing**	**< 0.001**	**-11.00**	**-0.680**	**-0.067**	**decreasing**	**< 0.001**	**-11.00**	**-0.680**	**-0.067**	**decreasing**
	SSP5-8.5	**< 0.001**	**-11.890**	**-0.730**	**-0.073**	**decreasing**	**< 0.001**	**-11.89**	**-0.730**	**-0.073**	**decreasing**	**< 0.001**	**-11.89**	**-0.730**	**-0.073**	**decreasing**

* Z represents the Man-Kendall test statistic result

** Ƭ is the rank correlation coefficient that shows the monotony of the slope

*** The unit for the mean temperature slope is (^{o}C/year), yield is (t DM/ha/year), and yield vs. mean air temperature is (t DM/ha/^{o}C)

Supplemental Table 5. statistical details of the Man-Kendall test and Thein-Slope estimator for Italy (Foggia) considering each model and future scenario

GCM	Scenario	Mean air temperature					Yield					Yield vs. mean air temperature				
		P_{value}	Z*	Ƭ**	Slope***	trend	P_{value}	Z	Ƭ	slope	trend	P_{value}	Z	Ƭ	slope	trend
GCM1	SSP1-2.6	**< 0.001**	**-3.280**	**-0.200**	**-0.005**	**decreasing**	**< 0.001**	**-3.28**	**-0.200**	**-0.005**	**decreasing**	**< 0.001**	**-3.28**	**-0.200**	**-0.005**	**decreasing**
	SSP3-7.0	**< 0.001**	**-5.670**	**-0.350**	**-0.018**	**decreasing**	**< 0.001**	**-5.67**	**-0.350**	**-0.018**	**decreasing**	**< 0.001**	**-5.67**	**-0.350**	**-0.018**	**decreasing**
	SSP5-8.5	**< 0.001**	**-5.900**	**-0.360**	**-0.028**	**decreasing**	**< 0.001**	**-5.90**	**-0.360**	**-0.028**	**decreasing**	**< 0.001**	**-5.90**	**-0.360**	**-0.028**	**decreasing**
GCM2	SSP1-2.6	**< 0.001**	**-5.320**	**-0.330**	**-0.012**	**decreasing**	**< 0.001**	**-5.32**	**-0.330**	**-0.012**	**decreasing**	**< 0.001**	**-5.32**	**-0.330**	**-0.012**	**decreasing**
	SSP3-7.0	**< 0.001**	**-9.080**	**-0.560**	**-0.046**	**decreasing**	**< 0.001**	**-9.08**	**-0.560**	**-0.046**	**decreasing**	**< 0.001**	**-9.08**	**-0.560**	**-0.046**	**decreasing**
	SSP5-8.5	**< 0.001**	**-10.420**	**-0.650**	**-0.071**	**decreasing**	**< 0.001**	**-10.42**	**-0.650**	**-0.071**	**decreasing**	**< 0.001**	**-10.42**	**-0.650**	**-0.071**	**decreasing**
GCM3	SSP1-2.6	**0.575**	**0.560**	**0.030**	**0.001**	**no trend**	**0.58**	**0.56**	**0.030**	**0.001**	**no trend**	**0.58**	**0.56**	**0.030**	**0.001**	**no trend**
	SSP3-7.0	**< 0.001**	**-4.190**	**-0.260**	**-0.015**	**decreasing**	**< 0.001**	**-4.19**	**-0.260**	**-0.015**	**decreasing**	**< 0.001**	**-4.19**	**-0.260**	**-0.015**	**decreasing**
	SSP5-8.5	**< 0.001**	**-6.630**	**-0.410**	**-0.036**	**decreasing**	**< 0.001**	**-6.63**	**-0.410**	**-0.036**	**decreasing**	**< 0.001**	**-6.63**	**-0.410**	**-0.036**	**decreasing**
GCM4	SSP1-2.6	**0.002**	**-3.130**	**-0.200**	**-0.007**	**decreasing**	**0.00**	**-3.13**	**-0.200**	**-0.007**	**decreasing**	**0.00**	**-3.13**	**-0.200**	**-0.007**	**decreasing**
	SSP3-7.0	**< 0.001**	**-6.610**	**-0.410**	**-0.037**	**decreasing**	**< 0.001**	**-6.61**	**-0.410**	**-0.037**	**decreasing**	**< 0.001**	**-6.61**	**-0.410**	**-0.037**	**decreasing**
	SSP5-8.5	**< 0.001**	**-9.240**	**-0.580**	**-0.051**	**decreasing**	**< 0.001**	**-9.24**	**-0.580**	**-0.051**	**decreasing**	**< 0.001**	**-9.24**	**-0.580**	**-0.051**	**decreasing**
GCM5	SSP1-2.6	**< 0.001**	**-6.700**	**-0.420**	**-0.016**	**decreasing**	**< 0.001**	**-6.70**	**-0.420**	**-0.016**	**decreasing**	**< 0.001**	**-6.70**	**-0.420**	**-0.016**	**decreasing**
	SSP3-7.0	**< 0.001**	**-10.380**	**-0.640**	**-0.066**	**decreasing**	**< 0.001**	**-10.38**	**-0.640**	**-0.066**	**decreasing**	**< 0.001**	**-10.38**	**-0.640**	**-0.066**	**decreasing**
	SSP5-8.5	**< 0.001**	**-11.510**	**-0.710**	**-0.073**	**decreasing**	**< 0.001**	**-11.51**	**-0.710**	**-0.073**	**decreasing**	**< 0.001**	**-11.51**	**-0.710**	**-0.073**	**decreasing**

* Z represents the Man-Kendall test statistic result

** Ƭ is the rank correlation coefficient that shows the monotony of the slope

*** The unit for the mean temperature slope is (°C/year), yield is (t DM/ha/year), and yield vs. mean air temperature is (t DM/ha/°C)

Supplemental Table 6. statistical details of the Man-Kendall test and Thein-Slope estimator for China (Gansu) considering each model and future scenario

GCM	Scenario	Mean air temperature					Yield					Yield vs. mean air temperature				
		P_{value}	Z*	Ţ**	Slope***	trend	P_{value}	Z	Ţ	slope	trend	P_{value}	Z	Ţ	slope	trend
GCM1	SSP1-2.6	**0.003**	**2.960**	**0.180**	**0.005**	**increasing**	**0.00**	**2.96**	**0.180**	**0.005**	**increasing**	**0.00**	**2.96**	**0.180**	**0.005**	**increasing**
	SSP3-7.0	**< 0.001**	**8.840**	**0.550**	**0.019**	**increasing**	**< 0.001**	**8.84**	**0.550**	**0.019**	**increasing**	**< 0.001**	**8.84**	**0.550**	**0.019**	**increasing**
	SSP5-8.5	**< 0.001**	**9.780**	**0.610**	**0.022**	**increasing**	**< 0.001**	**9.78**	**0.610**	**0.022**	**increasing**	**< 0.001**	**9.78**	**0.610**	**0.022**	**increasing**
GCM2	SSP1-2.6	**0.006**	**2.760**	**0.180**	**0.005**	**increasing**	**0.01**	**2.76**	**0.180**	**0.005**	**increasing**	**0.01**	**2.76**	**0.180**	**0.005**	**increasing**
	SSP3-7.0	**< 0.001**	**7.560**	**0.480**	**0.018**	**increasing**	**< 0.001**	**7.56**	**0.480**	**0.018**	**increasing**	**< 0.001**	**7.56**	**0.480**	**0.018**	**increasing**
	SSP5-8.5	**< 0.001**	**4.350**	**0.280**	**0.010**	**increasing**	**< 0.001**	**4.35**	**0.280**	**0.010**	**increasing**	**< 0.001**	**4.35**	**0.280**	**0.01**	**increasing**
GCM3	SSP1-2.6	**< 0.001**	**3.290**	**0.200**	**0.006**	**increasing**	**< 0.001**	**3.29**	**0.200**	**0.006**	**increasing**	**< 0.001**	**3.29**	**0.200**	**0.006**	**increasing**
	SSP3-7.0	**< 0.001**	**8.930**	**0.560**	**0.022**	**increasing**	**< 0.001**	**8.93**	**0.560**	**0.022**	**increasing**	**< 0.001**	**8.93**	**0.560**	**0.022**	**increasing**
	SSP5-8.5	**< 0.001**	**9.680**	**0.600**	**0.021**	**increasing**	**< 0.001**	**9.68**	**0.600**	**0.021**	**increasing**	**< 0.001**	**9.68**	**0.600**	**0.021**	**increasing**
GCM4	SSP1-2.6	**0.058**	**1.890**	**0.120**	**0.003**	**no trend**	**0.06**	**1.89**	**0.120**	**0.003**	**no trend**	**0.06**	**1.89**	**0.120**	**0.003**	**no trend**
	SSP3-7.0	**< 0.001**	**9.790**	**0.620**	**0.024**	**increasing**	**< 0.001**	**9.79**	**0.620**	**0.024**	**increasing**	**< 0.001**	**9.79**	**0.620**	**0.024**	**increasing**
	SSP5-8.5	**< 0.001**	**9.600**	**0.600**	**0.024**	**increasing**	**< 0.001**	**9.60**	**0.600**	**0.024**	**increasing**	**< 0.001**	**9.60**	**0.600**	**0.024**	**increasing**
GCM5	SSP1-2.6	**< 0.001**	**3.270**	**0.210**	**0.005**	**increasing**	**< 0.001**	**3.27**	**0.210**	**0.005**	**increasing**	**< 0.001**	**3.27**	**0.210**	**0.005**	**increasing**
	SSP3-7.0	**< 0.001**	**6.450**	**0.410**	**0.019**	**increasing**	**< 0.001**	**6.45**	**0.410**	**0.019**	**increasing**	**< 0.001**	**6.45**	**0.410**	**0.019**	**increasing**
	SSP5-8.5	**< 0.001**	**5.740**	**0.370**	**0.015**	**increasing**	**< 0.001**	**5.74**	**0.370**	**0.015**	**increasing**	**< 0.001**	**5.74**	**0.37**	**0.015**	**increasing**

* Z represents the Man-Kendall test statistic result

** Ţ is the rank correlation coefficient that shows the monotony of the slope

*** The unit for the mean temperature slope is (°C/year), yield is (t DM/ha/year), and yield vs. mean air temperature is (t DM/ha/°C)

Supplemental Table 7. statistical details of the Man-Kendall test and Thein-Slope estimator for China (Inner Mongolia) considering each model and future scenario

GCM	Scenario	Mean air temperature					Yield					Yield vs. mean air temperature				
		P_{value}	Z*	Ţ**	Slope***	trend	P_{value}	Z	Ţ	slope	trend	P_{value}	Z	Ţ	slope	trend
GCM1	SSP1-2.6	**< 0.001**	**4.840**	**0.300**	**0.008**	**increasing**	**< 0.001**	**4.84**	**0.300**	**0.008**	**increasing**	**< 0.001**	**4.84**	**0.300**	**0.008**	**increasing**
	SSP3-7.0	**< 0.001**	**10.100**	**0.620**	**0.025**	**increasing**	**< 0.001**	**10.10**	**0.620**	**0.025**	**increasing**	**< 0.001**	**10.10**	**0.620**	**0.025**	**increasing**
	SSP5-8.5	**< 0.001**	**10.350**	**0.640**	**0.028**	**increasing**	**< 0.001**	**10.35**	**0.640**	**0.028**	**increasing**	**< 0.001**	**10.35**	**0.640**	**0.028**	**increasing**
GCM2	SSP1-2.6	**< 0.001**	**5.010**	**0.310**	**0.008**	**increasing**	**< 0.001**	**5.01**	**0.310**	**0.008**	**increasing**	**< 0.001**	**5.01**	**0.310**	**0.008**	**increasing**
	SSP3-7.0	**< 0.001**	**8.830**	**0.550**	**0.022**	**increasing**	**< 0.001**	**8.83**	**0.550**	**0.022**	**increasing**	**< 0.001**	**8.83**	**0.550**	**0.022**	**increasing**
	SSP5-8.5	**< 0.001**	**4.770**	**0.290**	**0.016**	**increasing**	**< 0.001**	**4.77**	**0.290**	**0.016**	**increasing**	**< 0.001**	**4.77**	**0.290**	**0.016**	**increasing**
GCM3	SSP1-2.6	**< 0.001**	**4.200**	**0.260**	**0.007**	**increasing**	**< 0.001**	**4.20**	**0.260**	**0.007**	**increasing**	**< 0.001**	**4.20**	**0.260**	**0.007**	**increasing**
	SSP3-7.0	**< 0.001**	**9.800**	**0.610**	**0.025**	**increasing**	**< 0.001**	**9.80**	**0.610**	**0.025**	**increasing**	**< 0.001**	**9.80**	**0.610**	**0.025**	**increasing**
	SSP5-8.5	**< 0.001**	**10.070**	**0.620**	**0.026**	**increasing**	**< 0.001**	**10.07**	**0.620**	**0.026**	**increasing**	**< 0.001**	**10.07**	**0.620**	**0.026**	**increasing**
GCM4	SSP1-2.6	**< 0.001**	**6.020**	**0.370**	**0.010**	**increasing**	**< 0.001**	**6.02**	**0.370**	**0.010**	**increasing**	**< 0.001**	**6.02**	**0.370**	**0.01**	**increasing**
	SSP3-7.0	**< 0.001**	**11.440**	**0.710**	**0.027**	**increasing**	**< 0.001**	**11.44**	**0.710**	**0.027**	**increasing**	**< 0.001**	**11.44**	**0.710**	**0.027**	**increasing**
	SSP5-8.5	**< 0.001**	**8.950**	**0.550**	**0.023**	**increasing**	**< 0.001**	**8.95**	**0.550**	**0.023**	**increasing**	**< 0.001**	**8.95**	**0.550**	**0.023**	**increasing**
GCM5	SSP1-2.6	**< 0.001**	**6.900**	**0.430**	**0.011**	**increasing**	**< 0.001**	**6.90**	**0.430**	**0.011**	**increasing**	**< 0.001**	**6.90**	**0.430**	**0.011**	**increasing**
	SSP3-7.0	**< 0.001**	**5.510**	**0.340**	**0.015**	**increasing**	**< 0.001**	**5.51**	**0.340**	**0.015**	**increasing**	**< 0.001**	**5.51**	**0.340**	**0.015**	**increasing**
	SSP5-8.5	**0.007**	**2.680**	**0.170**	**0.010**	**increasing**	**0.01**	**2.68**	**0.170**	**0.01**	**increasing**	**0.01**	**2.68**	**0.170**	**0.01**	**increasing**

* Z represents the Man-Kendall test statistic result

** Ţ is the rank correlation coefficient that shows the monotony of the slope

*** The unit for the mean temperature slope is (^{o}C/year), yield is (t DM/ha/year), and Yield vs. mean air temperature is (t DM/ha/^{o}C)

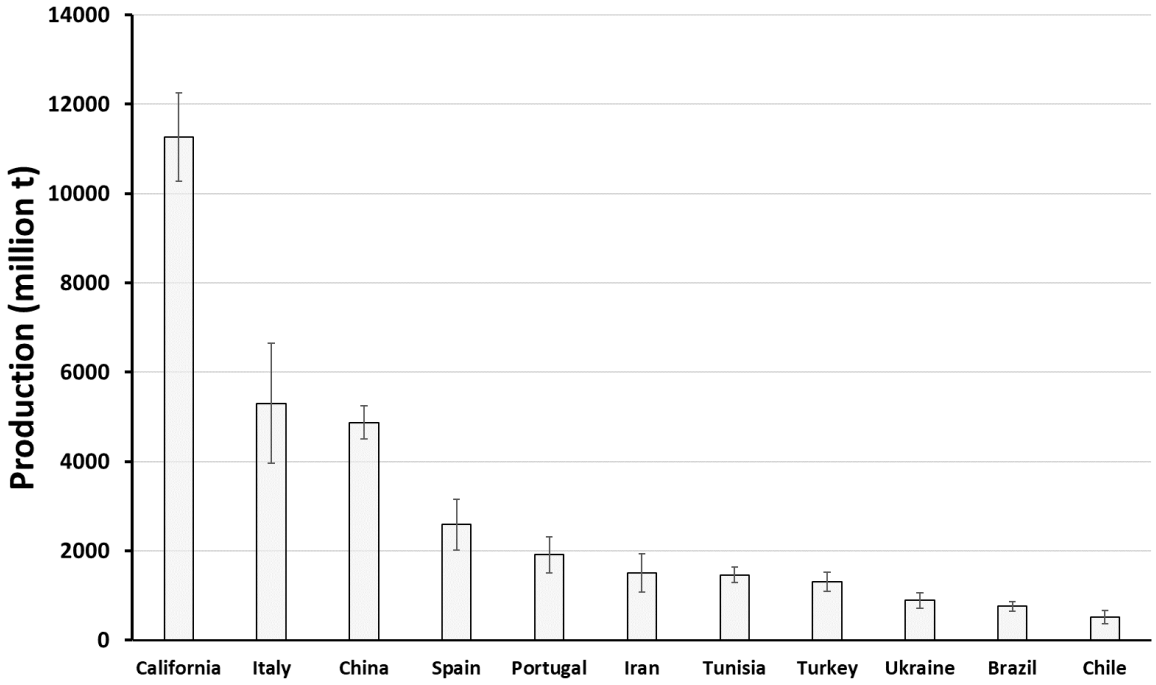
Supplemental Table 8. statistical details of the Man-Kendall test and Thein-Slope estimator for China (Xinjiang) considering each model and future scenario

GCM	Scenario	Mean air temperature					Yield					Yield vs. mean air temperature				
		P_{value}	Z*	Ƭ**	Slope***	trend	P_{value}	Z	Ƭ	slope	trend	P_{value}	Z	Ƭ	slope	trend
GCM1	SSP1-2.6	**0.080**	**1.750**	**0.110**	**0.002**	**no trend**	**0.08**	**1.75**	**0.110**	**0.002**	**no trend**	**0.08**	**1.75**	**0.110**	**0.002**	**no trend**
	SSP3-7.0	**< 0.001**	**3.320**	**0.210**	**0.005**	**increasing**	**< 0.001**	**3.32**	**0.210**	**0.005**	**increasing**	**< 0.001**	**3.32**	**0.210**	**0.005**	**increasing**
	SSP5-8.5	**0.277**	**1.090**	**0.070**	**0.002**	**no trend**	**0.28**	**1.09**	**0.070**	**0.002**	**no trend**	**0.28**	**1.09**	**0.070**	**0.002**	**no trend**
GCM2	SSP1-2.6	**< 0.001**	**-3.180**	**-0.200**	**-0.005**	**decreasing**	**< 0.001**	**-3.18**	**-0.200**	**-0.005**	**decreasing**	**< 0.001**	**-3.18**	**-0.200**	**-0.005**	**decreasing**
	SSP3-7.0	**< 0.001**	**-6.940**	**-0.430**	**-0.013**	**decreasing**	**< 0.001**	**-6.94**	**-0.430**	**-0.013**	**decreasing**	**< 0.001**	**-6.94**	**-0.430**	**-0.013**	**decreasing**
	SSP5-8.5	**< 0.001**	**-8.870**	**-0.550**	**-0.020**	**decreasing**	**< 0.001**	**-8.87**	**-0.550**	**-0.020**	**decreasing**	**< 0.001**	**-8.87**	**-0.550**	**-0.02**	**decreasing**
GCM3	SSP1-2.6	**< 0.001**	**3.990**	**0.250**	**0.005**	**increasing**	**< 0.001**	**3.99**	**0.250**	**0.005**	**increasing**	**< 0.001**	**3.99**	**0.250**	**0.005**	**increasing**
	SSP3-7.0	**0.048**	**1.980**	**0.120**	**0.003**	**increasing**	**0.05**	**1.98**	**0.120**	**0.003**	**increasing**	**0.05**	**1.98**	**0.120**	**0.003**	**increasing**
	SSP5-8.5	**0.365**	**-0.910**	**-0.060**	**-0.002**	**no trend**	**0.37**	**-0.91**	**-0.060**	**-0.002**	**no trend**	**0.37**	**-0.91**	**-0.060**	**-0.002**	**no trend**
GCM4	SSP1-2.6	**0.059**	**1.890**	**0.120**	**0.002**	**no trend**	**0.06**	**1.89**	**0.120**	**0.002**	**no trend**	**0.06**	**1.89**	**0.120**	**0.002**	**no trend**
	SSP3-7.0	**0.125**	**1.540**	**0.090**	**0.002**	**no trend**	**0.13**	**1.54**	**0.090**	**0.002**	**no trend**	**0.13**	**1.54**	**0.090**	**0.002**	**no trend**
	SSP5-8.5	**0.034**	**-2.130**	**-0.130**	**-0.003**	**decreasing**	**0.03**	**-2.13**	**-0.130**	**-0.003**	**decreasing**	**0.03**	**-2.13**	**-0.130**	**-0.003**	**decreasing**
GCM5	SSP1-2.6	**< 0.001**	**-6.100**	**-0.380**	**-0.007**	**decreasing**	**< 0.001**	**-6.10**	**-0.380**	**-0.007**	**decreasing**	**< 0.001**	**-6.10**	**-0.380**	**-0.007**	**decreasing**
	SSP3-7.0	**< 0.001**	**-6.190**	**-0.380**	**-0.009**	**decreasing**	**< 0.001**	**-6.19**	**-0.380**	**-0.009**	**decreasing**	**< 0.001**	**-6.19**	**-0.380**	**-0.009**	**decreasing**
	SSP5-8.5	**< 0.001**	**-8.280**	**-0.510**	**-0.015**	**decreasing**	**< 0.001**	**-8.28**	**-0.510**	**-0.015**	**decreasing**	**< 0.001**	**-8.28**	**-0.510**	**-0.015**	**decreasing**

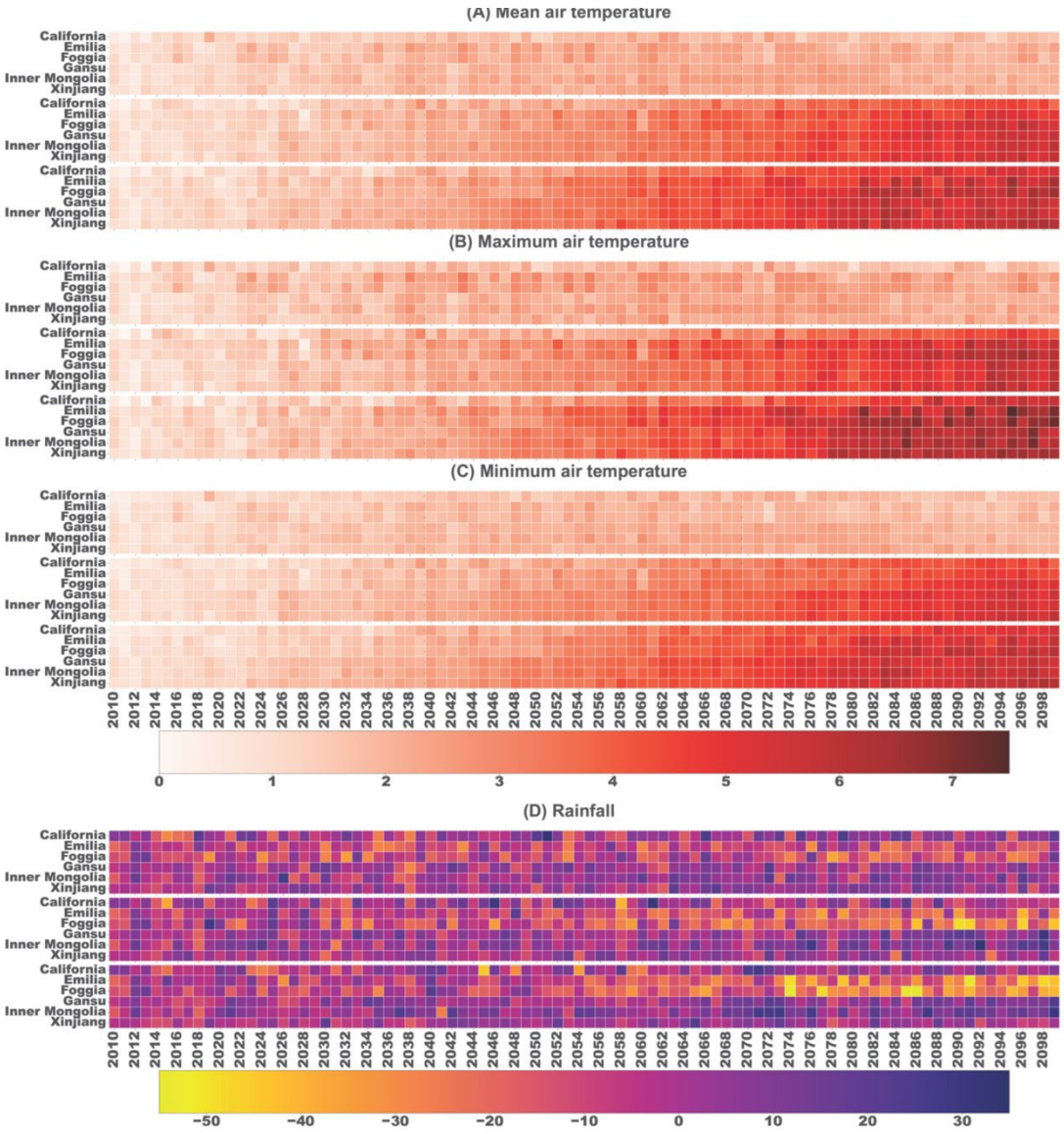
* Z represents the Man-Kendall test statistic result

** Ƭ is the rank correlation coefficient that shows the monotony of the slope

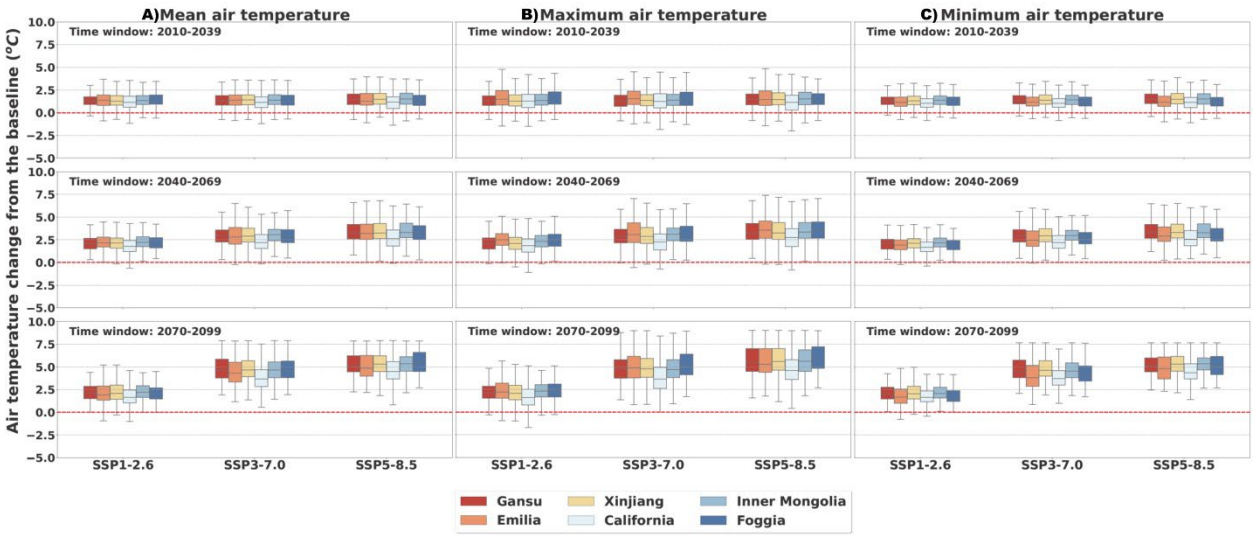
*** The unit for the mean temperature slope is (^{o}C/year), yield is (t DM/ha/year), and yield vs. mean air temperature is (t DM/ha/^{o}C)



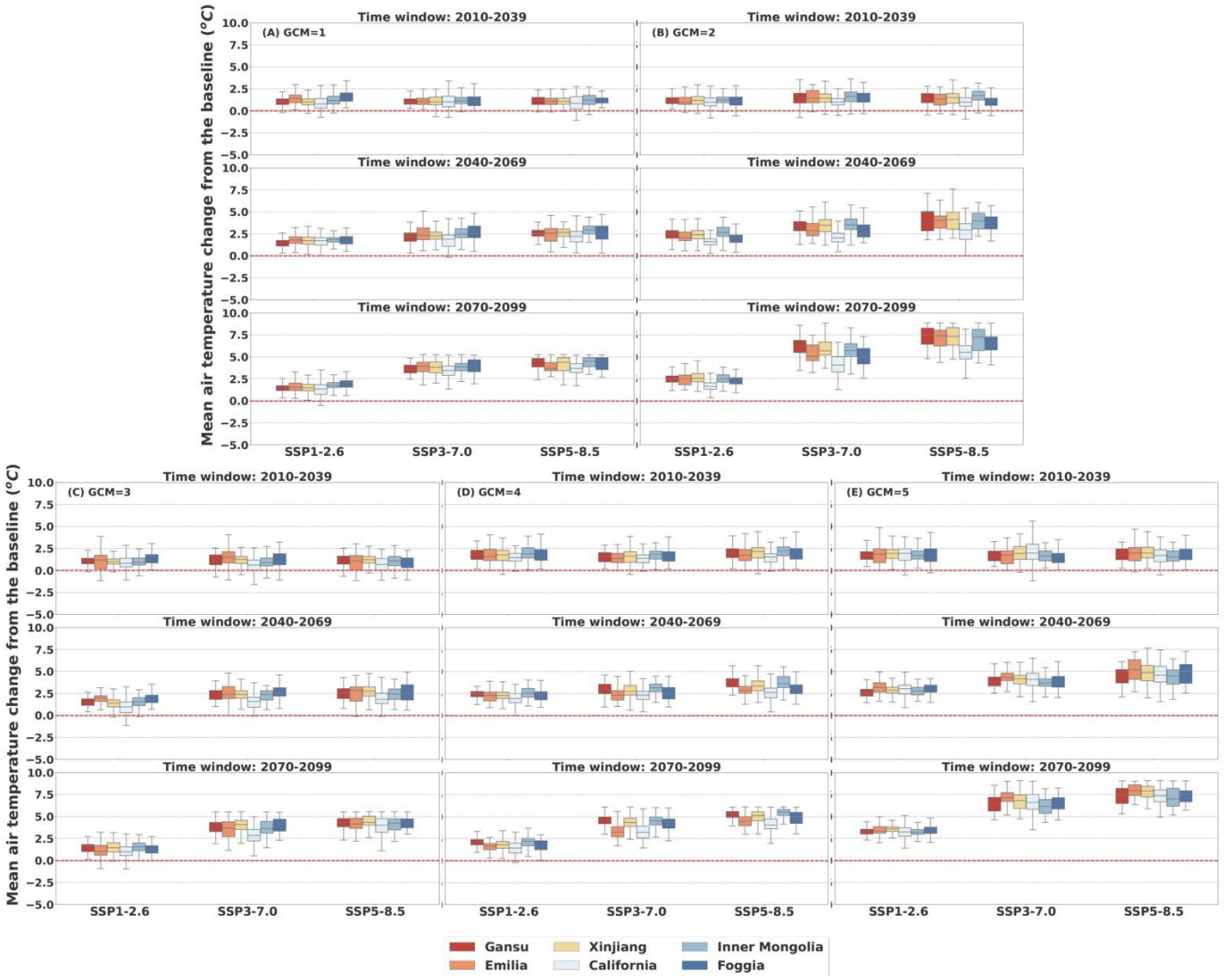
Supplemental Figure 1. Mean processing tomato production for the period 2010-2019 for the main producing countries (the error bar represents the standard deviation of the mean). The production data were retrieved from the World Processing Tomato Council (WPTC), http://www.tomatonews.com/en/wptc_3_411002.html



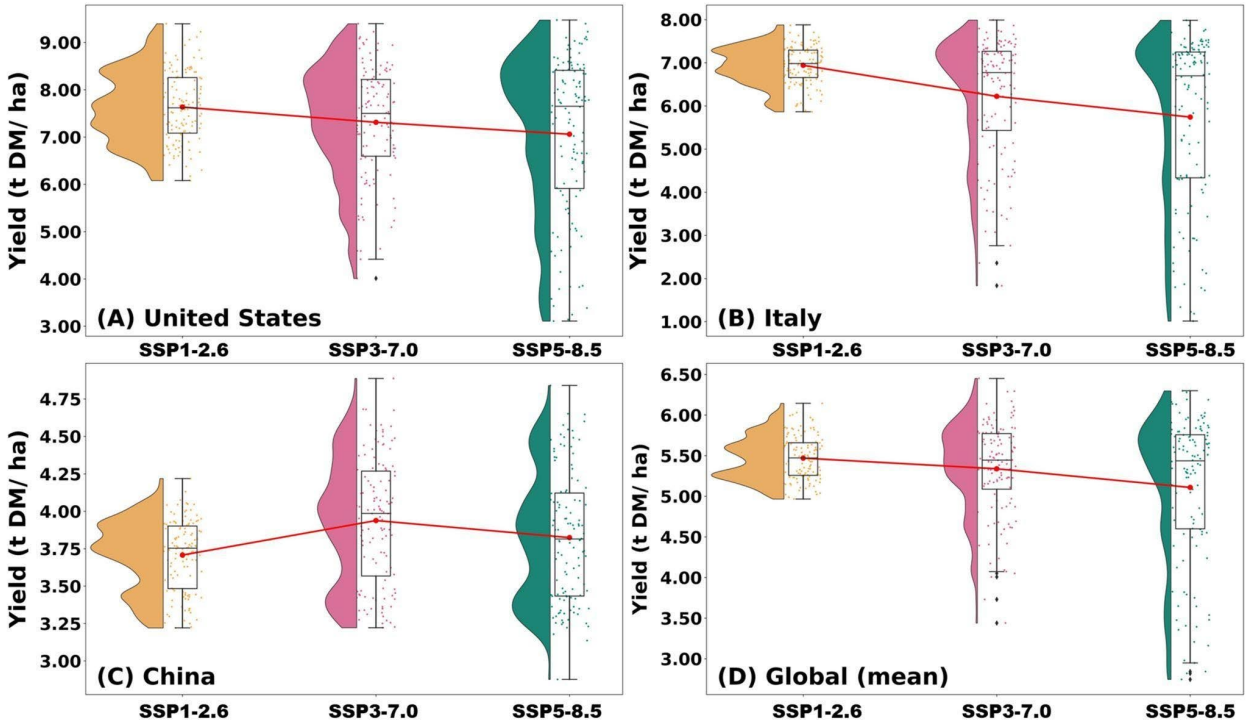
Supplemental Figure 2. Yearly relative changes in **(A)** mean air temperature; **(B)** maximum air temperature; **(C)** minimum air temperature; and **(D)** with respect to the baseline (1980-2009). Each panel provides data for the tomato growing regions and for the SSP1-2.6, SSP3-7.0, and SSP5-8.5 scenarios.



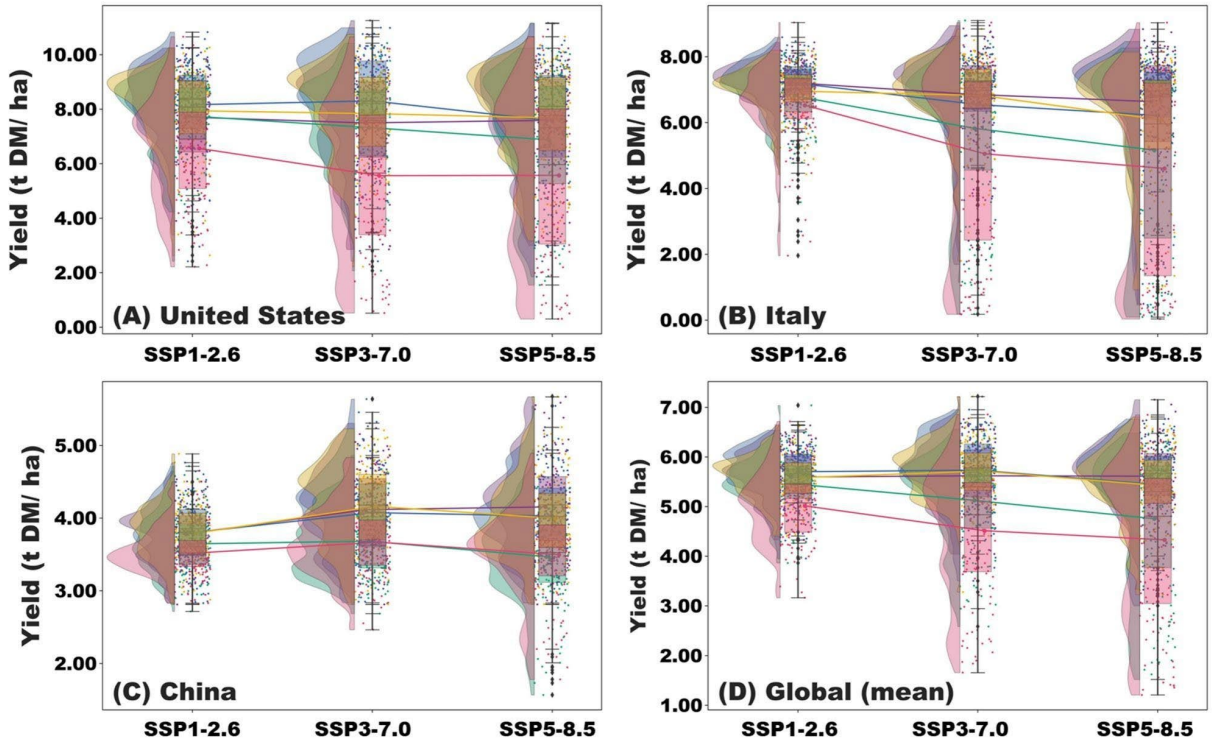
Supplemental Figure 3. Temperature changes with respect to the baseline period (1980-2009) for the A***)*** mean air temperature; B***)*** maximum air temperature; and ***C)*** minimum air temperature for the six locations of the study during 2010-2039; 2040-2069; 2070-2099. For each box-and-whiskers plot, the end of the whisker line represents the 10th and 90th percentiles. The lines of the box represent the 25th, median, and 75th percentiles.



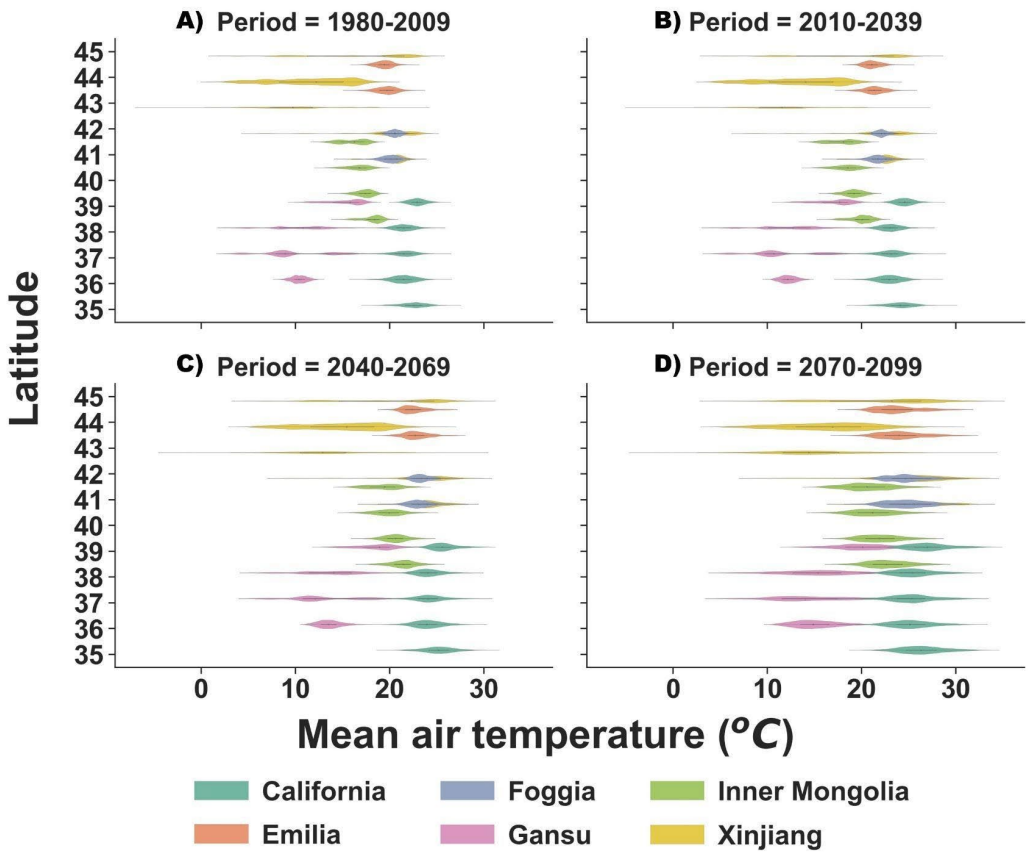
Supplemental Figure 4. Mean air temperature changes with respect to the baseline period (1980-2009) for the five Global Circulation Models (GCM) and for the six locations of the study during 2010-2039; 2040-2069; 2070-2099. For each box-and-whiskers plot, the end of the whisker line represents the 10th and 90th percentiles. The lines of the box represent the 25th, median, and 75th percentiles.



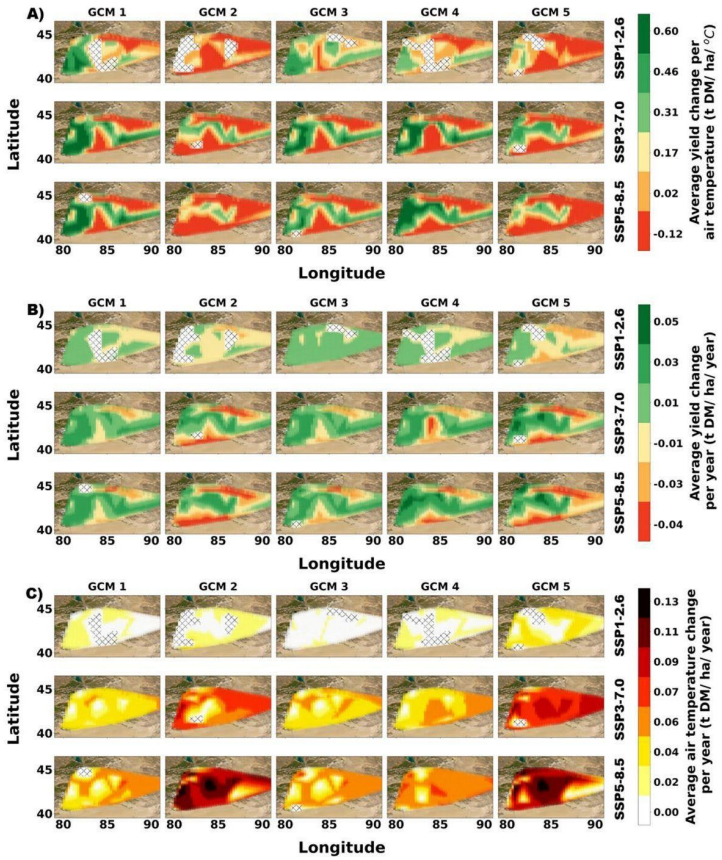
Supplemental Figure 5. The distribution of the simulated processing tomato yield (expressed as ton of dry matter per ha, "t DM/ha") for ***(A)*** the United States; ***(B)*** Italy; ***(C)*** China; and ***(D)*** global for SSP1-2.6 (yellow distribution), SSP3-7.0 (violet distribution), and SSP5-8.5 (green distribution). This plot considers the average of the five global circulation models considered in the study. For each box-and-whiskers plot, the end of the whisker line represents the 10^{th} and 90^{th} percentiles. The lines of the box represent the 25^{th}, median, and 75^{th} percentiles. The red dots and lines represent the mean simulated yield.



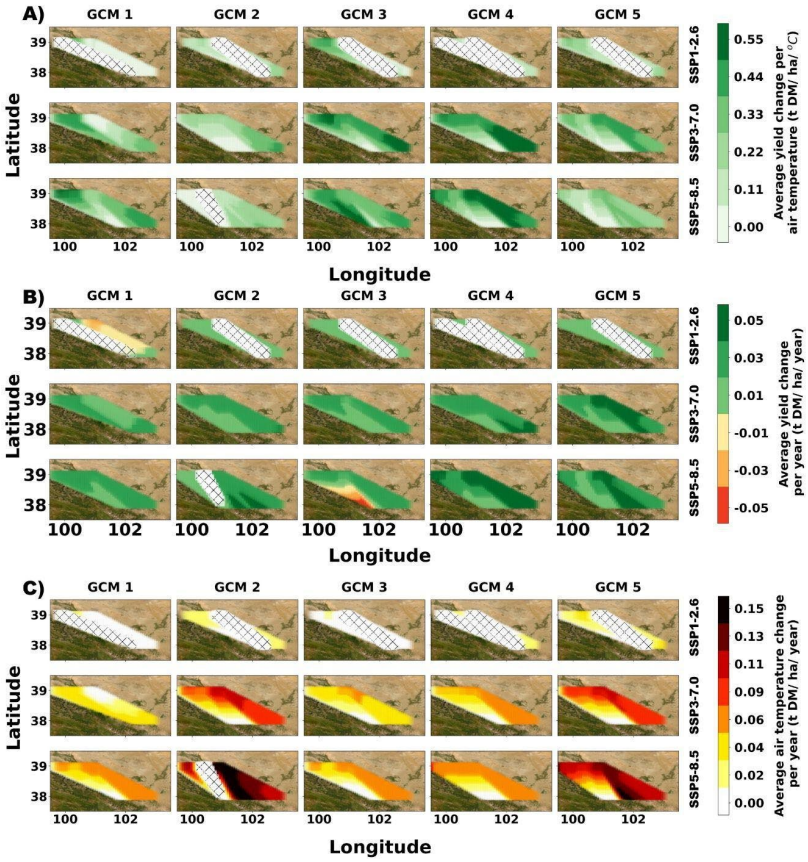
Supplemental Figure 6. The distribution of the simulated processing tomato yield (expressed as ton of dry matter per ha, "t DM/ha") for ***(A)*** The United States; ***(B)*** Italy; ***(C)*** China; and ***(D)*** global for SSP1-2.6 (yellow distribution), SSP3-7.0 (violet distribution), and SSP5-8.5 (green distribution). This plot represents the data for all global circulation models considered in the study. For each box-and-whiskers plot, the end of the whisker line represents the 10^{th} and 90^{th} percentiles. The lines of the box represent the 25^{th}, median, and 75^{th} percentiles. The red dots and lines represent the mean simulated yield.



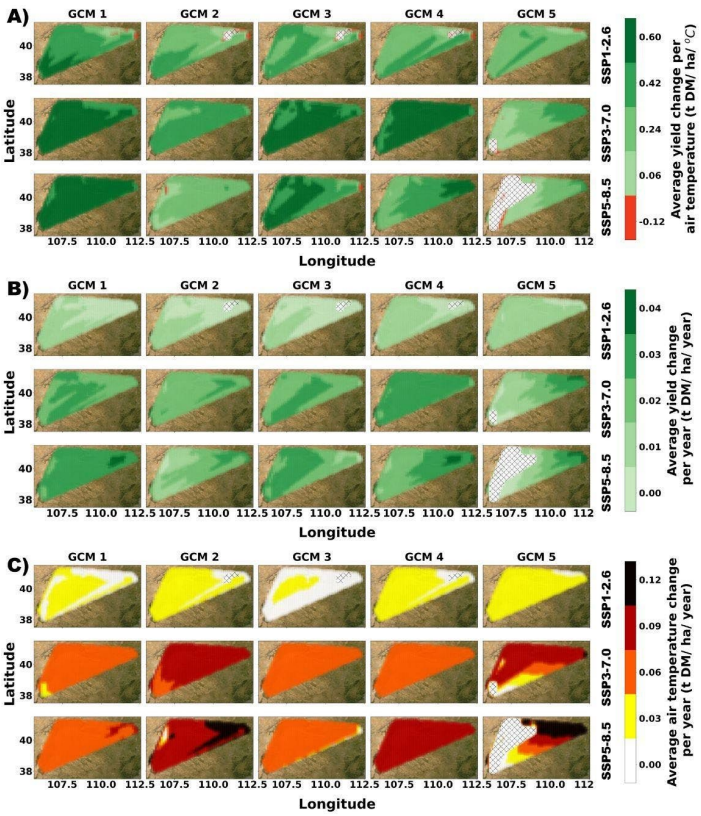
Supplemental Figure 7. Distribution of mean air temperature at different latitude during ***(A)*** 1980-2009; ***(B)*** 2010-2039; ***(C)*** 2040-2069; ***(D)*** 2070-2099. The color of each distribution corresponds to each growing tomato region.



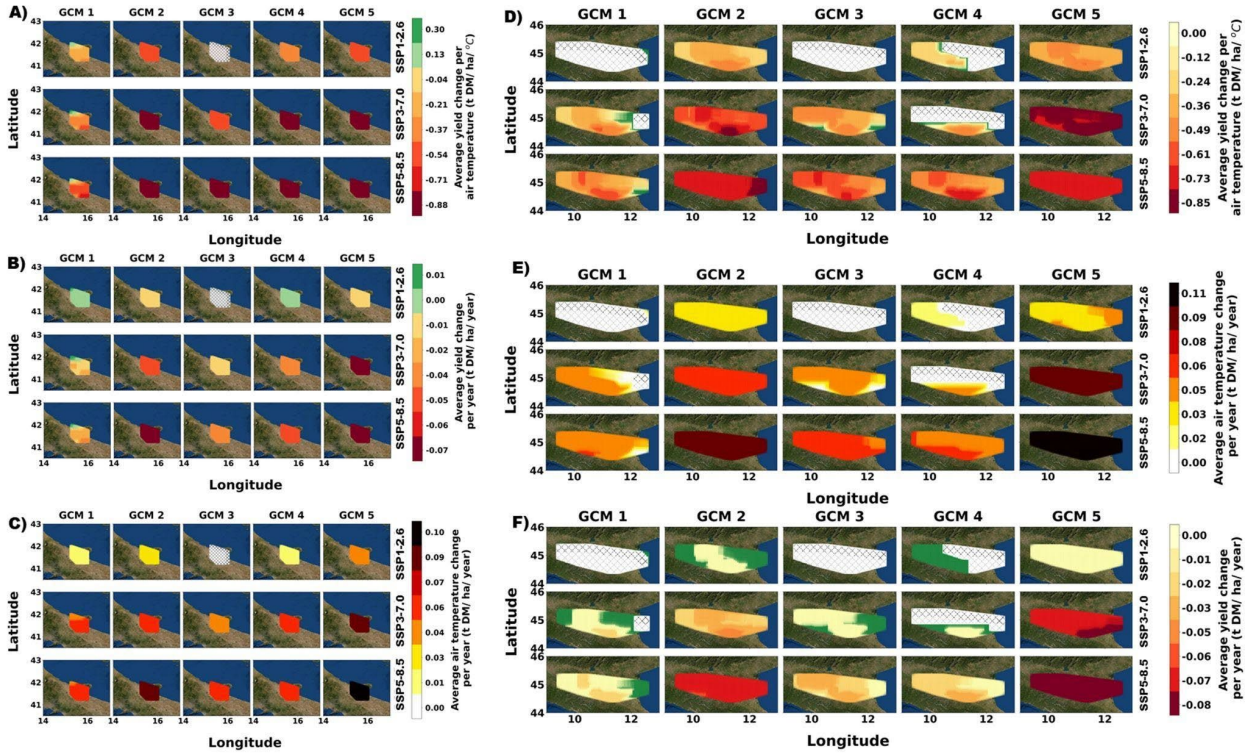
Supplemental Figure 8. Spatial distribution of ***(A)*** yield change per degree of air temperature, ***(B)*** yield change per year; and ***(C)*** average temperature change per year for the Xinjiang Province (China). The hatched areas show the locations where the changes in yield (A, and B) and temperature (C) were not statistically significant based on the Man-Kendall tests.



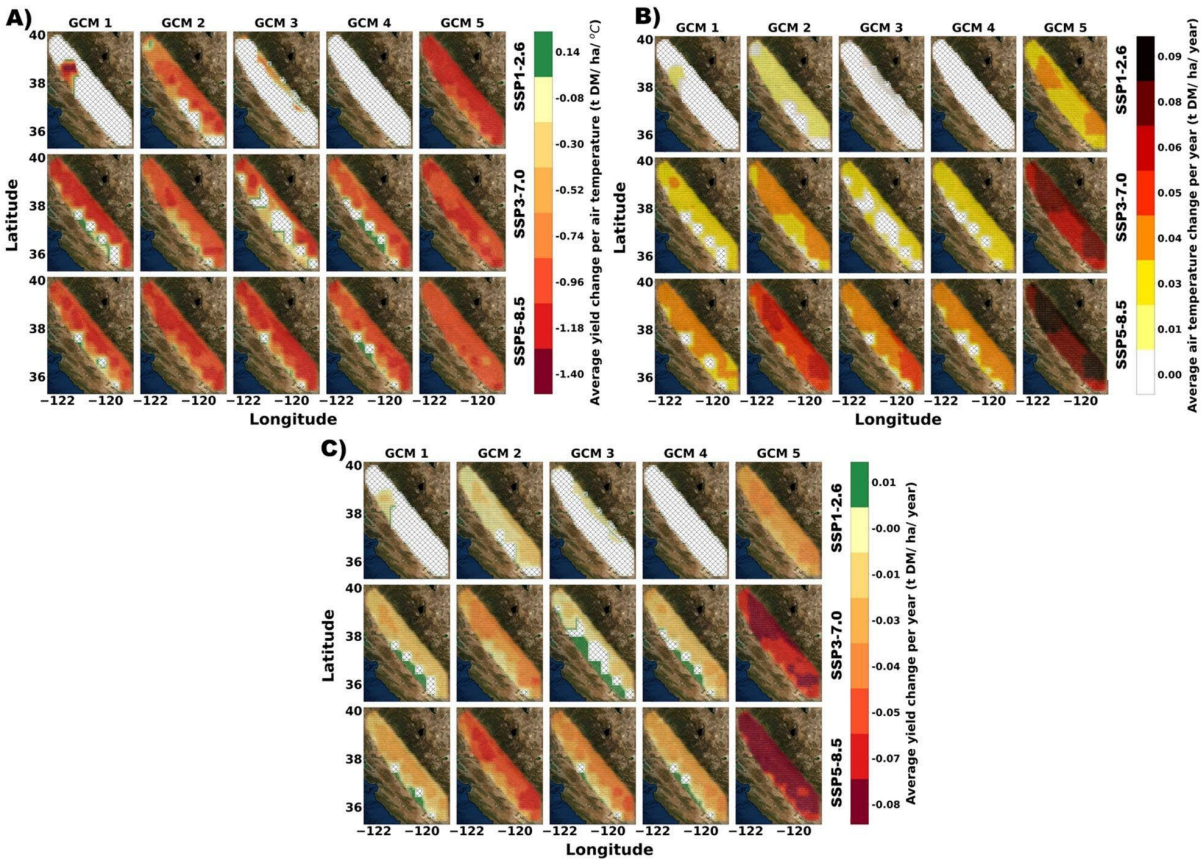
Supplemental Figure 9. Spatial distribution of ***(A)*** yield change per degree of air temperature, ***(B)*** yield change per year; and ***(C)*** average temperature change per year for the Gansu Province (China). The hatched areas show the locations where the changes in yield (A, and B) and temperature (C) were not statistically significant based on the Man-Kendall tests.



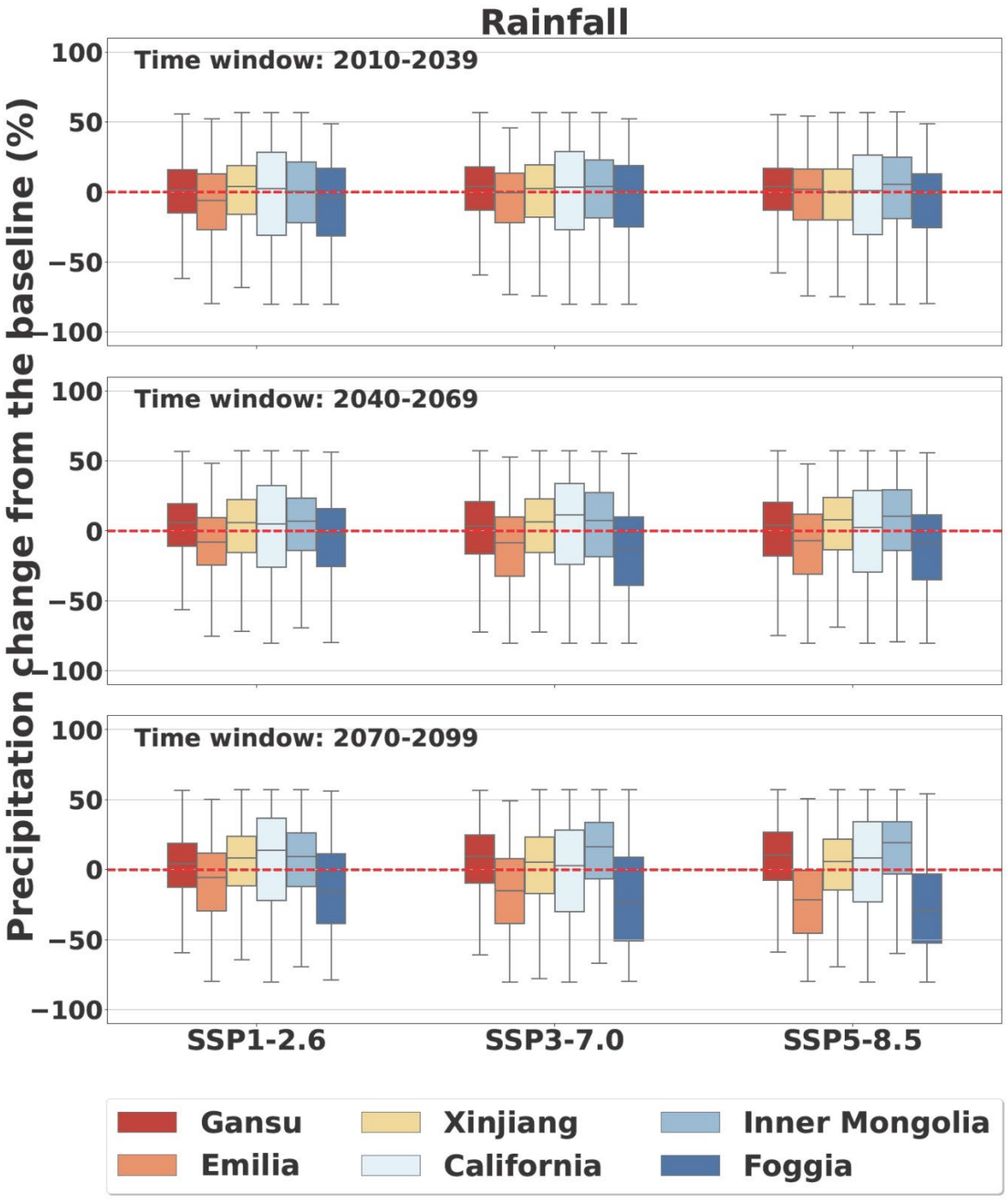
Supplemental Figure 10. Spatial distribution of ***(A)*** yield change per degree of air temperature, ***(B)*** yield change per year; and ***(C)*** average temperature change per year for Inner Mongolia Province (China). The hatched areas show the locations where the changes in yield (A, and B) and temperature (C) were not statistically significant based on the Man-Kendall tests.



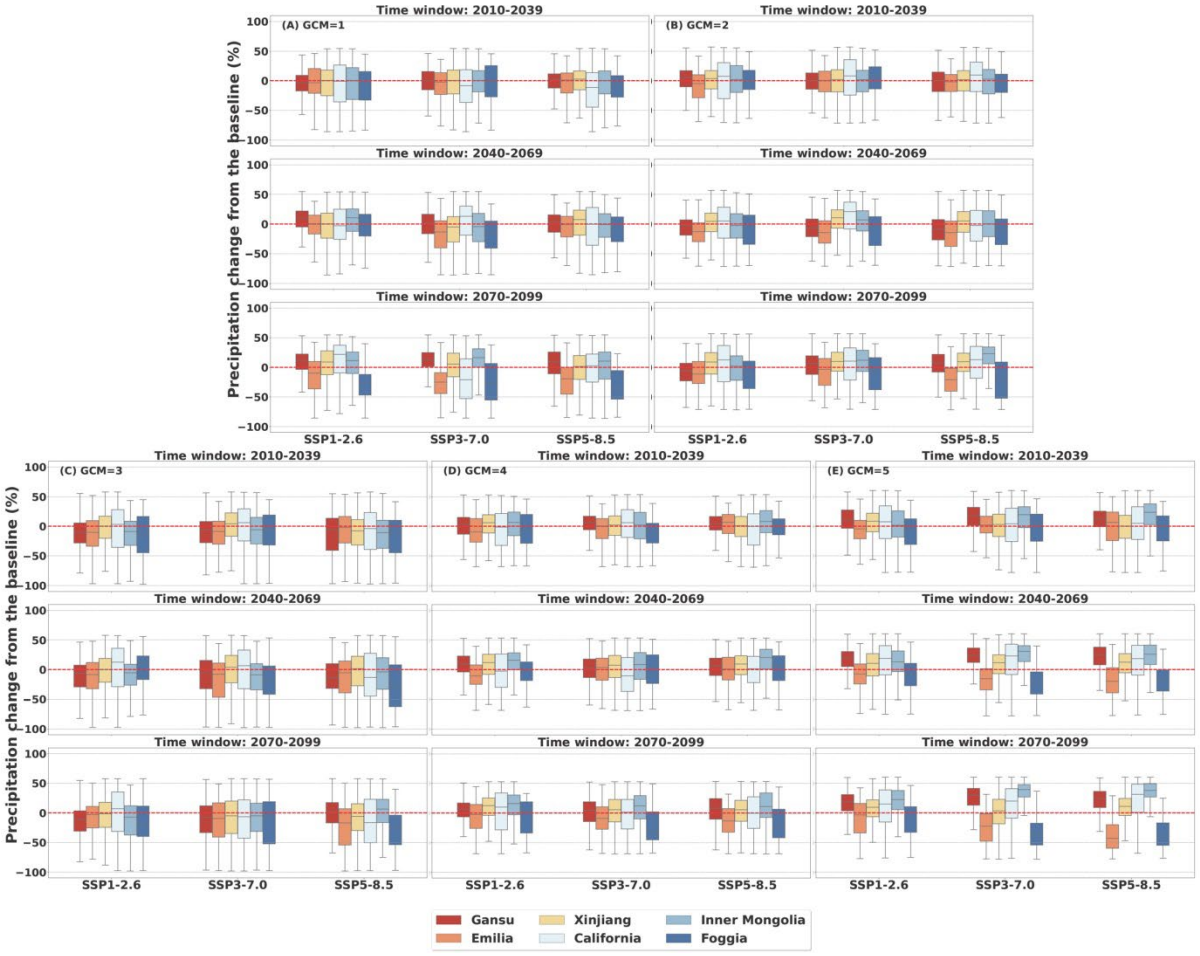
Supplemental Figure 11. Spatial distribution of ***(A, D)*** yield change per degree of air temperature, ***(B, E)*** yield change per year; and ***(C, F)*** average temperature change per year for Foggia ***(A-C)*** and Emilia-Romagna ***(E-F)*** Provinces (Italy). The hatched areas show the locations where the changes in yield (**A, B, *D, E***) and temperature (***C, F***) were not statistically significant based on the Man-Kendall tests.



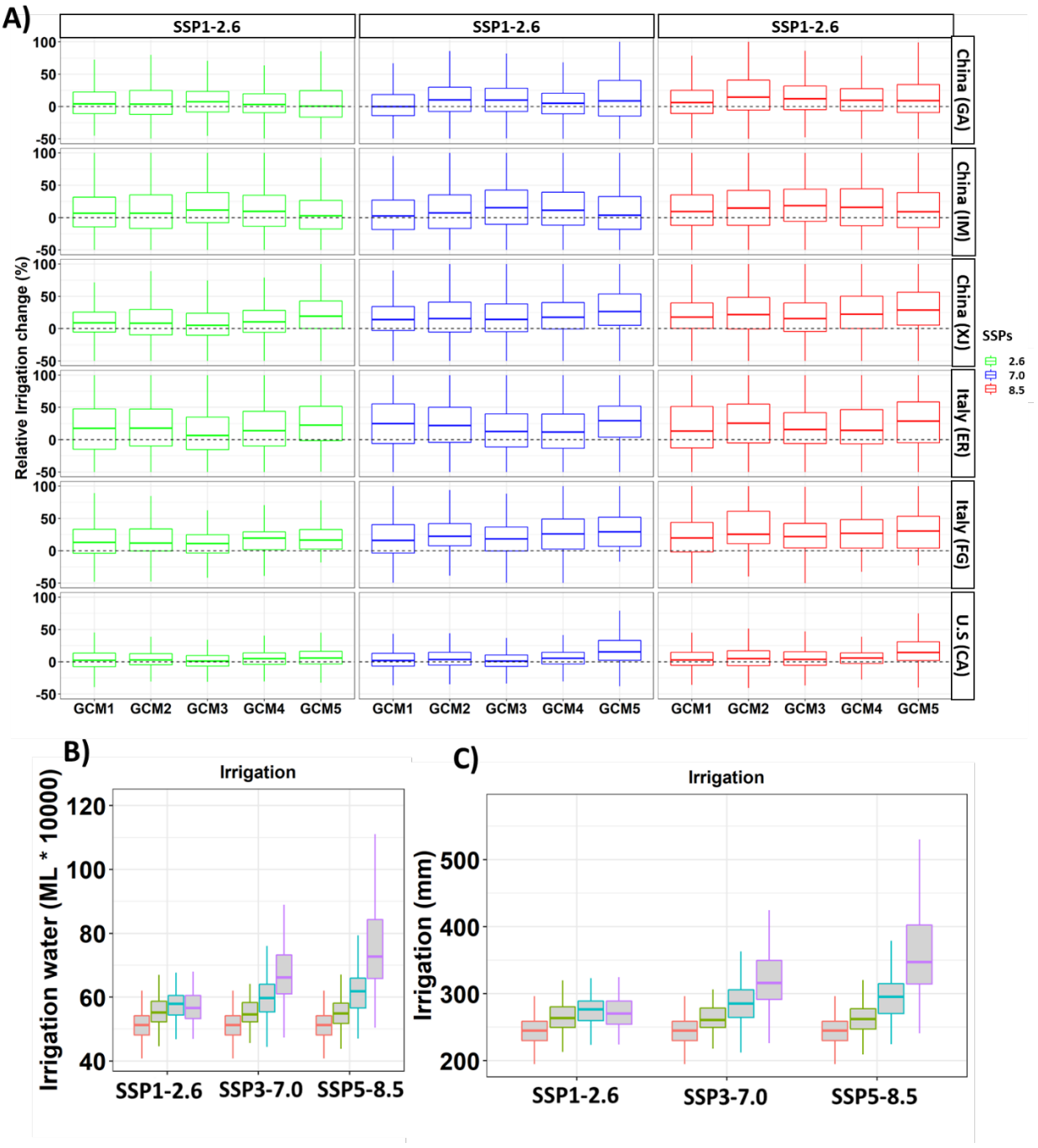
Supplemental Figure 12. Spatial distribution of ***(A)*** yield change per degree of air temperature, ***(B)*** yield change per year; and ***(C)*** average temperature change per year for California (USA). The hatched areas show the locations where the changes in yield (A, and B) and temperature (C) were not statistically significant based on the Man-Kendall tests.



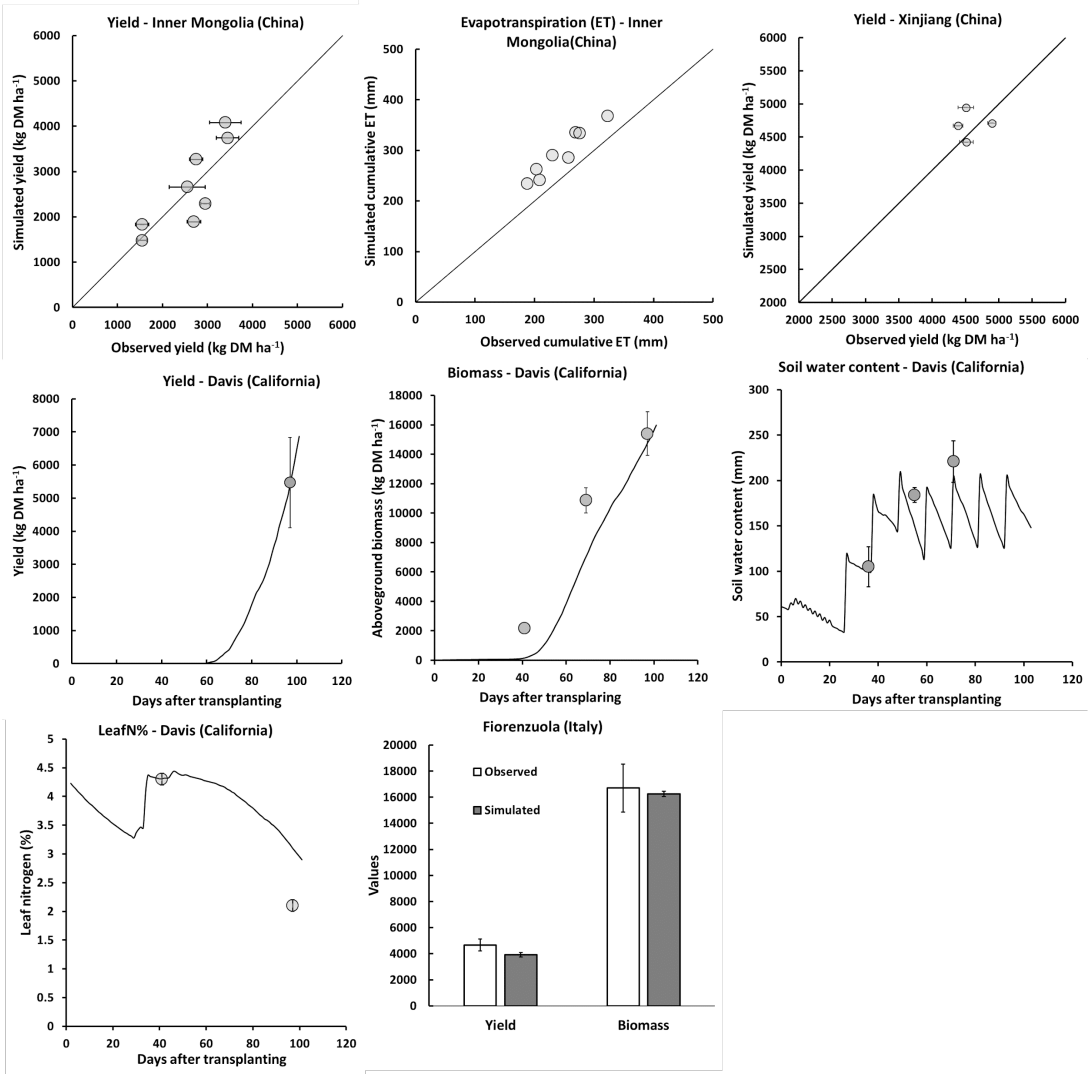
Supplemental Figure 13. Rainfall changes with respect to the baseline period (1980-2009) for the six locations of the study during 2010-2039; 2040-2069; 2070-2099. For each box-and-whiskers plot, the end of the whisker line represents the 10th and 90th percentiles. The lines of the box represent the 25th, median, and 75th percentiles.



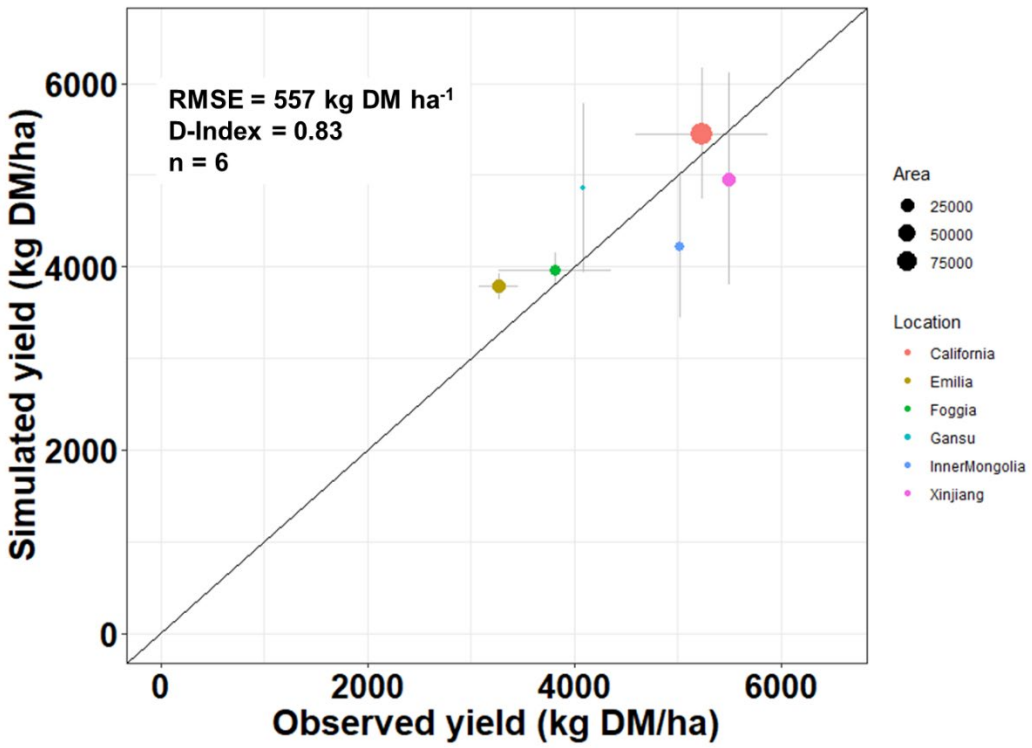
Supplemental Figure 14. Precipitation changes with respect to the baseline period (1980-2009) for the five GCMs and for the six locations of the study and during 2010-2039; 2040-2069; 2070-2099. For each box-and-whiskers plot, the end of the whisker line represents the 10th and 90th percentiles. The lines of the box represent the 25th, median, and 75th percentiles.



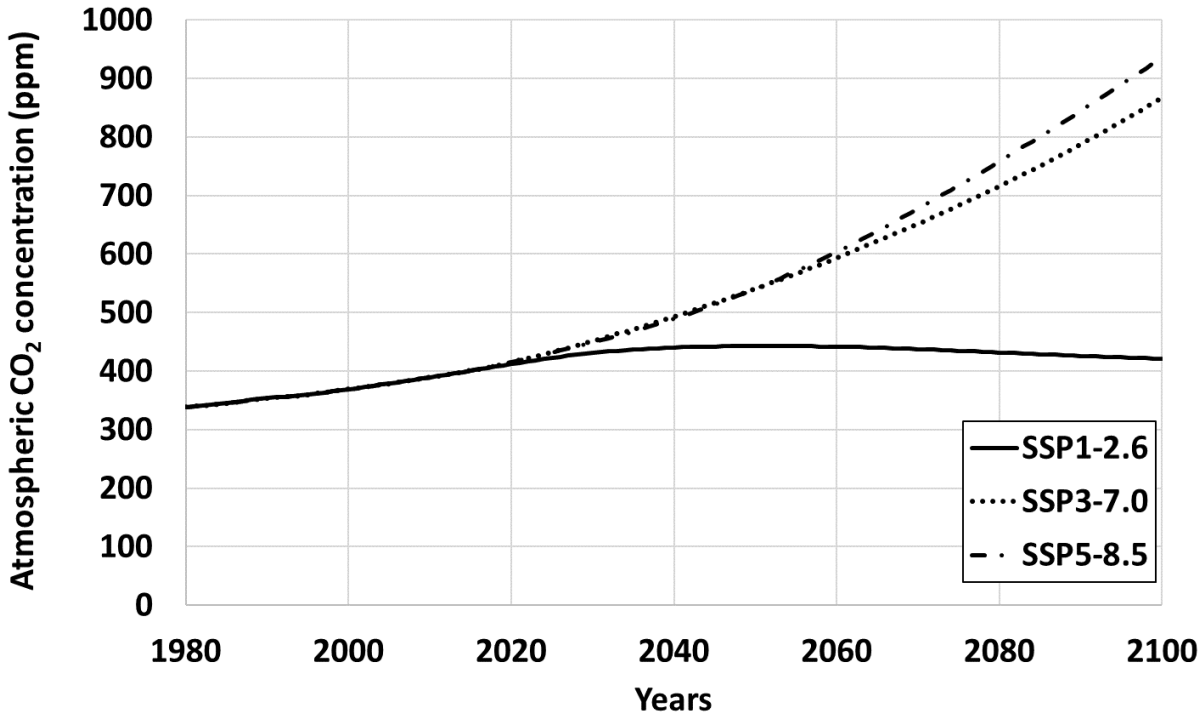
Supplemental Figure 15. Simulated **(*A*)** relative irrigation changes with respect to the baseline (1980-2009) for RCP2.6 (green boxplots), RCP7.0 (blue boxplots), and RCP8.5 (red boxplots); **(*B*)** total irrigation water and **(*C*)** irrigation unit for the 1980-2009 (red boxplots), 2010-2039 (green boxplots), 2040-2069 (blue boxplots), and 2070-2099 (violet boxplots). For each boxplot, the end of the vertical line represents, from top to bottom, the 10th and 90th percentile. The horizontal line of the box, from top to bottom, represents the 25th, median, and 75th percentile, respectively.



Supplemental Figure 16. Calibration of tomato yield for the different locations and for different variables available. Results of the phenology calibration were not shown because the model was fitted to simulate flowering and harvesting within +/- 4 days. Calibration did not happen in Foggia (Italy) because the DSSAT-Tomato model was calibrated and evaluated in that province in a previous study[1].



Supplemental Figure 17. Evaluation of regional tomato yield simulation vs. observed regional yield for each of the six locations. The horizontal standard deviation represents the reported observed yield by each province to the World Processing Tomato Council[7] and corresponds to the period of 2005-2019, except for Gansu and Inner Mongolia (China), where observed data were only available for one year. The vertical standard deviation bar represents the variability of multi-year (1980-2019) simulations.



Supplemental Figure 18. Atmospheric carbon dioxide (CO_2) concentration progress over time for SSP1-2.6 (full line), SSP3-7.0 (dotted line), and SSP5-8.5 (dot-dash line).

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