Supplementary information for

Identifying agronomic strategy for a low-carbon economy under the effects of climate change by using a simulation-optimization hybrid model

Haomiao Cheng [1], Siyu Sun [1], Wei Jiang [2], Qilin Yu [3], Wei Ma [4,*], Shaoyuan Feng [1], Fusheng Wang [5], Zuping Xu [1,6,*]

[1] School of Hydraulic Science and Engineering, Yangzhou University, Yangzhou 225127, China; yzchhm@yzu.edu.cn (H.C.); mx120240661@stu.yzu.edu.cn (S.S.); syfeng@yzu.edu.cn (S.F.)

[2] Jiangsu Rural Water Conservancy Science and Technology Development Center, Nanjing 210029, China; jssl_jiangwei@163.com

[3] Ningbo Dianxi Environmental Protection Technology Co., Ningbo 315100, China; mz120211219@stu.yzu.edu.cn

[4] Huaihe River Basin Eco-Environmental Monitoring and Scientific Research Center of Huaihe River Basin Ecological Environmental Supervision and Administration Bureau, The MEE, Bengbu 233000, China

[5] Huai'an Water Conservancy Survey and Design Institute Co., Ltd., Huai'an 223001, China; zzc000622@gmail.com

[6] School of Mechanical and Electrical Engineering, Taizhou University, Taizhou 225300, China

* Correspondence: mawei2030@huaihejg.mee.gov.cn (W.M.); 2025110004@tzu.edu.cn (Z.X.)

This file includes:

1. **Text S1.**
2. **Text S2.**
3. **Table S1.**
4. **Table S2.**
5. **Table S3.**
6. **Table S4.**
7. **Figure S1.**
8. **Figure S2.**
9. **Figure S3.**

1. Text S1: The method of downscaling

The delta change method was used to downscale the projections to the experimental site. Specifically, historical climate data served as baseline data representative of the historical climate. The daily climate variables in each RCM-GCM projections were aggregated into the monthly mean variables. Then, the monthly mean differences between (or the rate thereof) the corresponding historical and future climate predictions were added (or multiplied) to the daily historical climate observations. In this way, the modified future climate data were obtained, including minTair, maxTair, P, SR, WR, and RH. A caveat to this method is that it assumes the variance or time series behavior remains the same in the future climate, as it preserves the temporal structure and other characteristics of the observed data.

References

Cheng, Haomiao, et al. "Simulating synergistic effects of climate change and conservation practices on greenhouse gas emissions and crop growth in long-term maize cropping systems." *Computers and Electronics in Agriculture*215 (2023): 108404.

2. Text S2: Site description, soil characteristics, climate data, and agronomic management details of the study area

The study area was located at the Eastern Nebraska Research and Extension Cen-ter (41◦9’43” N, 96◦24’41” W, altitude 349 m), Ithaca, NE, USA. Soils at the site are mainly silt loam in the Tomek (fine, smectitic, mesic Pachic Argiudoll) and Filbert (fine, smectitic, mesic Vertic Argialboll) series. The average values of soil pH, total N, and SOC at this site are 7.1, 1.6 g-N/kg, and 19.3 g-C/kg, respectively. The mean annual precipitation and mean T_{air} are 698.8 mm and 10.4 ◦C from 2001 to 2020, respectively.

Historically, corn (Zea mays L.), soybean [Glycine max (L.) Merr.], oat (Avena sativa L.), and alfalfa (Medicago sativa L.) were grown at this site, and continuous corn has been established since 2001. Seeding occurred in late April or May at a rate of ~74,350 seeds/ha and depth of 0.05 m each year. Nitrogen fertilizer, i.e., granular urea (46-0-0) and ammonium nitrate (34-0-0), was applied between rows at a depth of 0.10-0.15 m, at the rate of ~202 kg N/ha/year. Based on field conditions, annual irrigation amounts in this experimental area ranged from 25 to 266 mm and were applied using an array of linear mobile sprinklers.

References

Cheng, Haomiao, et al. "Effects of residue removal and tillage on greenhouse gas emissions in continuous corn systems as simulated with RZWQM2." Journal of Environmental Management 285 (2021): 112097.

2. Table S1

Table S1: Agronomic practices from 2001 to 2020

Year	Sowing time (month-day)	Planting density (seeds/ha)	N fertilizer (kg/ha)	Irrigation amount (mm)	Tillage time (month-day)	Harvest time (month-day)
2001	04-27	73100	202	37	04-26, 11-14	11-14
2002	04-25	78300	202	150	04-25, 10-21	10-08
2003	05-14	77300	202	175	04-23, 10-23	10-23
2004	04-22	77300	202	50	04-20, 10-25	10-20
2005	05-03	74350	202	266	05-03, 11-01	11-01
2006	05-08	74350	202	164	05-08, 10-30	10-30
2007	05-01	74350	202	152	04-25, 11-19	11-05
2008	05-06	74350	202	101	12-02	12-02
2009	05-04	74350	202	76	04-22, 12-01	12-01
2010	05-04	74350	202	76	04-14, 11-10	11-08
2011	05-02	74350	202	38	04-25	11-30
2012	04-26	74350	202	166	01-09, 04-24	10-10
2013	05-13	74350	202	121	04-30	11-19
2014	05-05	74350	202	114	05-05	12-02
2015	05-01	74350	202	25	04-30	11-12
2016	05-02	74350	202	38	04-25	11-30
2017	04-26	74350	202	166	01-09, 04-24	10-10
2018	05-13	74350	202	121	04-30	11-19
2019	05-05	74350	202	114	05-05	12-02
2020	05-01	74350	202	25	04-30	11-12

References

Cheng, Haomiao, et al. "Effects of residue removal and tillage on greenhouse gas emissions in continuous corn systems as simulated with RZWQM2." Journal of Environmental Management 285 (2021): 112097.

3. Table S2

Table S2 Stover management, tillage practices, and N fertilizer application in each experimental treatment

Treatment	Harvest Type	Tillage date [a]				N fertilizer application (kg/ha) [b]
		2011	2012	2013	2014	
NRCT	Grain harvest only	25 Apr.	09 Jan., 24 Apr.	30 Apr.	05 May	202
HRCT	Grain and stover harvest	25 Apr.	09 Jan., 24 Apr.	30 Apr.	05 May	202
NRNT	Grain harvest only	/	/	/	/	202
HRNT	Grain and stover harvest	/	/	/	/	202

[a] Conventional tillage (CT) was implemented with a tandem disk to a depth of 15 cm. [b] Granular urea (46-0-0) was applied by using a 12-row applicator with injector knives between rows to a soil depth of 10–15 cm. The applications were conducted on Jun 14, 2011, Jun 5, 2012, Jun 19, 2013, and Jun 23, 2014. NRCT: no stover removal + conventional tillage; HRCT: high stover removal + conventional tillage; NRNT: no stover removal + no-till; HRNT: high stover removal + no-till.

4. Table S3

Table S3 Annual mean values of climatic variables derived from ensembles within modified future climate projections

RCMs-GCMs	minTair	maxTair	P	SR	WR	RH
CanRCM4 + CanESM2	6.97	19.99	746.16	13.78	303.94	70.09
CRCM5-UQAM + CanESM2	7.28	20	706.18	13.67	303.67	69.49
CRCM5-UQAM + MPI-ESM-LR	6.6	19.29	735.61	13.78	305.41	70.75
HIRHAM5 + EC-EARTH	5.65	18.57	758.25	13.79	307.6	71.07
RCA4 + CanESM2	7.33	20.42	756.97	13.66	303.2	69.23
RCA4 + EC-EARTH	6.36	19.3	761.91	13.71	306.61	70.47
RegCM4 + GFDL-ESM2M	6.4	18.75	798.43	13.52	308.37	71.47
RegCM4 + HadGEM2-ES	6.62	19.16	770.98	13.6	308.2	71.37
RegCM4 + MPI-ESM-LR	6.32	19.3	712.74	13.95	312.06	69.08
WRF + GFDL-ESM2M	6.78	19.38	769.18	13.62	307.27	70.7
WRF + HadGEM2-ES	7.65	20.25	779.37	13.61	307.32	69.44
WRF + MPI-ESM-LR	6.83	19.49	749.99	13.66	305.34	70.44
Future Mean (2065-2084)	6.73	19.49	753.81	13.7	306.58	70.3
Baseline (2001 to 2020)	3.94	16.94	698.83	13.86	304.23	71.2
Annual Mean Differences	＋2.79	＋2.56	-7.87%	-1.16%	-0.77%	-1.26%

$minT_{air}$ and $maxT_{air}$: minimum and maximum temperatures (°C); P: annual precipitation (mm); SR: shortwave radiation ($MJ/m^2/d$); WR: wind run (km/d); RH: relative humidity (%); Annual future mean: the mean values of 12 future climate data from 2065 to 2084; Baseline: the annual mean of historical climate observation from 2001 to 2020, which obtained from a weather station (Station ID: MEMPHIS5N) near the study area; Annual mean differences: the difference values between the future mean and baseline.

Reference

Cheng, Haomiao, et al. "Simulating synergistic effects of climate change and conservation practices on greenhouse gas emissions and crop growth in long-term maize cropping systems." Computers and Electronics in Agriculture 215 (2023): 108404.

Guo, D., Wang, H. Comparison of a very-fine-resolution GCM with RCM dynamical downscaling in simulating climate in China. *Adv. Atmos. Sci.* **33**, 559–570 (2016). https://doi.org/10.1007/s00376-015-5147-y

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5. Table S4

Table S4 Cost parameters in the process of farmland management

Type	Expression	Price	Source
Corn seed	C_1	263.20 $/t	https://www.worldbank.org
Seeding	C_2	61.78 $/ha	https://franklin.cce.cornell.edu
Rent	C_3	343.47 $/ha/yr	https://www.ers.usda.gov
Pesticide	C_4	139.20$/ha	https://ag.purdue.edu
Farming	C_5	180.00 $/ha	Afshar et al. (2022)
Fertilization	C_6	1.92 $/kg	https://www.usda.gov, https://www.cropscience.bayer.us
Irrigation	C_7	0.16 $/m^3	https://aquaoso.com/water-trends
Irrigation	C_7	0.16 $/m^3	https://aquaoso.com/water-trends
Harvest	C_8	10.43 $/t	Xu et al. (2022)
Agricultural machinery	C_9	2×10^6 $/yr	https://ardc@unl.edu
Maintenance and repair costs	C_{10}	2×10^5 $/yr	https://ardc@unl.edu
Carbon credit	RG	13.85 $/t	https://www.eia.gov
Carbon social price	RS	185.00 $/t	Rennert et al. (2022)
Discount rate	DR	7%	https://www.whitehouse.gov

6. Figure S1

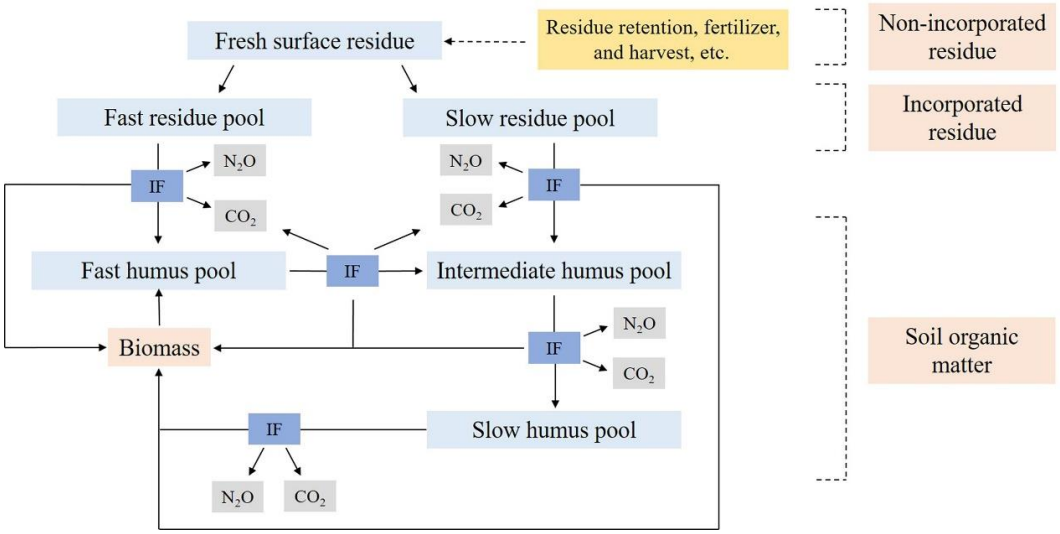

Fig.S1. Carbon (C), nitrogen (N) cycles and greenhouse gas (GHG) emissions in the organic Matter and Nitrogen module (OMNI). IF: Influencing factors, including fertilization, irrigation tillage, and straw treatment, etc.

7. Figure S2

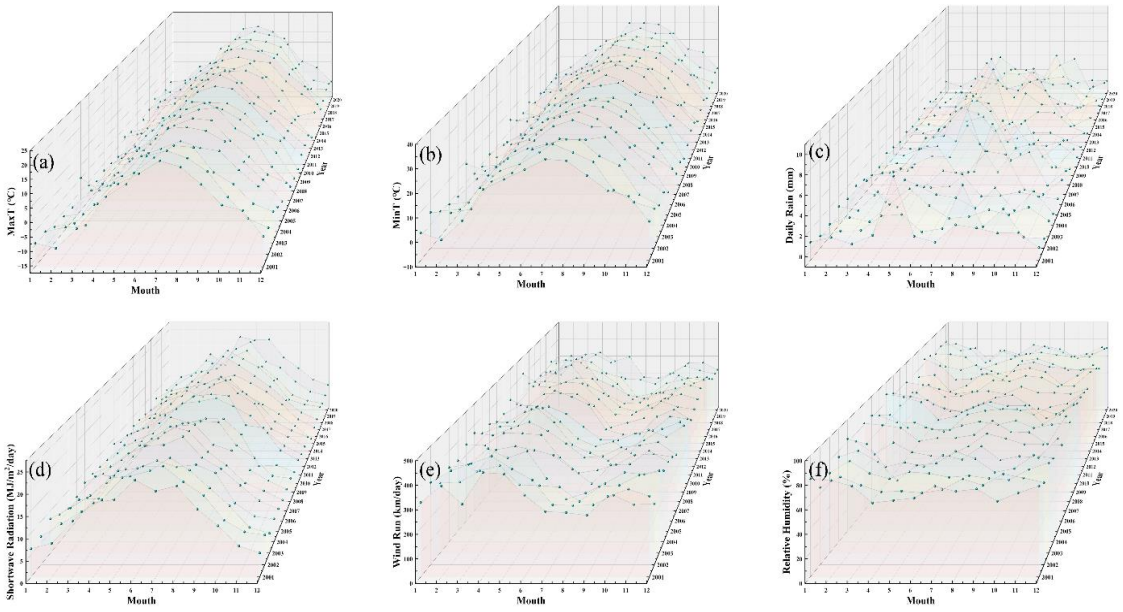

Fig. S2. Monthly average historical climate observation data from 2001 to 2020.

8. Figure S3

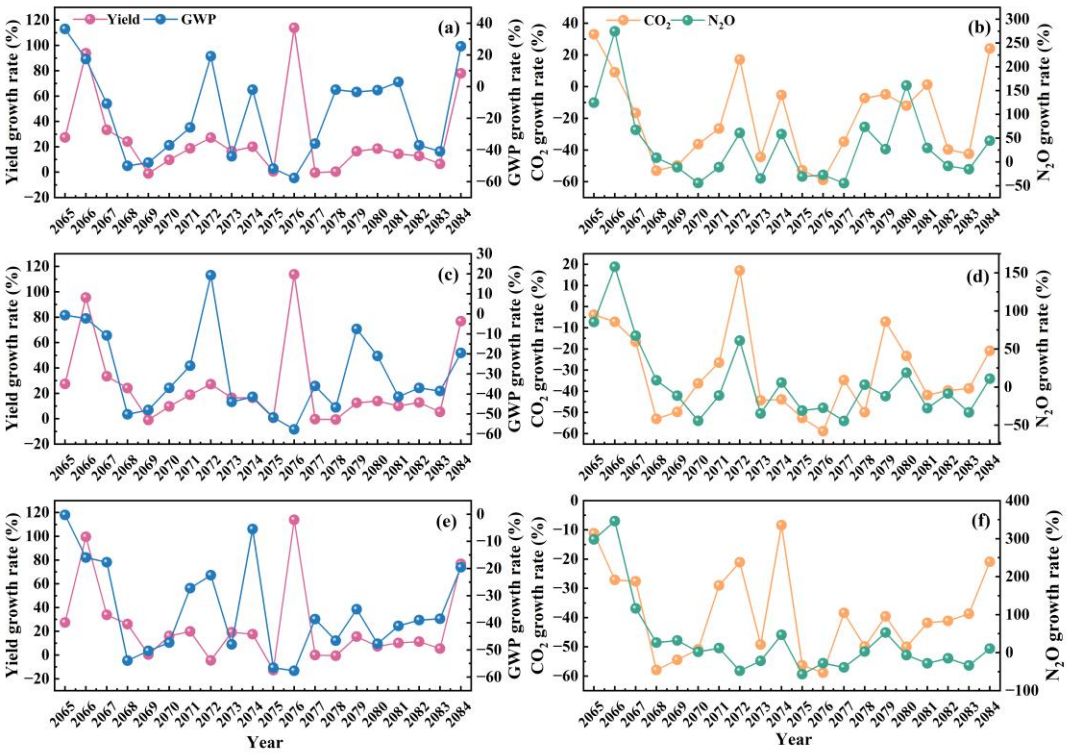

Fig. S3. Annual (2065-2084) parameter growth rate under the BMPs for maxF_1, maxF_2, and maxF_3 compared with the actual practice compared with the actual practice.