Long-term response and adaptation of farmland water, carbon and nitrogen balances to climate change in arid to semi-arid regions

Y. Li*[1,2,3], M. Herbst[3], Z. Chen[1,2], X. Chen[1,2], X. Xu[1,2], Y. Xiong[1,2], Q. Huang[1,2], G. Huang[1,2]

(1) Chinese-Israeli International Center for Research and Training in Agriculture, China Agricultural University, Beijing 100083, China; (2) Center for Agricultural Water Research in China, China Agricultural University, Beijing 100083, China; (3) Agrosphere (IBG-3), Forschungszentrum Jülich GmbH, Jülich 52425, Germany

***Contact: y.li@fz-juelich.de**

Motivation

- Climate change poses a challenge for resource utilization and environmental pollution issues caused by agricultural production, especially in arid to semi-arid regions.
- Farmland water, carbon and nitrogen balances (WCNBs) are closely related to these resource and environmental issues.
- Global climate change is accelerating, such as increases in atmospheric CO_2 concentrations and temperature as well as precipitation changes, which will significantly affect WCNBs.
- Appropriate strategies obtained in previous studies may not adapt to future climate change, but instead have negative impacts on the sustainable development of farmland ecosystems.

Objectives and hypothesis

The main objective of this study was to assess the response of the characteristics of farmland WCNBs to future climate change in the arid to semi-arid regions; and to devise appropriate compensation strategies to deal with the negative impacts (e.g., low crop N uptake, carbon assimilation and farmland carbon sinks, and high soil water percolation, carbon emissions and nitrogen leaching) of climate change on farmland WCNBs in study region.

Our hypothesis was that a field scale study provides response and adaptation results of farmland WCNBs to climate change which is representative for a large area.

Materials and methods

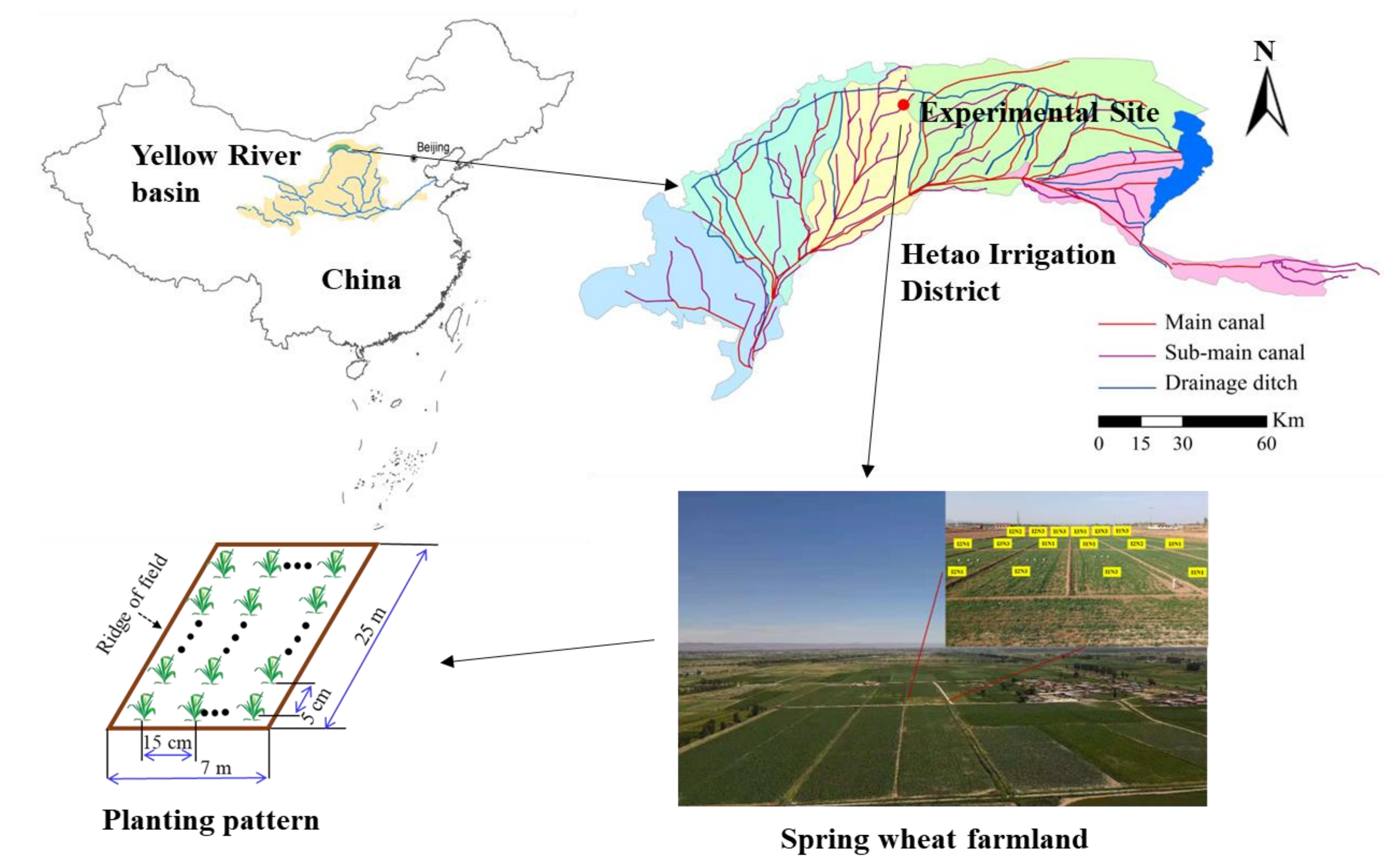


Fig.1. Location of field experiment. From 2019 to 2020, soil moisture content, NO_3^--N and NH_4^+-N contents, CO_2, CH_4, N_2O and NH_3 fluxes, and NO_3^--N and NH_4^+N leaching were collected under different irrigation depths and nitrogen fertilization amounts conditions

Table 1. Five GCM from CMIP6

GCM ID	Name	Abbreviation	Country	Spatial Resolution (lat°×lon°)
2	ACCESS-ESM1-5	ACC2	Australia	1.2×1.8
4	CanESM5	Can1	Canada	2.8×3.8
15	GFDL-ESM4	GFD2	America	1.0×1.3
16	GISS-E2-1-G	GISS	America	2.0×2.5
23	MPI-ESM1-2-HR	MPI1	Germany	0.9×0.9

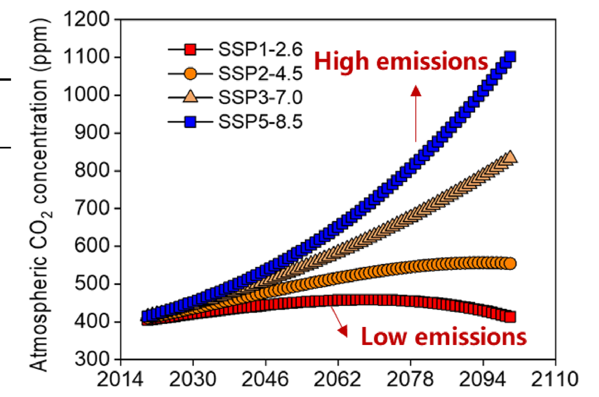
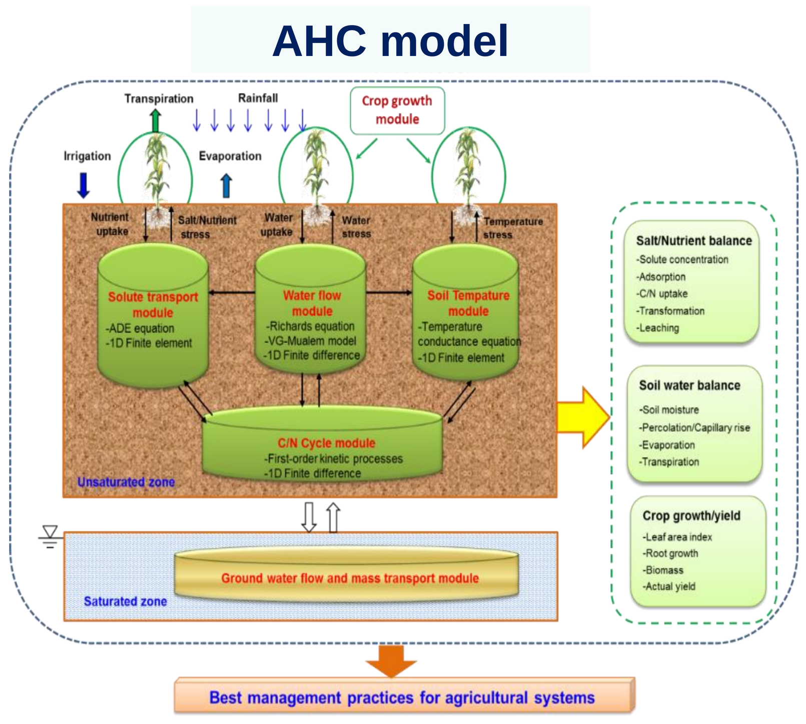


Fig.2 Atmospheric CO_2 concentration



- **Simulation period:** 2025-2100, **Base year:** 2020
- **Soil water consumption (ΔW)**

$$\Delta W = ET_a + R + F - I - P_e$$

ET_a-actual crop evapotranspiration
R- surface runoff
F- deep percolation
I-irrigation water
P_e- precipitation

- **Net ecosystem carbon budget (NECB)**

$$NECB = NPP + C_f - (R_s + C_h)$$

NPP-crop net primary production
C_f- carbon input caused by fertilization
R_s- soil CO_2 emissions
C_h-carbon output caused by grain

Analysis results

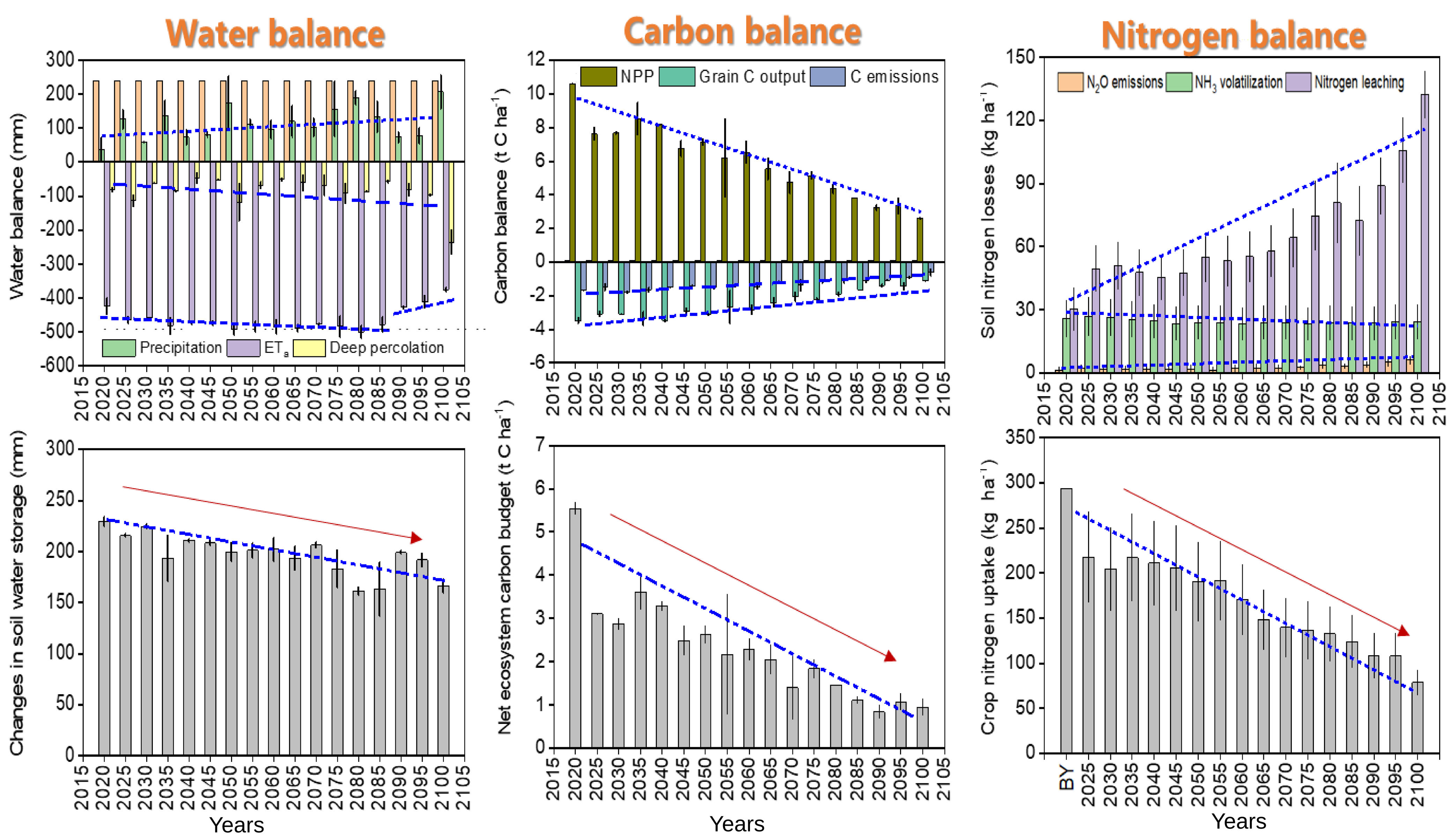


Fig. 2. Farmland WCNBs characteristics during spring wheat growing seasons under the SSP5-8.5 scenarios from 2025 to 2100.

Table 1. Fitting equation corresponding to each trend line of farmland carbon and nitrogen balance characteristics under high emissions scenario

SSPs	Items	Fitting equation	Change 10 year^{-1}
SSP5-8.5	Crop C assimilation	y=−0.37x+9.42	-0.74 t C ha^{-1}
	Soil CO_2 emissions	y=−0.04x+1.45	-0.08 t C ha^{-1}
	NECB	y=−0.22x+4.51	-0.44 t C ha^{-1}
	N leaching	y=4.43x+25.57	+8.86kg ha^{-1}
	Soil N_2O emissions	y=0.23x+0.53	+0.46 kg ha^{-1}
	Soil NH_3 volatilization	y=−0.14x+25.69	-0.28kg ha^{-1}
	Crop N uptake	y=-10.28x+262	-20.56kg ha^{-1}

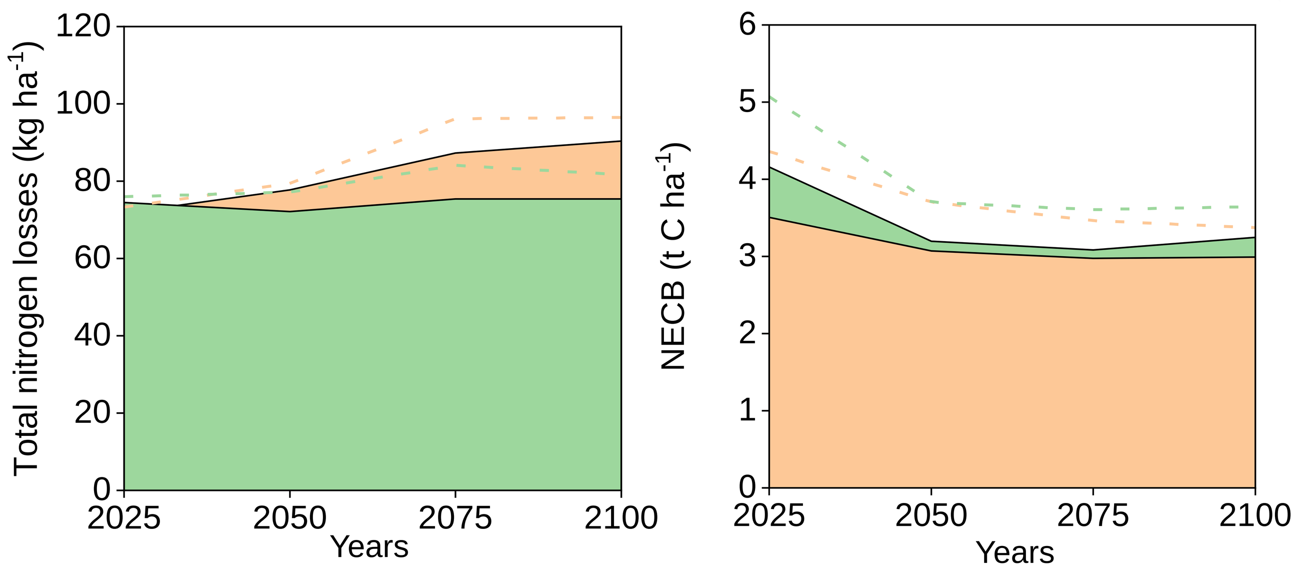


Fig. 3. Comparison between current strategy (yellow) and compensation strategy (green) under the SSP5-8.5 scenario. Compared with the current strategy, the compensation strategy reduced irrigation by 45%, increased N fertilization by 45%.

Conclusions and outlook

- Precipitation showed an increasing trend, thus percolation increased and soil water consumption decreased from 2025 to 2100.
- Although the soil CO_2 emissions tend to decrease, the crop C assimilation was also significantly reduced, which resulted in declining farmland C sinks under future climatic conditions.
- Higher temperature and increased precipitation enhanced soil inorganic N leaching and N_2O emissions but reduced NH_3 volatilization from 2025 to 2100. Overall, the soil total N loss was increased over time, whereas crop N uptake was significantly reduced.
- Reducing irrigation and increasing N fertilization can mitigate the negative effects of climate change on WCNBs to some extent, but these negative effects cannot be completely offset by adjusting irrigation and fertilization management. Developing crop varieties that are resistant to high temperatures and high CO_2 concentrations may be a potential way to address these negative impacts caused by future climate change.

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