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Potential water stress caused by climate change and cropland expansion on the Northern Slope of the Tianshan Mountains

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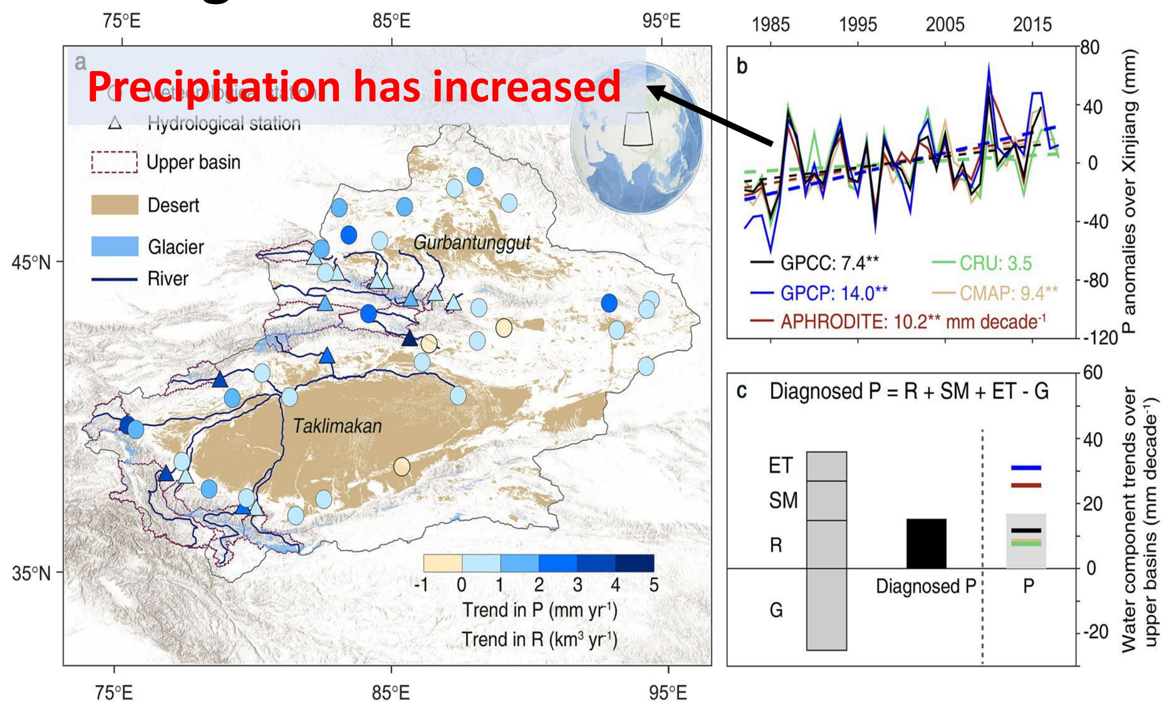
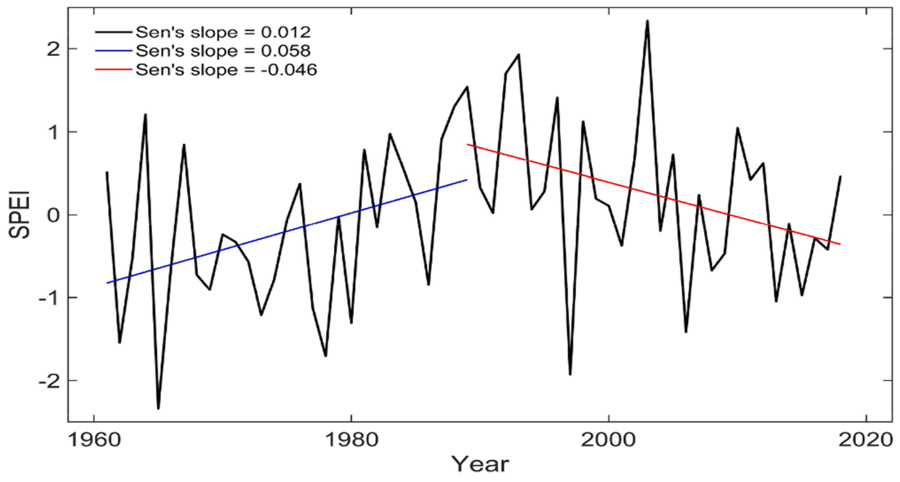
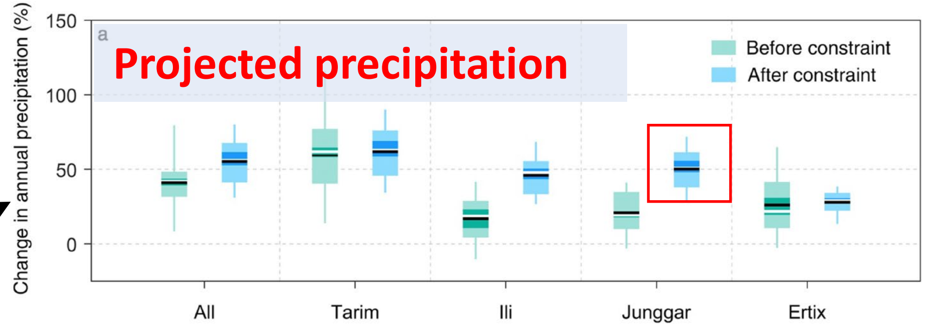
Background

Wetting trend has been reported in most regions of Xinjiang or Northwest China. However, increased evapotranspiration due to warming climate may offset the wetting trend.





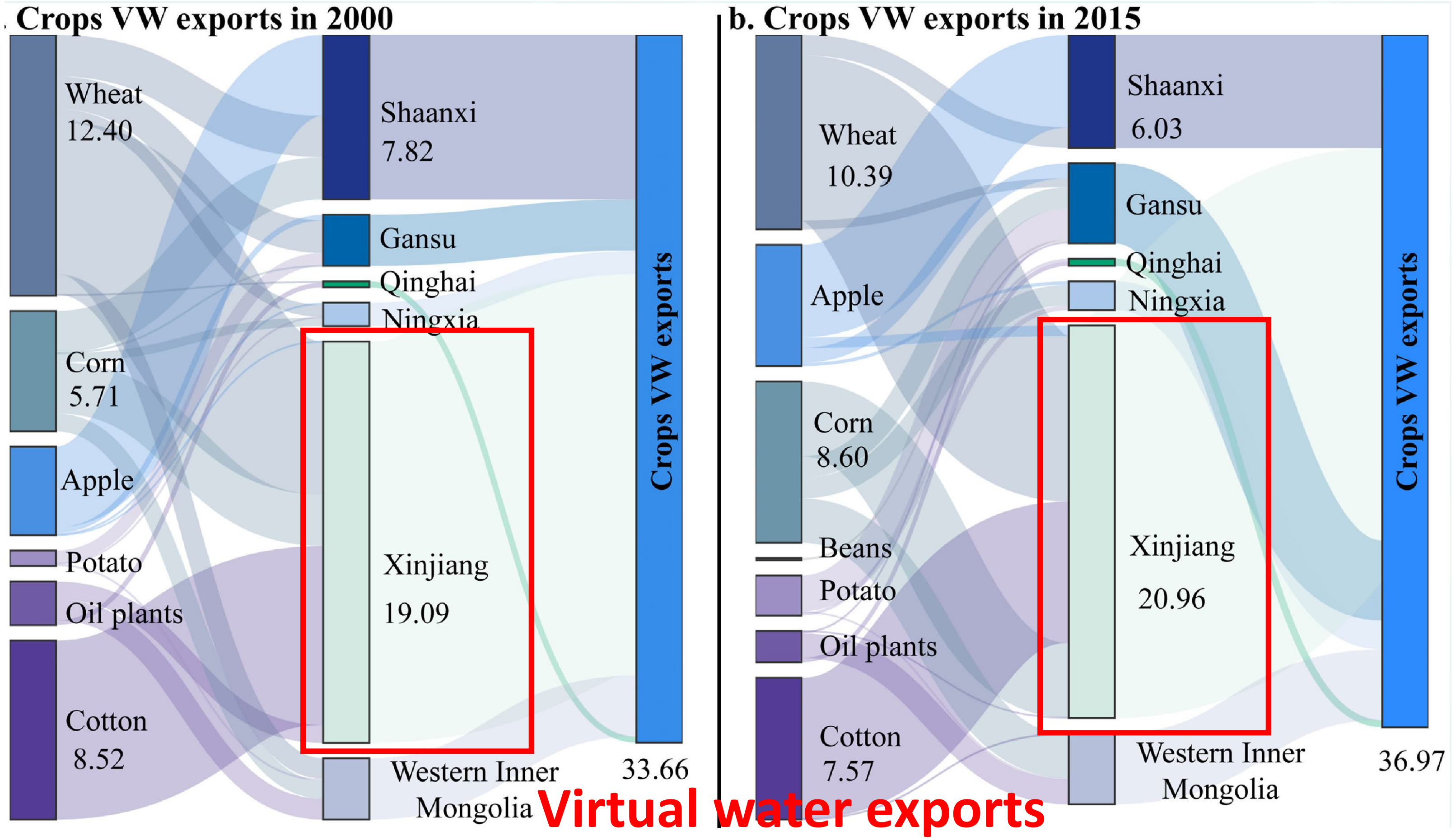


Precipitation would increase by more than 40% in Northern Xinjiang at the end of 21st century.

Deng et al. 2022; Feng et al. 2022

Background

Xinjiang is one of the major crop production area in China, and has the largest ratio of virtual water flow to water footprint in Northwest China.



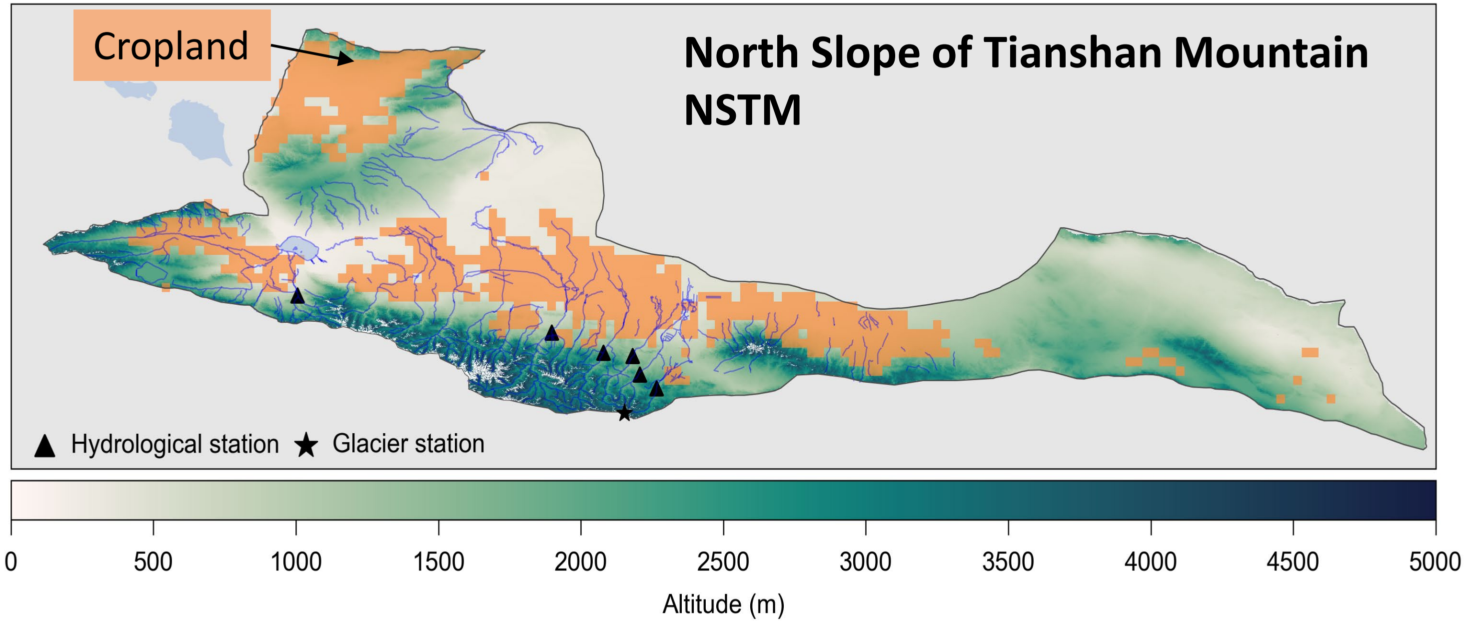
For the coming decades with increasing precipitation and warming climate:

Food security?
Water security?
How to maintain the high crop production exports?

Background

Water security in the Northern Slope of the Tianshan Mountains (NSTM) is important for future development in Xinjiang.

- NSTM is the major area of crop production and industry of Xinjiang.
- Irrigation >85% of total water use
- Glacier/snow melt runoff accounts for up to 40% of total runoff
- Groundwater depletion issue



Question:

- How much would water stress be intensified by increasing crop water requirement resulted from cropland expansion and climate change?
- How much would water-saving measures (e.g., mulching) alleviate the water stress?

Dataset

Historical meteorological forcing

China Meteorological Forcing Dataset (1979-2018), 0.1 degree

Future climate change (2030-2050):

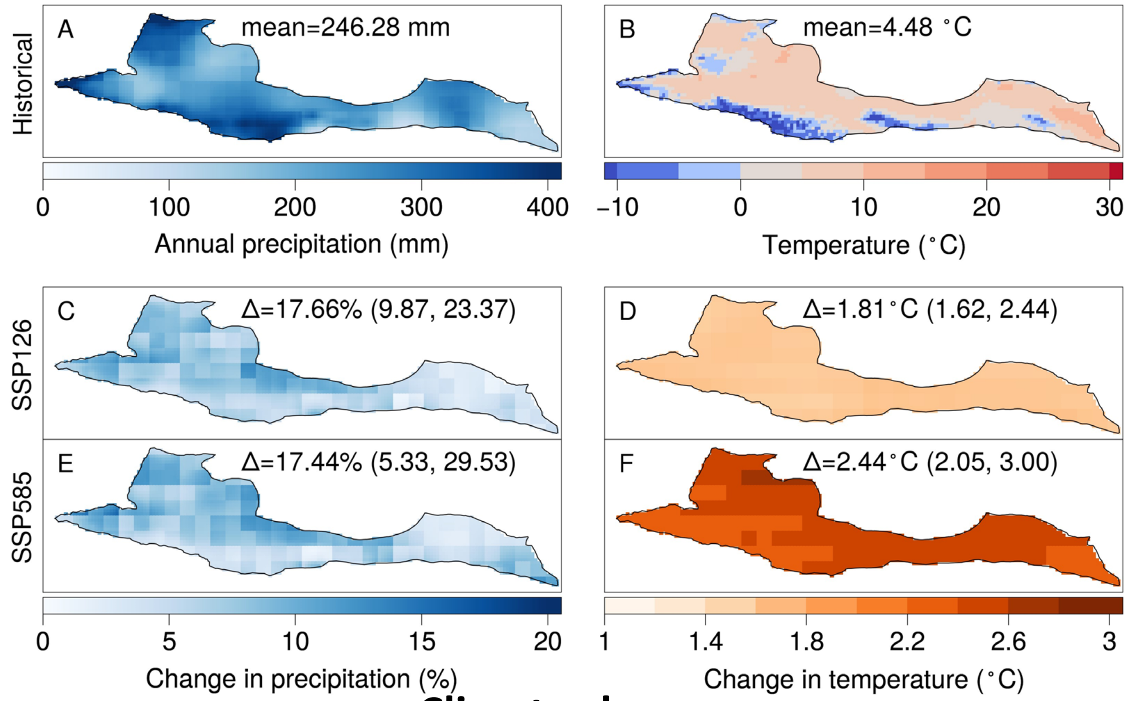
Bias-corrected projection from 10 GCMs (ISIMIP3b), 0.1 degree

Streamflow
monthly streamflow at several stations for model validation

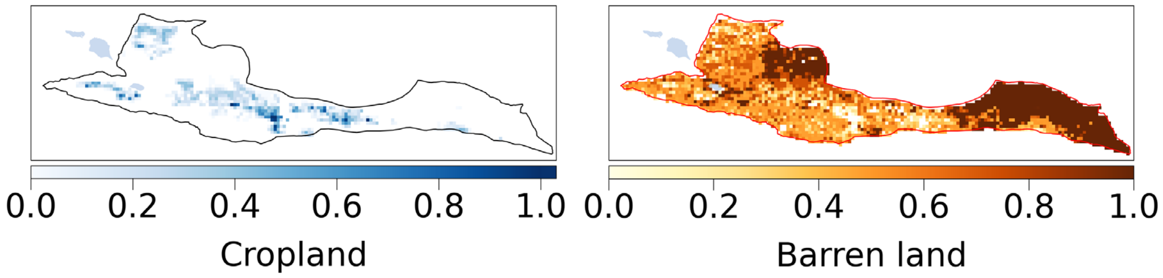
Cropland

Historical: Global gridded agricultural-production map (Yu et al., 2020), 0.1 degree, ~2010

Cropland expansion: 20% increase in total



Climate change



Cropland expansion scenario

Method

Crop water requirement

FAO-56 Penman-Monteith method (with dual crop coefficient):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Domestic and industrial water use

Historical data from Huang et al. (2018);

Water stress and Groundwater depletion risk

$$\boldsymbol{WSI = \frac{WD}{TWA}}$$

WD = sum of irrigation, domestic and industrial water use.

$$\boldsymbol{R_d = \frac{WD - SWA}{R_g}}$$

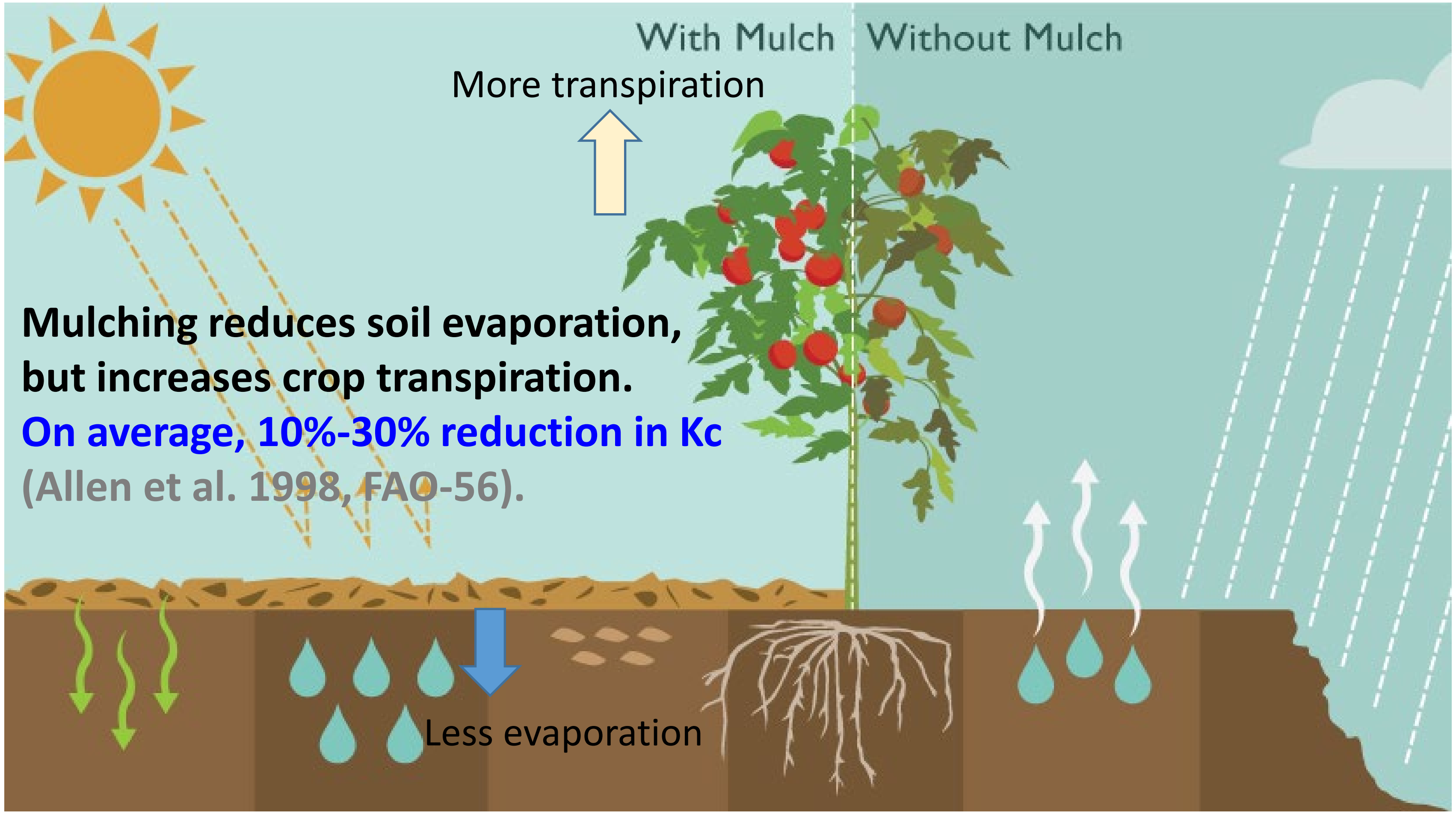
TWA = surface runoff (*SWA*) + groundwater recharge (R_g)

Degree-day model for melt runoff

$\boldsymbol{R_m = DDF_{ice} \cdot \Delta M_{ice} + DDF_{snow} \cdot \Delta M_{snow}}$, DDF_{ice}=6.3-9.3, DDF_{snow}=4.1-6.4

Method

Effect of mulching on estimating ETc



In this study, in case of mulched cropland, the crop coefficient Kc will reduce by 20% in the computation of crop ET.

Method

Experiment design

Quantify the effects of climate change, cropland expansion, and crop management by comparing the experiments

Experiment	Configuration
Baseline	Historical conditions (mulching in 30% cropland)
Climate change	Future climate (ISIMIP3b)
Cropland expansion	Future climate, Historical cropland + 20%
Water management	Mulching in all cropland (100%)

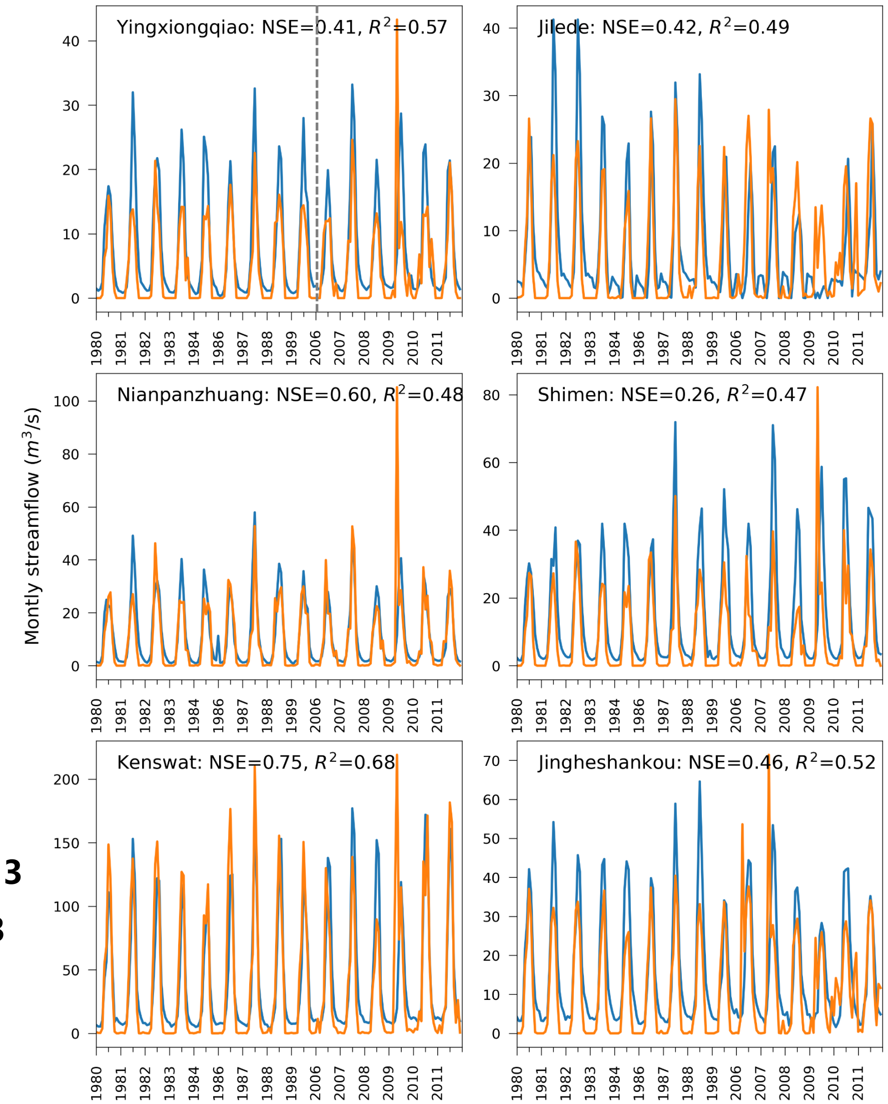
Results

Model validation

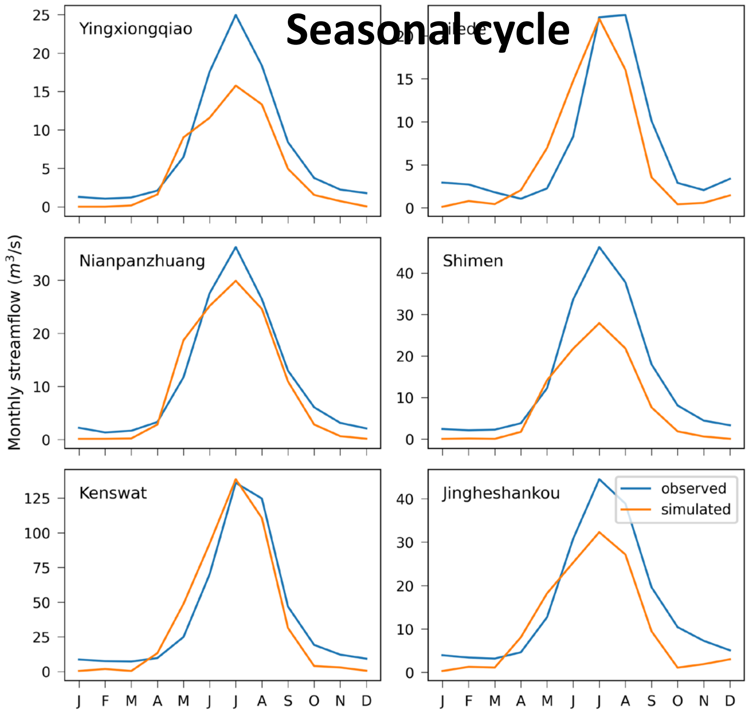
Generally underestimate the flow in flood season.

Possible reason: groundwater recharge is not well represented in some basins.

Irrigation withdrawal (2009-2018):
Simulated: 11.0×10⁹m³
Reported: 11.8×10⁹m³
Relative error: -6%



Seasonal cycle

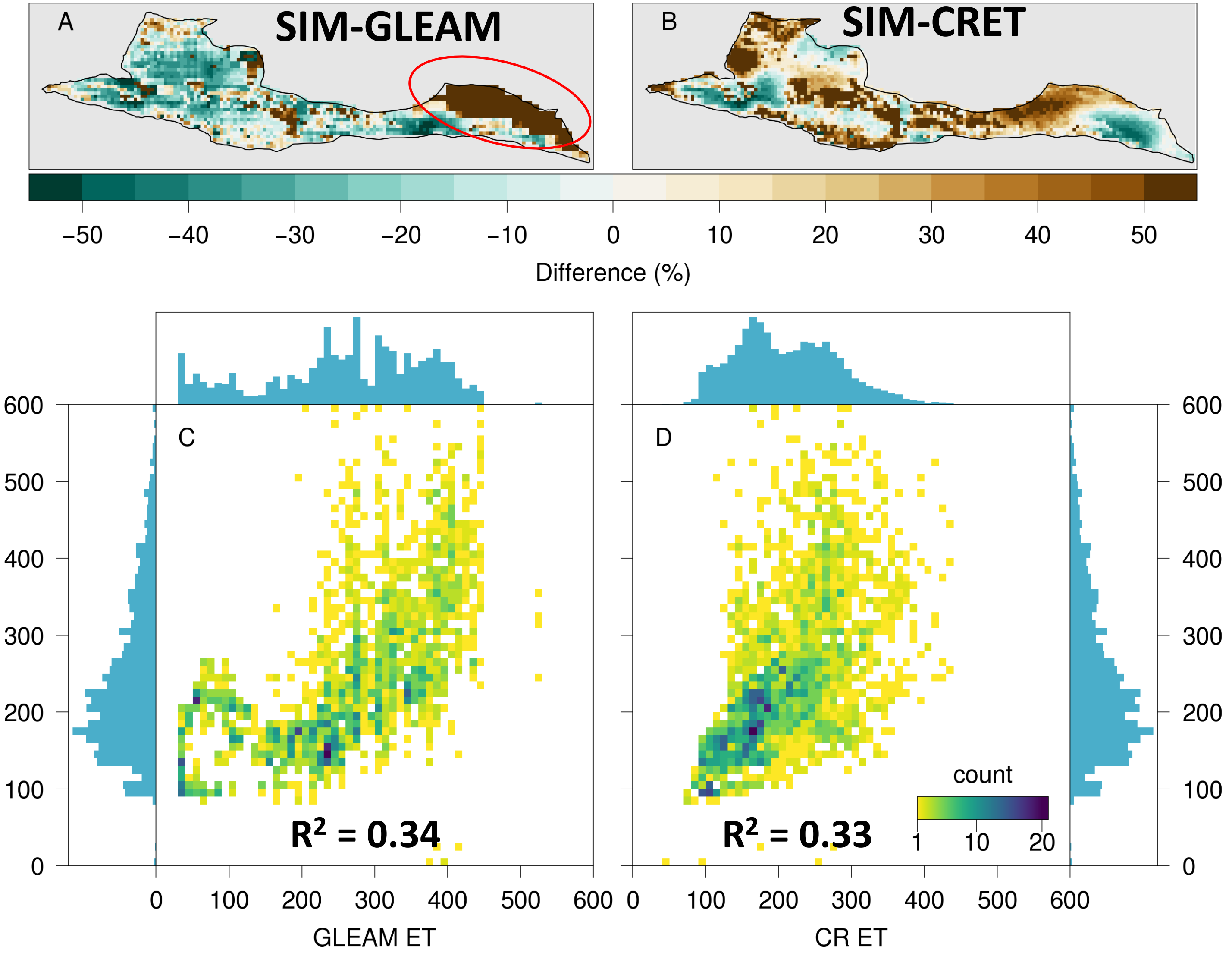


Station	Calibration	Validation
Yingxiongqiao	0.51	0.30
Jilede	0.54	0.32
Nianpanzhuang	**0.74**	**0.48**
Shimen	0.51	0.02
Kenswat	**0.87**	**0.59**
Jingheshankou	0.61	0.25

Results

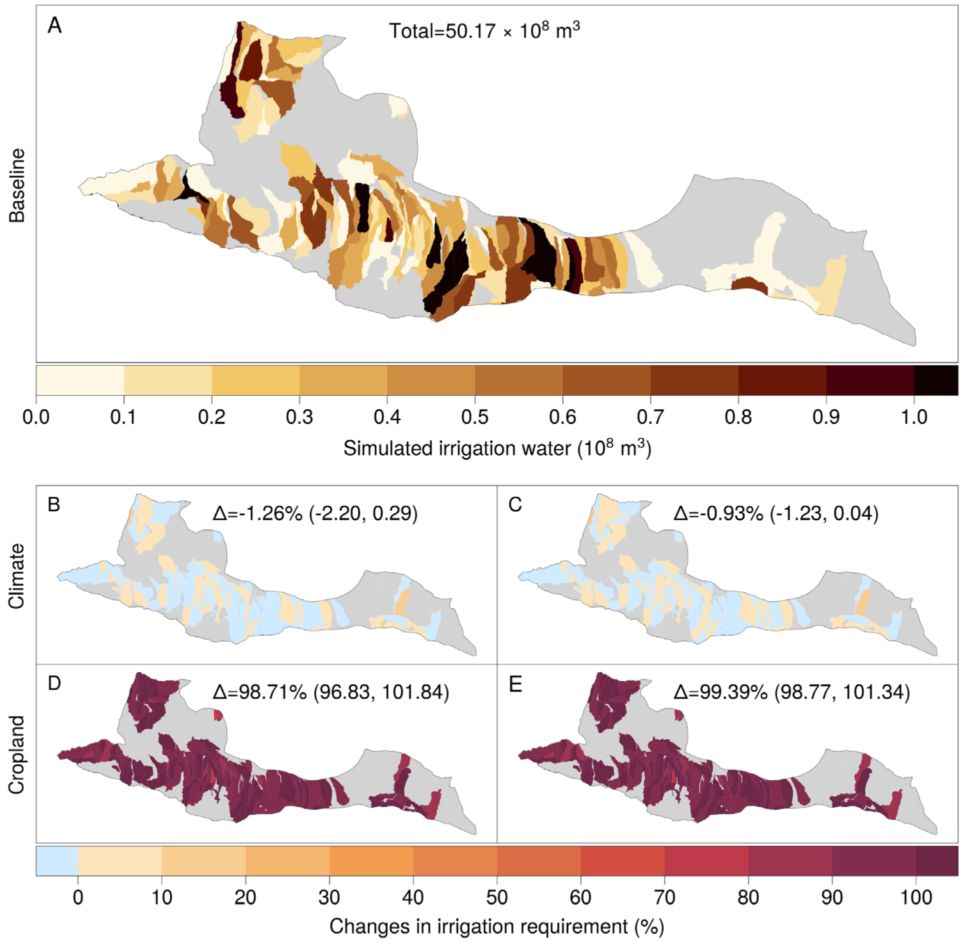
Comparison between simulated ET and GLEAM, CR ET data

Overall, simulated ET is higher than both GLEAM and CR ET data.
For 1990-2018:
Simulated: 257 mm
GLEAM: 252 mm
CR ET: 211 mm



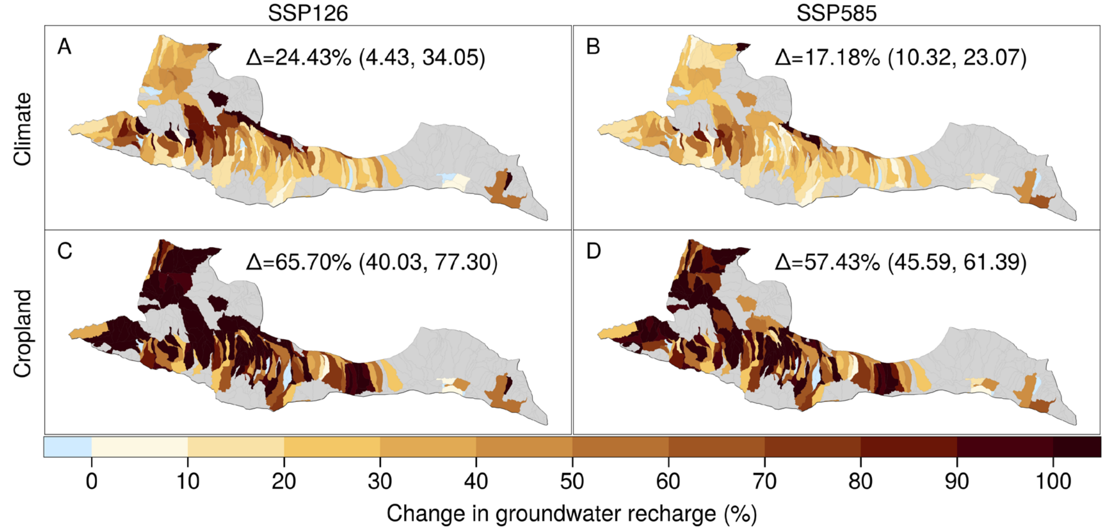
Results

Changes in irrigation under different scenarios (2030-2050)



Climate scenarios:
Irrigation will slightly decreases by 0.9% to 1.2% in total; groundwater recharge increase by 17% to 24%

Cropland expansion:
Irrigation will increase ~100% in total, groundwater recharge increase by 57% to 66%

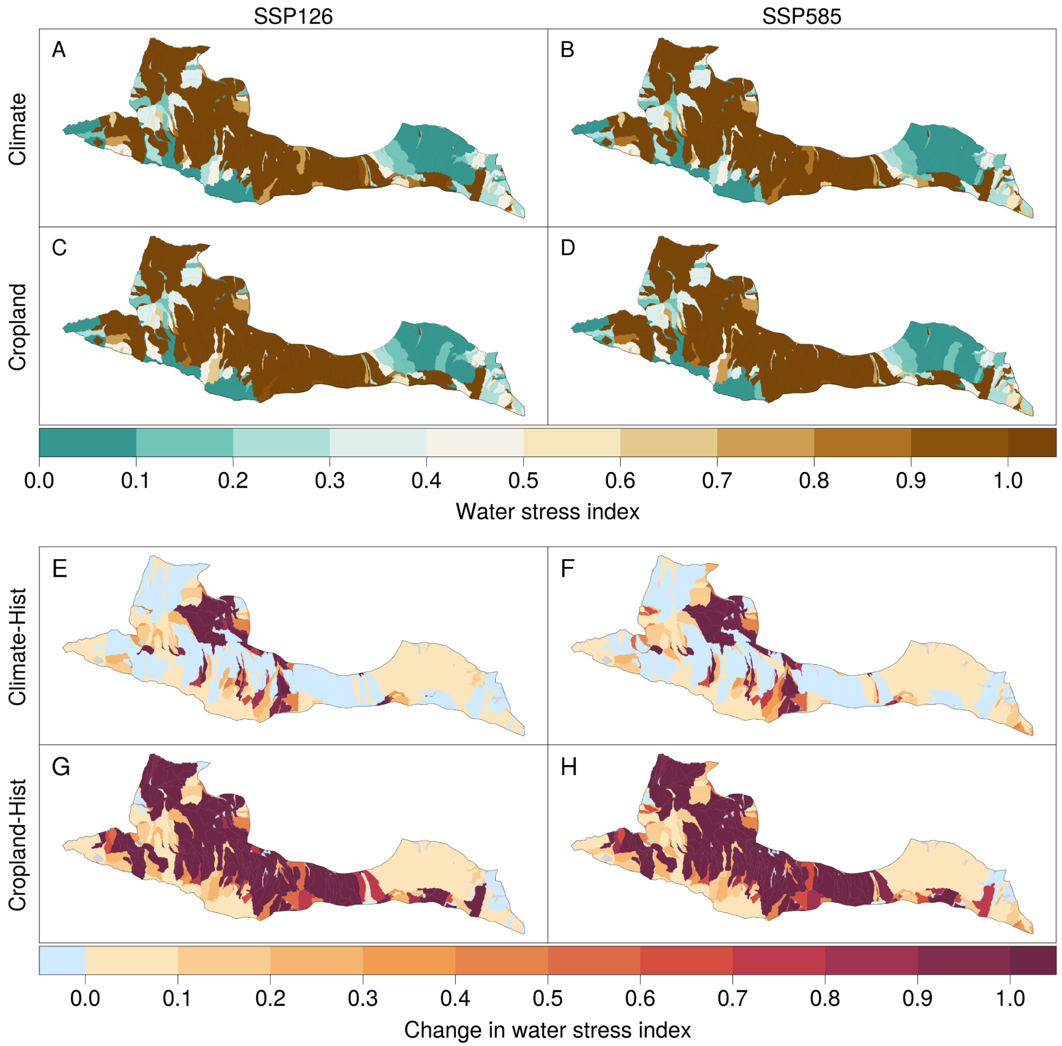


Results

Changes in water stress index WSI>0.4 indicates severe water stress

Severe water stress is found in cropland areas under both scenarios

Compared to historical conditions, water stress will alleviate to some degree under climate scenarios, but will significantly increase under the cropland expansion scenario.



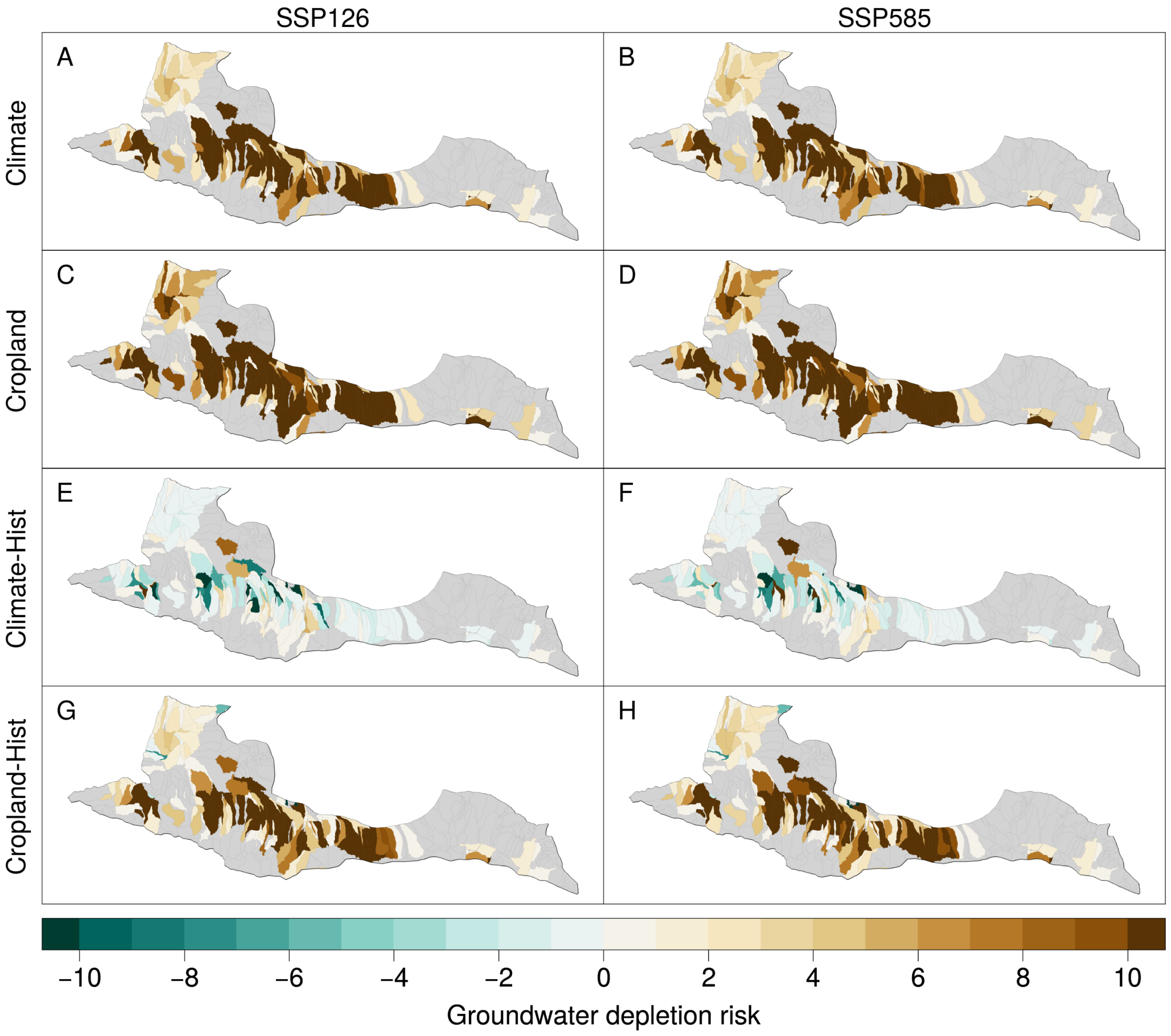
Water stress index (2030-2050)

Results

Potential groundwater depletion risk under different scenarios

Climate change: risk may exist over most cropland areas, but alleviate to some degree compared to historical conditions

Cropland expansion: higher risk compared to climate scenarios and historical conditions



Groundwater depletion risk (2030-2050)

Results

Effects of crop management on irrigation changes (2030-2050)
Mulching may alleviate some water stress

Experiment	Median	25th	75th
SSP126			
Climate	-1.28%	-2.20%	0.30%
mulching effect	-5.48%	-5.50%	-5.46%
Cropland Expansion	98.7%	96.8%	101.8%
mulching effect	-11.13%	-11.19%	-11.07%
SSP585			
Climate	-0.93%	-1.24%	0.04%
mulching effect	-5.50%	-5.50%	-5.46%
Cropland Expansion	99.4%	98.8%	101.3%
mulching effect	-11.15%	-11.19%	-11.11%

Compared to historical conditions (1981-2010)

Climate change may slightly reduce irrigation
Crop management (mulching) can reduce irrigation by 5.5%

Cropland expansion will double irrigation
Crop management can reduce irrigation by 11%

Summary

- The model shows acceptable performance of simulations of runoff and irrigation water on the NSTM
- Precipitation will increase by ~17%, and air temperature will increase by 1.8-2.4 °C on the NSTM during 2030-2050
- Under future climate change, Irrigation will slightly decreases by 0.9% to 1.2% in total and groundwater recharge increase by 17% to 24%, which may slightly alleviate groundwater depletion risk
- Cropland expansion (+20%) will double the irrigation requirement, which may largely aggravate groundwater depletion risk
- Crop management (mulching and microirrigation) can reduce irrigation requirement by 5% to 11% and alleviate groundwater depletion risk

Thank you!