Assessing the influence of climate variability on land use change from cotton to perennial bioenergy grasses: implications on watershed hydrology and water quality

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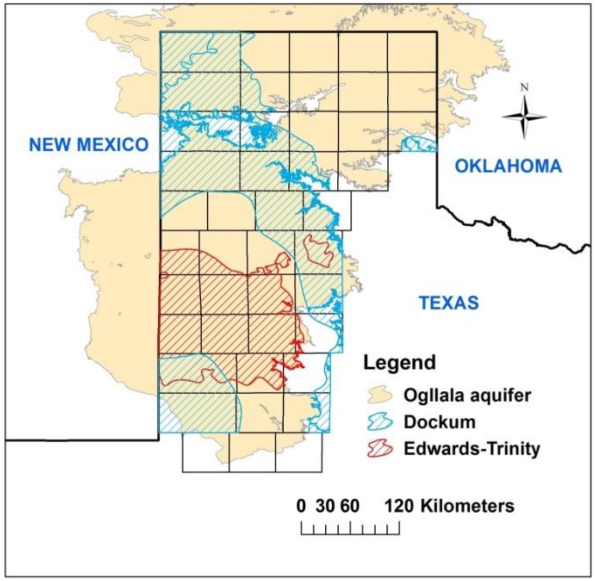
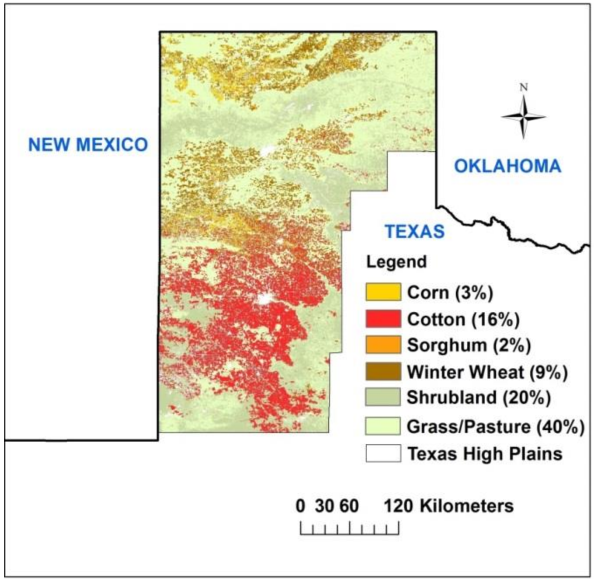
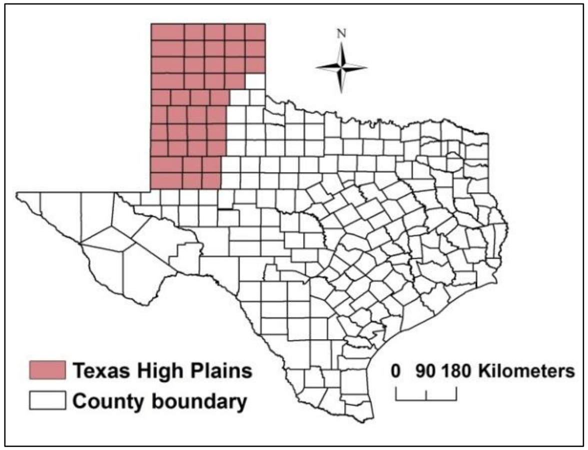
*Presenter

Introduction

- Texas High Plains (THP) is one of the intensive agricultural regions in the US.
- Cotton is a major crop grown in the THP region, and this region produced approximately 25% of U.S. cotton in 2013.
- Annual precipitation in the THP ranges from about 36 cm in the west to 61 cm in the east.
- Ogallala Aquifer is the primary source of irrigation water.
- About 97% of water from the Ogallala Aquifer is used for crop irrigation.







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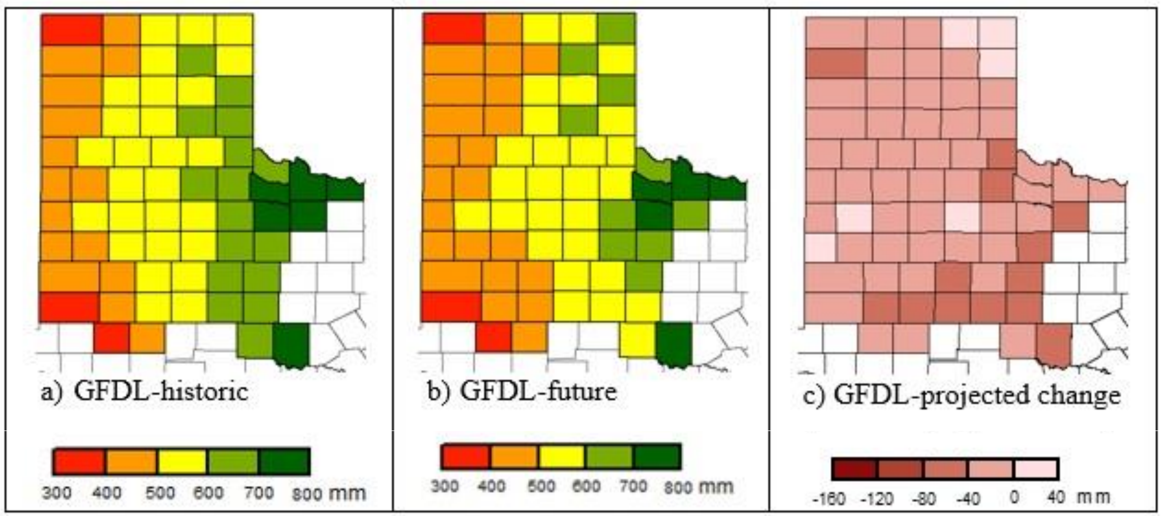
Challenges being faced by THP agriculture

- Recurring droughts in the recent times.
- Rapidly declining groundwater levels in the Ogallala aquifer.
- Ground water pumping restrictions (50/50 management rule):
  - 46 cm (18 inches) per year.
- Climate change studies predict warmer summers and reductions in annual rainfall in this region in the future.

Projected changes in average annual precipitation



Modala, Ale et al., 2015 (Theoretical and Applied Climatology, In Review)

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Potential land use changes in the THP

- Potential land use change from irrigated to high water use efficient and/or rainfed crops in the future.
- Perennial bioenergy grasses offer an alternative and they can play a significant role in minimizing the negative effects of climate change.
- The USDA has also estimated that about 11.4% of existing croplands and pastures in the Southeastern U.S. region, which includes the THP, will be required for meeting the 2022 national cellulosic biofuel target.
- Land use change from croplands to cellulosic bioenergy crops in the THP may significantly affect regional hydrology and water quality.
- Climate change impacts may further pose some risks to the water resources availability and crop production.

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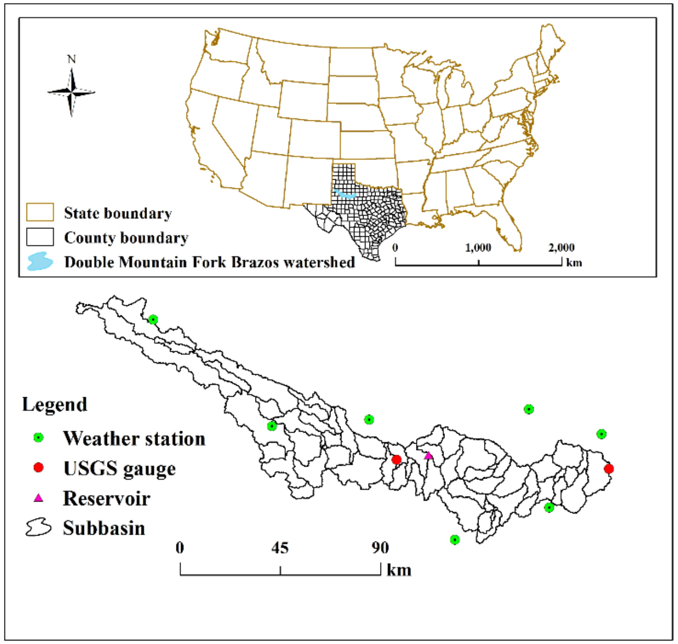
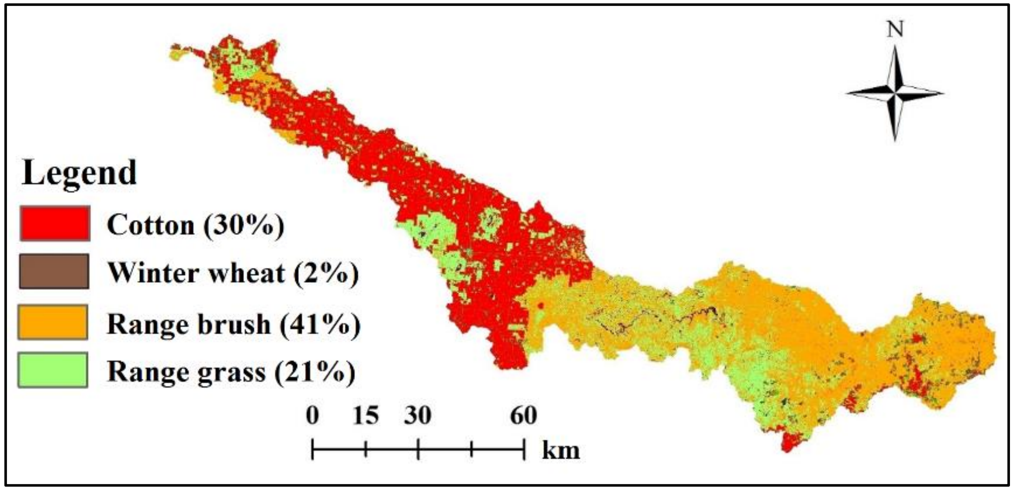
Objectives

- The overarching goal of this study was to assess the influence of climate variability on hydrology and water quality under potential land use change from cotton to perennial bioenergy grasses.
- The specific objectives were to:
  - Calibrate the SWAT model using the observed streamflow, crop yield and total nitrogen (TN) load data.
  - Study the effects of climate variability on water balance parameters, TN load and crop yield under the base line (cotton) and proposed land use change (cotton replaced by switchgrass and *Miscanthus*) scenarios.
    - Climate parameters considered in the sensitivity analysis include:
      - Atmospheric CO_2 concentrations
      - Precipitation
      - Temperature.

Study watershed

- Double Mountain Fork Brazos watershed (HUC # 12050004)
- Total delineated area: ~ 6000 km^2.
- Average (1981-2010) annual precipitation: 46 to 56 cm.
- Average annual T_{max} and T_{min} are about 23 to 25°C and 8 to 10°C, respectively.
- Soil types: Amarillo sandy loam, Acuff sandy clay loam and Olton clay loam.
- Major land uses: cotton, range brush and range grasses





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SWAT model parameterization

- Digital elevation model (DEM): 30×30 m resolution from the USGS.
- Land use: 2008 NASS Cropland Data layer (CDL).
- Soils: Finer scale Soil Survey Geographic Database (SSURGO).
- Soil slope: 4 classes: ≤ 1%, 1%-3%, 3%-5% and > 5%.
- Land use, soil and slope thresholds of 5%, 5% and 10%.
- 60 Subbasins and 2160 HRUs.
- Auto-irrigation was simulated in an appropriate number of cotton HRUs in such a way that ~ 39% of cotton acres (NASS, 2014) were irrigated.
- Auto-irrigation operation applied water whenever 10% reduction in plant growth occurred due to water stress until the soil moisture reached field capacity.

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Model calibration – Parameters adjusted

Parameter	Description	Default value	Calibrated value	Reference
Hydrologic parameters				
ESCO	Soil evaporation compensation factor	0.95	0.855	--
SOL_AWC	Available soil water capacity (mm H_2O mm^{-1} soil)	0.1-0.17	10% increase	--
CN2	Curve number for moisture condition II	39-84	-6.5% Gauge I -9% Gauge II	--
ALPHA_BF	Base flow recession constant	0.048	0.0765	--
Dryland cotton parameters				
BIO_E	Biomass/energy ratio	15	16.8	Sarkar et al., 2011
HVSTI	Harvest index	0.5	0.49	Wanjura et al., 2014
BLAI	Max leaf area index	4	4.5	Sarkar et al., 2011
Irrigated cotton parameters				
BIO_E	Biomass/energy ratio	15	19.95	Sarkar et al., 2011
BLAI	Max leaf area index	4	5.98	Sarkar et al., 2011
EXT_COEF	Light extinction coefficient	0.65	0.78	Sarkar et al., 2011

Chen, Ale et al., 2015 (Global Change Biology Bioenergy, doi: 10.1111/gcbb.12304)

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Model calibration – Parameters adjusted

Parameter	Description	Default value	Calibrated value
Water quality parameters			
CDN	Denitrification exponential rate coefficient	1.4	0.5
SDNCO	Denitrification threshold water content	1.1	0.0*
NPERCO	Nitrogen percolation coefficient	0.2	0.4
ERORGN	Organic N enrichment ratio	0	0.11
RS4	Rate coefficient for organic N settling in the reach at 20 °C (day^{-1})	0.05	0.1
N_UPDIS	Nitrogen uptake distribution parameter	20	15
BC1	Rate constant for biological oxidation of NH_4 to NO_2 in the reach at 20 °C in the well-aerated conditions (day^{-1})	0.55	1
BC2	Rate constant for biological oxidation of NO_2 to NO_3 in the reach at 20 °C in the well-aerated conditions (day^{-1})	1.1	2
BC3	Rate constant for hydrolysis of organic N to NH_4 in the reach at 20 °C (day^{-1})	0.21	0.4
SOL_NO3	Initial NO_3 concentration in the soil layer (mg/kg)	0	3.5

**Akhavan et al., 2010 (Agriculture, Ecosystems and Environment)*

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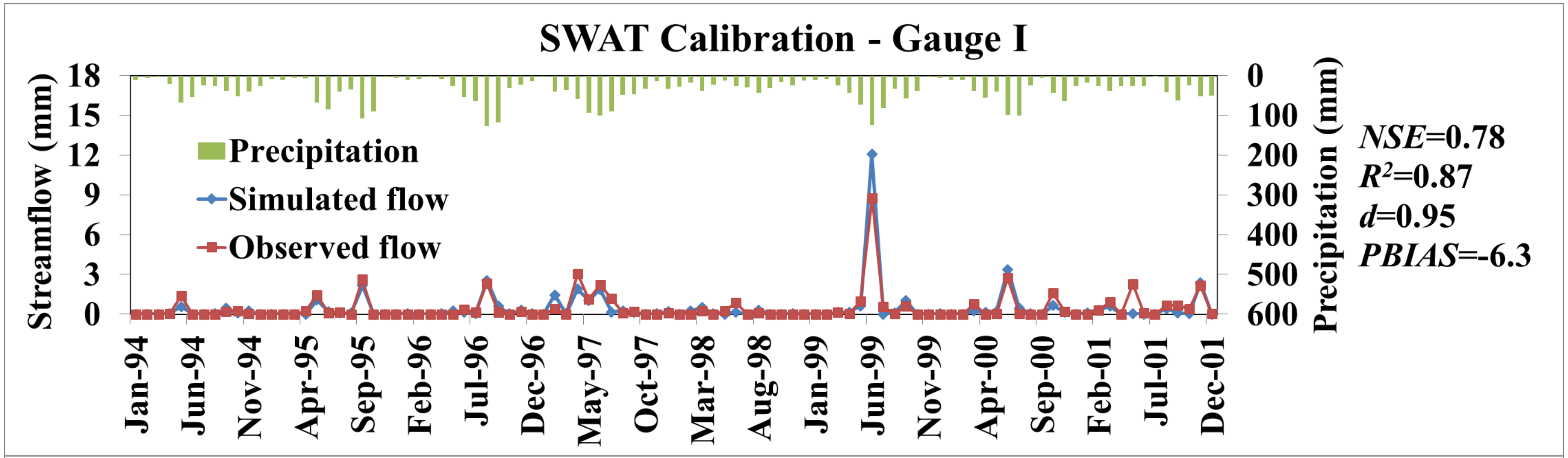
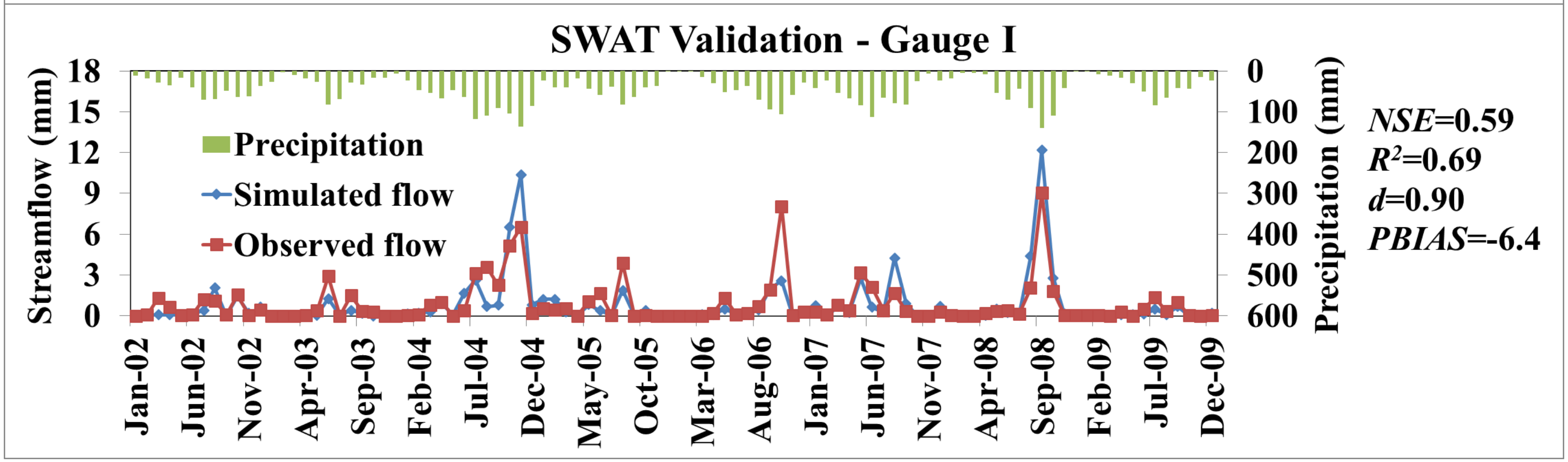
Model calibration – Comparison of streamflow – Gauge I





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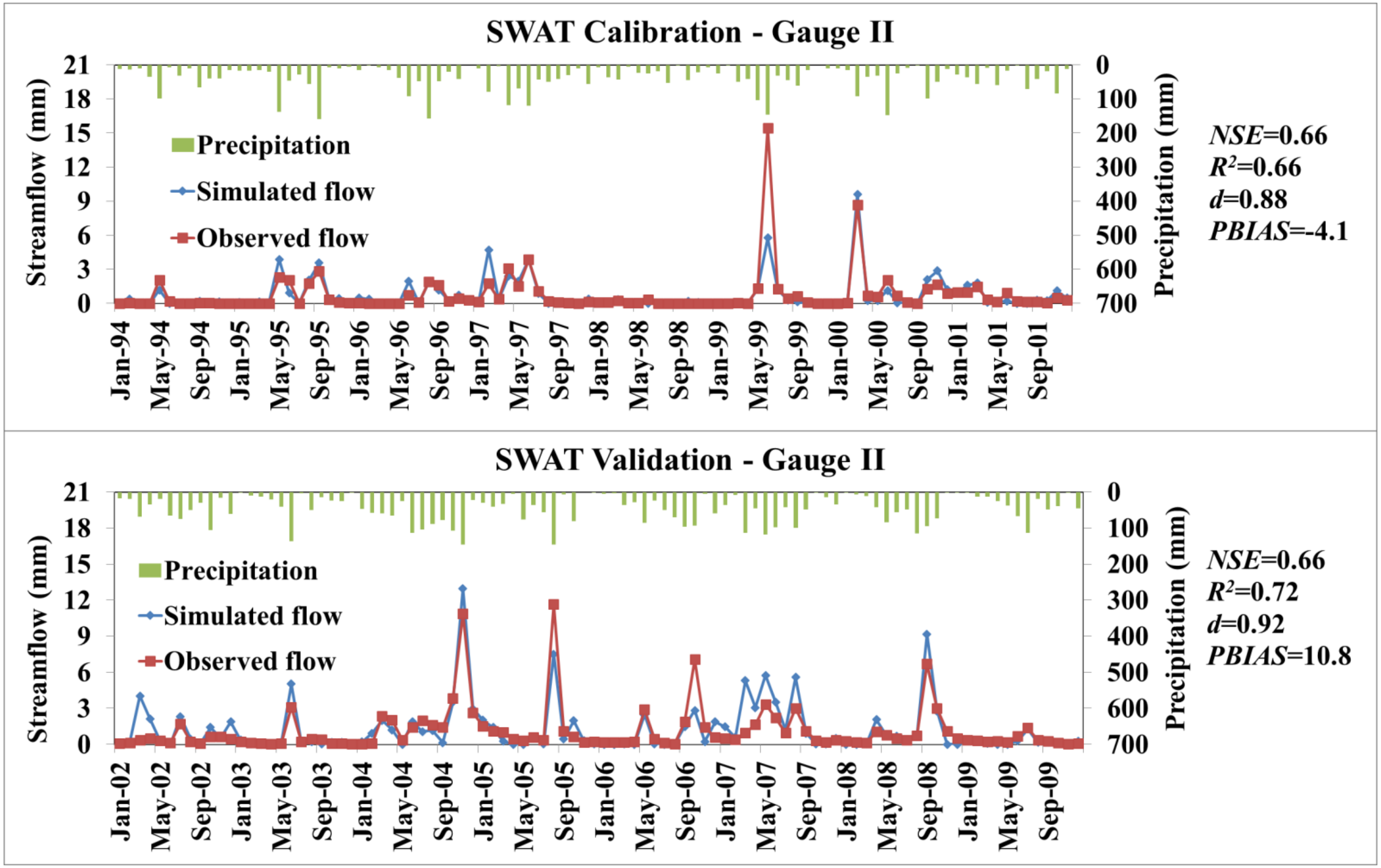
Model calibration – Comparison of streamflow – Gauge II



Chen, Ale et al., 2015 (Global Change Biology Bioenergy, doi: 10.1111/gcbb.12304)

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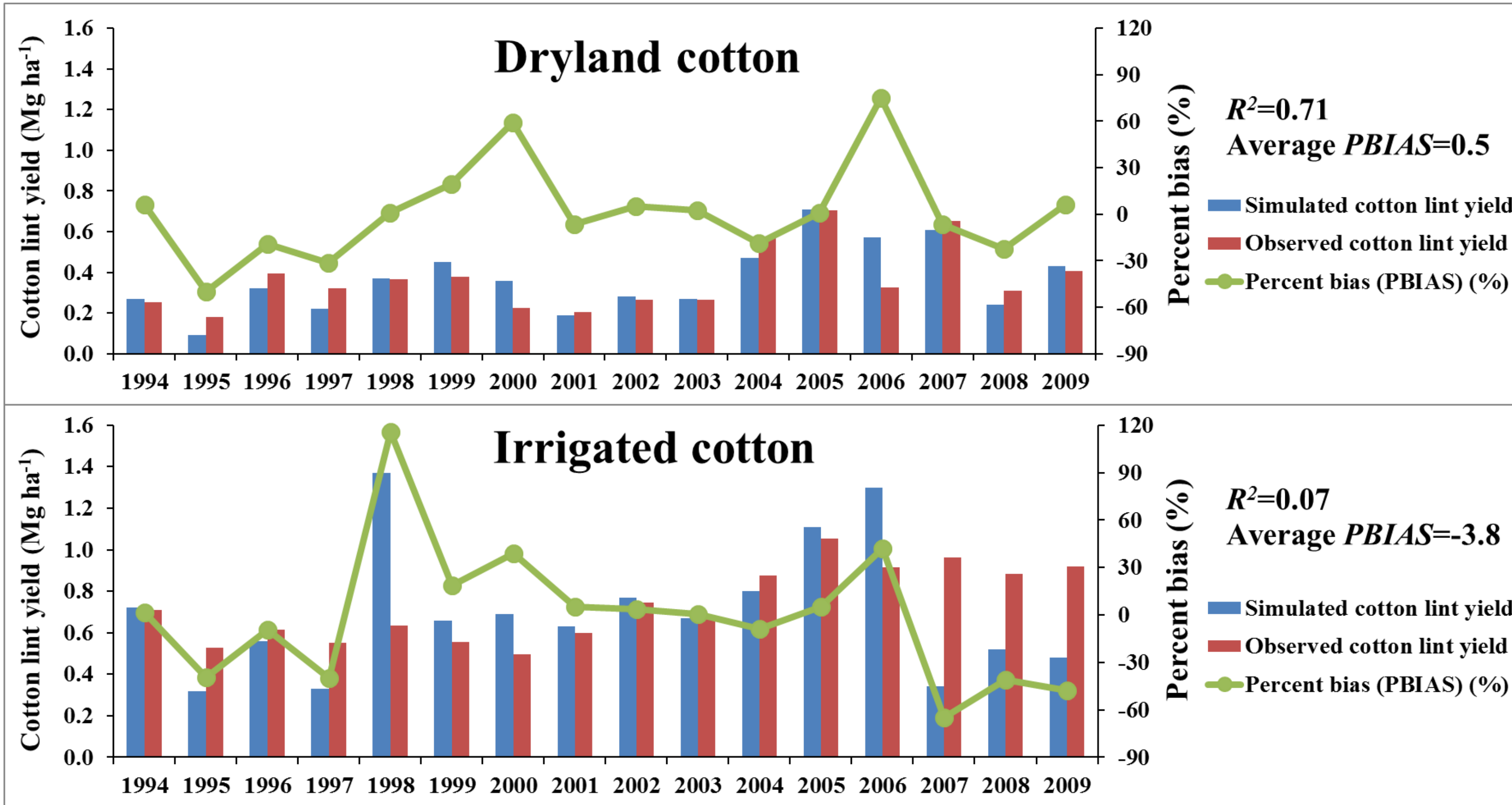
Model calibration – Comparison of cotton lint yield



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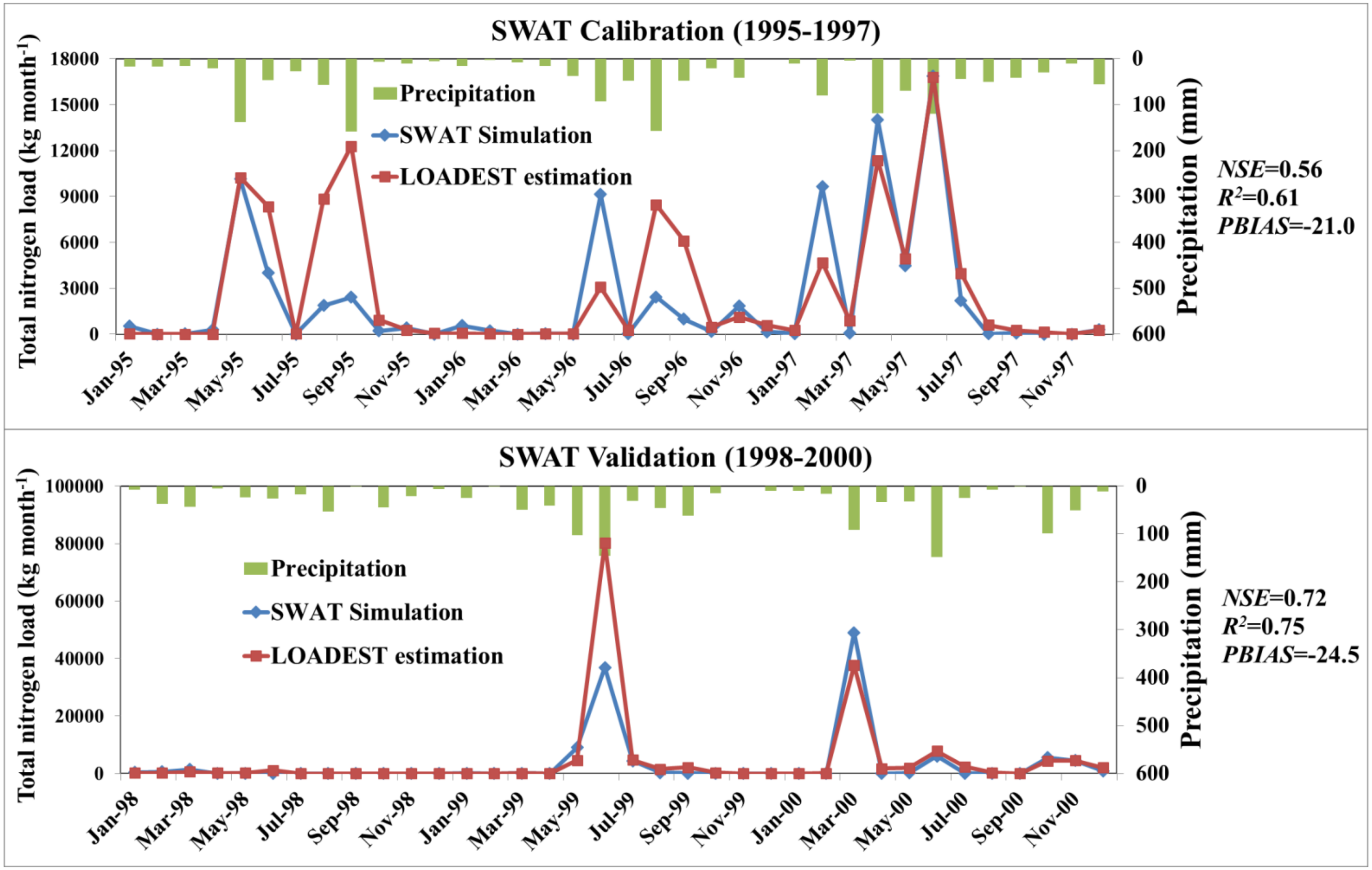
Model calibration – Comparison of Total Nitrogen (TN) loads



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Ideal perennial bioenergy grasses for the Texas High Plains

Average value (1994-2009)	**Switchgrass**	***Miscanthus***
Baseline irrigated cotton HRUs		
Irrigation water (mm)	284.3	**324.3**
Biomass production (Mg ha^{-1})	17.5	27.1
Irrigated water use efficiency (kg ha^{-1} mm^{-1})	**32.2**	**35.5**
Baseline dryland cotton HRUs		
Biomass production (Mg ha^{-1})	8.3	15.6
Water use efficiency (kg ha^{-1} mm^{-1})	16.7	**31.5**

- Switchgrass was identified as an ideal bioenergy crop under irrigated conditions due to high IWUE, less irrigation water requirement and TN load.
- *Miscanthus* was found to be an ideal bioenergy crop under dryland conditions due to higher WUE and greater biomass production potential.

Chen, Ale et al., 2015 (Global Change Biology Bioenergy, doi: 10.1111/gcbb.12304)

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Effects of land use change on water balance parameters and water quality

Land use change		Irrigation (mm)	ET (mm)	Surface runoff (mm)	TN load (tons)
Entire Watershed	Cotton	32.1	527	2.9	78
	Perennial grasses	32.9 (2.6%*)	525 (-0.5%)	0.6 (-79%)	23 (-71%)
Irrigated	cotton	277	755	3.4	120
	switchgrass	284 (2.6%*)	759 (0.6%)	0.6 (-83%)	12 (-91%)
Dryland	cotton	-	498	2.8	72
	Miscanthus	-	494 (-0.7%)	0.6 (-78%)	24 (-67%)

*Percent change with perennial grasses relative to baseline cotton

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Climate sensitivity analysis – 13 Scenarios

Climate parameters	CO_2 concentration (ppm)	Change in Precipitation (%)	Temp increase (°C)
Baseline	330	0	0
Scenario 1	495	0	0
Scenario 2	660	0	0
Scenario 3	330	-40%	0
Scenario 4	330	-30%	0
Scenario 5	330	-20%	0
Scenario 6	330	-10%	0
Scenario 7	330	+10%	0
Scenario 8	330	+20%	0
Scenario 9	330	+30%	0
Scenario 10	330	+40%	0
Scenario 11	330	0	+2°C
Scenario 12	330	0	+4°C
Scenario 13	330	0	+6°C

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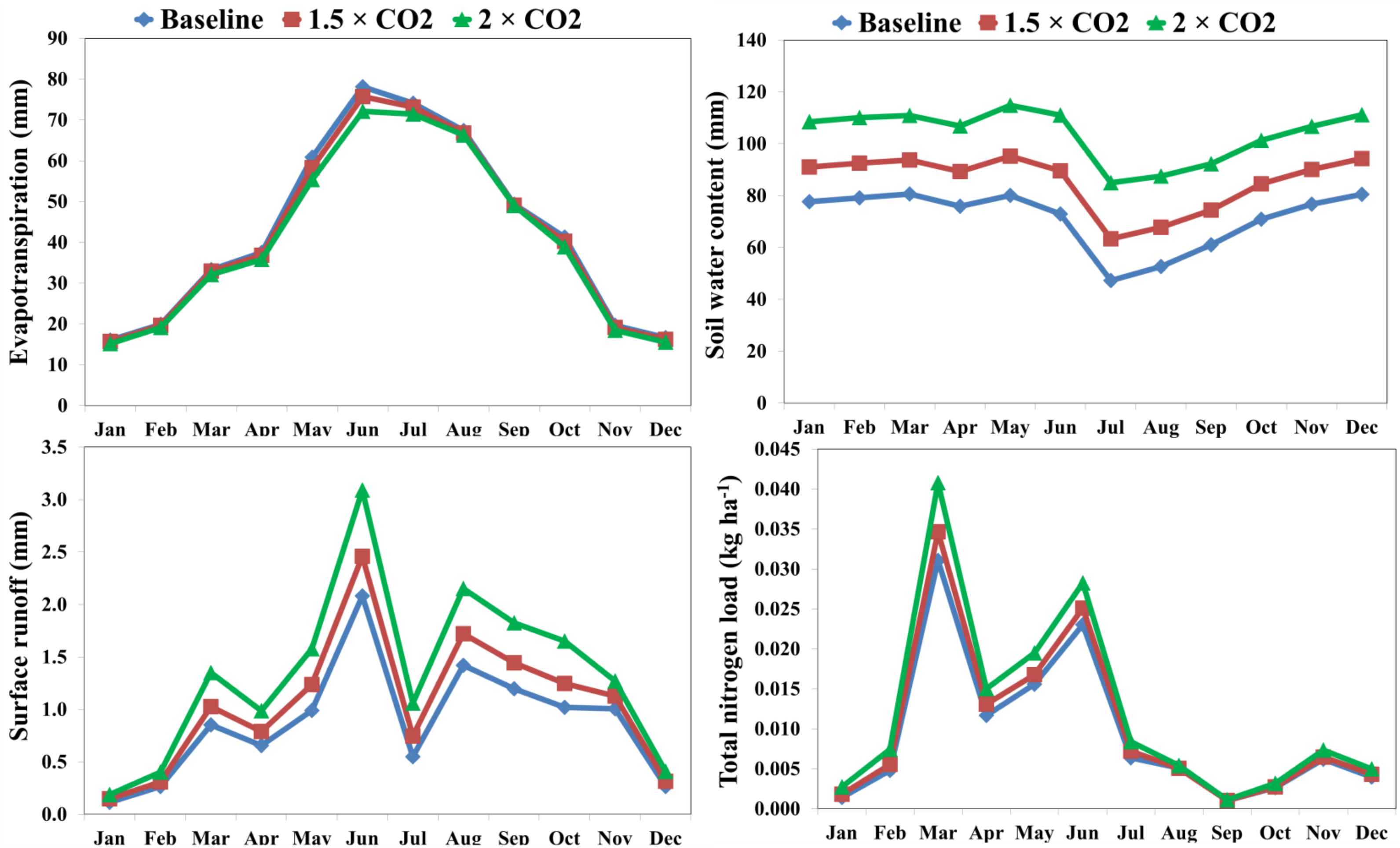
Effect of increase in CO_2 concentration on WB&TN under cotton land use (monthly)



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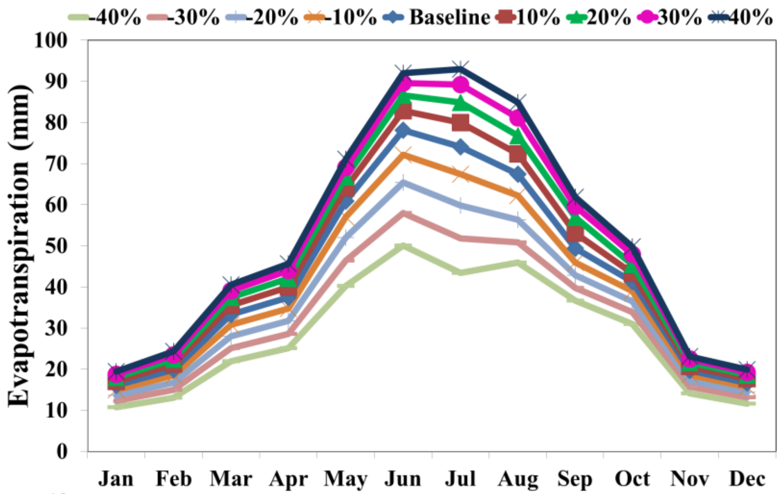
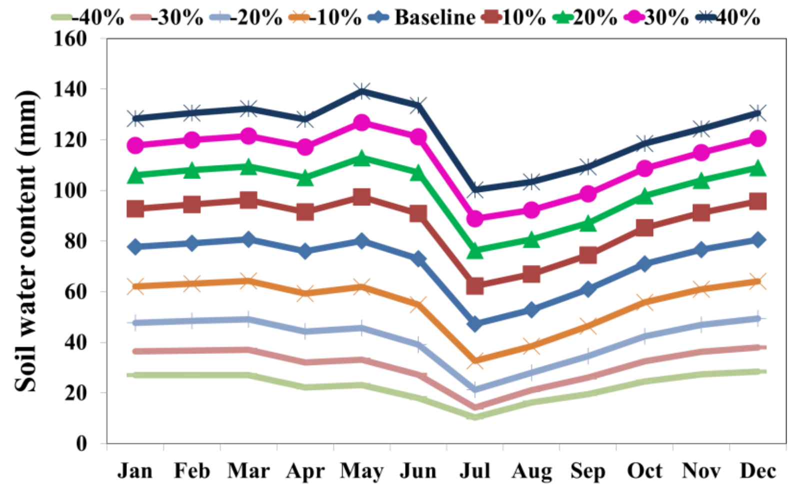
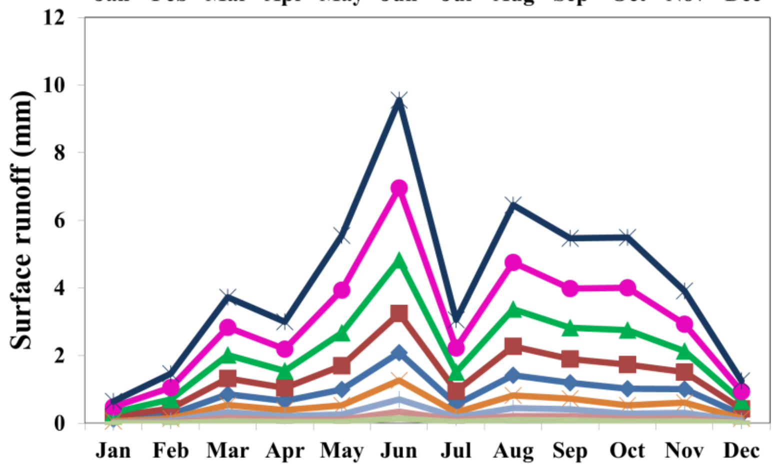
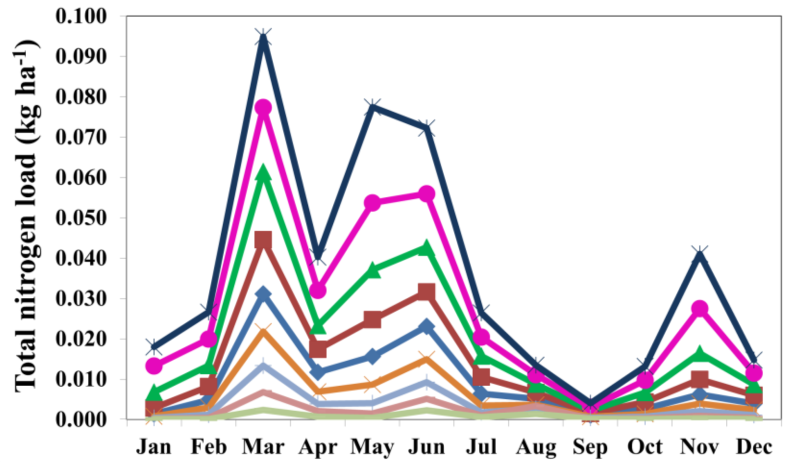
Effect of changes in precipitation on WB&TN under cotton land use (monthly)









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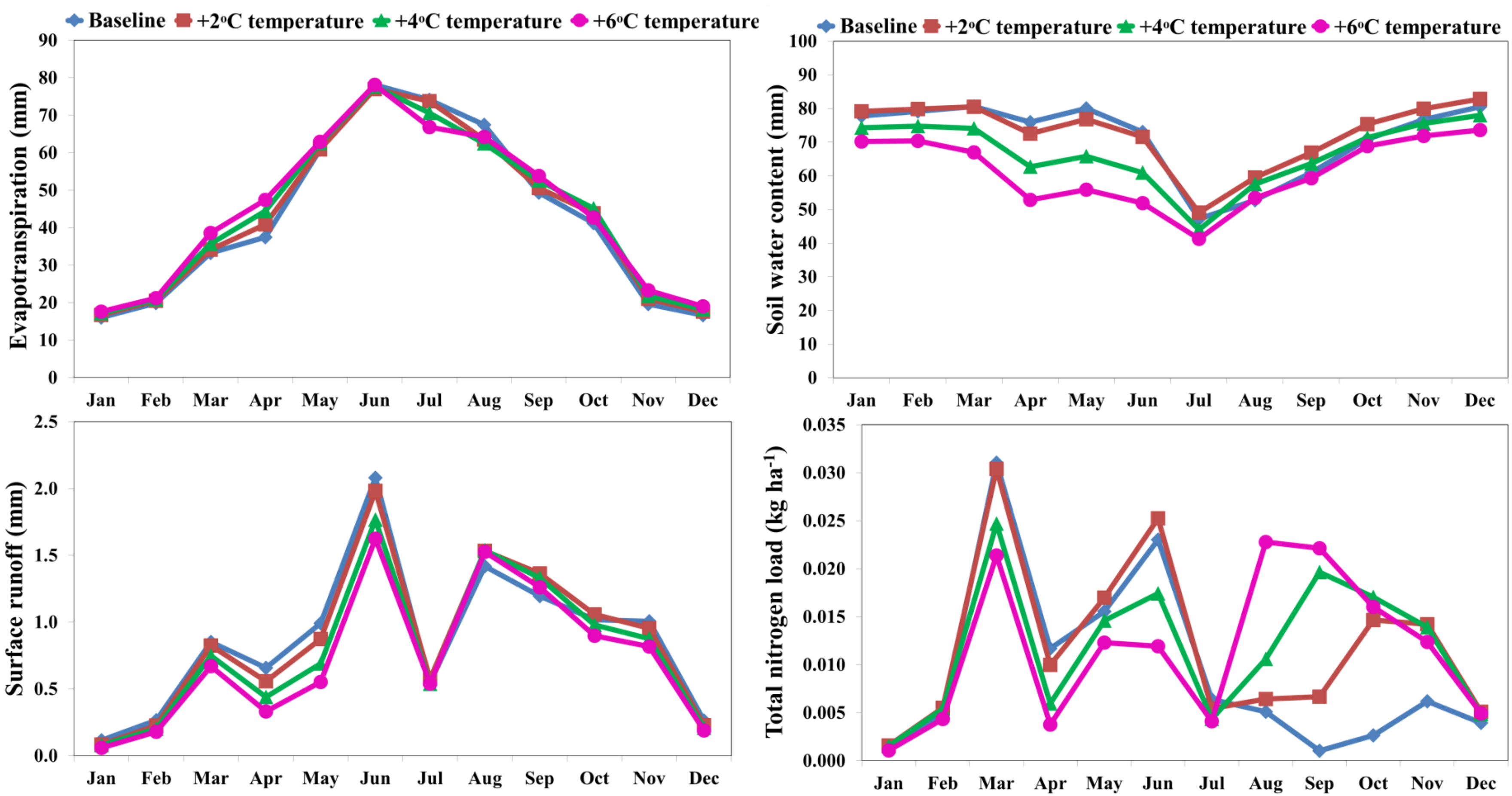
Effect of changes in temperature on WB&TN under cotton land use (monthly)



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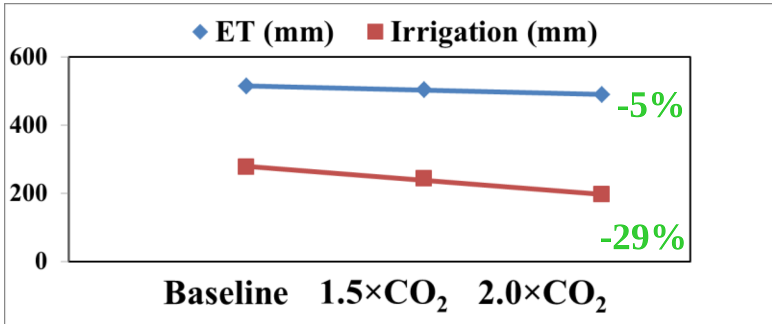
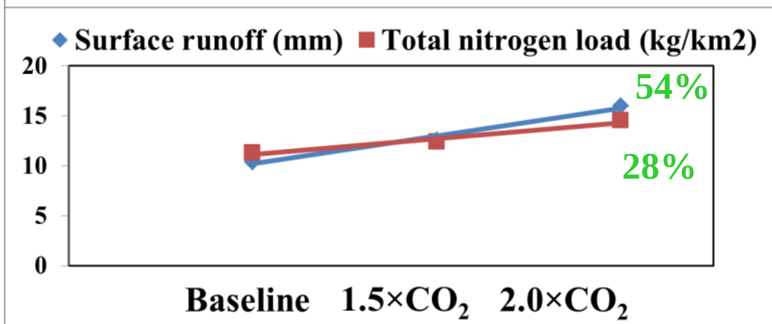
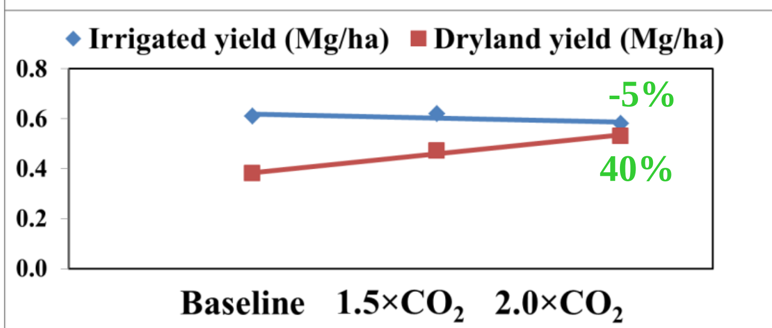
Effect of increase in CO_2 conc. on average annual WB, TN and yield

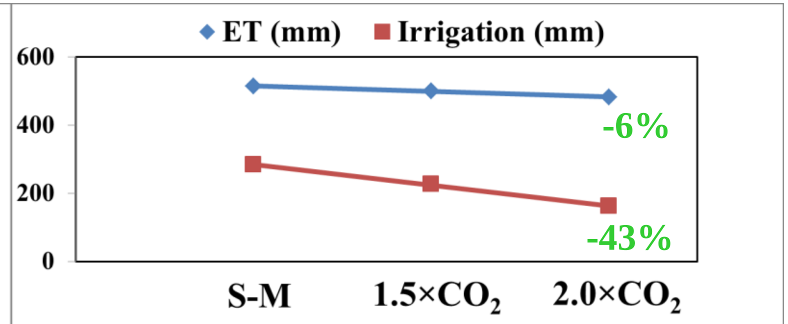
Cotton

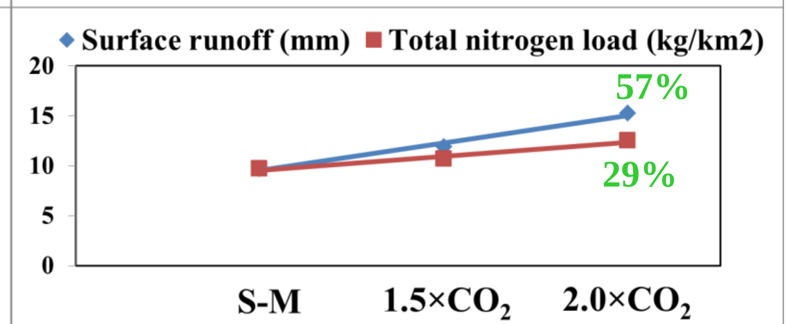


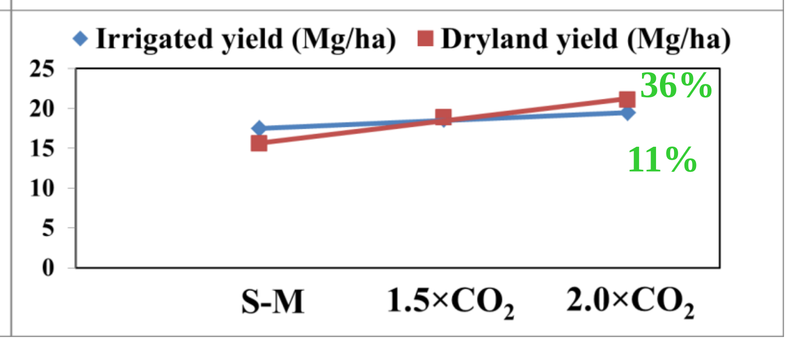




Perennial grasses







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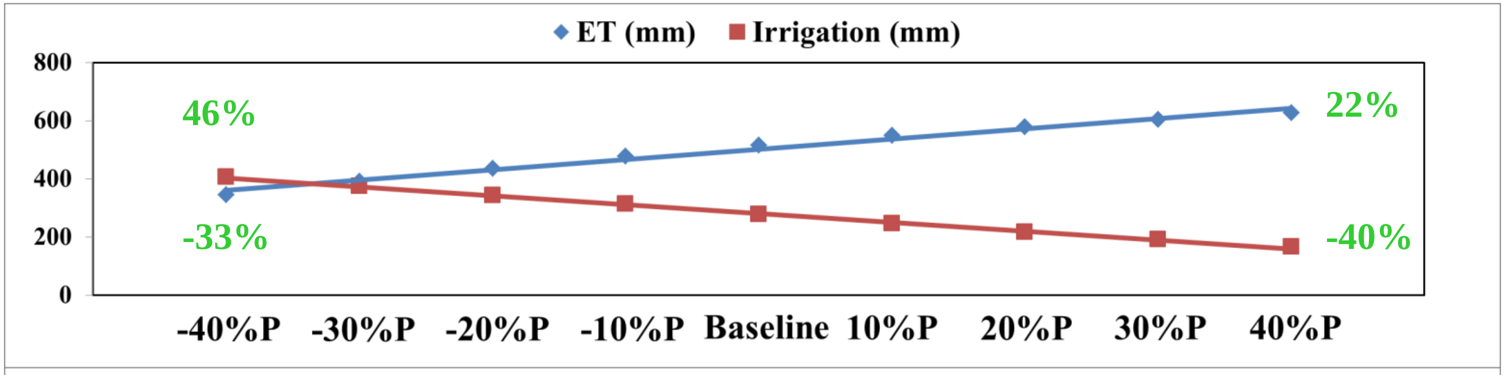
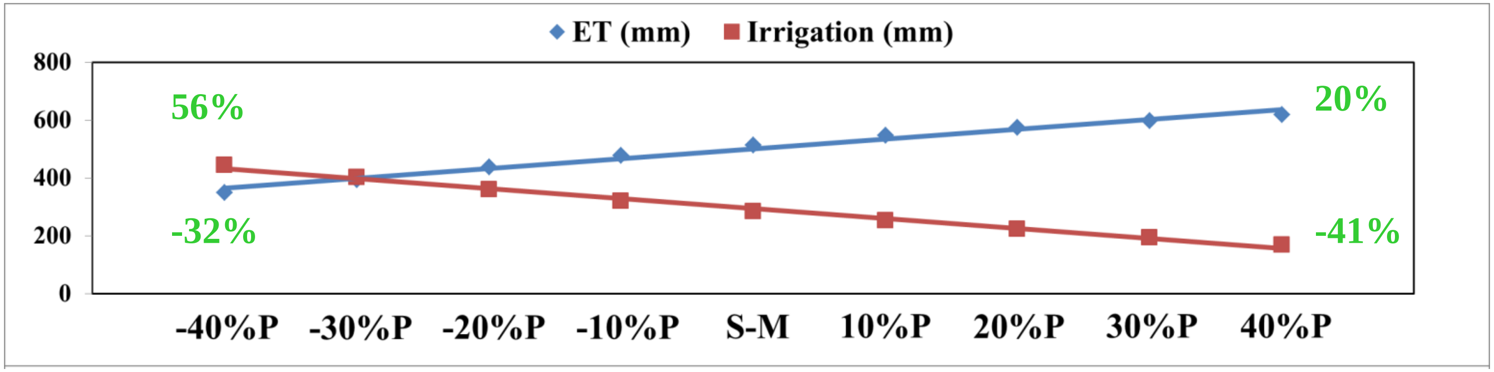
Effect of changes in precipitation on average annual ET and irrigation

Cotton



Perennial grasses



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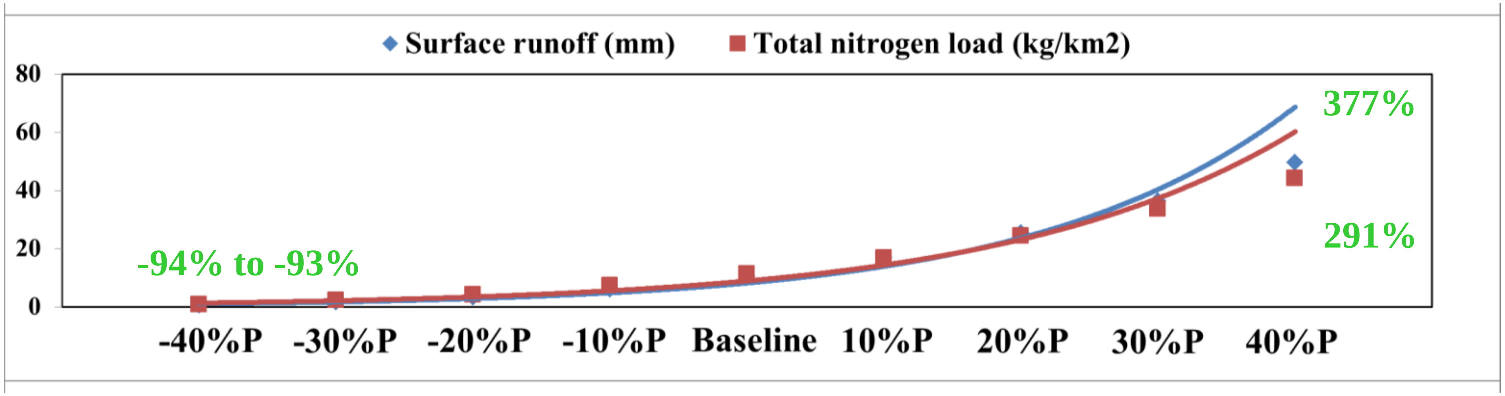
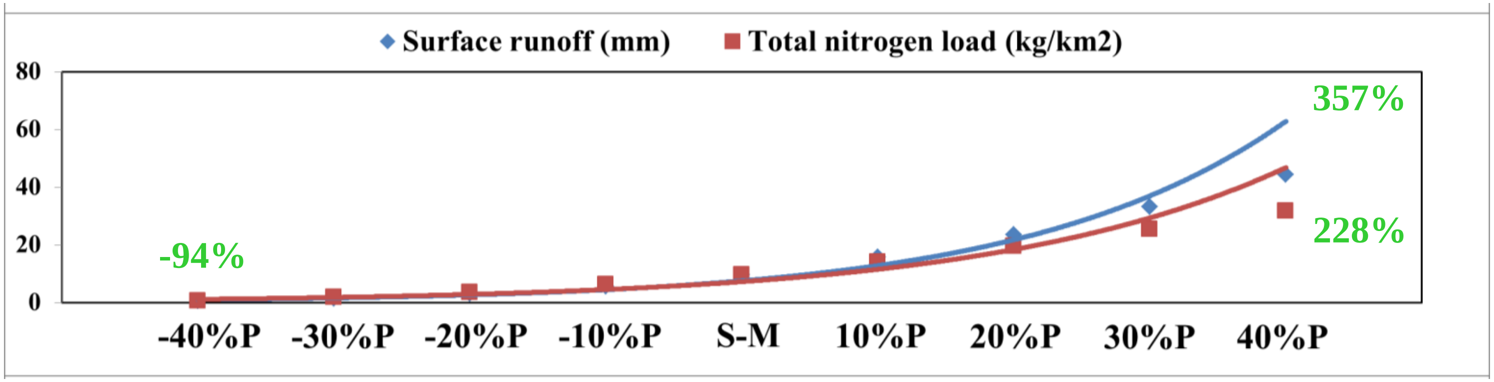
Effect of changes in precipitation on average annual surface runoff and TN

Cotton



Perennial grasses



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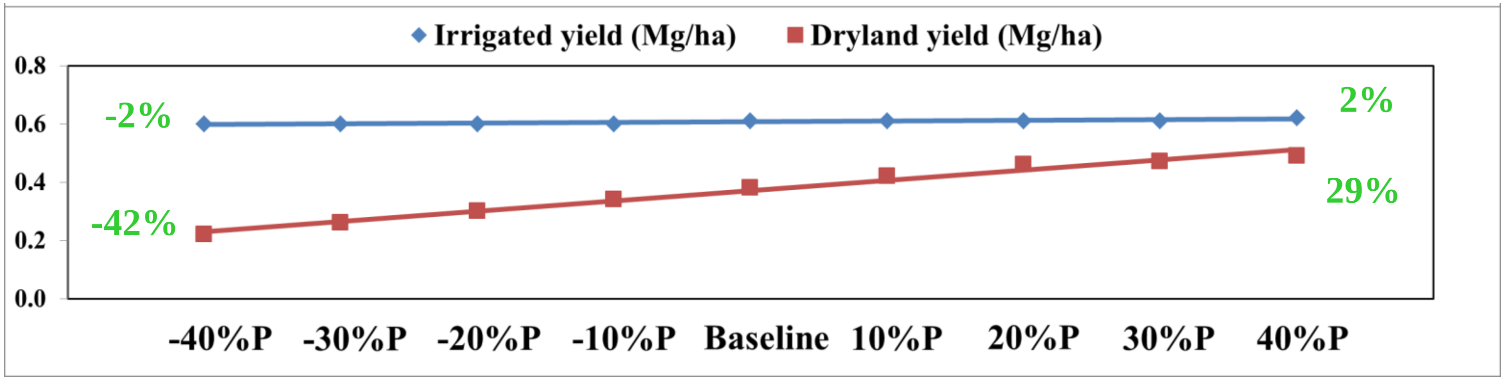
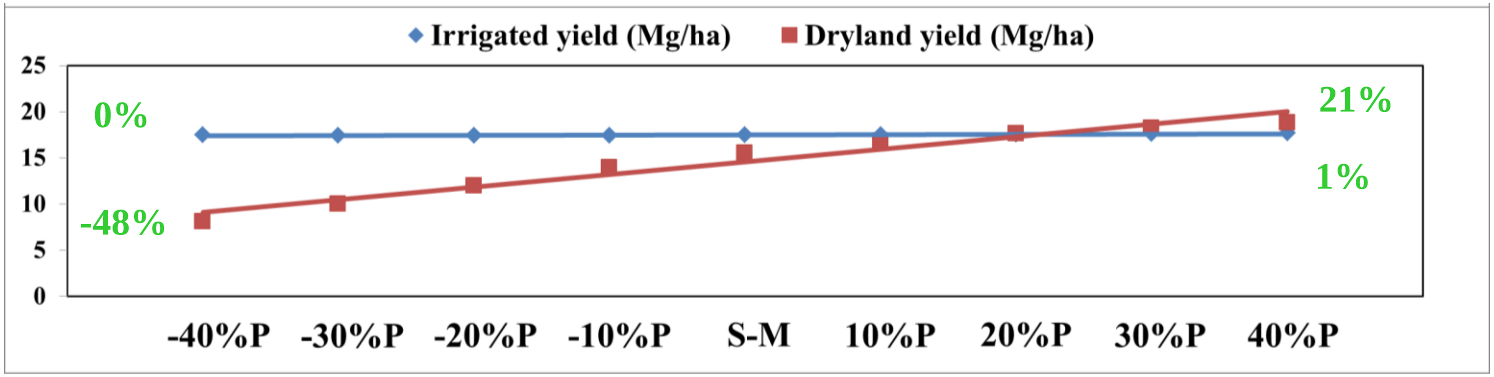
Effect of changes in precipitation on average annual yield

Cotton



Perennial grasses



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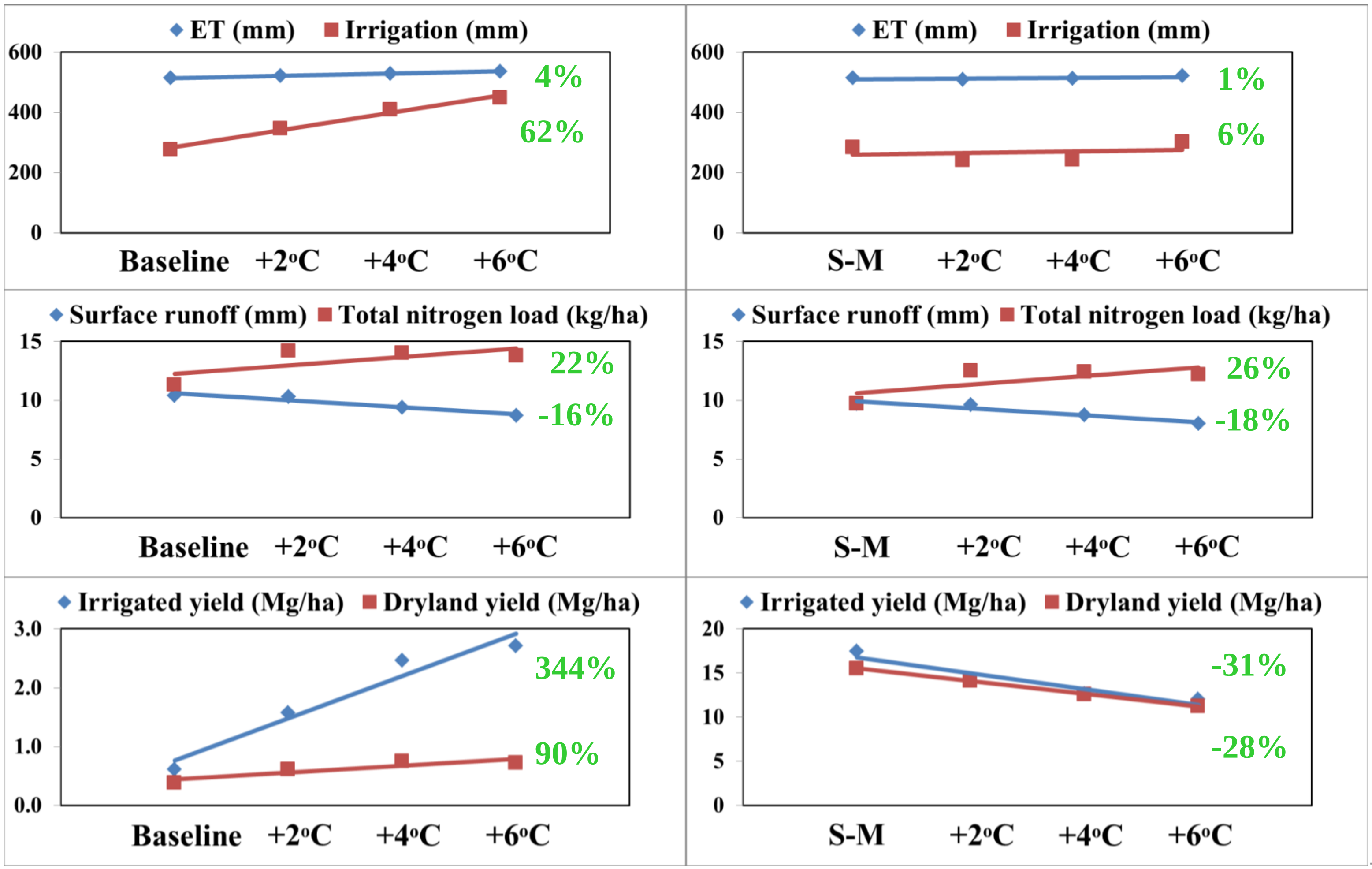
Effect of changes in temperature on average annual water balances and yield

Cotton | Perennial grasses



Summary

- *Miscanthus* and switchgrass were identified as ideal bioenergy grasses under dryland and irrigated systems, respectively.
- Land use change from (irrigated) cotton to switchgrass might slightly increase (~3%) groundwater withdrawals, but enhance soil and water conservation.
- Water balance parameters, TN load and crop yield were more sensitive to changes in precipitation than CO_2 concentration and temperature.
- The TN load increased exponentially when the amount of precipitation was increased.
- Global warming could potentially increase cotton yields, but it could reduce *Miscanthus* and switchgrass yields.

Acknowledgements

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USDA NIFA

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