Climate Change and Water Use Efficiency in Field Crops: Implications for Agricultural Adaptation in the U.S.

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USDA Economic Research Service

Workshop: Agricultural Productivity and the Environment
USDA-ERS
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The views expressed are those of the author(s) and should not be attributed to the Economic Research Service or USDA.
Research Questions

- What are the impacts of climate change on plant water use efficiency of field crops in the United States?
  - biophysical effects on crop yields (precipitation, temperature, CO₂)

- How do adjustments in water use efficiency affect irrigation demand under changing growing conditions?
  - Regional farmer adaptation
  - Irrigation as an adaptive response

- How might shifting water regimes under a warming climate affect water-supply availability for irrigation?

- To what extent is irrigation a constraint to adaptation and national production under climate change?
  - Regional variation
Climate Change Modeling System

**IPCC Emission Scenarios**
- SRES A1B
- SRES A2
- SRES B2

**GCM Climate Projections**
- CSIRO: “current”
- CGCM: 2020
- MIROC: 2040
- HADLEY: 2060, 2080

**Regional Crop Yield Impacts: EPIC**
- Temp, Precip., CO₂
- Yield Impacts
- Environ. Indicators
  - Erosion
  - Nutrient loading
  - GHGs

**Regional Water Resource Changes**
- Precip. Changes
- Groundwater Projection
- Demand for water in other sectors

**Economic Impacts: Regional Environment and Agriculture Production Model (REAP)**
Calculates shifts in aggregate production, acreage, practices, prices, and returns in response to changing productivity impacts of changing climate, shifts in regional water resources, and new drought tolerance technologies.

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Climate Change Modeling System

IPCC Emission Scenarios
- SRES A1B
- SRES A2
- SRES B2

GCM Climate Projections
- CSIRO
- CGCM
- MIROC
- HADLEY
  - reference
  - 2020
  - 2040
  - 2060
  - 2080

Regional Crop Yield Impacts: EPIC
- Temp, Precip., CO₂
- Yield Impacts
- Environ. Indicators
  - Erosion
  - Nutrient loading
  - GHGs

Crop Budget Generator

Regional Water Resource Changes
- Precipitation patterns and amount
- Surface-water and groundwater supplies

Economic Impacts: Regional Environment and Agriculture Programming Model (REAP)
- shifts in production, acreage, practices, prices, and returns
- shifts in regional water resources, agricultural use and irrigation constraints

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REAP Model Production Regions

267 Model Regions

Combination of:
- USDA Farm Production Regions
- NRCS Land Resource Regions
- Assessment Sub-Regions (ASRs)

-- HEL and NHEL land types (NRI)
-- Predominant soil type per roughly 1 mill. acres by land type (SSURGO)
-- Tiled and non-tiled
U.S. Climate Projections

Temperature and Precipitation

Temperature

Precipitation

Change in Growing Season T-max Relative to Reference (May-October, °C)

Growing Season Precip (mm)

United States Department of Agriculture, Economic Research Service
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Factors Driving Productivity Impacts

• **Moisture stress**
  – Increased moisture stress where rising evapotranspiration (ET) demands are not satisfied.
  – Reduced stress where higher precipitation offsets rising ET demand.

• **Temperature stress**
  – Reduced biomass and grain-yield production where temperature exceeds optimal growing conditions; offsetting decline in crop ET demand.

• **Atmospheric CO₂**
  – Increased plant-water use efficiency, reducing crop ET demands.
  – Increased yield through photosynthesis on C₃ crops (wheat, hay, cotton, rice, soybeans); yield effect for C₄ crops (corn, sorghum) more limited.
### Corn Yields, 2060

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Crop Water Use Efficiency

Yield per unit ET (bu./in.)

Corn: N. Plains

- Dryland
- Irrigated
- Dryland Reference
- Irrigated Reference

Corn: S. Plains

- Dryland
- Irrigated
- Dryland Reference
- Irrigated Reference

Wheat: N. Plains

- Dryland
- Irrigated
- Dryland Reference
- Irrigated Reference

Wheat: S. Plains

- Dryland
- Irrigated
- Dryland Reference
- Irrigated Reference
Crop Water Use Efficiency

Yield per unit ET (bu./in.)

Soybeans: N. Plains

Soybeans: Delta

Hay: N. Plains

Hay: S. Plains
Factors Driving Adaptation Response

- Changing patterns of relative profitability among crops, crop systems, and production systems under climate change
  - Irrigation returns may be more sensitive than dryland systems to % declines in crop yields; yield premiums are required to cover higher-cost irrigated production systems.

- Possible constraints on adaptation due to irrigation shortages
  - Irrigation demand depends on changing patterns of precipitation as well as adjustments in crops grown and changing levels of crop water demand
    - changing extent and intensity of irrigation
  - Irrigation supply
    - **Surface water supplies under climate change:** 2010 Resources Policy Act (RPA) National Assessment produced projected water shortages by hydrologic sub-basin
      - Water yield, routing/storage models
      - Water demand by sector
    - **Groundwater supplies:** not climate-related
## Shifting Relative Profitability of Irrigated Production, 2060

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Groundwater Withdrawal Reductions

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Change in Irrigated Acreage
(from Reference Case), 2060

Pacific States

Mountain States

Southern Plains

Northern Plains

Delta States

Million Acres

Million Acres

Million Acres

Million Acres

Order of Columns
- CGCM_B2
- CSIRO_B2
- HADN_B2
- CGCM_A1B
- CSIRO_A1B
- MIROC_A1B
- CGCM_A2
- CSIRO_A2
- MIROC_A2

- w/o water-supply constraints
- w/GW constraints
- w/ surface-water constraints

United States Department of Agriculture, Economic Research Service
The views expressed are those of the author(s) and should not be attributed to the Economic Research Service or USDA.
Increase in Value of Water Under Climate Scenarios ($/af)

Order of Columns
- CGCM_B2
- CSIRO_B2
- HADN_B2
- CGCM_A1B
- CSIRO_A1B
- MIROC_A1B
- CGCM_A2
- CSIRO_A2
- MIROC_A2
Change in National Production
(relative to reference production levels)
averaged across climate futures, 2060

% Change in Production

-20  -15  -10  -5  0  5  10

corn  cotton  hay  rice  silage  sorghum  soybeans  wheat

Fixed Acreage
Adaptation
GW Constraints
GW and SW Constraints
Change in Commodity Prices
(relative to reference price levels)
averaged across climate futures, 2060

% Change in Price

-5  0  5  10  15  20  25  30  35

corn  cotton  hay  rice  silage  sorghum  soybeans  wheat

- Fixed Acreage
- Adaptation
- GW Constraints
- GW and SW Constraints
Conclusions

• Differential yield impacts across dryland and irrigated production:
  – Precipitation patterns, moisture stress, and irrigation requirements;
  – Temperature, biomass heat stress, and ET response;
  – CO₂, water-use efficiency, and yield of C₃ crops;
• Irrigation demand declines beyond mid-century (relative to reference case), due in part to shifting water productivity in crop production.
• Relative importance of climate impacts on irrigation varies regionally:
  – Surface-water shortages restrict irrigated area in PA, MN regions;
  – Relative profitability of irrigation the primary driver elsewhere.
• Price and production impacts of surface-water supply reductions small relative to initial biophysical impacts of changing climate conditions.