Adoption of Irrigation and No-till Cropping Systems under Climate Change

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Introduction

• Agricultural water use in southeastern US has received relatively little attention
  • Share of irrigated acres is relatively small but increasing...
  • Number of irrigated acres in Tennessee increased by 200% from 1997 to 2012

• Potential for conflict over water use in southeastern US

• Increasingly important to understand
  • Implications of water scarcity for agriculture in southeastern U.S., and
  • Availability of cost-effective adaptations to increase resiliency of southeastern agricultural sector to reduced water availability
Objectives

• Estimate the economic value of water for row crop production given temporal and spatial variation in water availability; and

• Identify cost-effective adaptations to increase resiliency of agriculture in southeastern U.S. to climate change
Research Methods

• Hydrologic Modeling
  • Generate temporally- and spatially-explicit estimates of water availability and scarcity, using the Variable Infiltration Capacity (VIC)/Water Erosion Prediction Project (WEPP) water balance model under current and projected economic and environmental conditions

• Economic Modeling
  • Develop and use a regional agricultural sector model to estimate the crop/tillage/irrigation (“production activities”) given the VIC/WEPP simulations and commodity price projections
Modeling Systems

Variable Infiltration Capacity (VIC) — macro scale hydrologic model (Liang et al., 1994)
Water Erosion Prediction Project (WEPP) — field-scale crop simulation model (USDA, 2006)
Policy Analysis System (POLYSYS) — national agricultural sector model (Ray et al., 1998)
Tennessee Agricultural Sector Production Model (TNAP) — regional agricultural sector model
Tennessee Agricultural Sector Production Model (TNAP)

- Crops
  - Corn
  - Soybean
  - Wheat
  - Cotton
  - Sorghum

- Water
  - Irrigation (irrigated)
  - Precipitation (rain-fed)

- Tillage
  - Conventional Tillage (CT)
  - No Tillage (NT)

- 6 regions: HUC 4 sub-regions

- Model Inputs
  - Regional crop, tillage, and irrigation acreages and yields
  - State or regional crop, tillage and irrigation costs
  - Crop commodity prices
  - Water use for irrigation

- Model Output
  - Regional production activities
  - Irrigation water use
Tennessee Agricultural Sector Production Model (TNAP)

• Mathematical Programming Model:
  ▪ Nonlinear objective function
  ▪ Optimize total profit from row crop production subject to resource constraints

• Calibration: Positive Mathematical Programming (PMP)
  ▪ Calibrate to baseline without artificial constraints
  ▪ Estimate implicit costs
  ▪ Follow approach of Arfini and Donati (2013) for introduction of ‘latent’ crop activities
## Baseline Acres

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<th>Tillage</th>
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Real. Life. Solutions.
PMP procedures

• Step 1

\[
\min \sum_{n,k} u_{n,k}^2 / 2 + \sum_n (\gamma_n \sum_k \bar{x}_{n,k}) + \sum_{n,k} (c_{n,k} + \lambda_{n,k} - p_{n,k})\bar{x}_{n,k}
\]

s.t. \( c_{n,k} + \lambda_{n,k} + \gamma_n a_{n,k} \geq p_{n,k} \quad \forall \bar{x}_{n,k} > 0 \)

\( Q_{k,k} \bar{x}_{n,k} + u_{n,k} = c_{n,k} + \lambda_{n,k} \quad \forall \bar{x}_{n,k} > 0 \)

\( Q_{k,k} \bar{x}_{n,k} + u_{n,k} \geq c_{n,k} + \lambda_{n,k} \quad \forall \bar{x}_{n,k} = 0 \)

\( Q_{k,k} = [L_{k,kk}H_{k,kk}^{1/2}] [L_{k,kk}H_{k,kk}]^{-\gamma} \)

\( H_{k,kk}, \gamma_n, \lambda_{n,k} \geq 0 \)

• Step 2

\[
\max \sum_{n,k} p_{n,k}x_{n,k} - \sum_{n,k} u_{n,k}x_{k} - \sum_{n,k} \frac{1}{2}Q_{k,k}x_{n,k}^2
\]

s.t. \( \sum_k a_{n,k}x_{n,k} \leq b_n \)

\( x_{n,k} \geq 0 \)
Mathematical Model: Objective

Max

\[
\sum_{i,j,k,l} P_j Y_{ijkl} X_{ijkl} - \sum_{ijkl} u'_{ijkl} X_{ijkl} - \sum_{ijkl'k'l'} \frac{1}{2} X_{ijkl} Q'_{jklj'k'l'} X_{ij'k'l'}
\]

i: HUC-4 regions \( i = 1, \ldots, 6 \);

j: crop \( j = 1, \ldots, 5 \);

k: irrigation or dryland;

l: tillage options (till or no-till)
Mathematical Model: Constraints

• Land Constraint

\[ \sum_{jkl} a_{ijkl} X_{ijkl} \leq L_i \]

• Water Constraint

\[ \sum_{jkl} w_{ijkl} X_{ijkl} \leq W_i \]
Yields and Prices of Corresponding Climate Change Scenarios

- Yields (using WEPP/VIC) and prices (using POLYSYS) were simulated for 6 climate scenarios:
  - CGCM-MID
  - CGCM-HIGH
  - CSIRO-MID
  - CSIRO-HIGH
  - MIROC-MID
  - MIROC-HIGH
Water Availability

• Constrained Water Availability (CWA)
  Assumes that water is constrained to its current irrigation water used

• Unconstrained Water Availability (UWA)
  Assumes that water for irrigation is not a constraint
Monte Carlo Simulation

• Step 1: Random draw from the 6 yield and price combinations
• Step 2: Solve TNAP model
• Step 3: Record solution for land allocation and water use
• Step 4: Plot CDF of land allocation for all production activities combinations
West TN (0801): Crop Acres CDFs

Real. Life. Solutions.
Conclusions and next steps

• Regions react differently under two water availability scenarios

• The water availability needs to be refined to better estimate the changes