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

Lixia He Lambert, Burton C. English, Christopher D. Clark,
Dayton Lambert, Chris Boyer, Aaron Smith,
Thanos Papanicolaou, Chad M. Hellwinckel

Southern Agricultural Economics Association

Jacksonville, Florida
February 2-6, 2018

THE UNIVERSITY of TENNESSEE KNOXVILLE

USDA NIFA
United States Department of Agriculture
National Institute of Food and Agriculture

Support

Agriculture and Food Research Initiative Competitive Grants from the USDA National Institute of Food and Agriculture:

- "Using Hydro-Economic Modeling to Optimally Allocate Water in the Humid Southeastern U.S.," 2014-2017
- "Increasing the Resilience of Agricultural Production in the Tennessee and Cumberland River Basins through More Efficient Water Resource Use," 2015-2020

United States Department of Agriculture
National Institute of Food and Agriculture

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

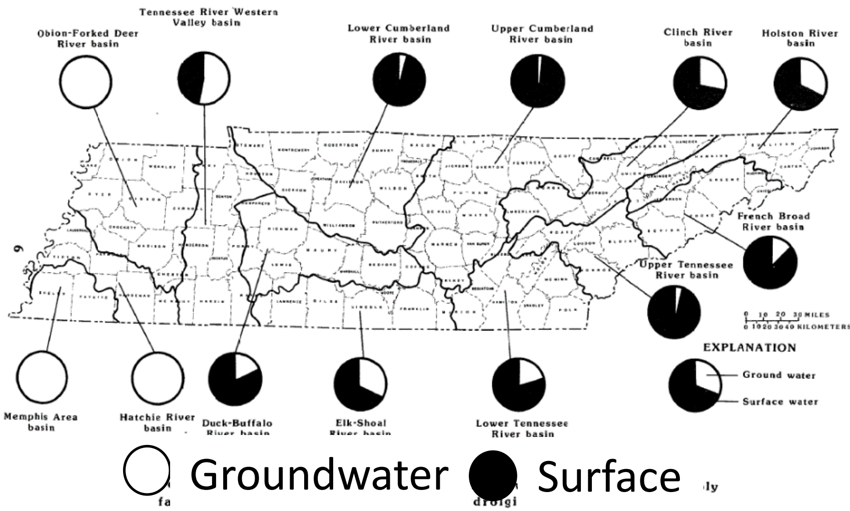
- Potential for conflict over water use in southeastern US

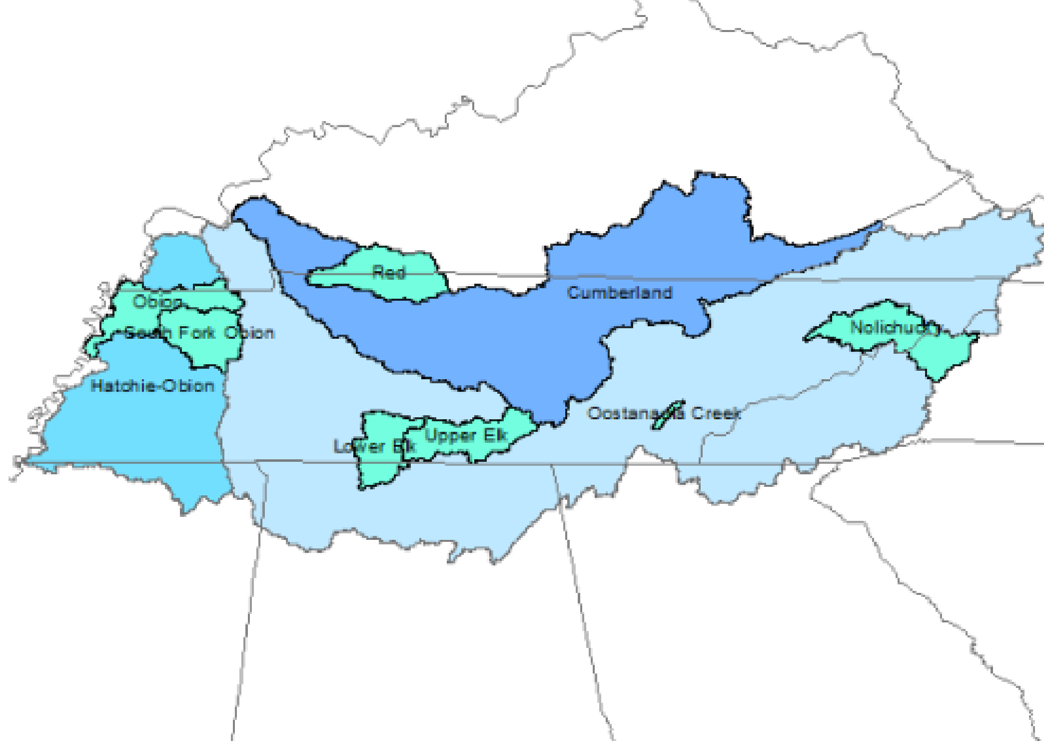
- Increasingly important to understand
  - Implications of water scarcity for agriculture in southeastern U.S., and
  - Availability of cost-effective adaptations to increase resiliency of southeastern agricultural sector to reduced water availability

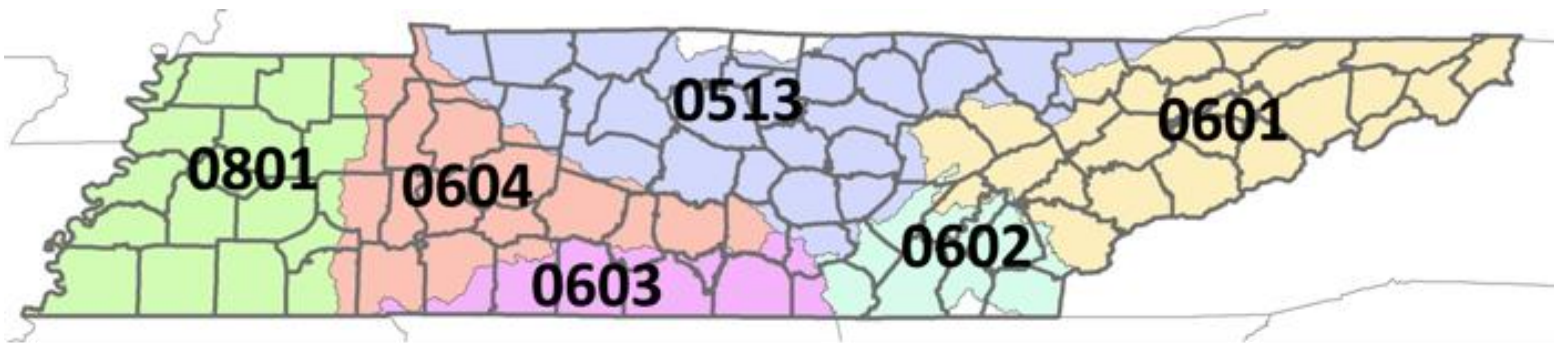
Objectives

- 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

Study Region



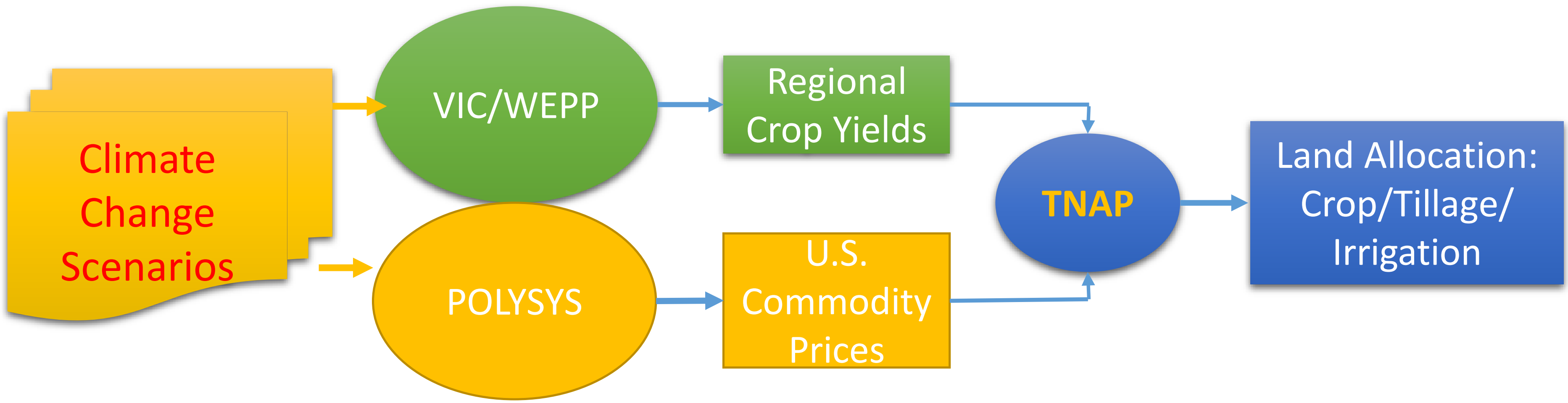




Research Methods

- 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

Region	Irrigation	Tillage	Corn	Soybean	Wheat	Soy-Wheat-Double	Sorghum	Cotton
HUC0513	Irrigation	CT	38					
		NT	23					
	Rainfed	CT	54,565	29,823	37,001			
		NT	69,774	108,977	7,099			
HUC0601	Rainfed	CT	12,448	6,827	4,158			
		NT	15,252	15,473	6,341			
HUC0602	Rainfed	CT	5,011	3,397	7,218			
		NT	3,489	8,302	2,282			
HUC0603	Irrigation	CT	1,041	124				
		NT	2,423	441				
	Rainfed	CT	24,992	10,017	10,609	4,547		
		NT	53,544	48,858	9,831	4,213		
HUC0604	Irrigation	CT	641	221				
		NT	3,153	684				
	Rainfed	CT	25,051	16,890	16,246	6,962		24,690
		NT	115,455	141,885	7,134	3,058	1,300	5,310
HUC0801	Irrigation	CT	16,286	7,753				9,775
		NT	29,456	14,008				10,291
	Rainfed	CT	202,158	255,086	147,581	63,250		85,016
		NT	350,400	438,772	74,739	32,031	13,100	154,118

PMP procedures

- Step 1

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

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

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

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

$$Q_{k,k} = [L_{k,kk} H_{k,kk}^{1/2}][L_{k,kk} H_{k,kk}^{1/2}]'$$

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

- Step 2

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

$$\text{s.t.} \sum_{k} a_{n,k} x_{n,k} \leq b_n$$

$$x_{n,k} \geq 0$$

Mathematical Model: Objective

Max

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

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

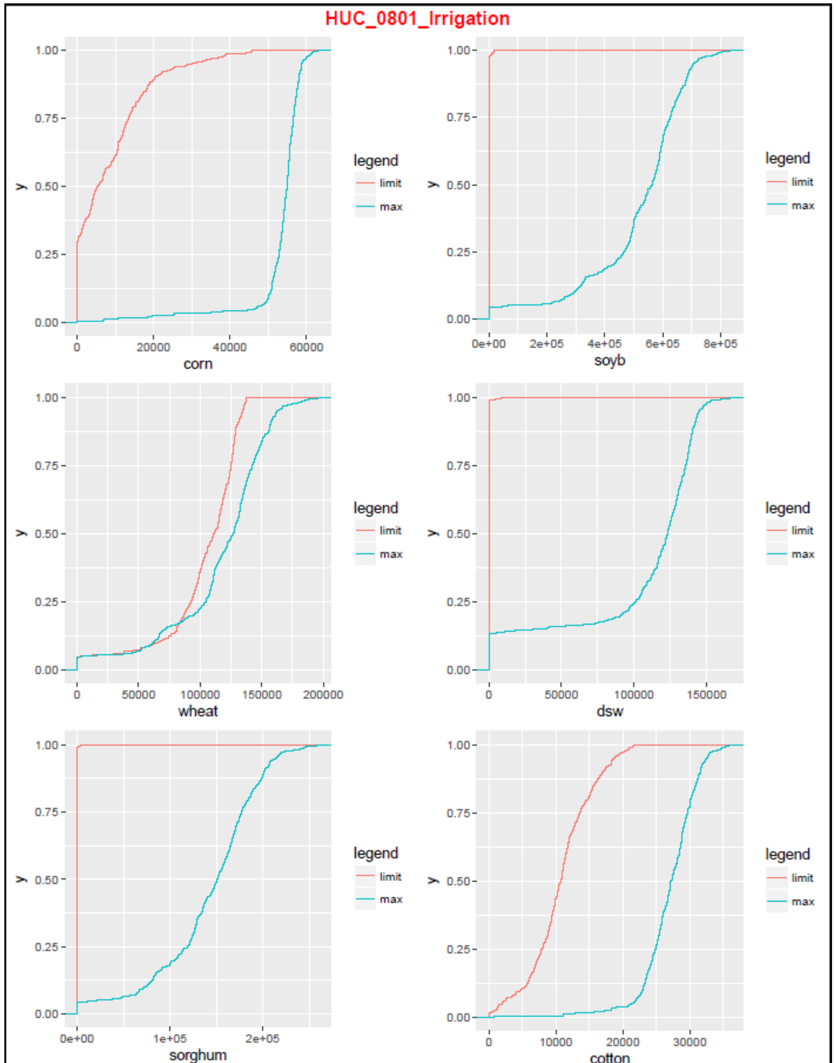
- Unconstrained Water Availability (UWA)

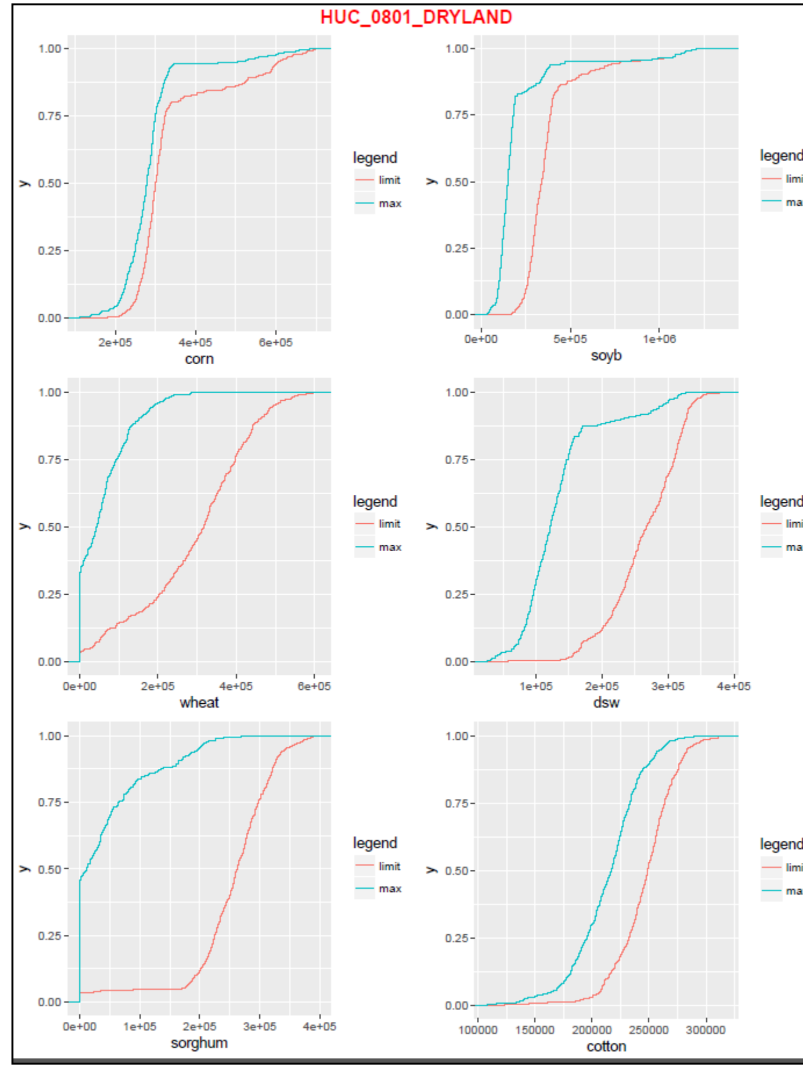
Assumes that water for irrigation is not a constraint

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

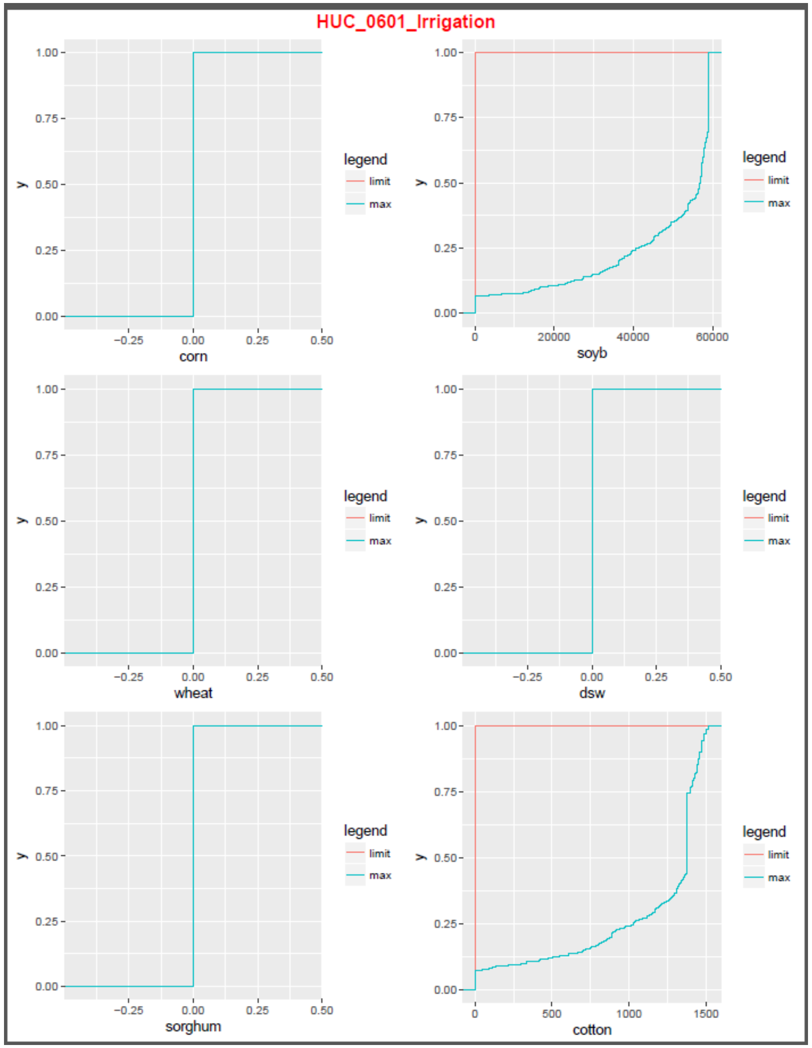


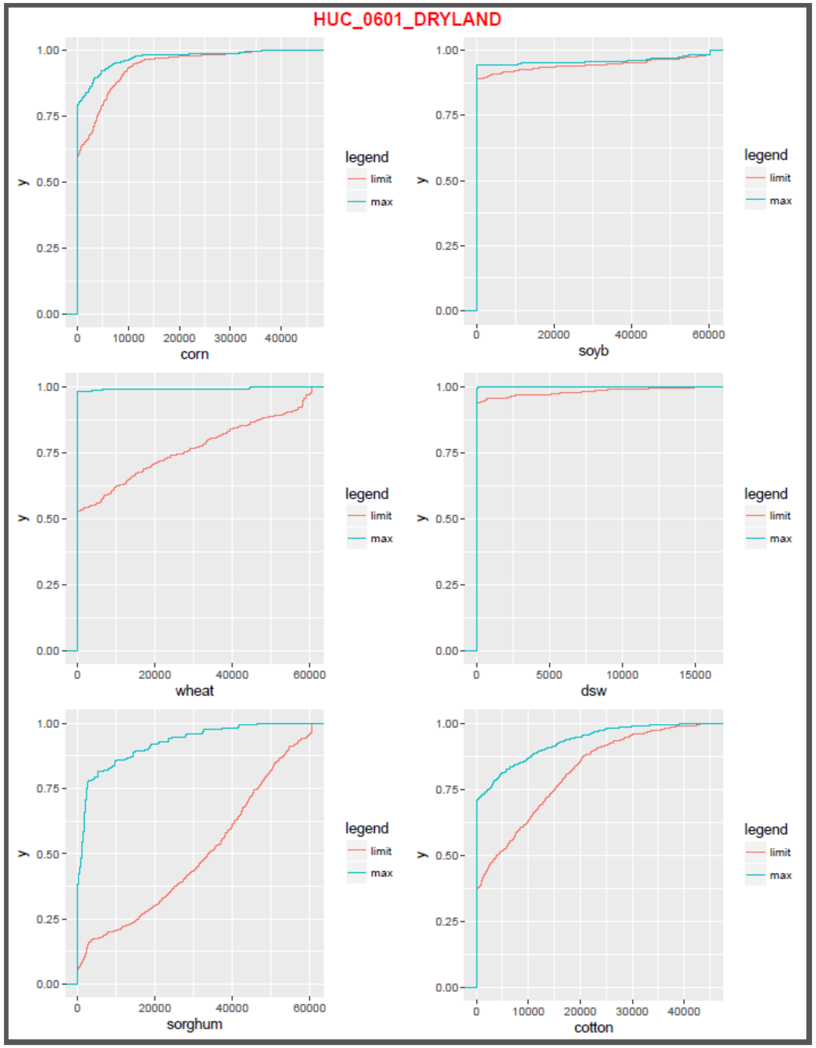


Real. Life. Solutions.

UT AGRESEARCH
INSTITUTE OF AGRICULTURE
THE UNIVERSITY OF TENNESSEE

East TN (0601): Crop Acres CDFs





Conclusions and next steps

- Regions react differently under two water availability scenarios

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