Modeling Steady-State Irrigated Production

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Agricultural History

- Early agriculture initiated by
  - Crop selection
  - Cultivation
  - Irrigation
  - Rotation
- Agricultural intensification
  - Information
  - Energy
  - Chemical inputs and fertilizers
- Problems
  - Resource depletion
  - Accumulation of external costs

Defining Sustainable Irrigated Production

- Land and water stocks are in steady-state
- Water pollution stocks are in steady-state
- Steady-states consistent with long run utility maximization
- Do not use a definition that allows resource depletion with constant utility

Margins of Adjustment

- Agricultural producers can adjust on three margins
  - Extensive margin
  - Intensive margin
  - Dynamic margin
- Most sustainable solutions result in reductions at the extensive and/or intensive margins
- Productivity losses result from these two adjustments
- Explore dynamic margin adjustments and rotational research as a way to partially reconcile sustainability and intensification

Empirical Example

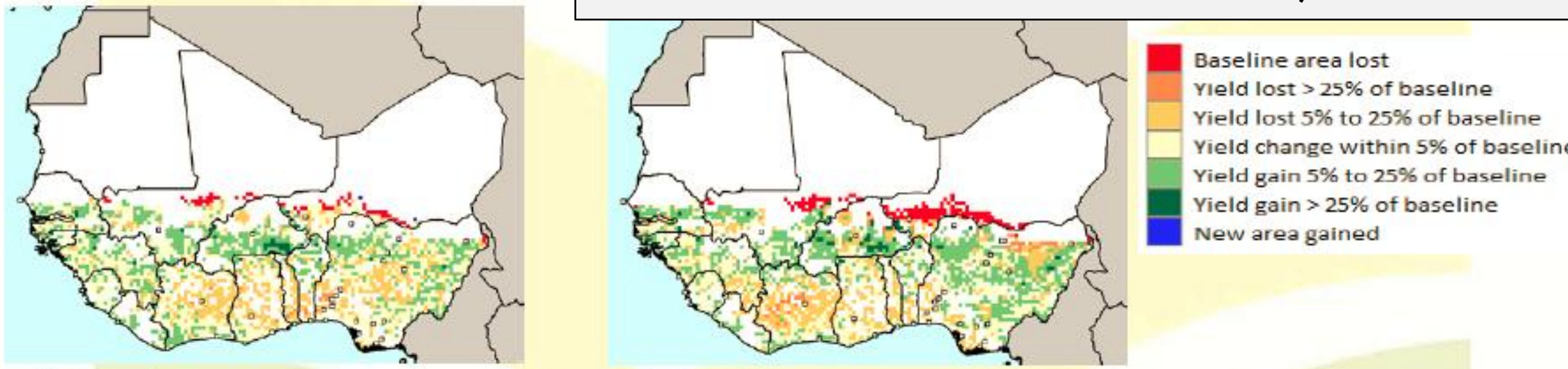
- Location
  - Southern California Kern County field data available
- Crops
  - Alfalfa and cotton rotation
- Water quantity
  - Measured in this case by depth to groundwater
- Water quality
  - Measured by the concentration of nitrates in the groundwater

Changes in yields, 2010-2050, from DSSAT crop model, Rice and maize (rainfed), CSIRO A1B(left) and MIROC A1B (right)

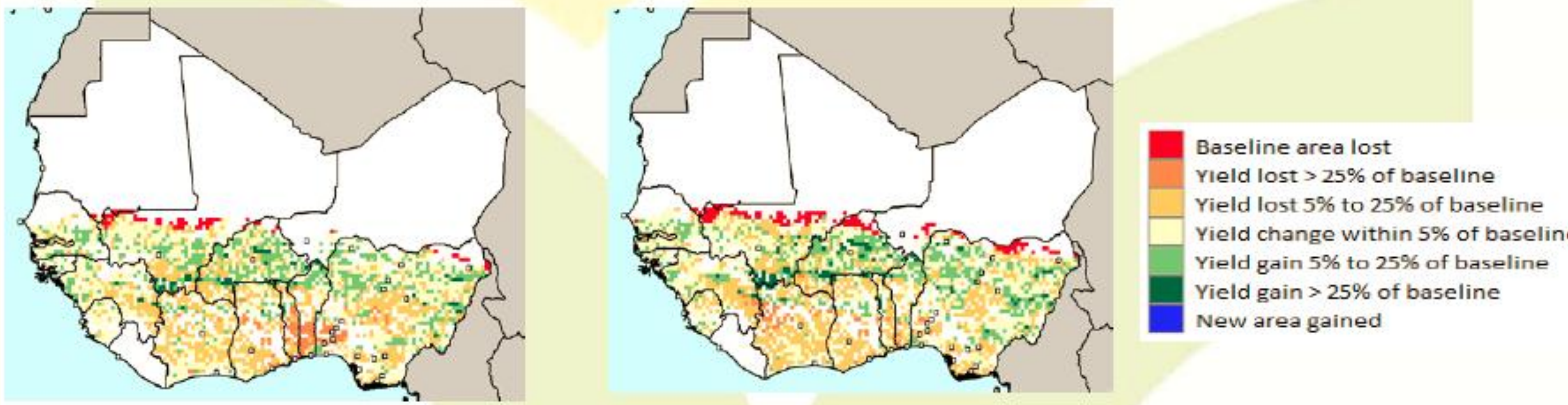
CORAF/WECARD

From Dr. A. Jalloh. Addis Ababa, June 2013

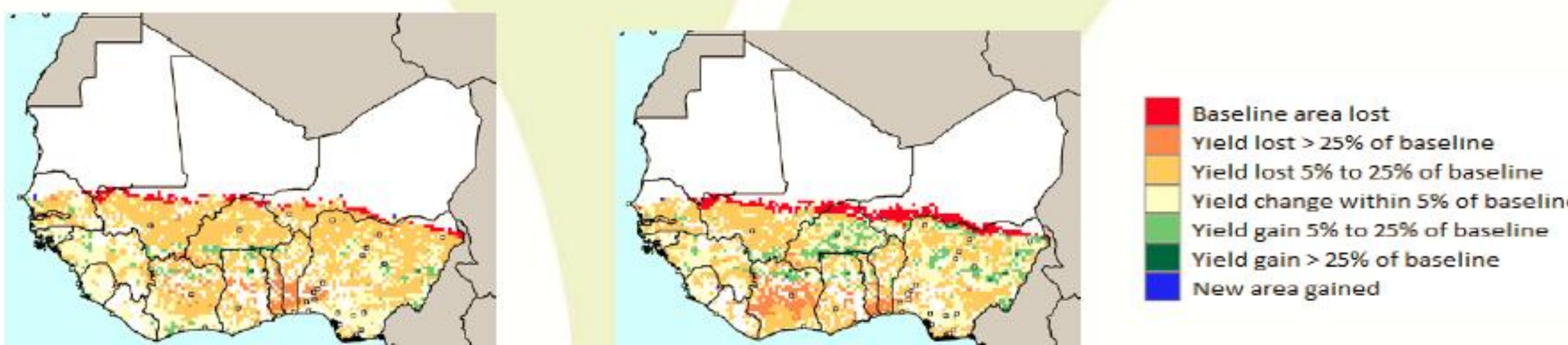
Rice



Maize



Groundnut



Rotation Tradeoffs

- One fundamental tradeoff is between net-nitrogen using crops and net-nitrogen fixing crops
- Nitrogen using crops have higher net returns than nitrogen fixing crops
- Nitrogen fixing crops have a higher water use per unit revenue
- Rotation shifts that have lower applied nitrogen reduce leaching of nitrates but increase groundwater depletion

Model Estimation and Calibration

- Three-stages in sequential-estimation framework

1. Estimate the rotation dynamic first-order conditions using geo-referenced field-level data
2. Incorporate the estimated rotation parameters into farm-level calibrated economic production model
3. Use the outputs from the calibrated production model to drive the equations of motion for groundwater use and changes in nitrate pollution

Estimating Rotation Effects

- Crop profit with rotation and biophysical effects

$$\pi_{t,i} = p_{t,i}\left(\left(\bar{y}_i + \varepsilon_i\right) - \Gamma_{i|k}\right) - F_i$$

- Euler conditions which must hold at any time *t*,

$$\pi_{n,a|c} \geq \pi_{n,c|c}$$

$$\pi_{n,c|a} \geq \pi_{n,a|a}$$

- Maximum Entropy estimation procedure
  - Rotation effect can alternatively be estimated from crop growth models

Calibrated Production Model - I

- Constant Elasticity of Substitution (CES) Production

$$Y_i = \tau_i \left[\beta_{i,land} x_{i,land}^{\rho_i} + \beta_{i,labor} x_{i,labor}^{\rho_i} + \beta_{i,supply} x_{i,supply}^{\rho_i} + \beta_{i,water} x_{i,water}^{\rho_i} \right]^{\upsilon/\rho_i},$$

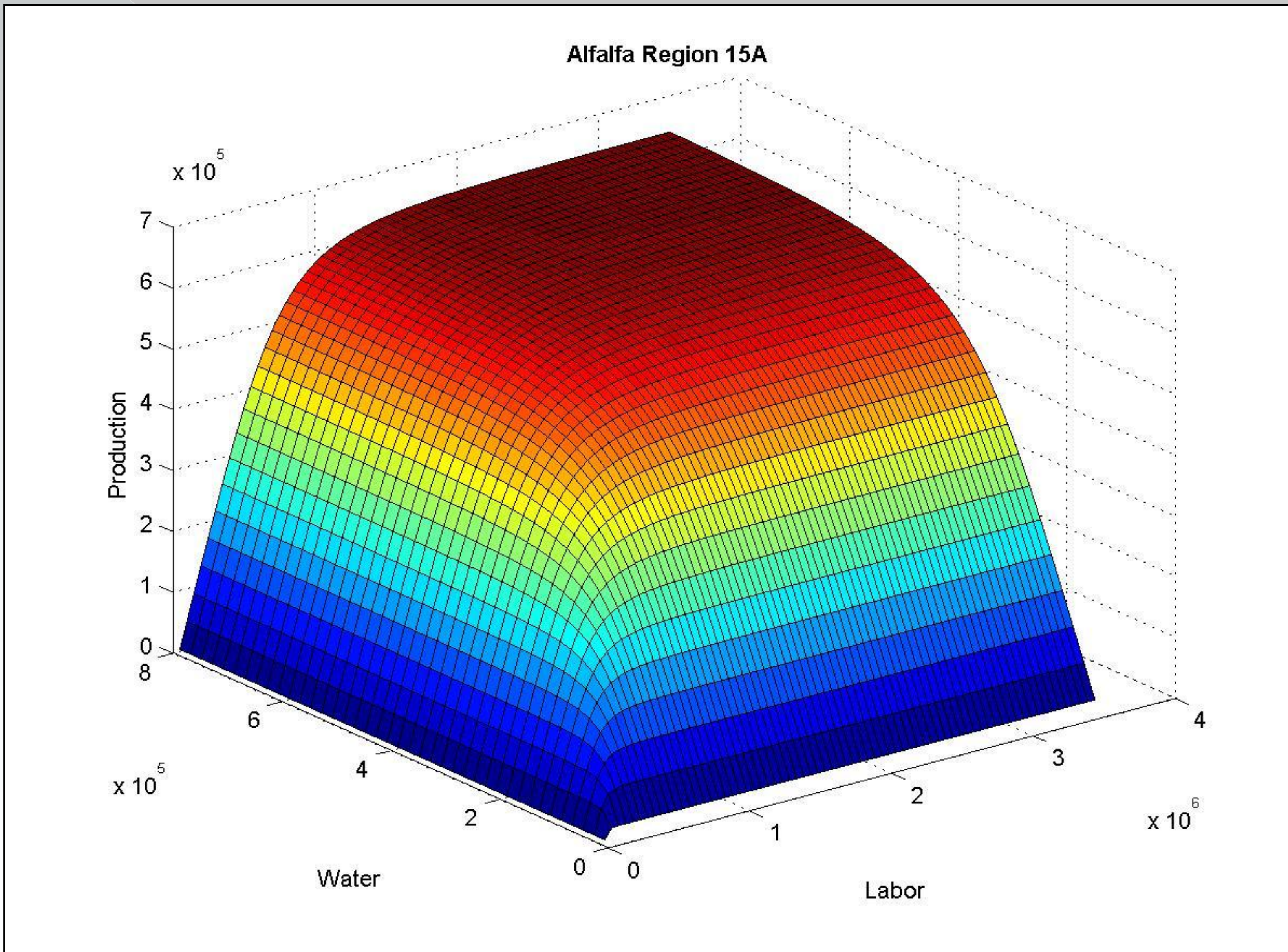
- Rotation yield adjustment, $R_{t,i}$

$$R_{t,a} = \frac{\left(\Gamma_{a,a} \left(\varphi XB_{t-1,a} \right) + \Gamma_{a,c} \left((1-\varphi) XB_{t-1,a} \right) \right)}{XB_{t-1,a}},$$

- Rotation-adjusted yield

$$YR_{t,i} = \bar{y}_{t,i} + R_{t,i}.$$

Representative Production Function



Calibrated Production Model - II

- Calibrated profit-maximization problem with rotation-adjusted yields becomes

$$\max\ p_i YR_i - C_i(x_{i,land}) - \sum_{j \neq land} \sum_i \omega_j x_{i,j}$$

subject to

$$\sum_i x_{i,j} \leq B_j$$

$$\sum_i x_{i,water} \leq \mathrm{GW} + \mathrm{SW}$$

Resource Equations of Motion

- Nitrate dynamic equation

$$N_{t+1} = N_t + \frac{\sum_i nf \cdot AN_{t,i} \cdot x_{i,land} - \sum_i N_t \cdot x_{t,i,water}}{nl \cdot \left(TDL_t - RC_t\right)}$$

- Change in depth to groundwater, and corresponding change in pumping costs (not shown)

$$AF_{t+1} = RC_t - \sum_i \left(1 - DP_i\right) x_{t,i,water}$$

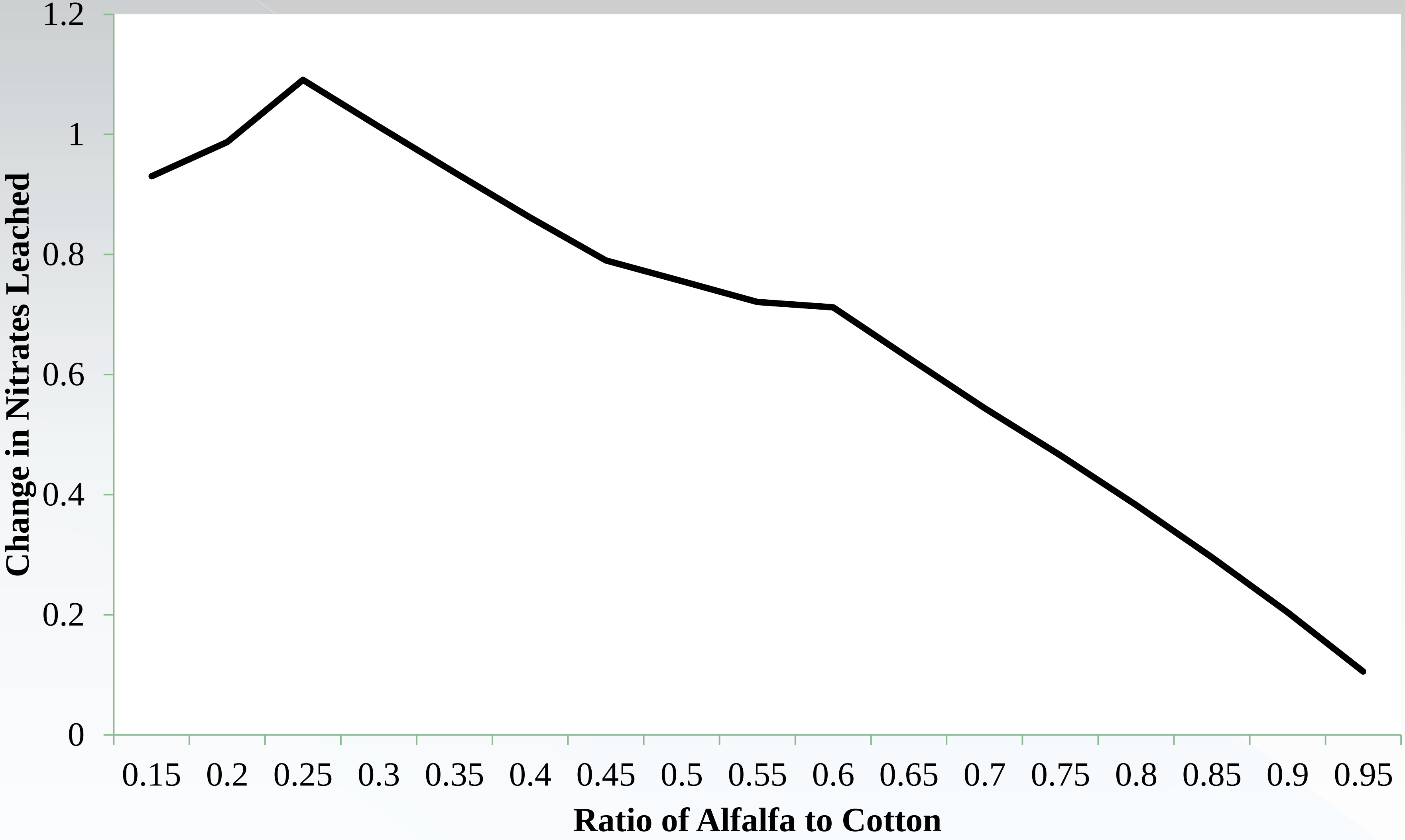
$$CHG_{t+1} = \frac{AF_{t+1}}{BAS}.$$

Crop Rotation Parameters

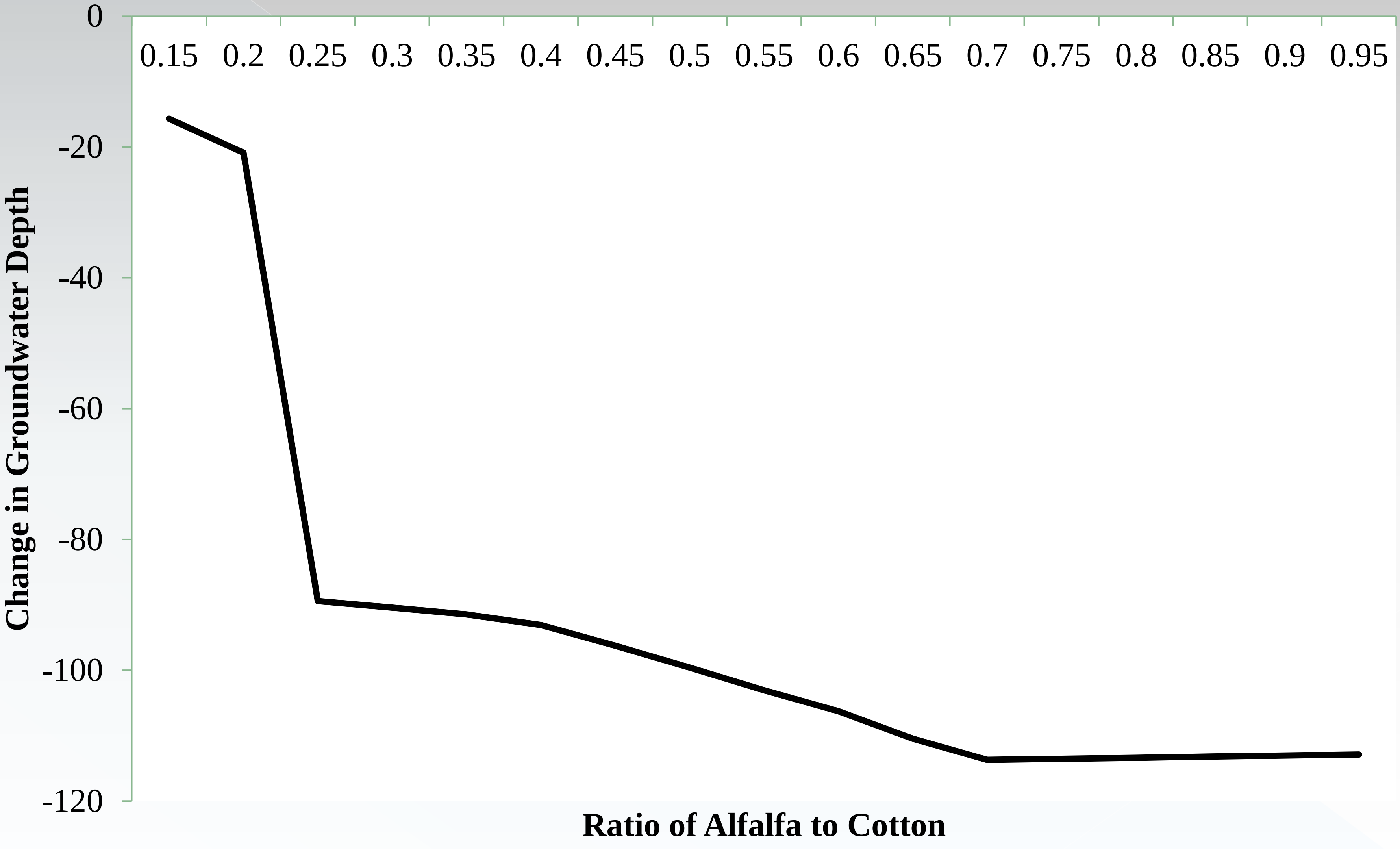
- Yield adjustment in tons/acre
  - Given that crop (row) follows crop (column)

	Alfalfa	Cotton
Alfalfa	-0.284	0.406
Cotton	0.025	-0.035

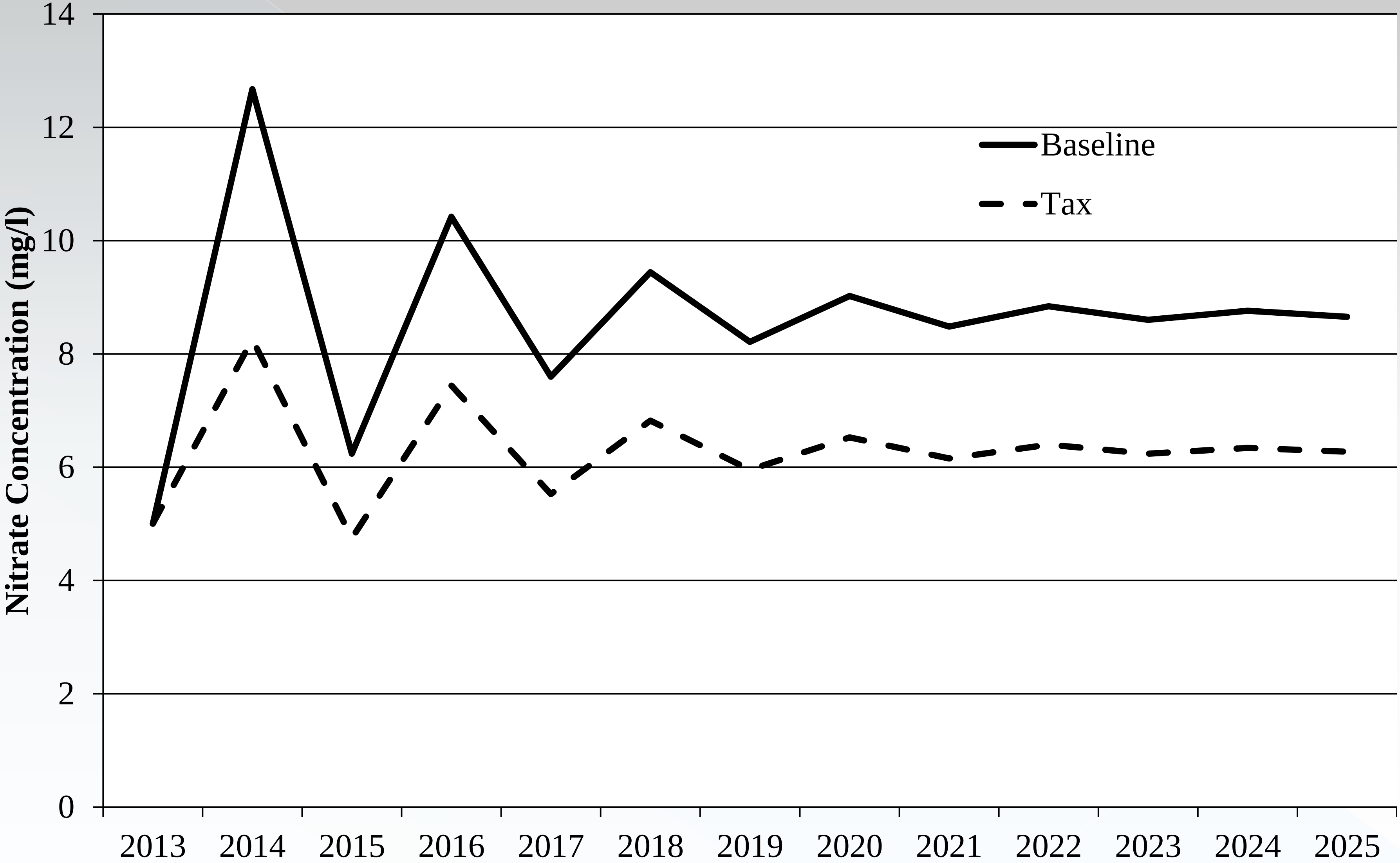
Change in Nitrates as Rotation Shifts



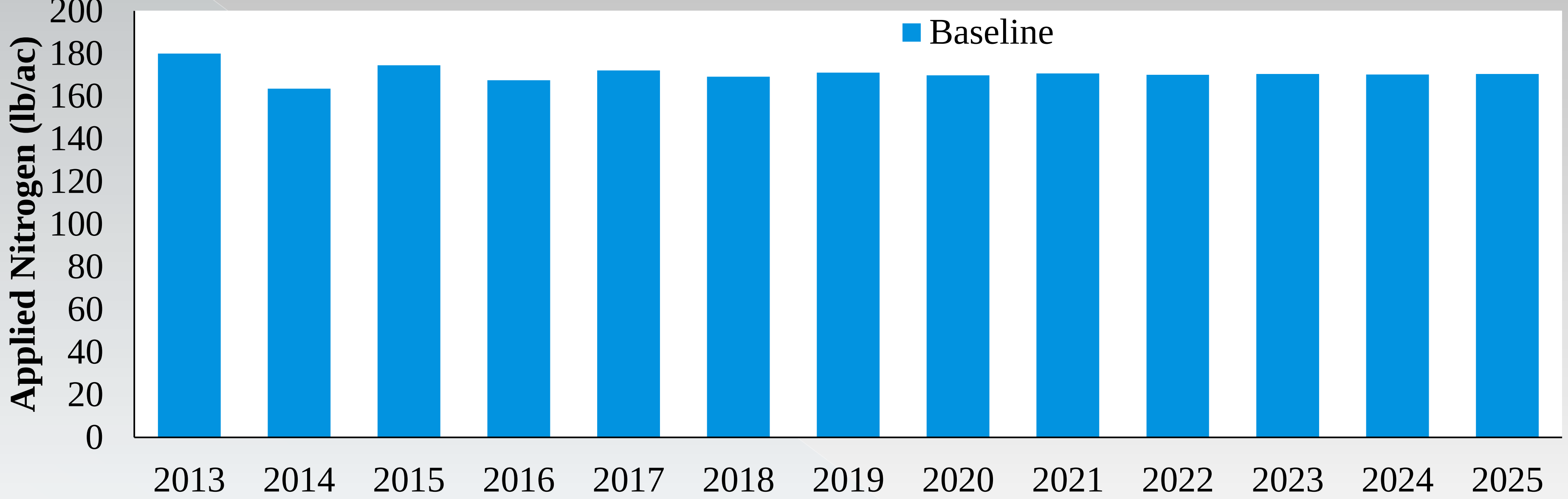
Change in Groundwater Depth as Rotation Shifts

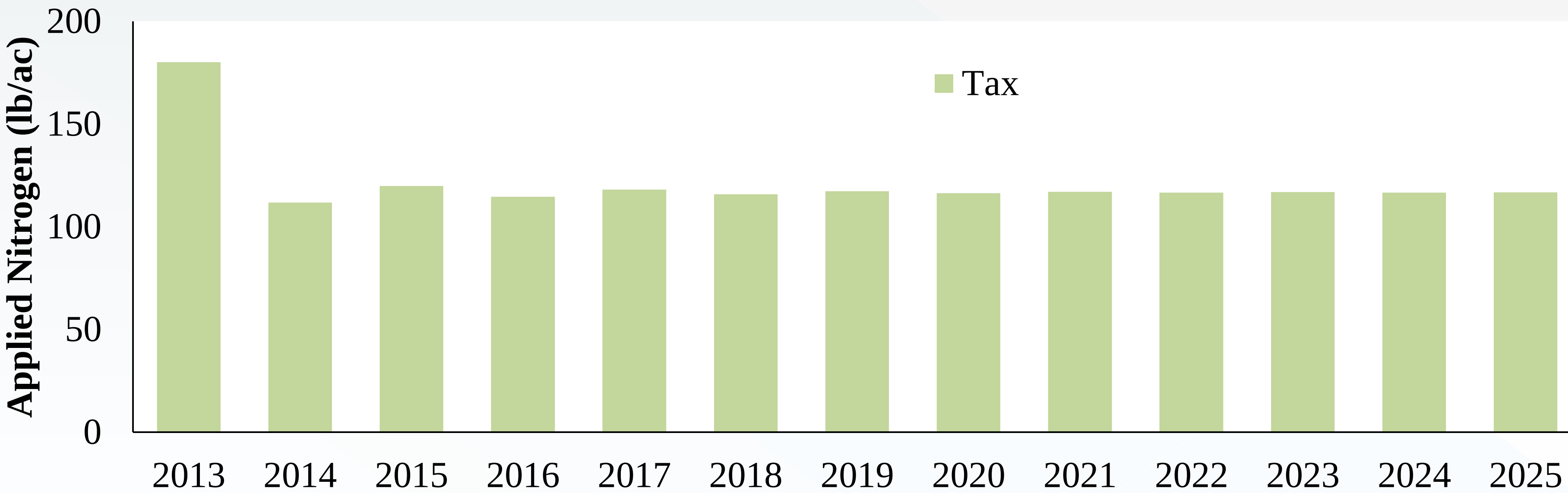


Groundwater nitrates

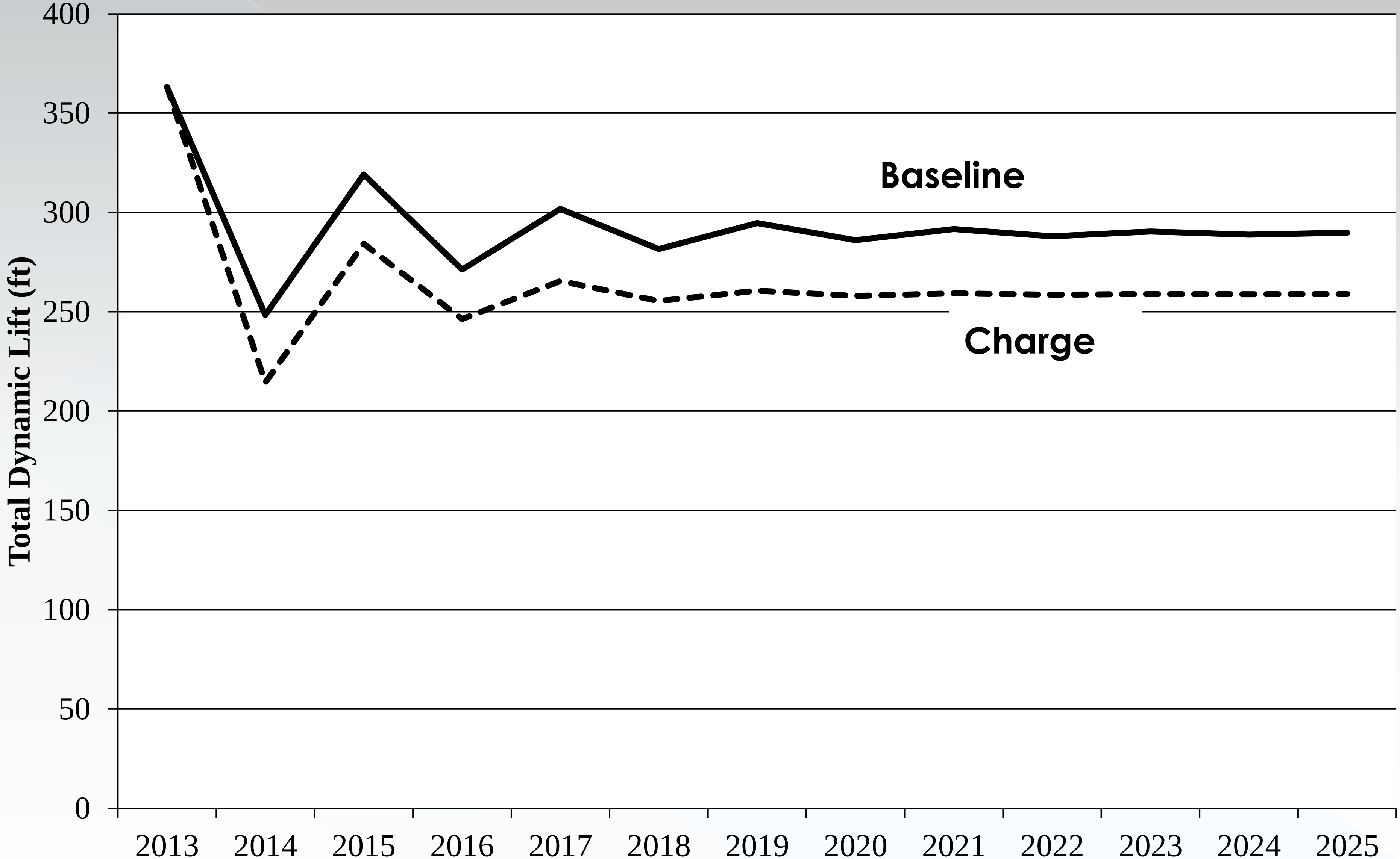


Cotton applied nitrogen per ac





Groundwater Depth



Summary

- Rotations have a significant role in achieving intensive sustainable agriculture
- Rotation effects can be estimated and integrated with primal production models
- Sustainable irrigated agriculture is unlikely to be achieved without significant technological innovations
- New technology needs to be rotation enhancing rather than rotation reducing
- Extensions of the model to developing countries may require plant growth models to estimate rotation effects