Applying models for research on the impacts of climate change on agriculture

Allison M. Thomson

Joint Global Change Research Institute

Pacific Northwest National Laboratory and the University of Maryland

Climate Change, Agricultural Production, & Water Resources

A Regional Science Forum for the Mid-Atlantic

June 23, 2010

PNNL-SA-73530

Pacific Northwest NATIONAL LABORATORY

Climate Impacts and Agriculture Research at the JGCRI

- Regional to global scale analyses of
  - Climate change impacts on agriculture
  - Climate mitigation opportunities from agriculture and land use
    - Soil carbon sequestration
    - Bioenergy – production of feedstocks and use in the energy system
  - Vulnerability and adaptive capacity of societies to cope with climate change and other environmental stress
- Model development
  - GCAM integrated energy-agriculture assessment model
  - EPIC agro-ecosystem model

Two examples of work with the EPIC model

- Application of EPIC and a Regional Climate Model to eastern China (Chavas et al., 2009)
  - Projecting long term climate impacts on crop yield
  - Assessing the potential shifts in cultivating areas of major crops

- Nutrient management studies on Maryland's eastern shore (Izaurralde, 2009)
  - When validated, simulations can show more detail than measurements on the fate of nutrients

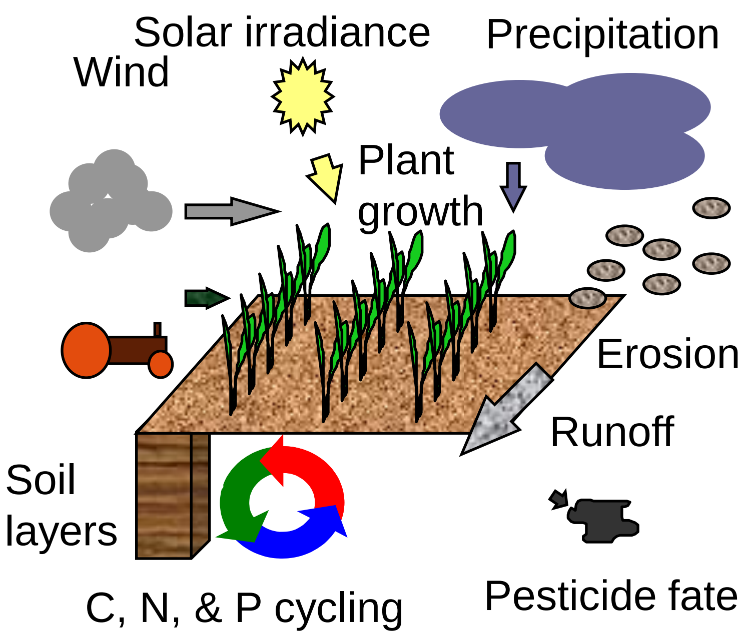
Long term climate impacts in China

- The key questions for this research:
  - 1) How does overall potential productivity change?
  - 2) How does productivity change in each crop's current primary production zones?
  - 3) At the regional scale, where does potential productivity change significantly (either up or down)?

- Why China?
  - 22% of the global population but only 7% of the global supply of arable land
  - ~30% of total food production in China comes from rain-fed agriculture
  - The Huang-Hai Plain (the "bread basket" of China): produces 39.2% of national grain supply and 32.4% of gross domestic product despite having only 7.7% of national water resources

Step 1: Select a modeling tool and objective

- EPIC to assess **changes in potential productivity**:
  - Grow the crop everywhere in both periods
  - Look at relative changes in crop yields
- Use SAS to determine statistical significance and analysis of variance (ANOVA)



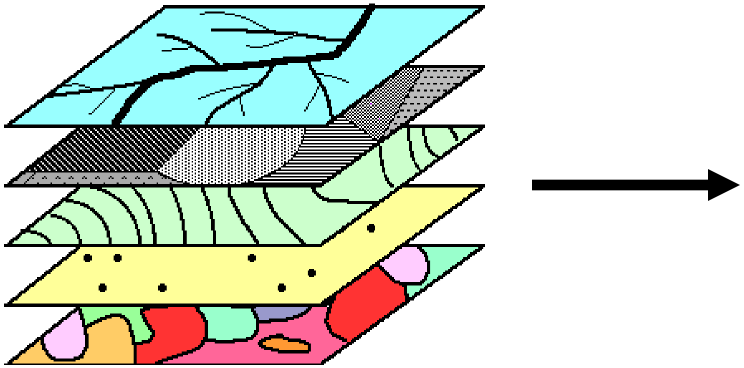
Representative EPIC modules

- EPIC is a process-based model built to describe climate-soil-management interactions at point or small watershed scales
  - Crops, grasses, trees
  - Up to 100 plants
  - Up to 12 plant species together
- Key processes simulated
  - Weather
  - Plant growth
    - Light use efficiency, PAR
    - CO_2 fertilization effect
    - Plant stress
  - Erosion by wind and water
  - Hydrology
  - Soil temperature and heat flow
  - Carbon, Nitrogen, and Phosphorus cycling
  - Tillage
  - Plant environment control: fertilizers, irrigation, pesticides
  - Pesticide fate
  - Economics

Pacific Northwest NATIONAL LABORATORY

Step 2: Designing a series of model runs

- Study Design
  - Simulate five major crops: canola, corn, potato, rice, winter wheat
  - Under long-term climate change:
    - IPCC A2 scenario: CO2 conc = 850 ppmv by 2100
    - We compare a baseline period (1961-1990) with a future period(2071-2100)
- Use GIS to create "representative farms" by assigning to each weather gridpoint corresponding soil profile and county cropland data



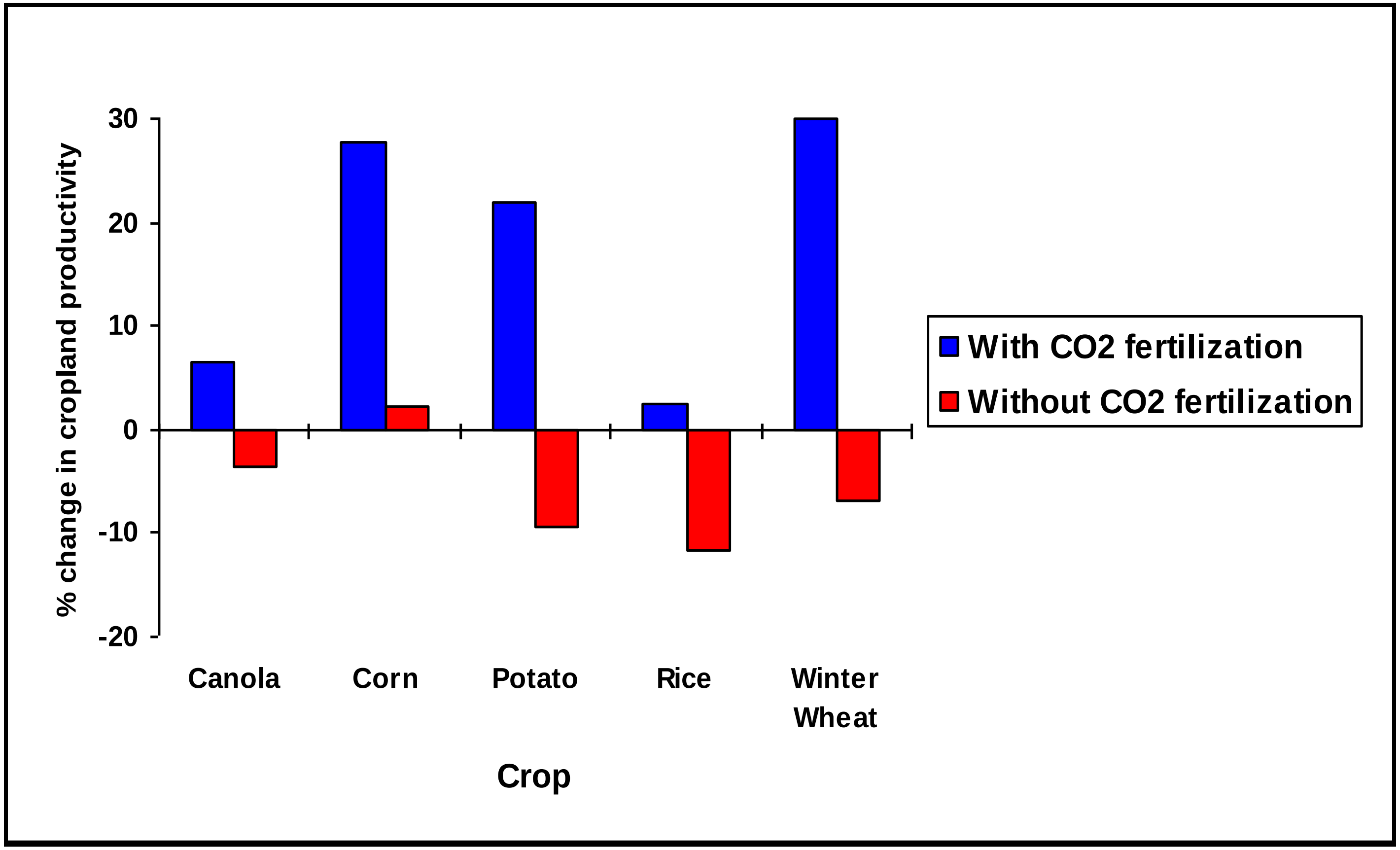
Step 3: Assembling input data

- What does EPIC need as input?
  - Climate data: ICTP RegCM3 regional climate model at .25º x .25º resolution (Gao et al., 2008)
  - Soil layer data: WISE global soil database
    - Layer depth, bulk density, soil texture, pH, soil carbon content, calcium carbonate content, cation exchange capacity
  - Farm management data:
    - Common farm practices (N & P inputs, tillage)
    - Irrigation
    - Field operations performed according to potential heat unit (PHU) scheduling rather than pre-defined dates
      - Implicit adaptation to both spatial and temporal climate variability
- County-level database of cultivated area for each crop (University of New Hampshire 1990)

Step 4: Run the model

Aggregate domain-wide changes in productivity

Key question #1: How does overall potential productivity change?



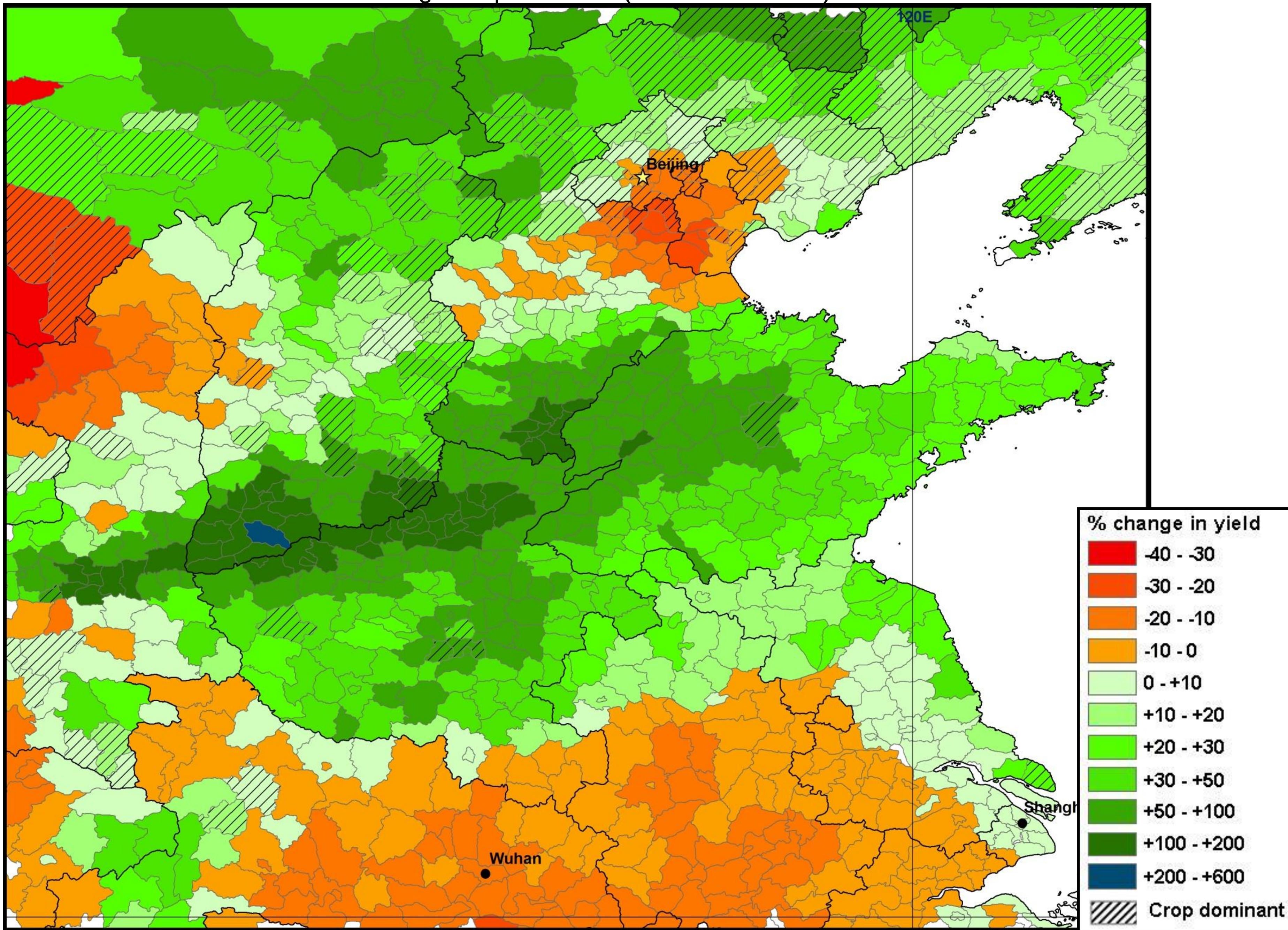
Yields weighted according to 1990 crop distribution
(i.e. if crop is grown only in current production zones)

Yields weighted according to total available cropland
(i.e. crop is grown everywhere)

Pacific Northwest NATIONAL LABORATORY

Regional Yield Change: Corn

changes in production (future – baseline)



Projections for corn production in 2070-2100

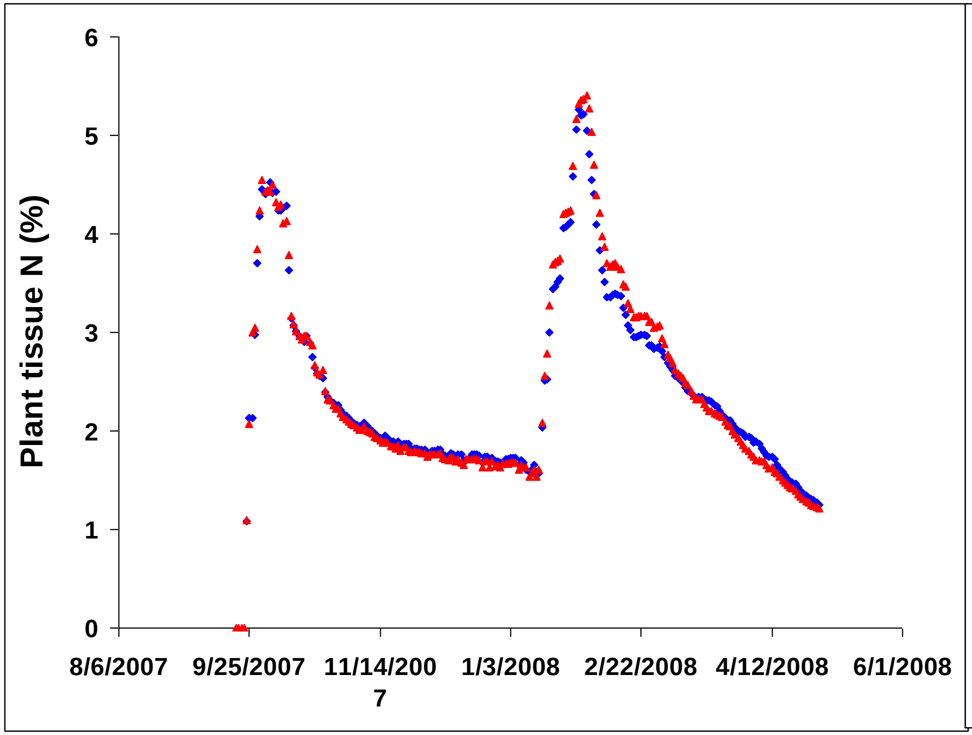
- **Key production zone**: central and northeast
  - Central (Huang-Hai Plain):
    - S Hebei, W Shandong, N Henan: 20-200% increase
    - Near Beijing: 10-30% decrease
    - Closely correlates with shifts in precipitation
  - Northeast: 10-80% increase
    - Driver: warmer temps, increased precip
- **Vulnerable regions**
  - South: 10-20% decrease
    - Driver: increased water stress (temps up, precip down)
- **Emergent regions**
  - Huang-Hai Plain: northwestward shift in high-yield corn belt

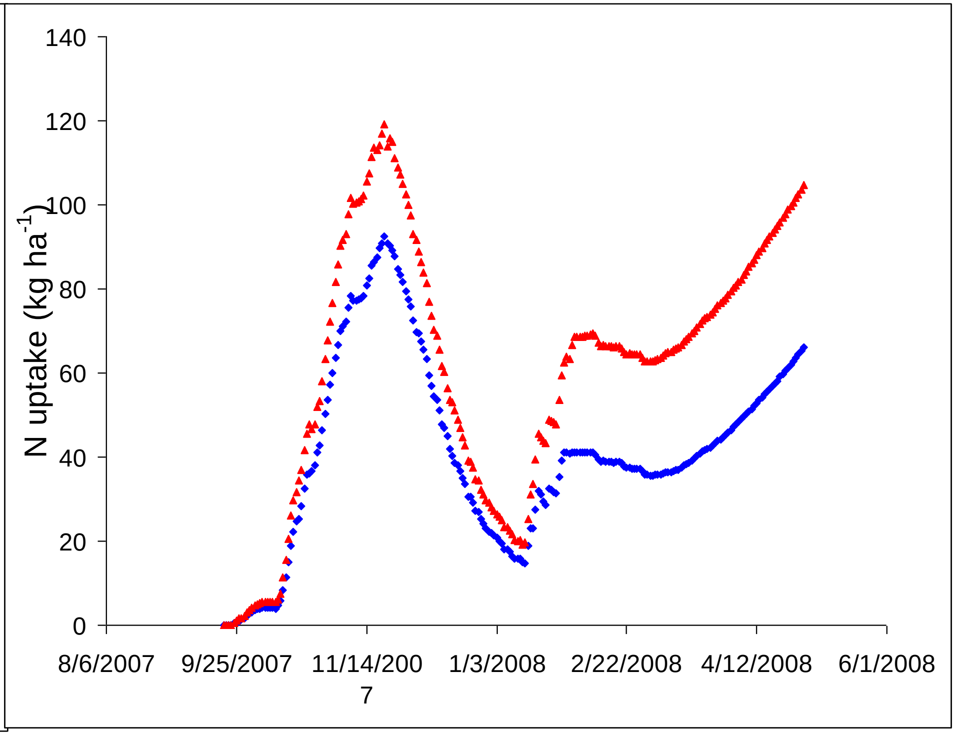
Developing an Assessment of Potential Reductions in Nitrate Leaching from Cover Crops

- Simulations with EPIC for Maryland's eastern shore - the Wye Recreational and Education Center
- Crop biomass, nitrogen uptake and leaching under
  - Summer fallow + fall rye
  - Corn no N + fall rye
  - Corn with N + fall rye
- This study aims to replicate existing conditions, for which measurements are scarce
- Once a simulation is established, it can be used to investigate:
  - Different crop management effects
  - Different climate futures

Rye tissue N (%): simulated with BWIA weather (blue), simulated with WREC weather (red)

Rye N uptake (kg ha^{-1}): simulated with BWIA weather (blue), simulated with WREC weather (red)

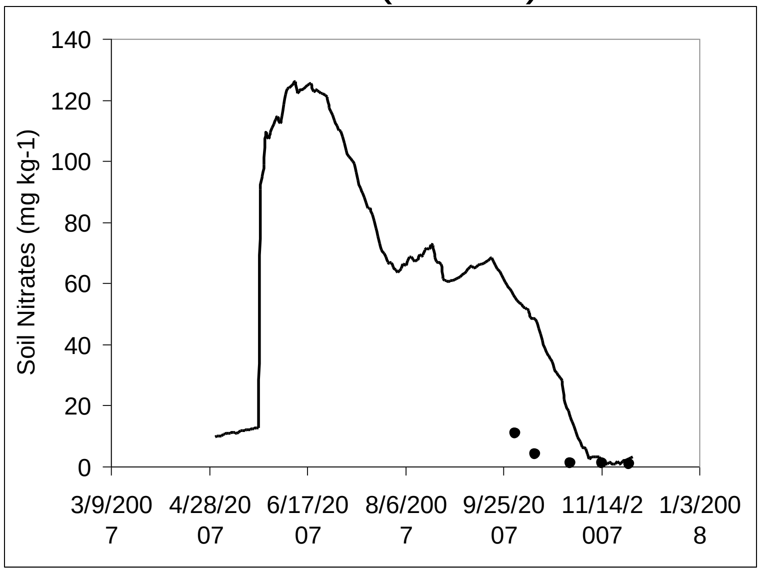


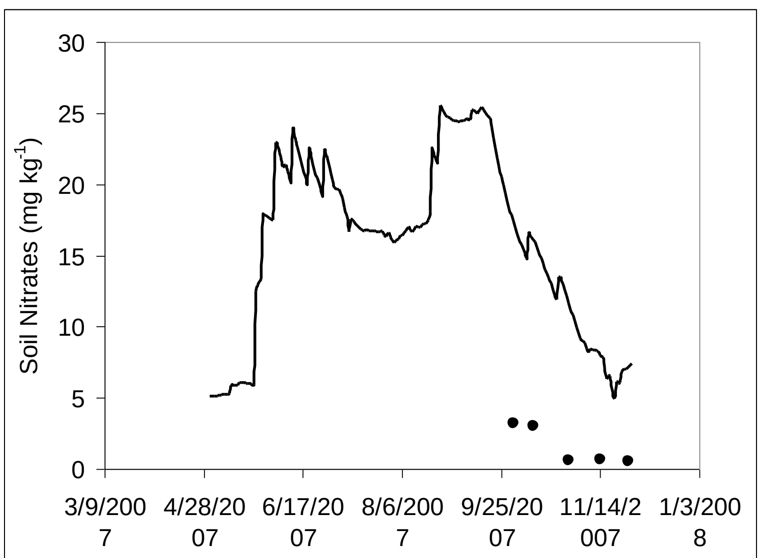


Pacific Northwest NATIONAL LABORATORY

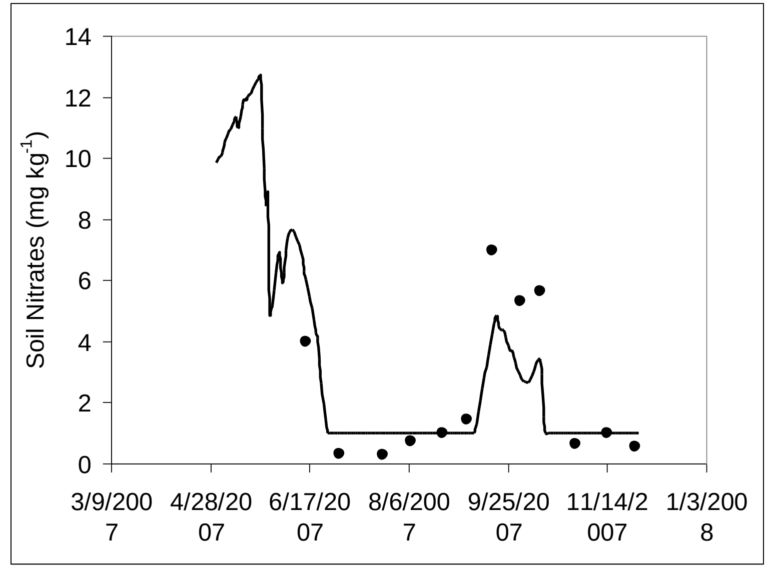
Soil nitrates at two soil depths (0-15 and 15-30 cm)

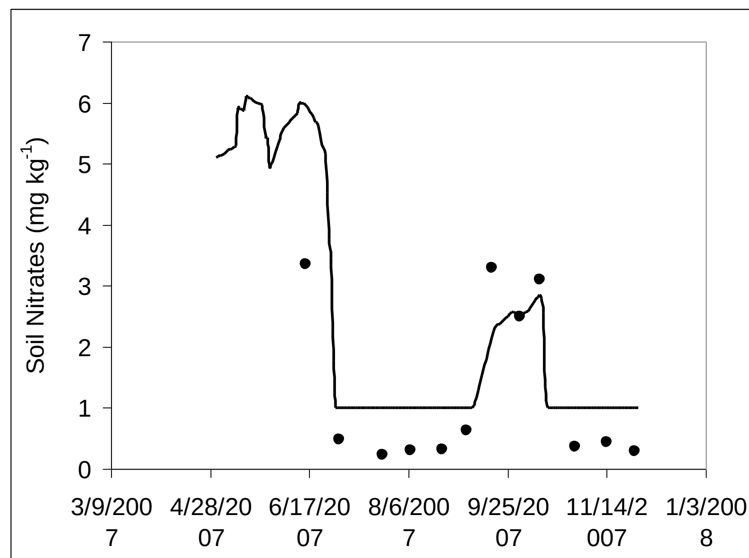
Corn (with N)





Corn (without N)





Resources for scientists

- Many available crop models can be used in impact studies
- The IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA)
  - The IPCC Data Distribution Center (http://www.ipcc-data.org/)
- NARCCAP (http://www.narccap.ucar.edu/)