Potato and Climate Extremes - Exploring Responses at Different Scales -

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Presentation Outline

- Three Major Research Themes:
  - Investigate influence of abiotic factors on crop growth and development
    - A summary of experimental responses to C x T
  - Quantify crop responses with mathematical algorithms and ‘explanatory’ crop models
    - Integrate empirical knowledge into process-level prediction tools
  - Decision support on effects of climate, management, genetics, and other factors on agricultural production systems
    - Use of models for scientific inquiry, impact assessments, adaptation studies, and food security

Why Potato?

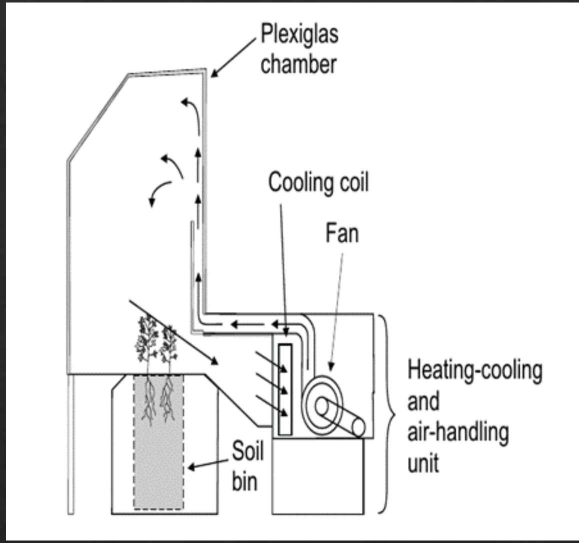
- The U.S. is the 5th largest producer in terms of yield
- Knowledge lags behind other major commodities such as maize, soybean, rice, and wheat
- Significant knowledge gaps exist regarding interaction of abiotic factors (C x T x W)
- C3 biochemistry shows positive responses to increasing C levels
- Drought and T sensitive and is highly susceptible to changes in climate and in-season weather oscillations
- Tremendous genetic resources
- Accuracy of existing decision support tools need to be improve to facilitate studies involving food security – not just in the U.S. but globally!

Experimental Responses

Aggregated C, C x T, C x W

Soil-Plant-Atmosphere-Research (SPAR)

- SPAR Research Facilities
  - Natural sunlight and soil volume
  - Control and monitor aerial and soil environments
    - C, T, W, RH, Nutrients
    - SRAD, Gas Exchange
  - Monitor whole canopy gas exchange
    - Photosynthesis; Transpiration
  - C, T, W studies

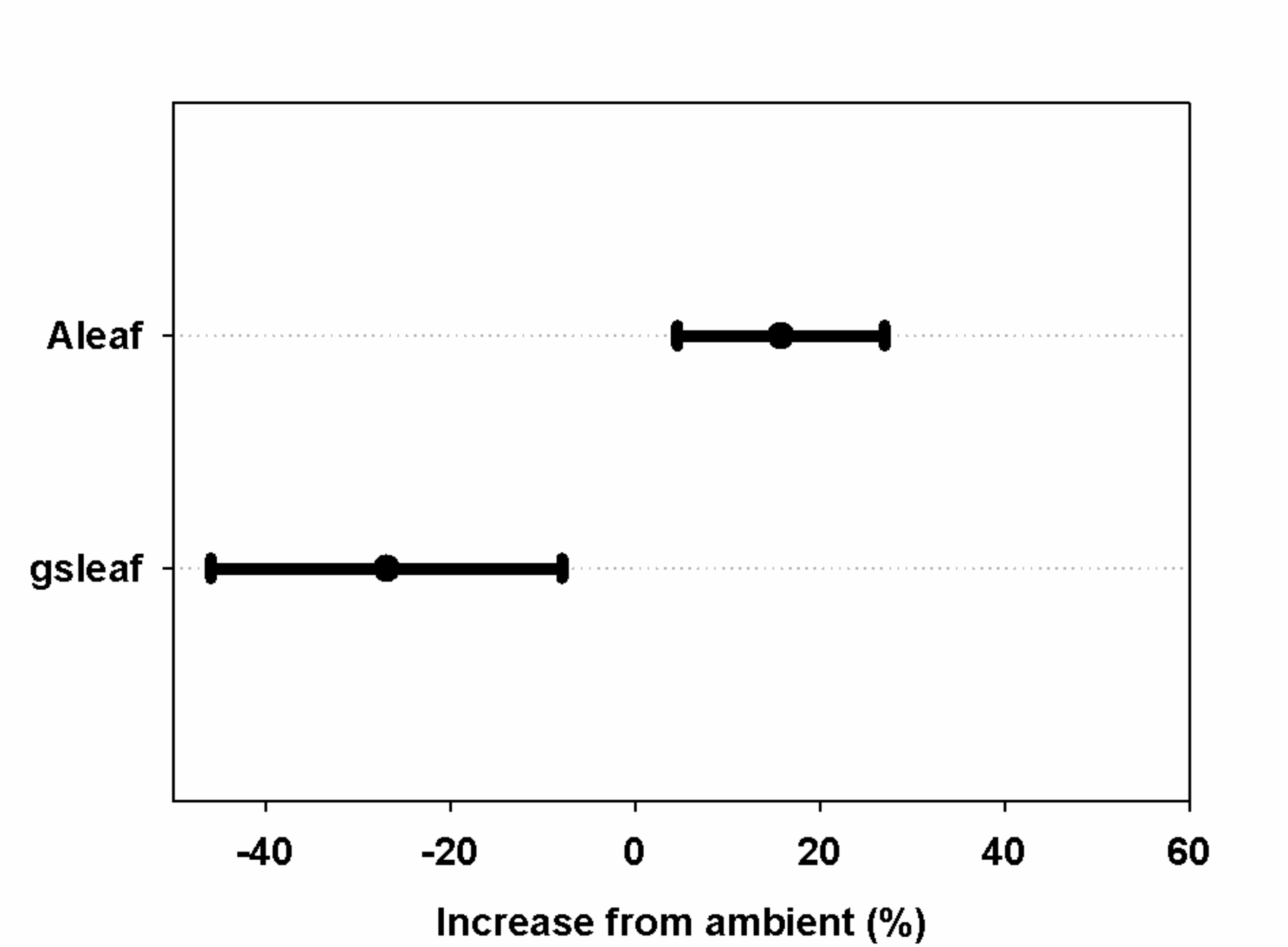


Typical SPAR Data

- Leaf gas exchange
  - Photosynthesis
  - Transpiration / Conductance
- Canopy-level gas exchange
  - Photosynthesis
  - Transpiration
- Destructive measurements
  - Biomass, leaf area, leaf senescence
- Phenology
  - Expansion; Elongation; Tasseling; Leaf Counts; Grain Fill
- C-H-N contents
  - C:N ratios for select tissues

Time-series & End-of-Season data collected

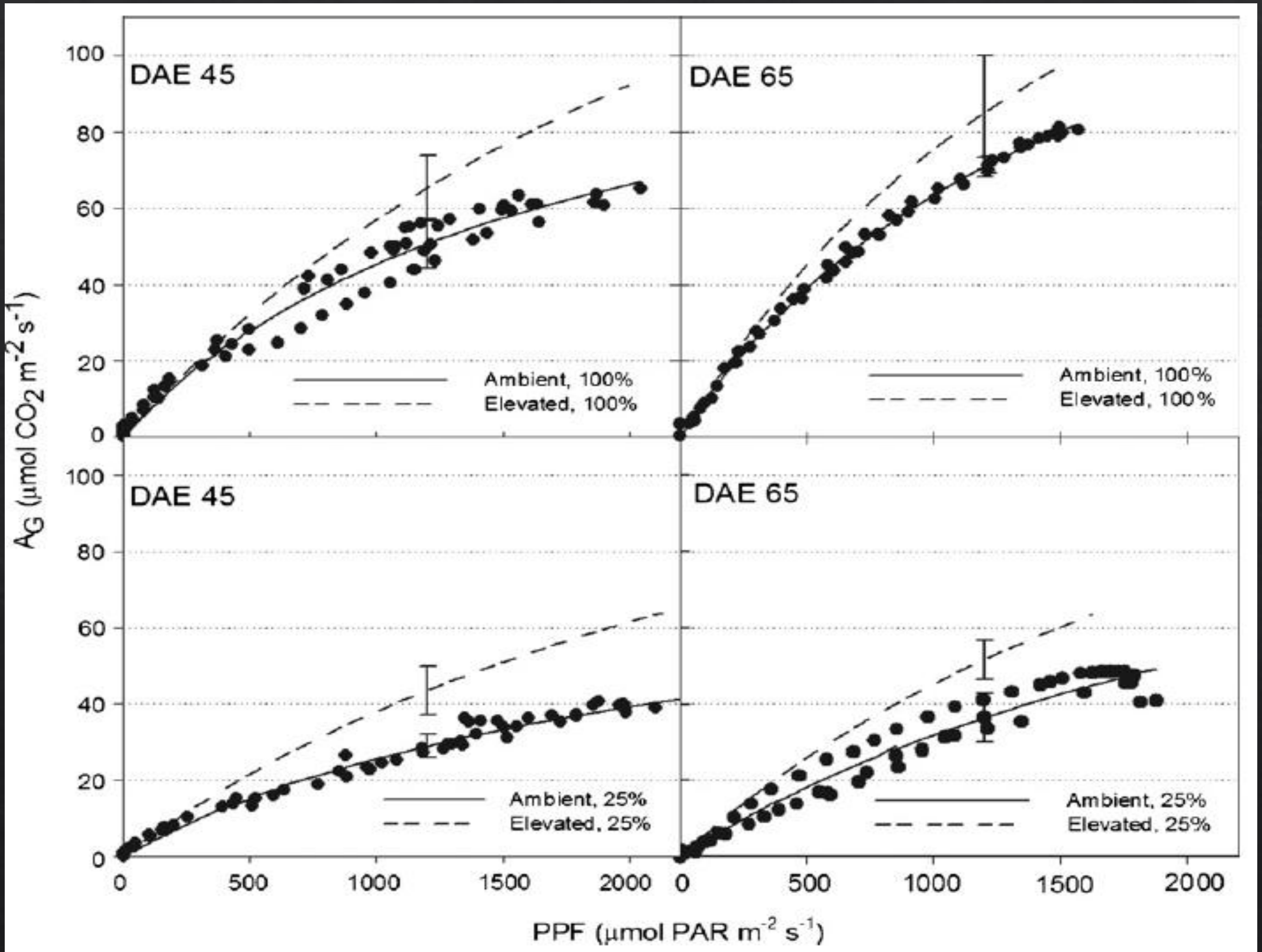
Leaf Scale - Gas Exchange Response



Data normalized wrt ambient C and aggregated across all treatments (P, ρ) from two SPAR experiments, cv Kennebec

- Leaf-level responses normalized with respect to ambient C (n = 2)
- Responses similar to other C3 crops:
  - Aleaf: +16%
  - gs: -27%
- Photosynthetic acclimation :
  - Enrichment effect on net photosynthetic rate persistent over duration of studies

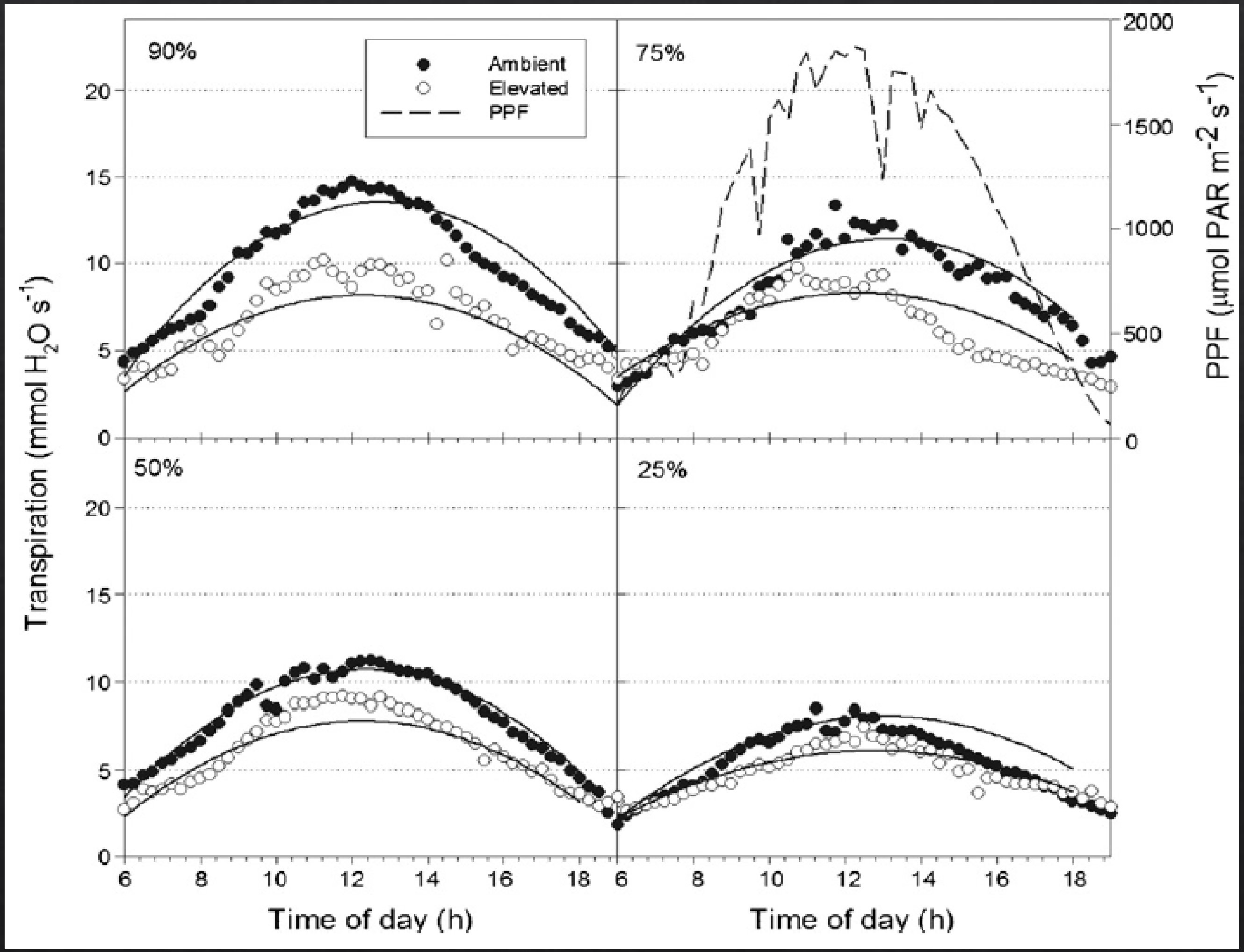
Plant Scale – Diurnal Gas Exchange Response



Diurnal net photosynthesis versus PAR at different dates, cv Kennebec

- Light response curves
  - Canopy Ag versus PAR
  - Two different dates
  - Two different water regimes
- Leaf-level responses to C are reflected to canopy level at different W levels
  - Not 1:1 scaling throughout
  - About 14% increase at high PAR

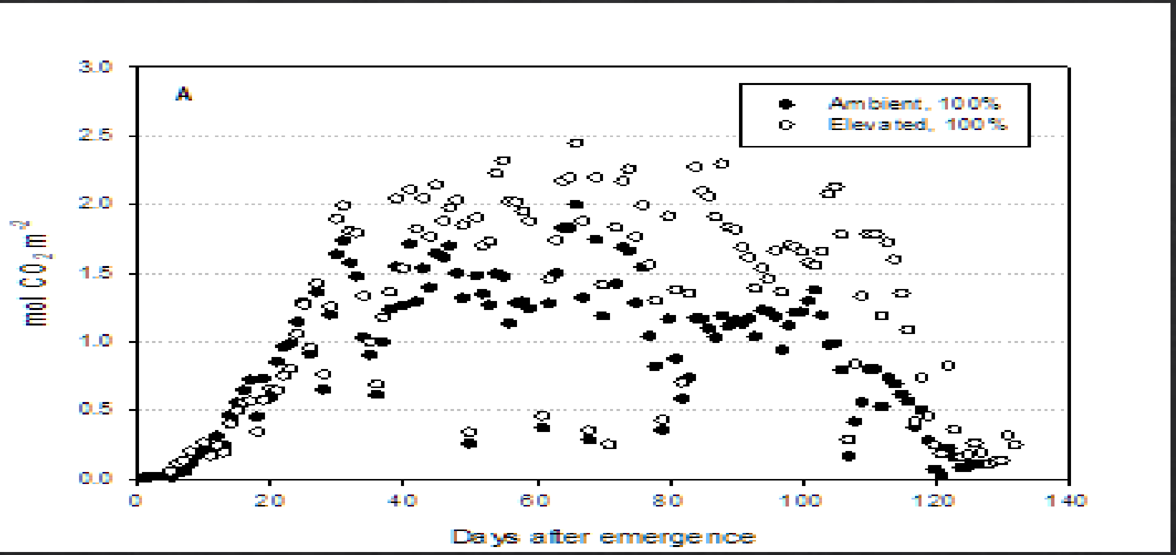
Plant Scale – Diurnal Gas Exchange Response

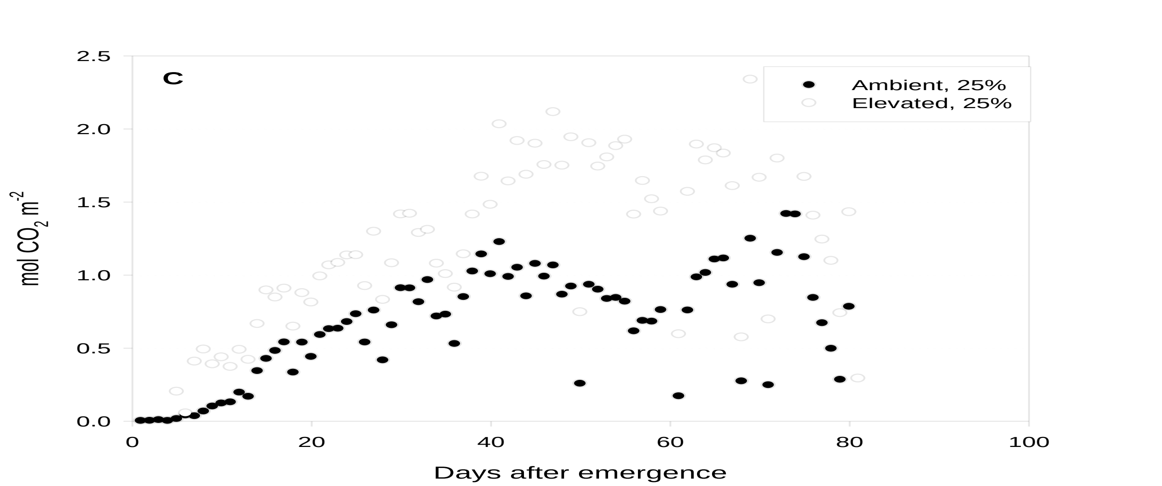


Diurnal ET at 4 water treatments, cv Kennebec

- Diurnal ET (45 DAE)
  - Four different watered treatments
- Transpiration reduced under ↑C
  - Less for all W treatments
  - About 8% reduced ET across multiple experiments

Plant Scale – Seasonal Gas Exchange Response

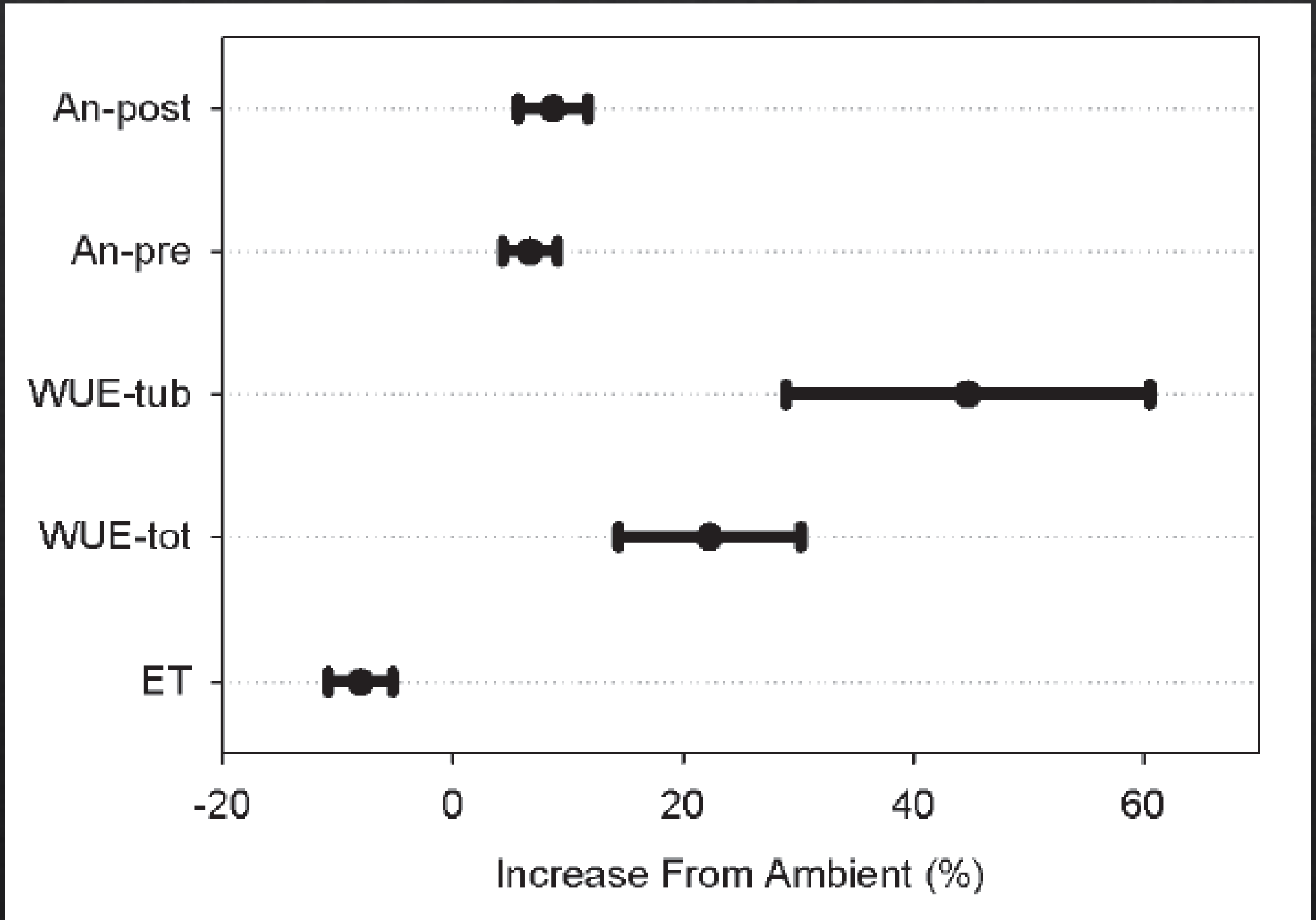




Seasonal Canopy Anet versus DAE at 2 water treatments, cv Kennebec

- Daily Canopy Anet
  - Well watered (top)
  - 25% ET (bottom)
- Maintenance of Anet apparent ↑C
  - (next slides)

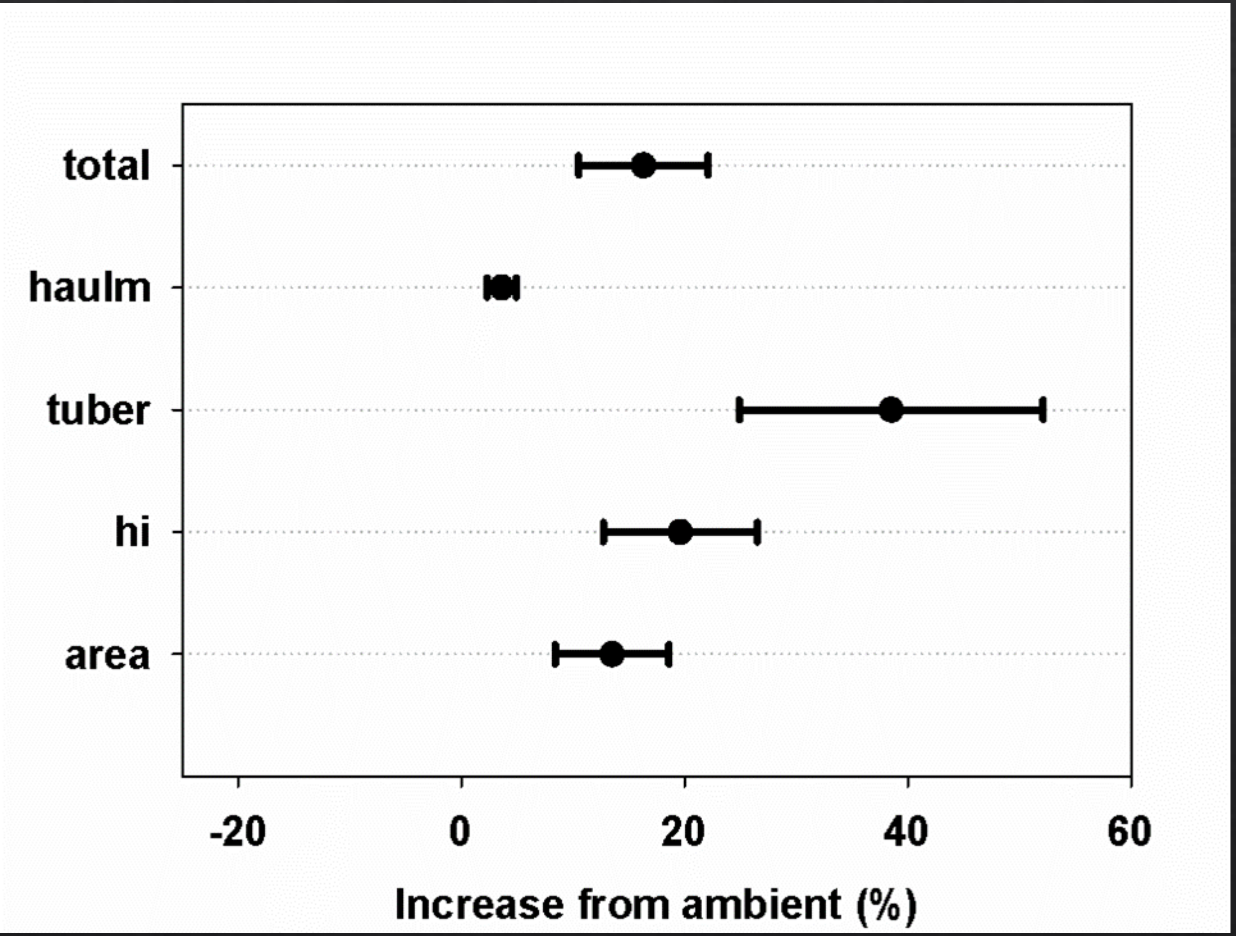
Plant Scale – Seasonal Gas Exchange Response



Aggregated response to C across multiple C, C x T, C x W studies (cv. Kennebec, Harley Blackwell, Snowden)

- Whole plant / Canopy responses
  - Aggregate of 8 SPAR studies
  - Leaf-level responses to C are reflected to canopy level
  - Not necessarily 1:1 scaling
    - Anet: ≈7 to 9% increase due to ↑C
    - ET: ≈8% reduction
    - WUEtotal: ≈22% increase
    - WUEtuber: ≈45% increase

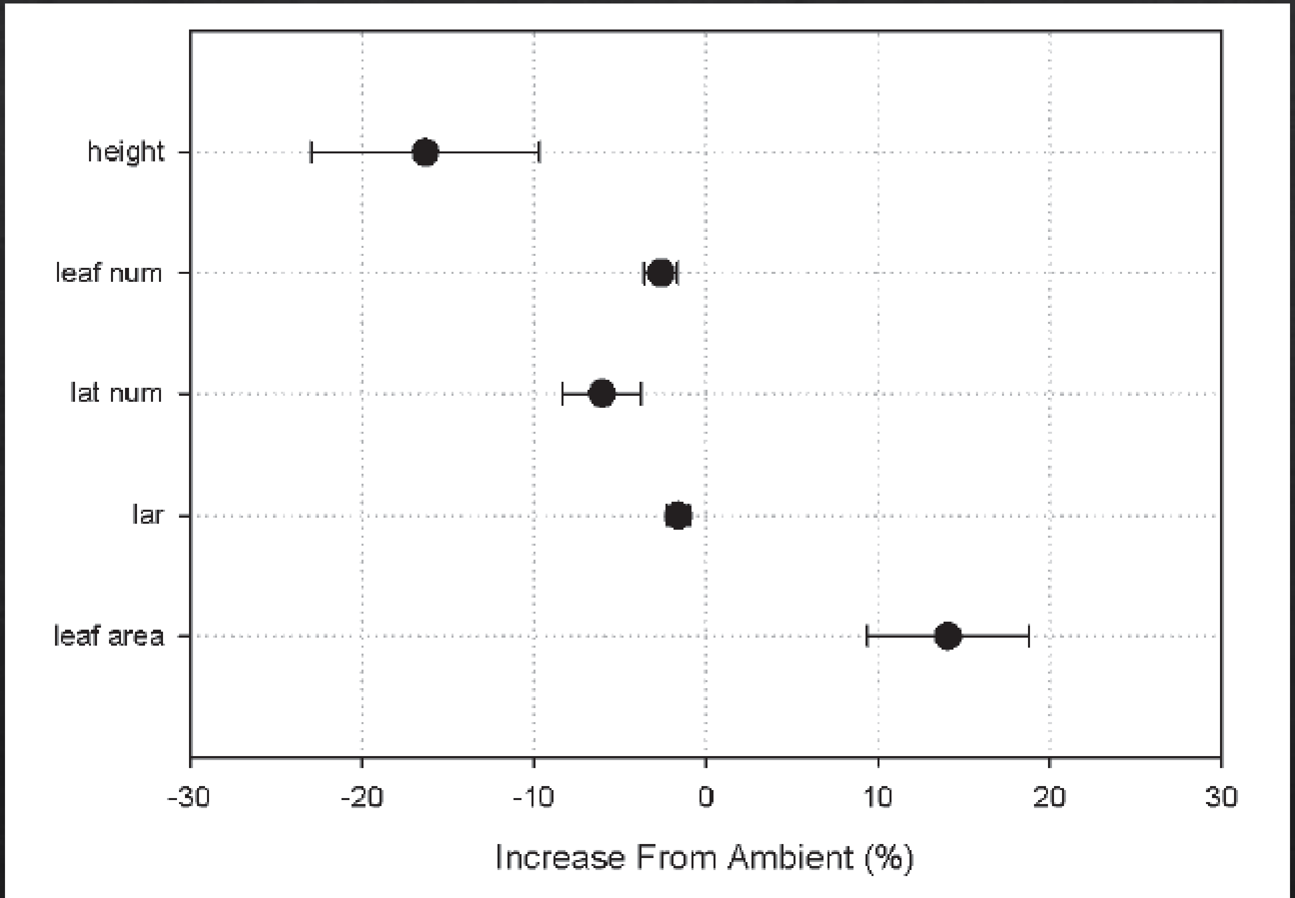
Plant Scale – Seasonal Production



- Whole plant responses
  - Aggregate of 9 SPAR studies
- Majority of biomass increase due to ↑C was allocated to tuber sink
  - Total: ≈18% increase
  - HI: ≈ 17%
  - Haulm: ≈ 4%
  - Tuber: ≈ 39%
  - Area (mid-season): ≈ 14%

Aggregated response to C across multiple C, C x T, C x W studies (cv. Kennebec, Harley Blackwell, Snowden)

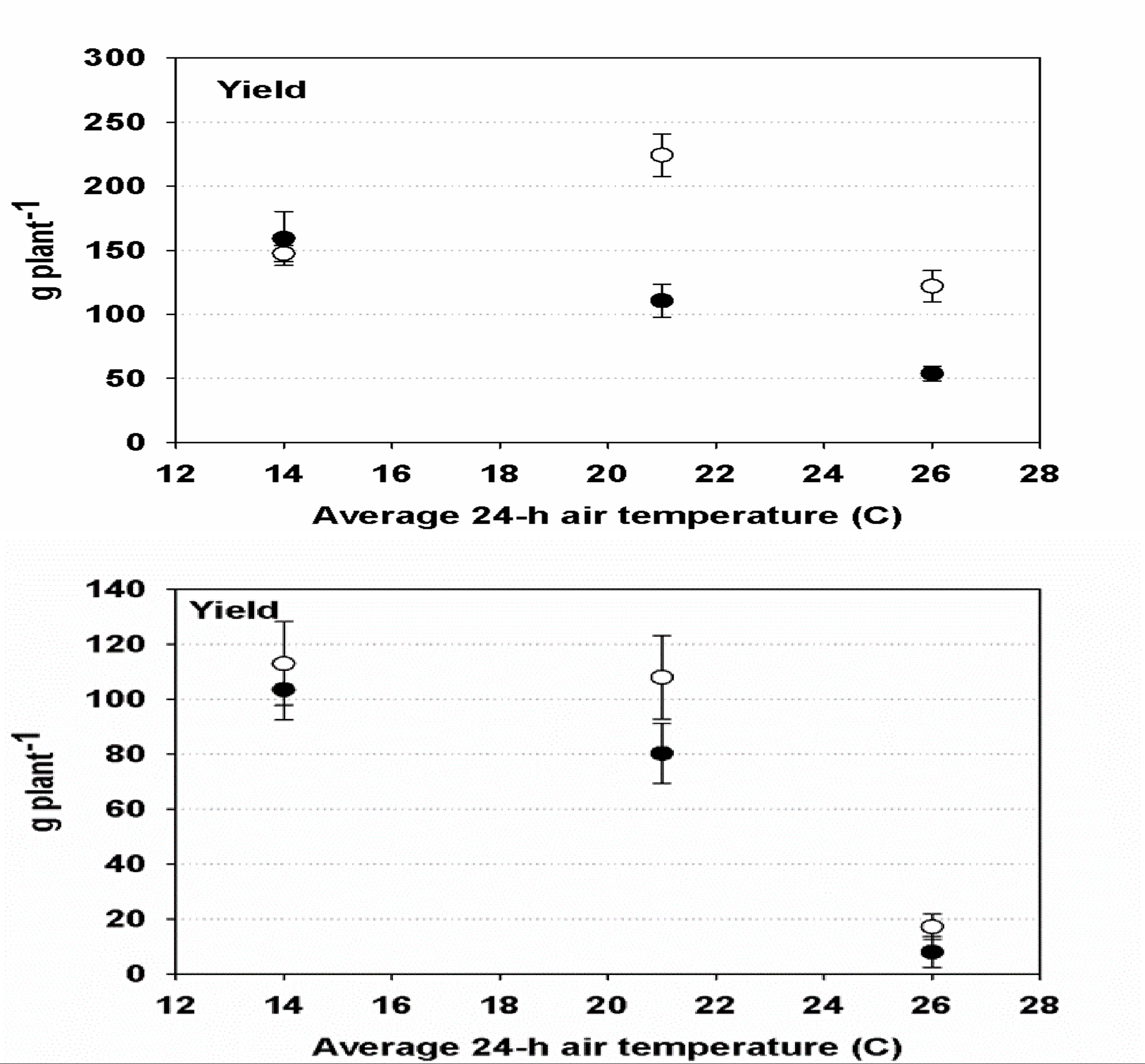
Plant Scale – Morphological Response



Aggregated response to C across multiple C, C x T, C x W studies (cv. Kennebec, Harley Blackwell, Snowden)

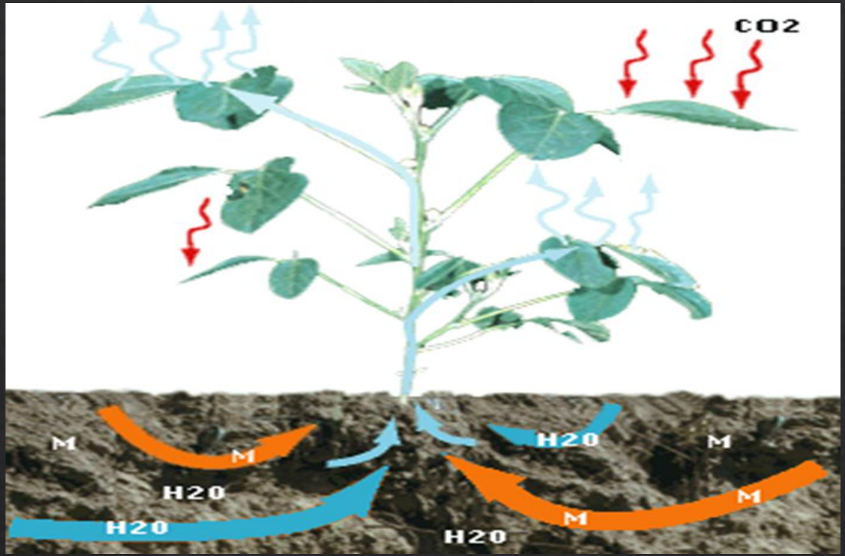
- Whole plant responses
  - Aggregate of 6 SPAR studies
- Conflicting evidence in literature regarding morphological and canopy development responses
- SPAR Results
  - Height: ≈16% shorter
  - Leaf Area: ≈14% increase in mid-season
  - Other responses likely not significant
  - Did not see differences in senescence rates

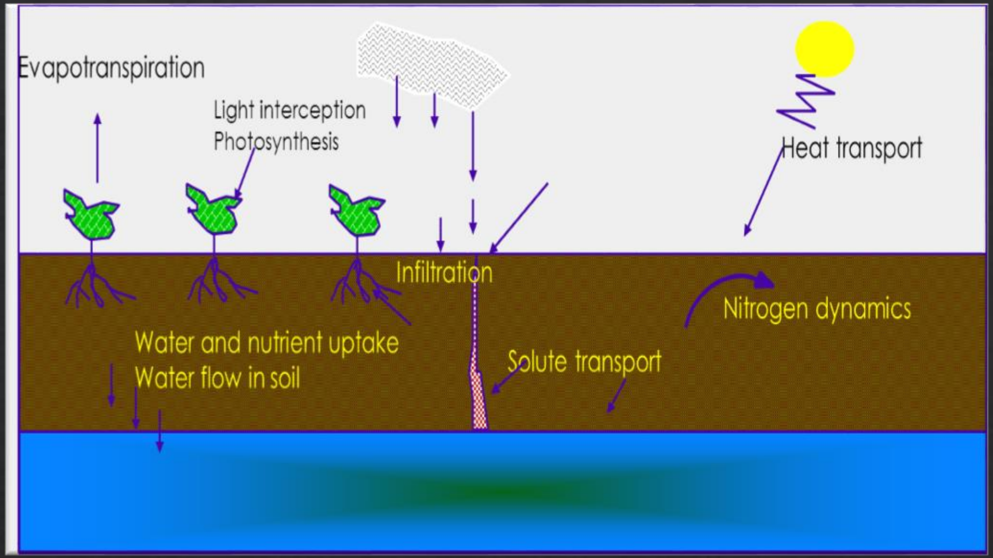
Plant Scale – Specific Interactions



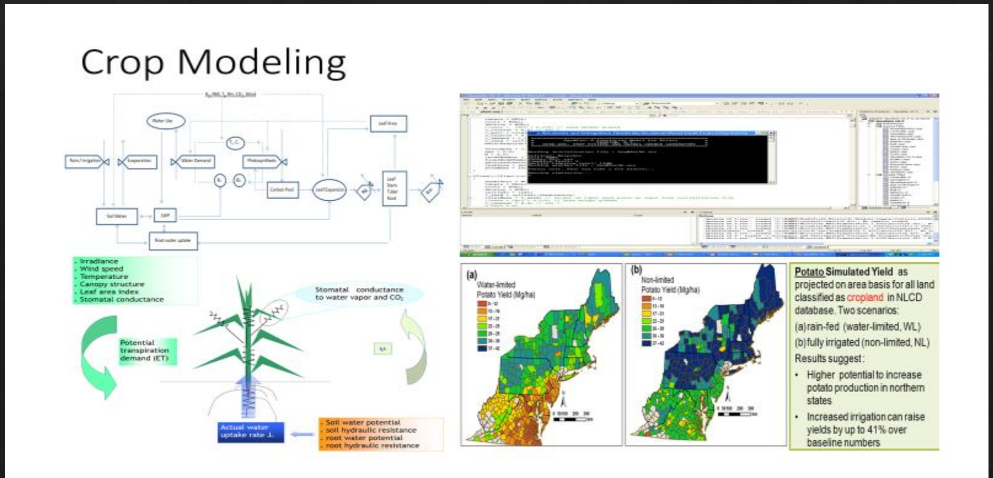
C x T response for mid- (HB variety top), and late- (SN variety bottom) maturating cultivars

- C x T
  - ↑C somewhat offset high T response on yield but also stimulated relatively more biomass (reduced HI)
  - Cultivars differed in response!
  - General thought is that ↑C may exacerbate T stress at higher levels due to effect on stomatal conductance
- C x W
  - ↑C conferred better WUE enabling higher yields under droughted conditions

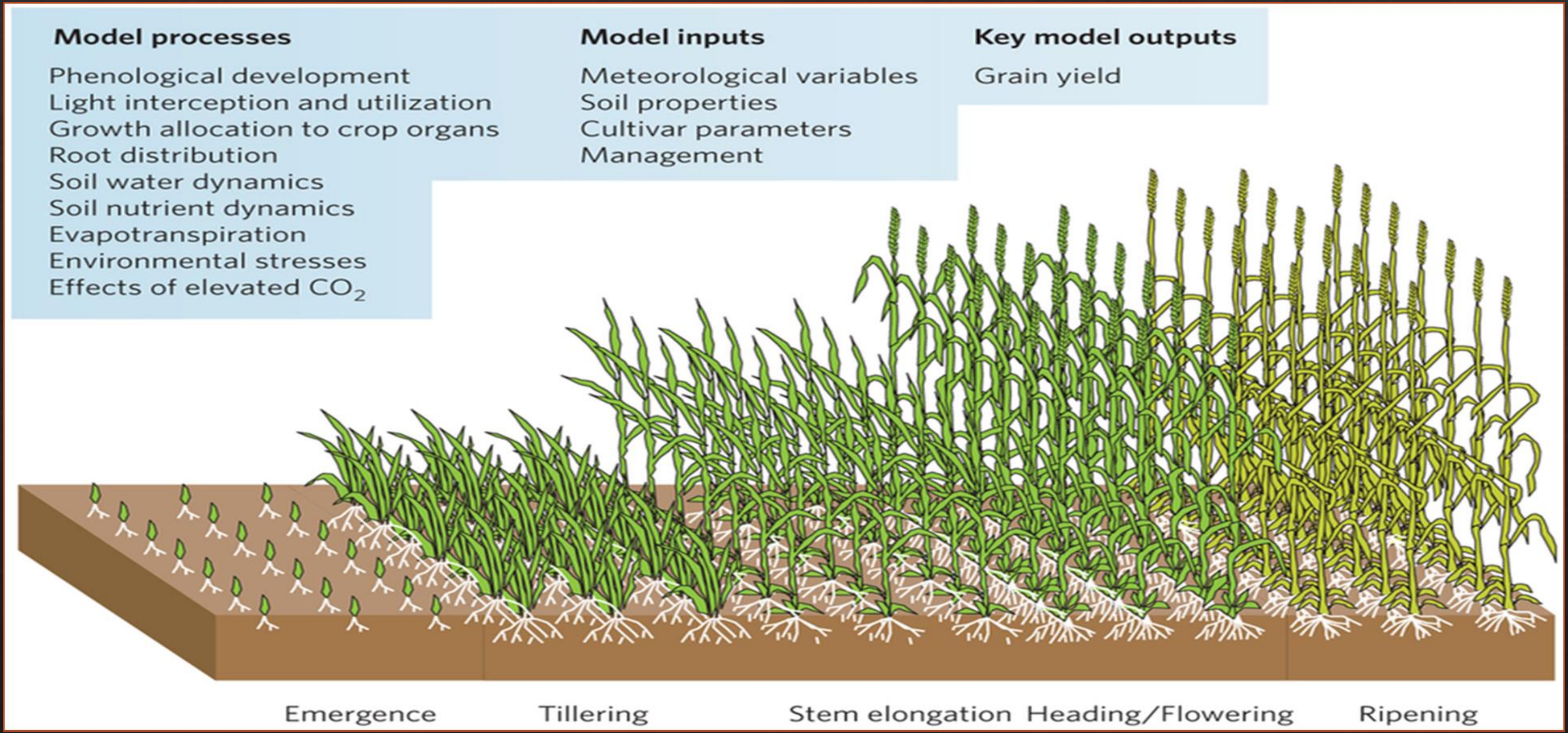




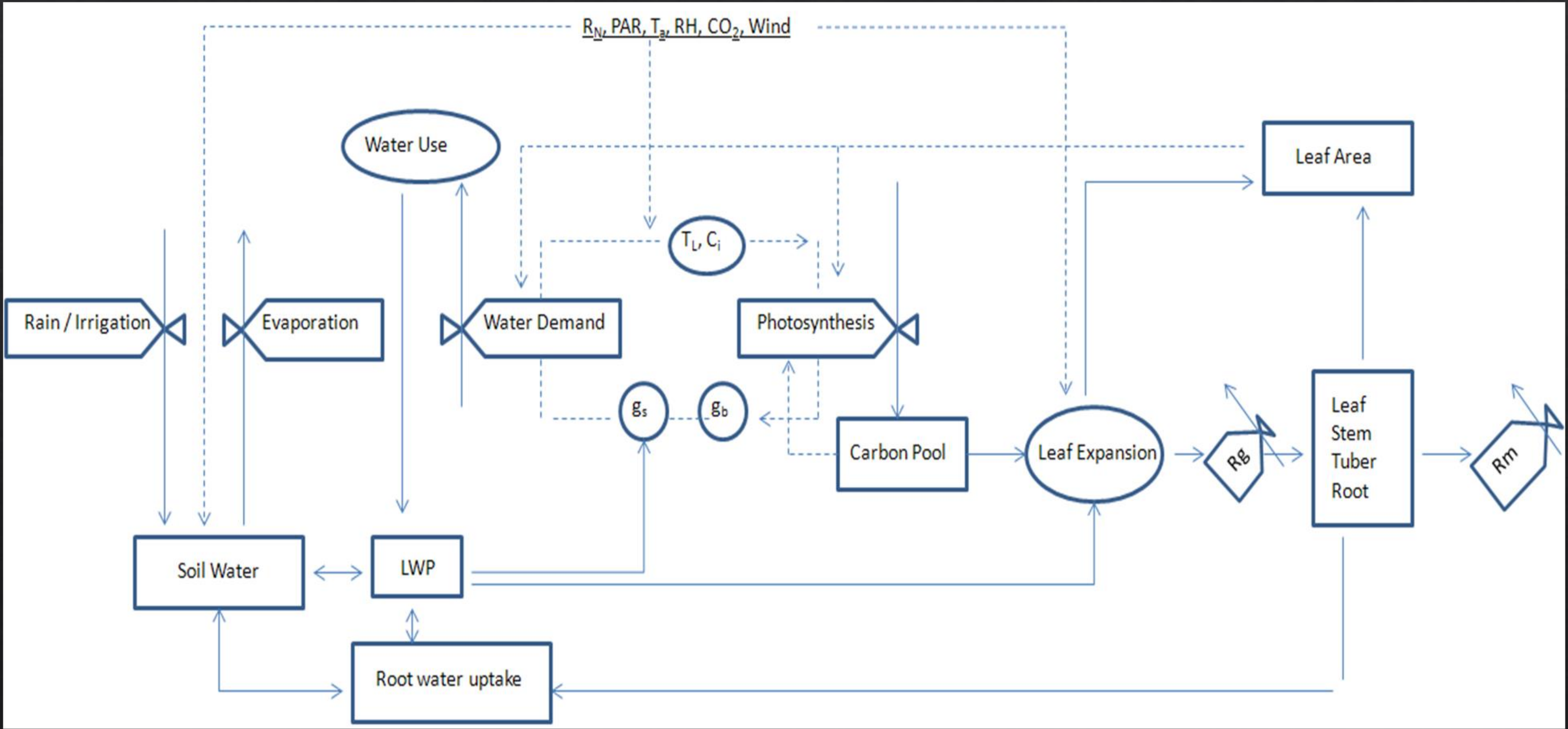
Explanatory crop modeling?



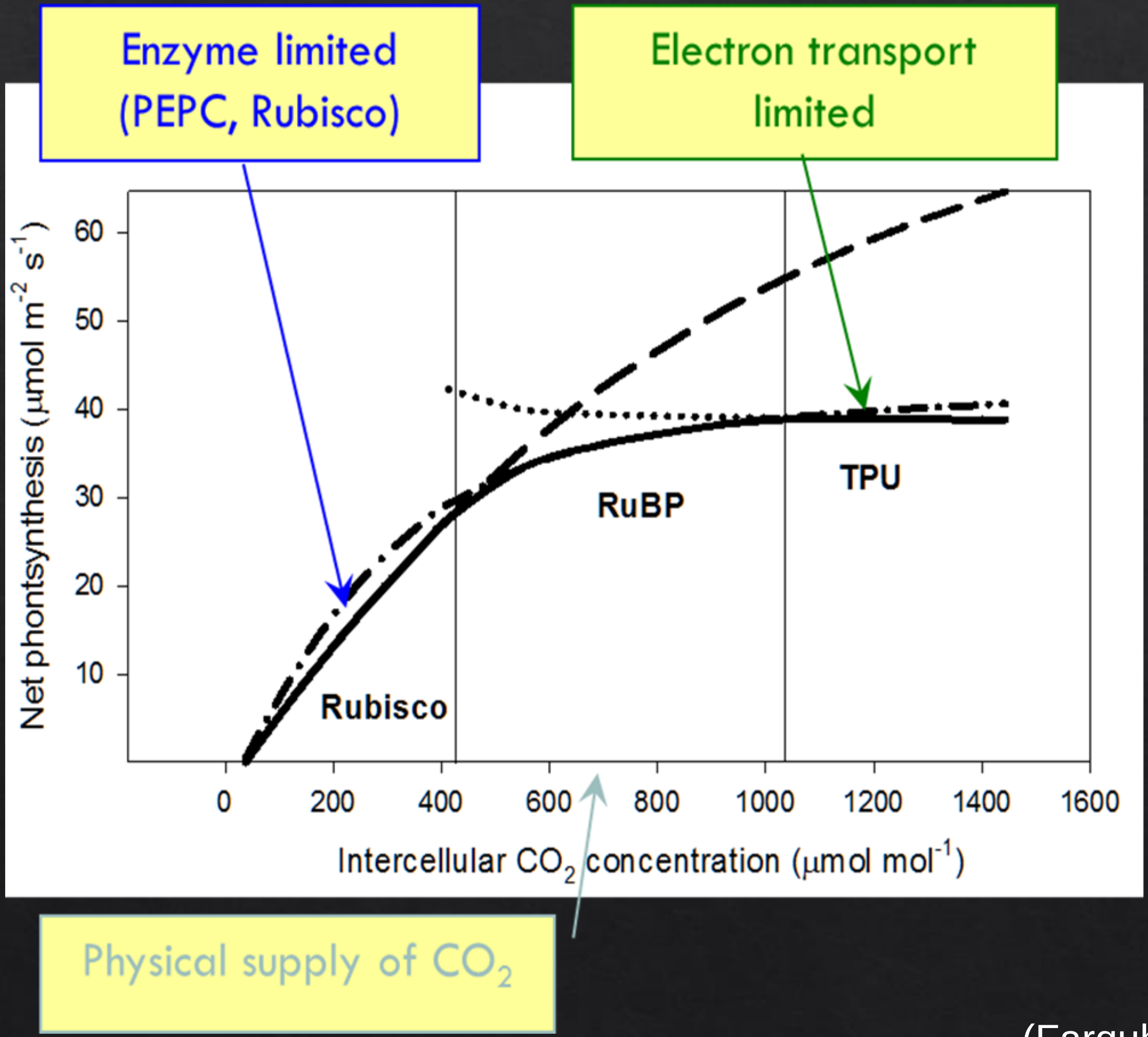
Conceptualize G x E x M Processes



State Variables and Rate Processes



Example – Leaf Photosynthesis



$$A_n = min\{W_c, W_j, W_p\}\left(1 - \frac{\Gamma^*}{C_c}\right) - R_d$$

- Carboxylation limited:

$$w_c = \frac{V_{c,max} \cdot C}{C + K_c(1 + O/K_o)},$$

- Regeneration limited:

$$Wj = \frac{JC}{4C + 8\Gamma^*}$$

$$J = \frac{I\alpha\varphi + J_{max} - \sqrt{(I\alpha\varphi + J_{max})^2 - 4\theta I\alpha\varphi J_{max}}}{2\theta}$$

(Farquhar et al., 1980; Harley et al., 1992; de Pury and Farquar, 1997)

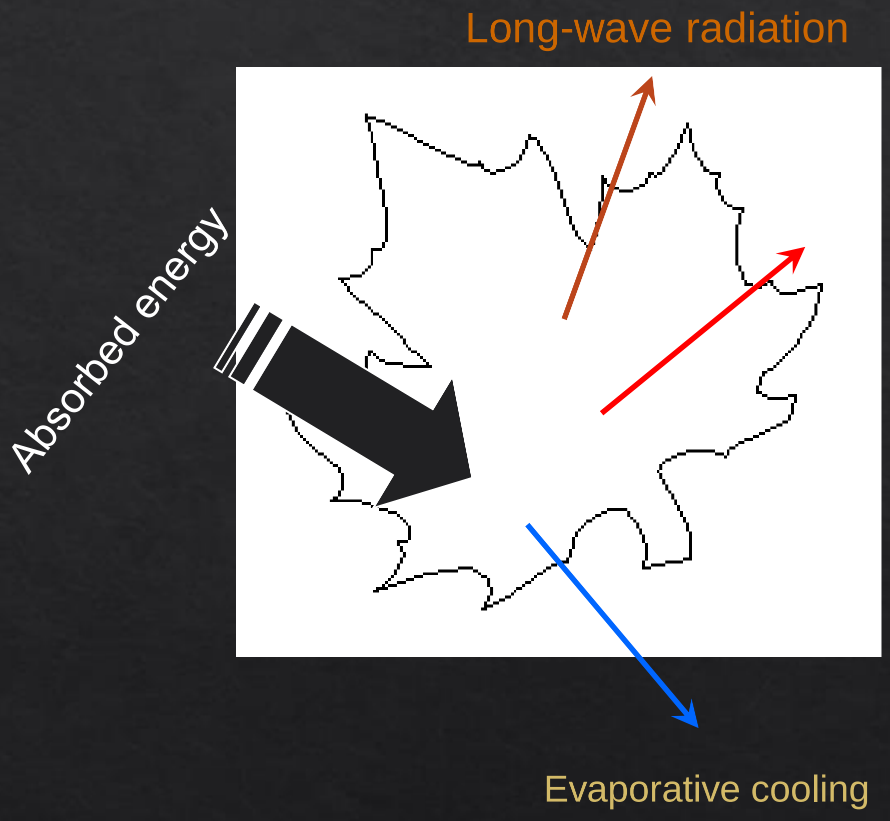
Example - Stomatal Conductance

- Regulation of stomatal conductance using Ball, Woodrow, Berry model (1987):

$$g_s = b + m(Ah_s/C_s)$$

- g_s: stomatal conductance for water vapor
- *b, m*: empirical coefficients
- *A*: net CO_2 assimilation rate
- h_s: relative humidity at leaf surface
- C_s: leaf surface [CO_2]

Example - Energy Balance



$$R_{abs} = L + H + \lambda E$$

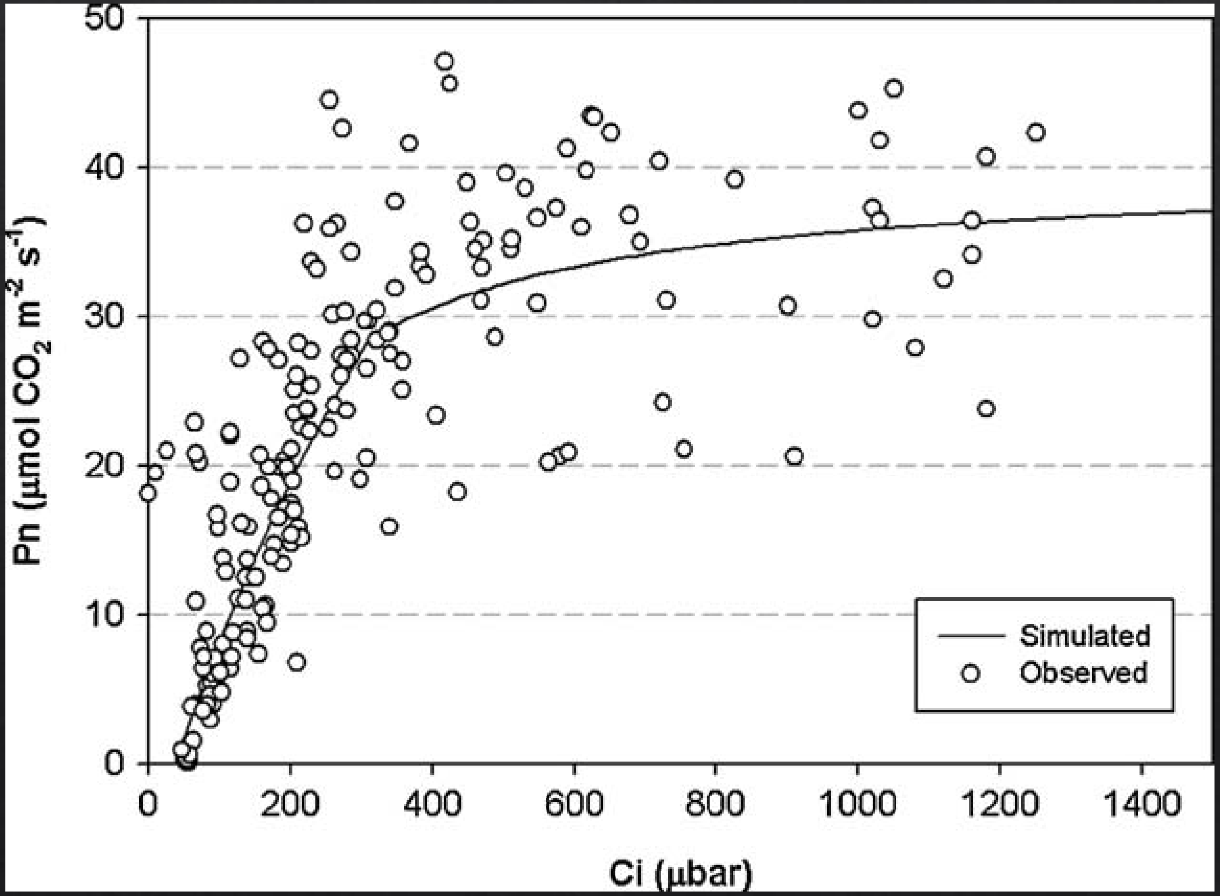
- R_{abs}: Absorbed radiation
- L: Long-wave radiation
- H: Sensible heat loss
- λE: Latent heat loss (evaporative cooling)

- Use linearized Penman model:
- T, R_{abs}, Wind, VPD, Geometry

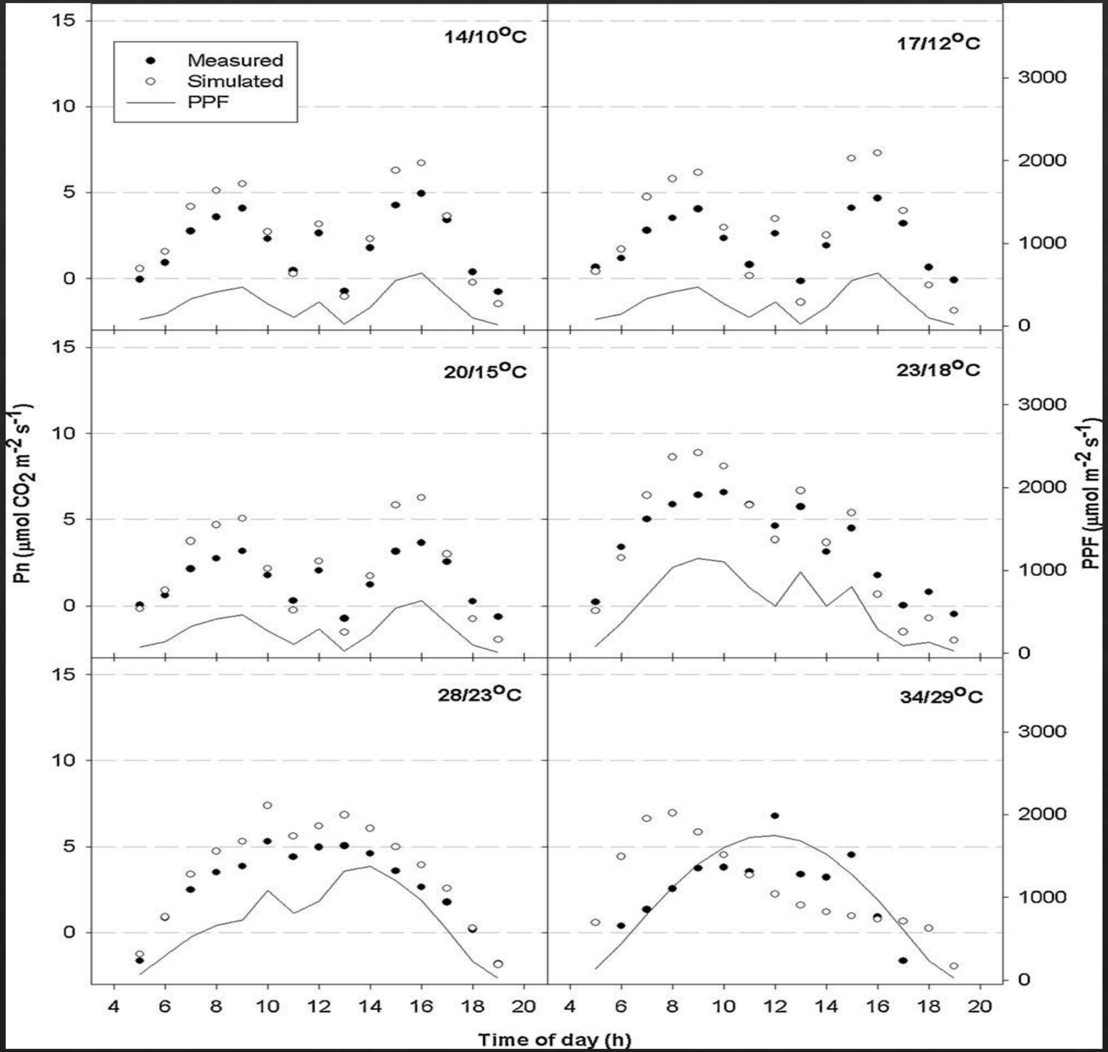
$$T_L = T_a + \frac{R_{abs} - \varepsilon\sigma T_a^{\,4} - \lambda g_v D / P_a}{c_p(g_h + g_r) + \lambda((de_s(T_a)/dT)/P_a) g_v}$$

Example –Photosynthesis Calibration

- Parameterize model sub-components from experimental data

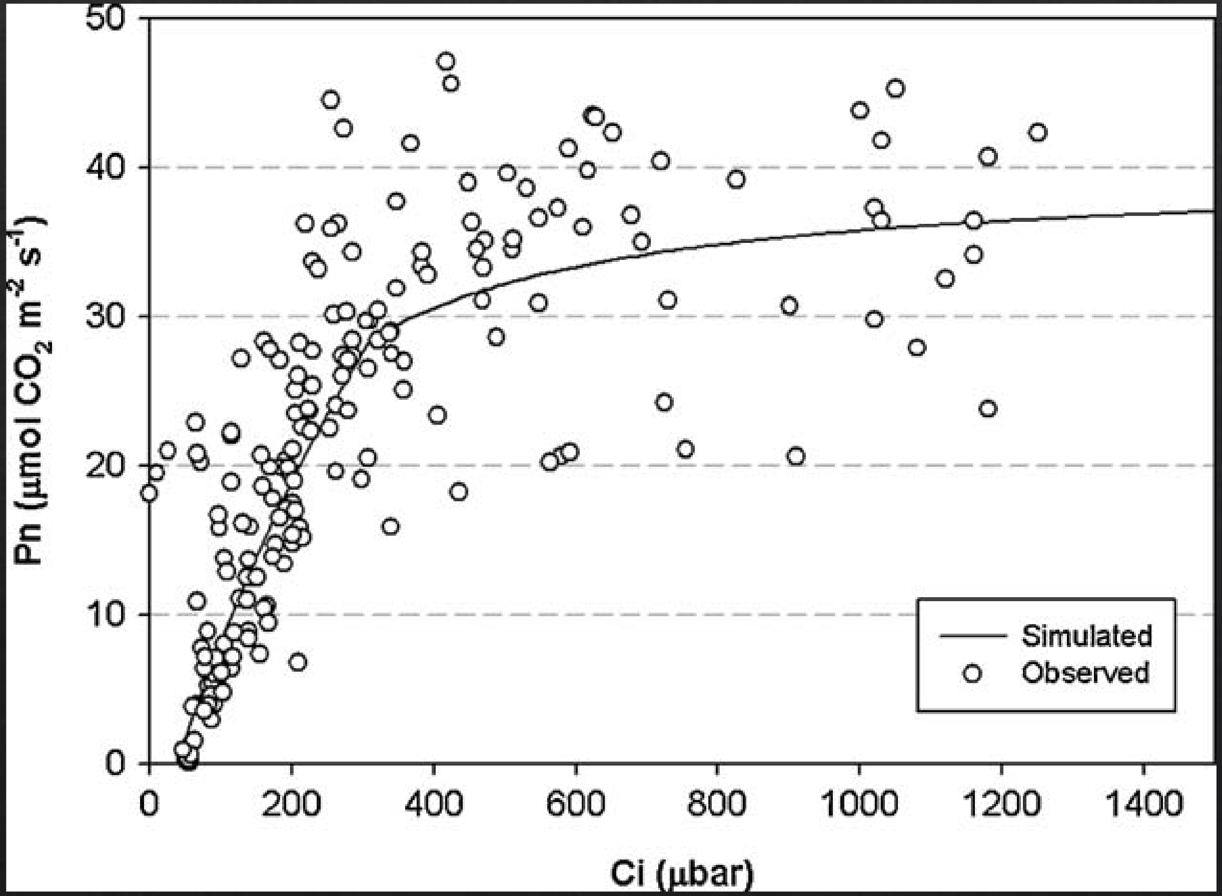


- Scale from leaf to whole canopy



Model calibration and validation

- Parameterize model sub-components from experimental data



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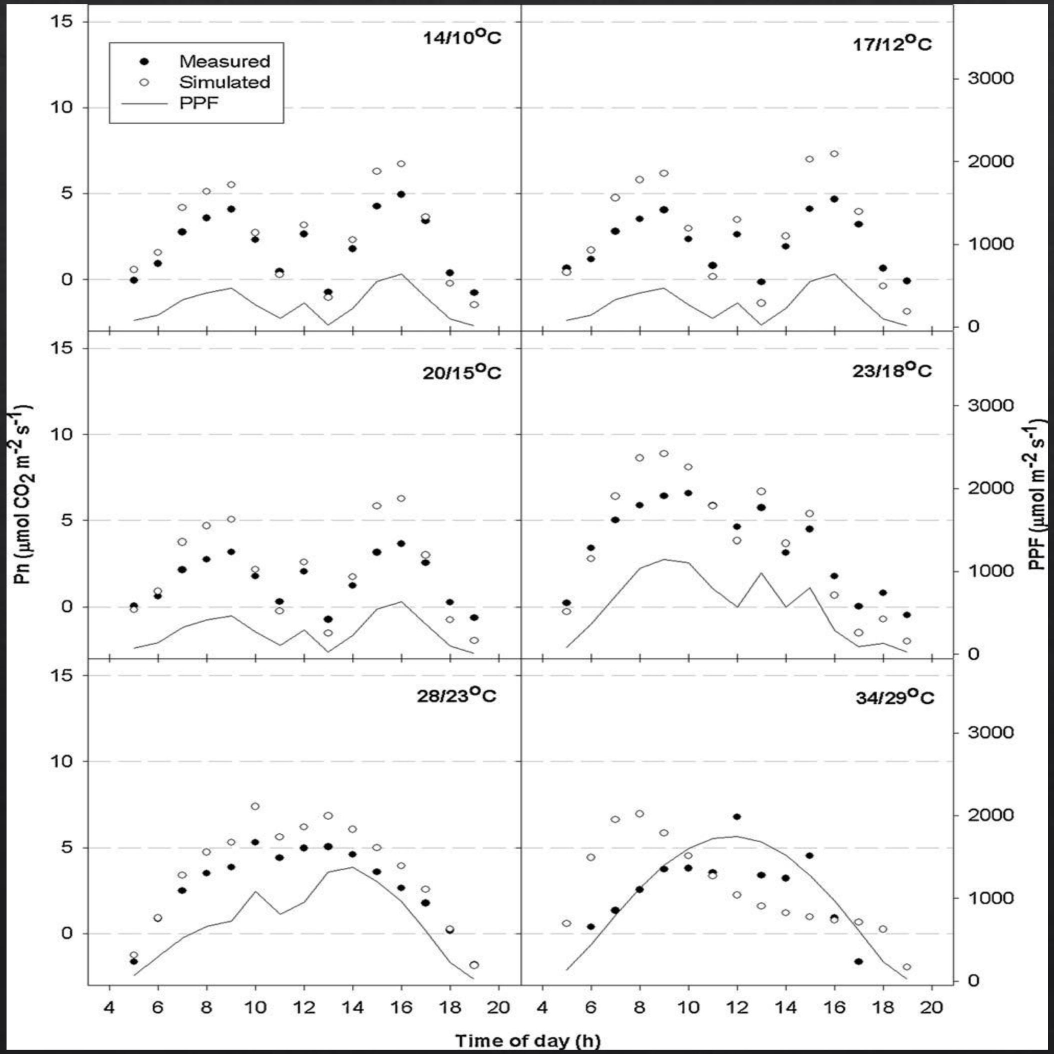
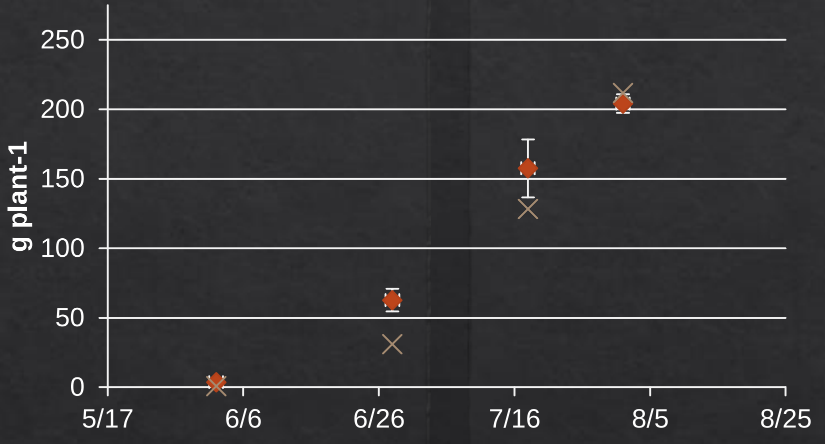
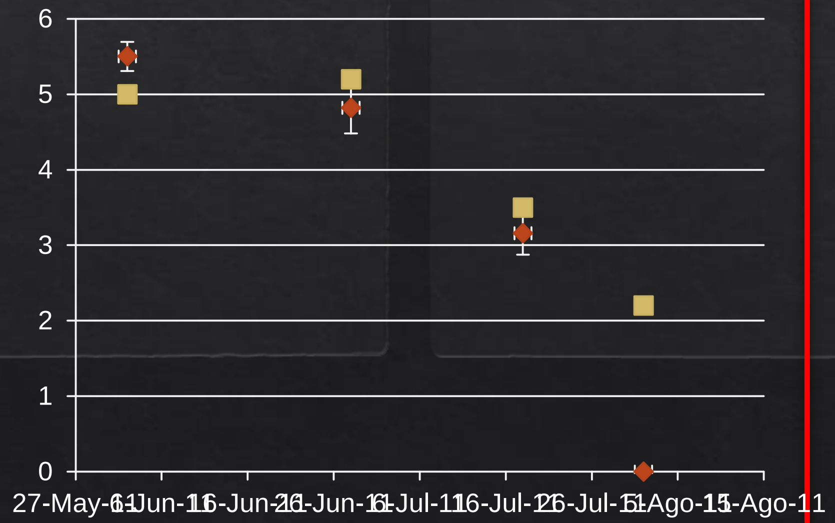


Model calibration and validation

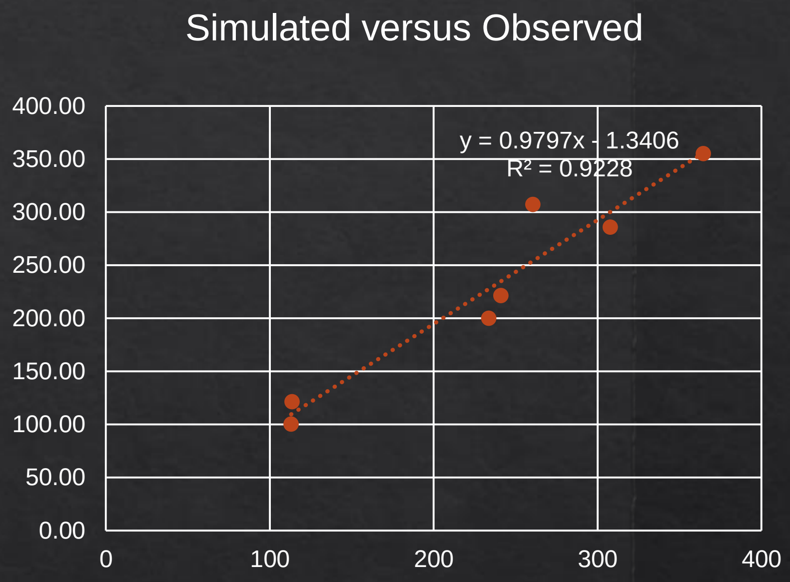
Field Data

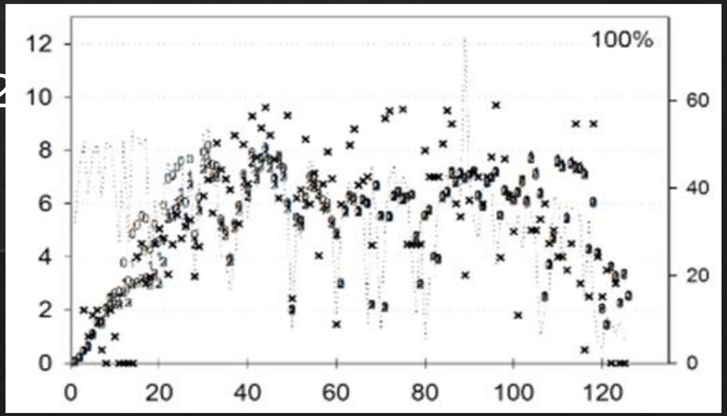
Model Comparisons





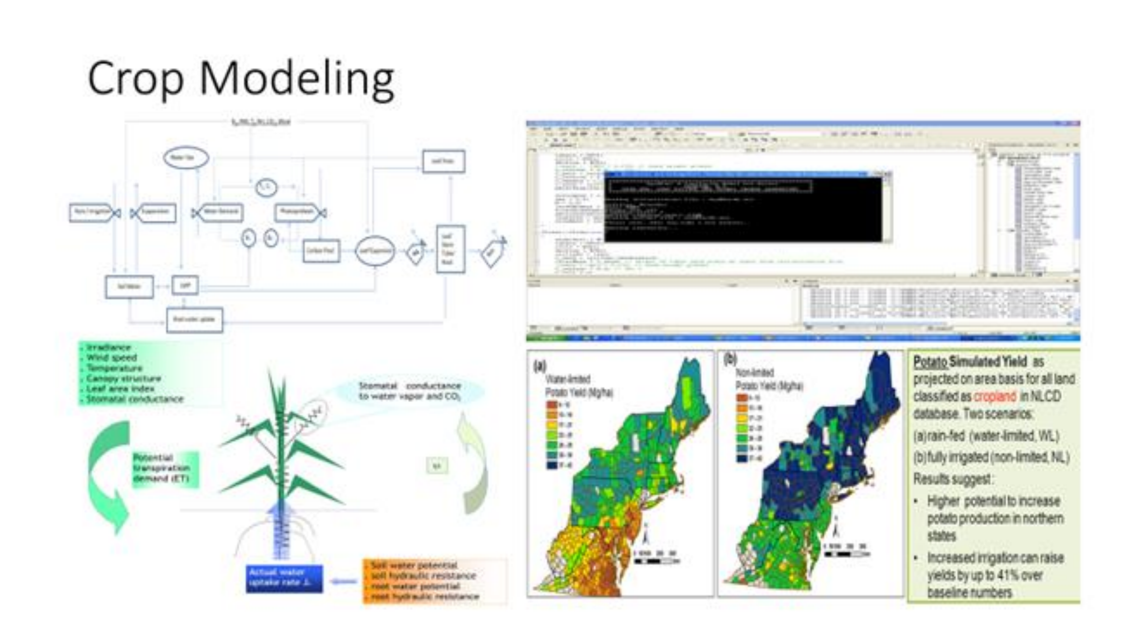
Model Validation





Application Examples

Climate Assessments & Food Security



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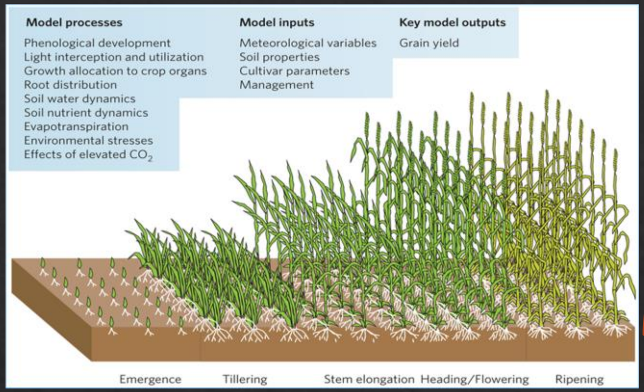
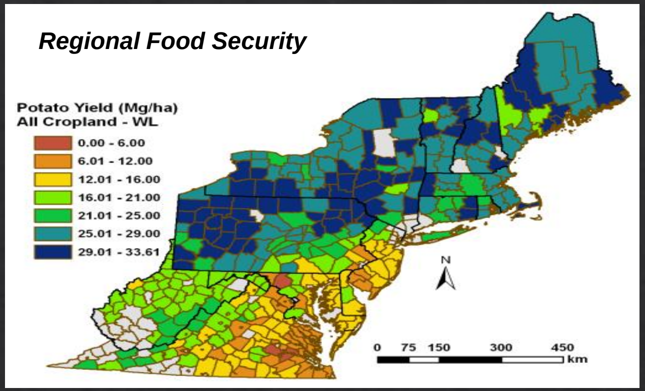
Production Forecasts

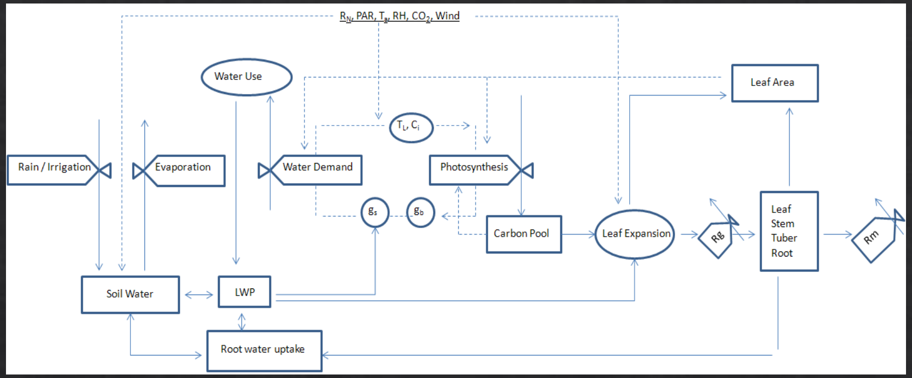


Food Security

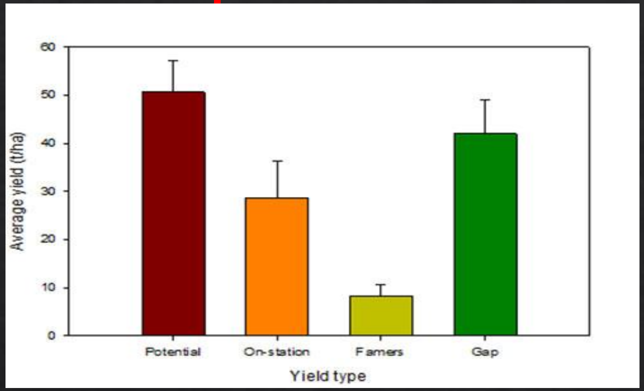


CLIMATE SOIL CROP VARIETY MANAGEMENT

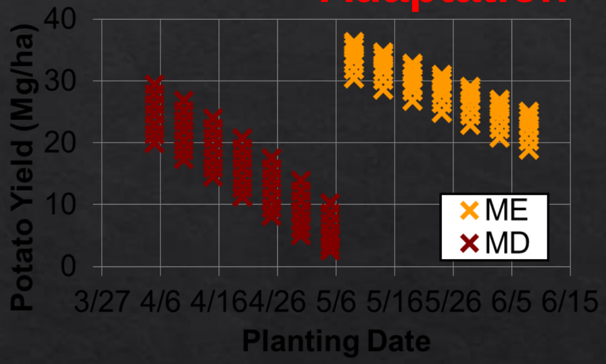
INPUT

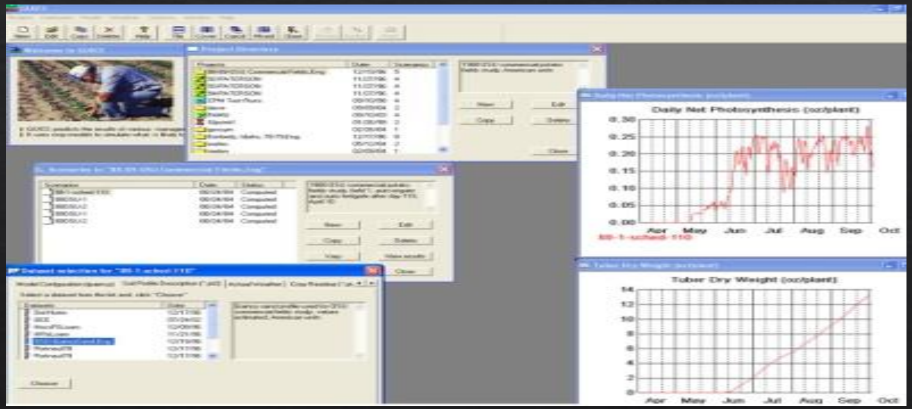


Yield Gaps

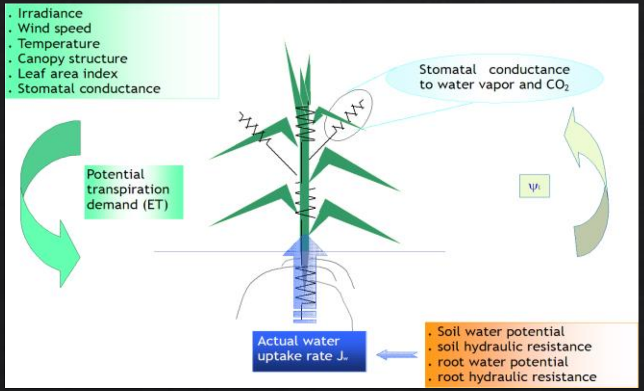


Adaptation

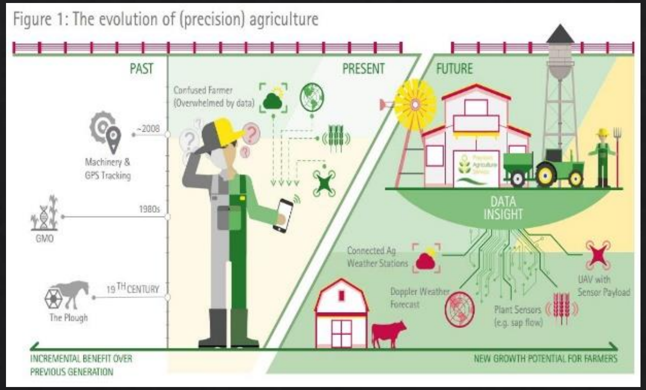




Scientific Inquiry



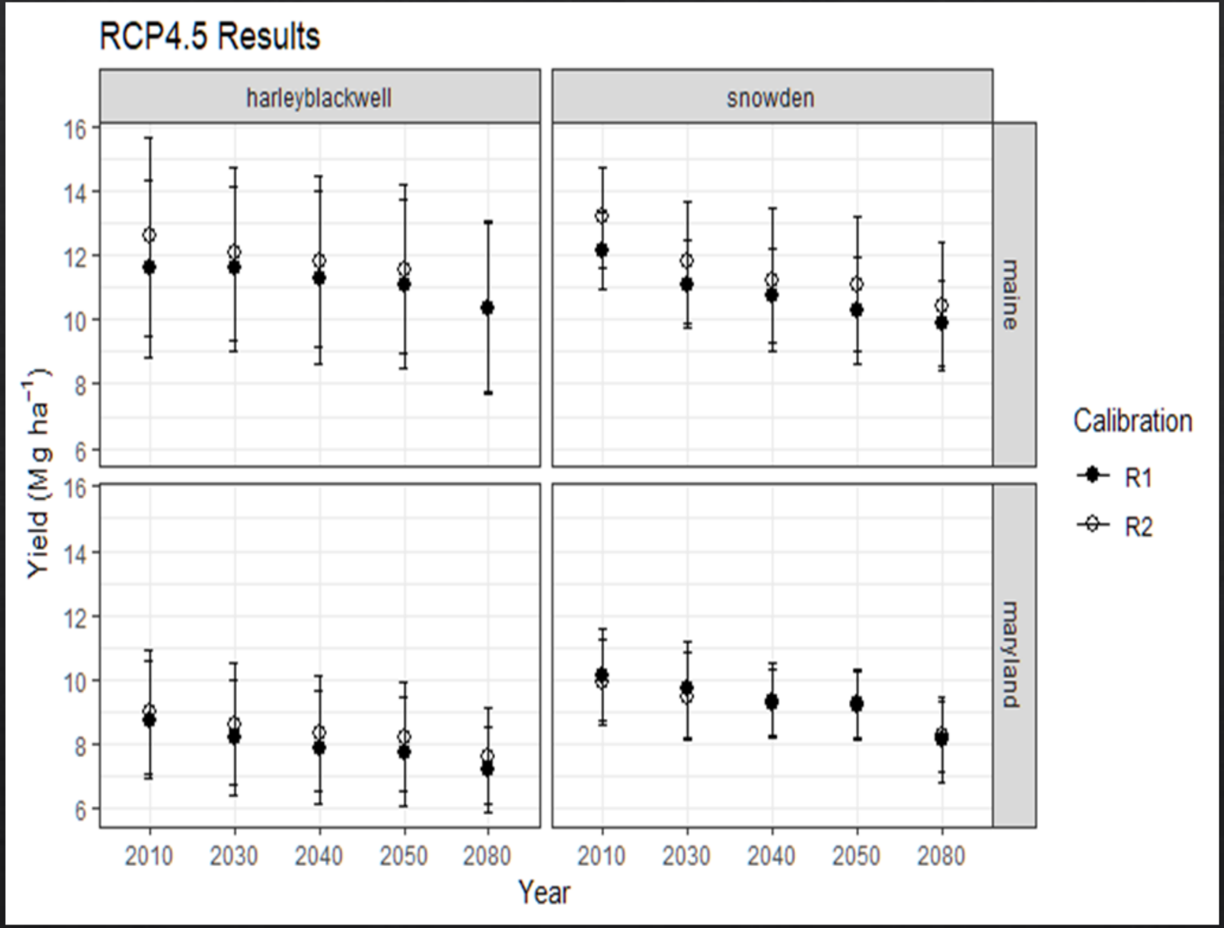
Sustainability & Management

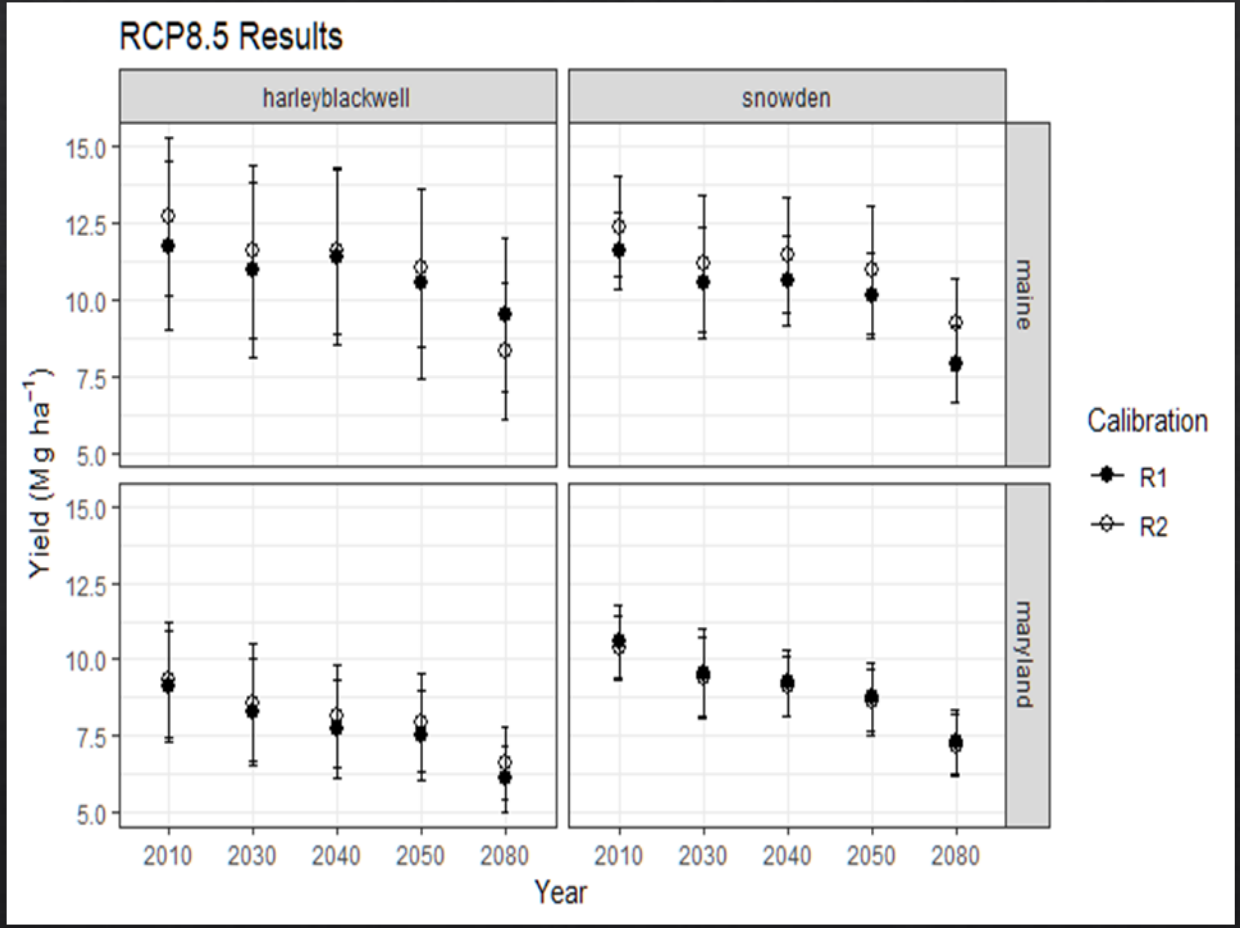


OUTPUT

GROWTH YIELD SOIL RESOURCE USE

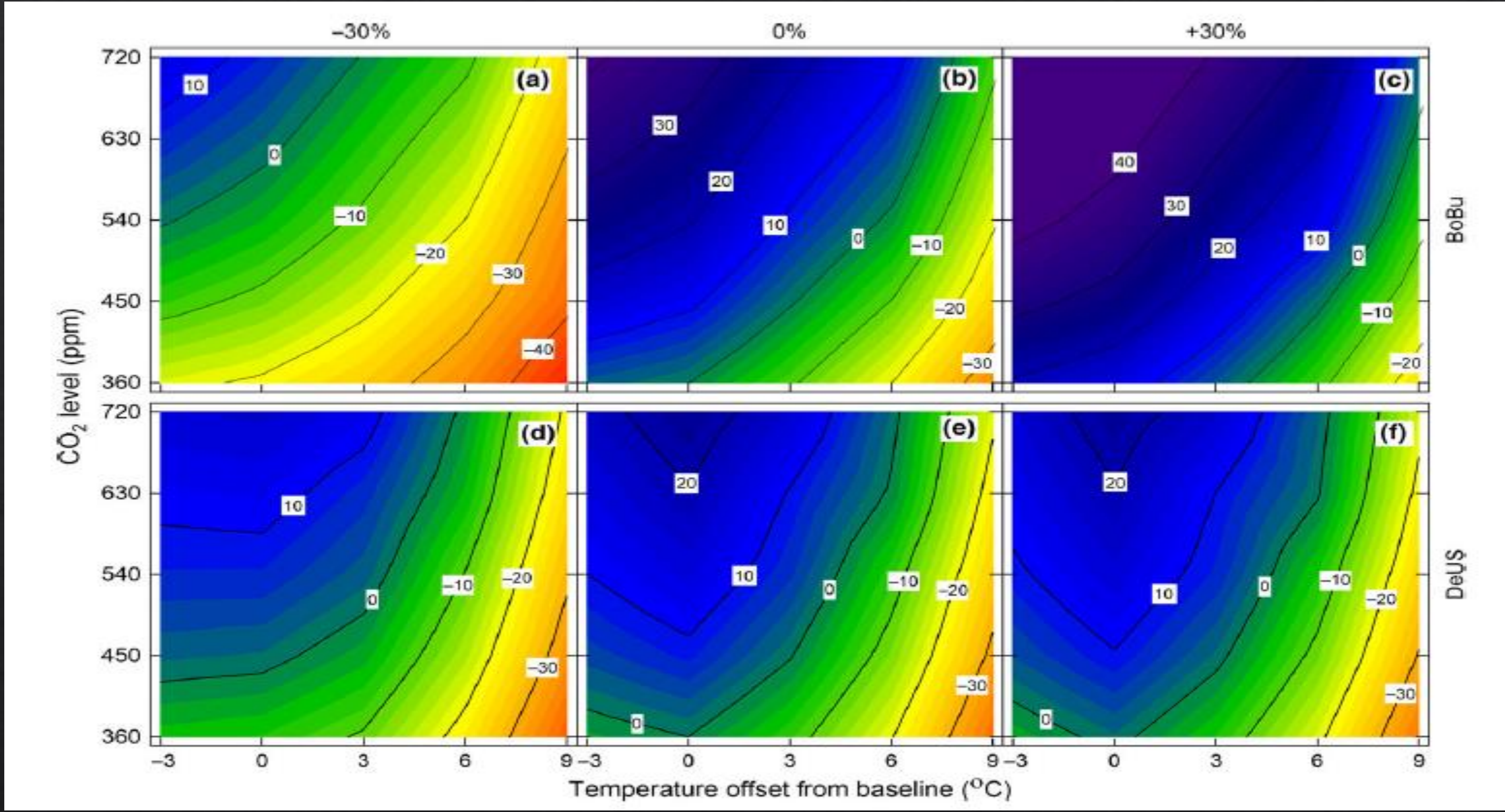
Point Level Climate Impact Assessment





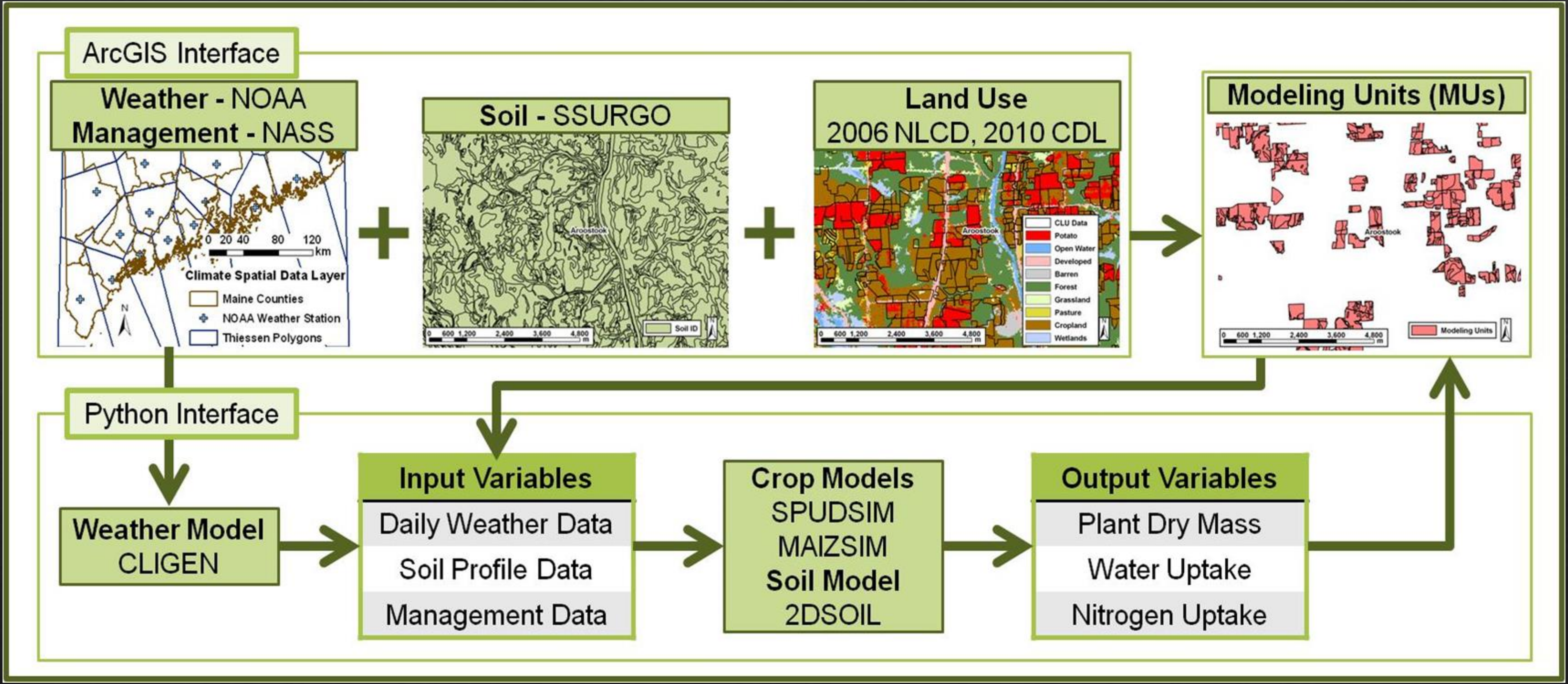
SPUDSIM model forecasting cultivar yields under current and future climate scenarios in two locations in the U.S.

Multi-Factor Assessments

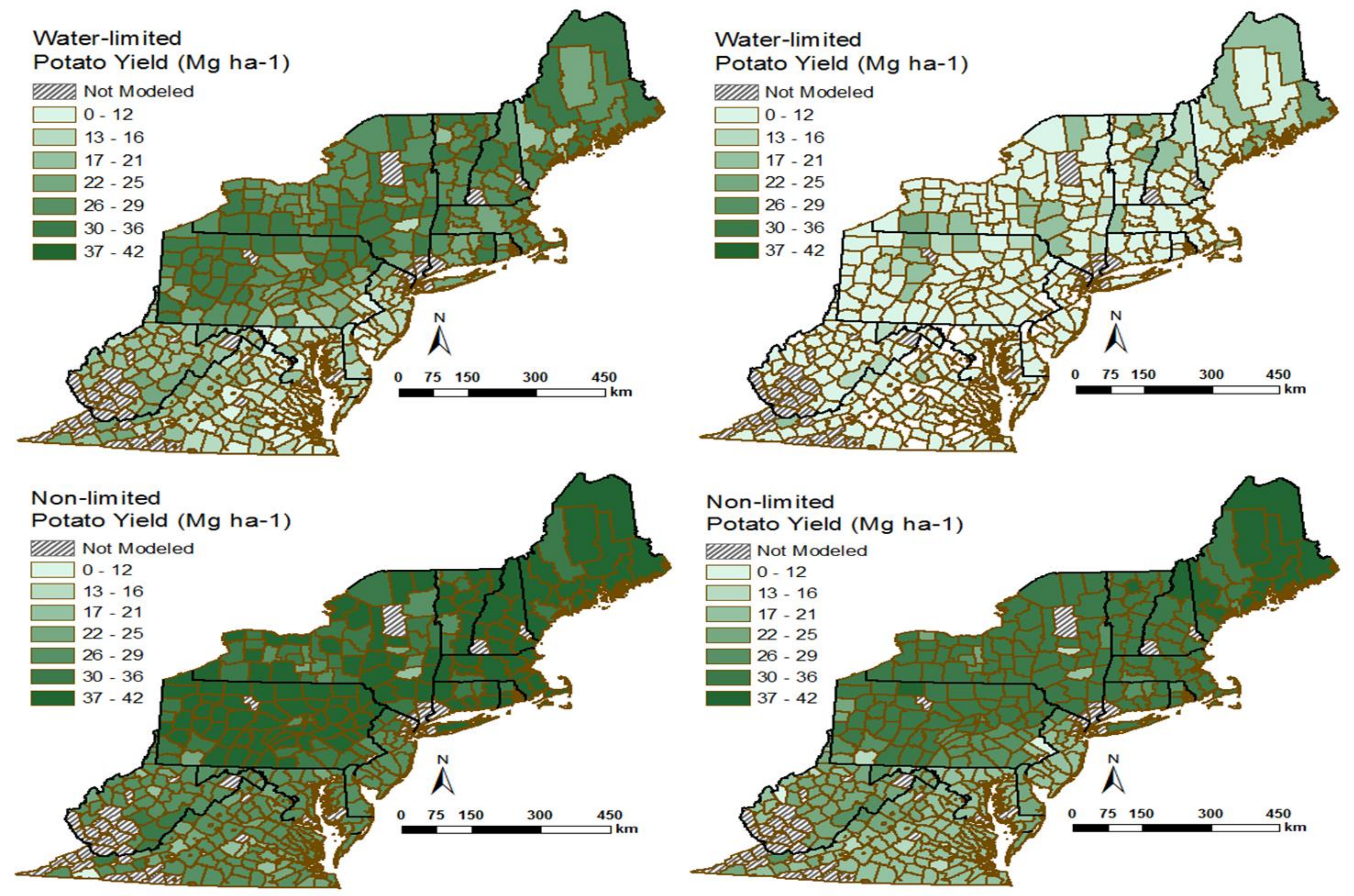


Ensemble (n = 10) of calibrated potato models across 4 locations showing response surface of relative predictions of C at different T x W in the AgMIP Potato Pilot

Geospatial Application



Potato Yields & Future Climate



Percent Yield Change			
State	WL	NL	***
ME	-45	-7	-45
VT	-54	-10	-54
RI	-79	-19	-79
NH	-54	-9	-54
MA	-74	-16	-74
CT	-76	-21	-76
NY	-75	-9	-75
PA	-78	-22	-78
NJ	-91	-27	-27
MD	-90	-21	-21
DE	-92	-21	-21
WV	-81	-20	-20
VA	-87	-20	-20
MEAN	**-75%**	**-18%**	**-50%**

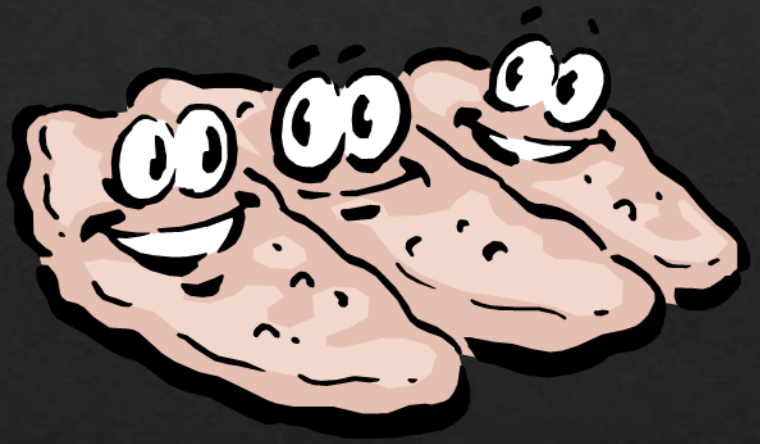
SUMMARY

Summary

- Experimental data (still) needed to fill knowledge gaps regarding abiotic factors on potato
  - Knowledge at leaf or small spatial scale needed to understand responses at whole plant level
- Data drives testing of conceptual hypothesis in the soil-plant-atmospheric continuum and developing of process-driven mathematical models
  - More mechanism requires more knowledge
- Models are needed to understand and respond to impacts at different spatial scales
  - Single field locations
  - Local / Regional / Global scales
- Model accuracy depends on appropriate data, quantification methods, and scaling across different spatial (and temporal) state variables

Thanks, Acknowledgements, & Questions

- Jonathan Resop
- Jinyoung Barnaby
- Sanai Li
- Dee Mutiibwa
- Emily Morris
- Jackson Fisher
- Robert Erdman
- Dennis Timlin
- V.R. Reddy
- Bruno Condori



EFSNE
Enhancing Food Security in the Northeast

AgMIP The Agricultural Model Intercomparison and Improvement Project

USDA ARS