INVITED 02

Drivers of Crop Productivity and Resource Use Efficiencies in Apple between Western and Eastern States in the US

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Abstract

Apple is cultivated under various climatic conditions in many parts of the world. Better understanding of how climate, genotype, soil, and management factors interact to determine crop productivity will improve our ability to optimize crop selection, management strategies, and resource use efficiencies. We developed and applied a physiology-based apple canopy model to evaluate how climatic factors and crop phenotypes interact to determine biomass accumulation, radiation use efficiency (RUE), and water use efficiency (WUE) at multiple production sites between western and eastern states of the US including WA, CA, NY, WV, and PA. Our results indicate that solar radiation is a dominant factor limiting biomass production in the eastern states while VPD is the primary factor governing crop water use across eastern and western states during the peak growing season. Crop RUE and WUE were strongly correlated in the western states but not in the eastern states while VPD showed highly negative correlation with both RUE and WUE across all locations. The RUE improved with increasing fraction of diffuse radiation (f_{df}) and the RUE-f_{df} relationships revealed distinctive responses between western and eastern states. Overall, the eastern locations exhibited slightly higher RUE and WUE than the western locations. However, overall productivity and total water use were greater in the western states. A clear decline of productivity with increasing temperature and afternoon VPD past an optimum was predicted in the western locations but this pattern was less clear in the eastern locations. We also discuss potential phenotypes with specific physiological and morphological traits that are differentially suitable for western and eastern locations. Our results provide plausible, spatially explicit explanations and insights to disentangle the complex relationships between crop productivity, resource use efficiencies, phenotype, and climate drivers in apple grown in the US.

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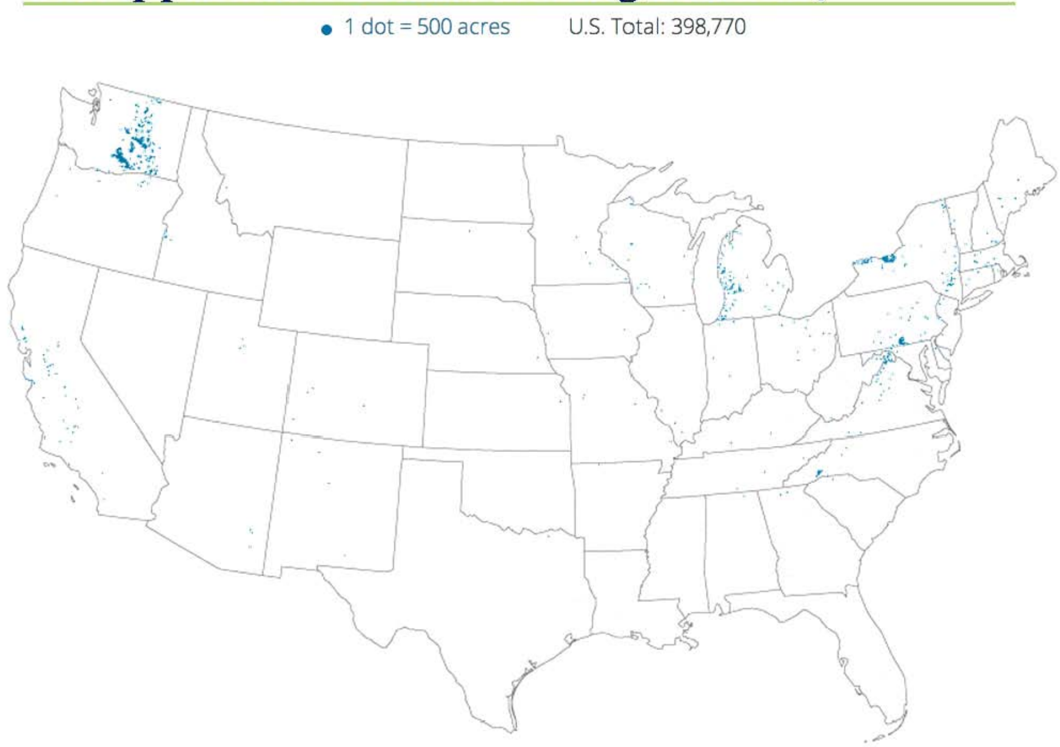
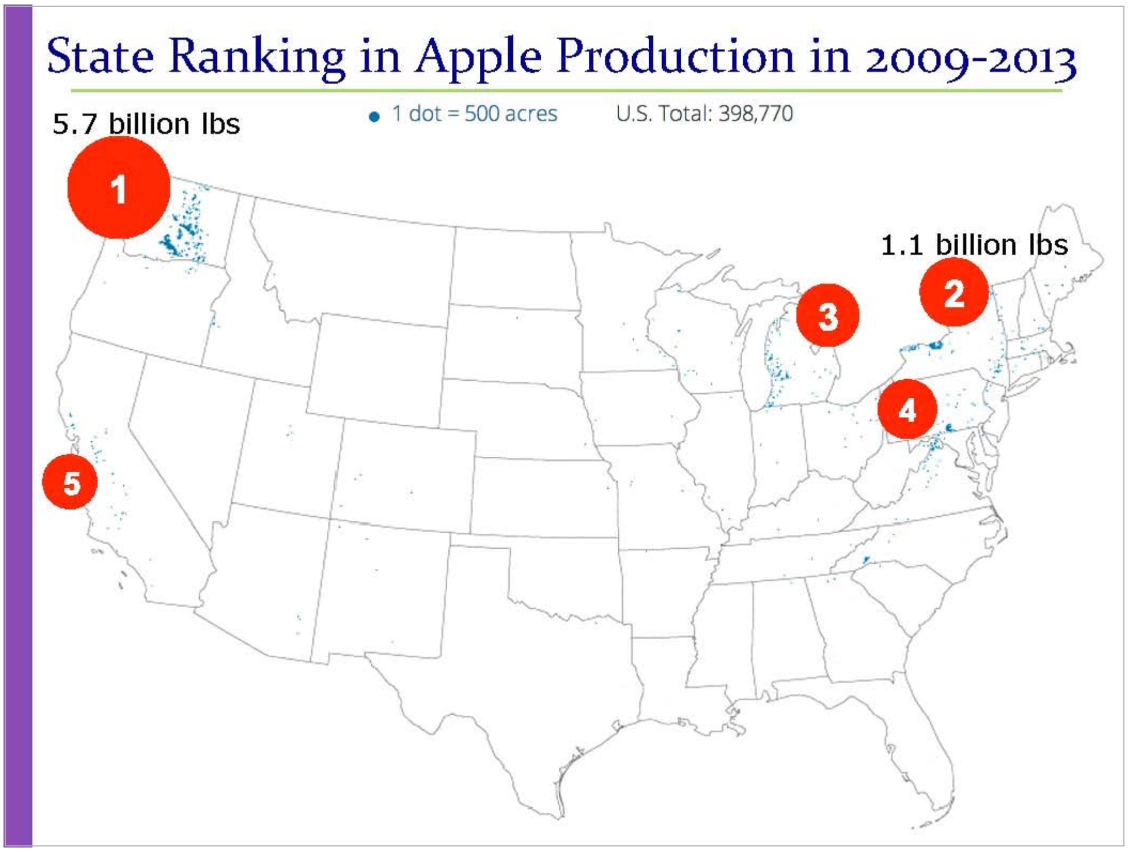
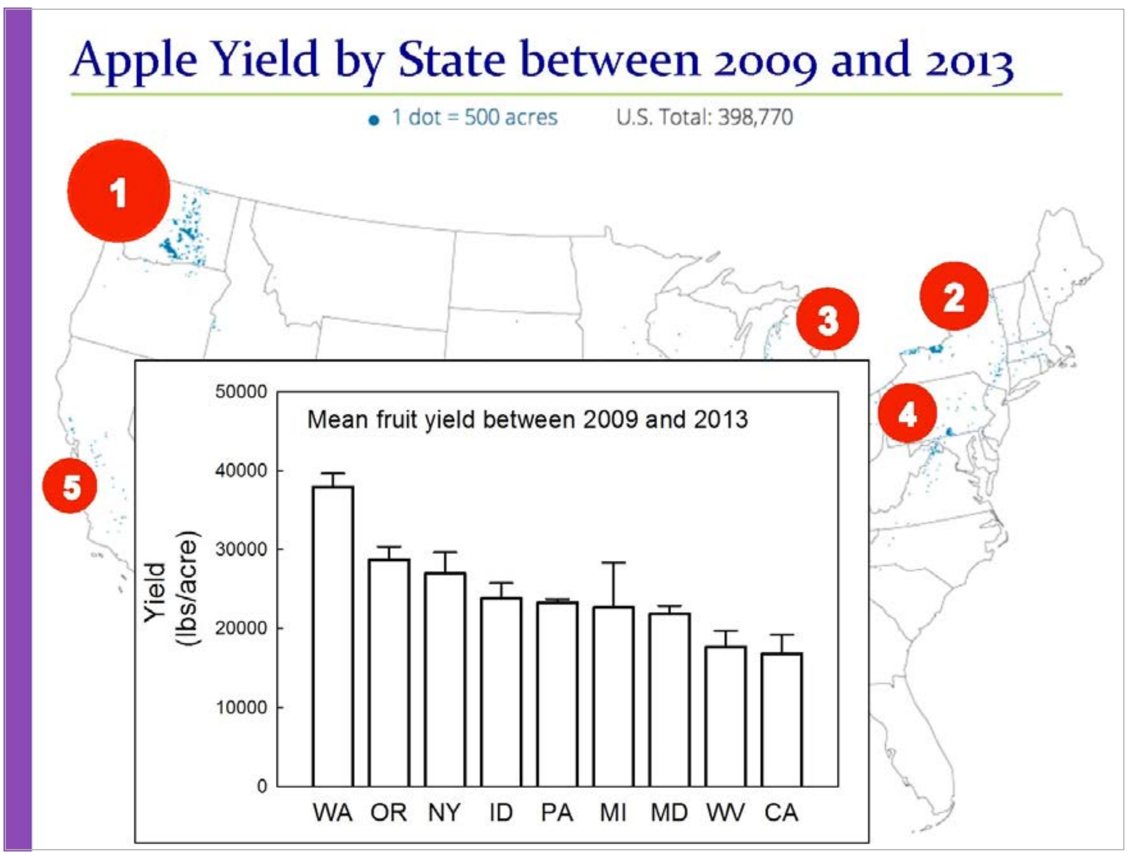
US Apple Production Acreage in 2007




State Ranking in Apple Production in 2009-2013
5.7 billion lbs
1 dot = 500 acres
U.S. Total: 398,770
1.1 billion lbs
1
2
3
4
5


Apple Yield by State between 2009 and 2013
1 dot = 500 acres
U.S. Total: 398,770
1
2
3
4
5
Mean fruit yield between 2009 and 2013
Yield (lbs/acre)
50000
40000
30000
20000
10000
0
WA OR NY ID PA MI MD WV CA

What makes western states, especially Washington apples yield more?

Objectives

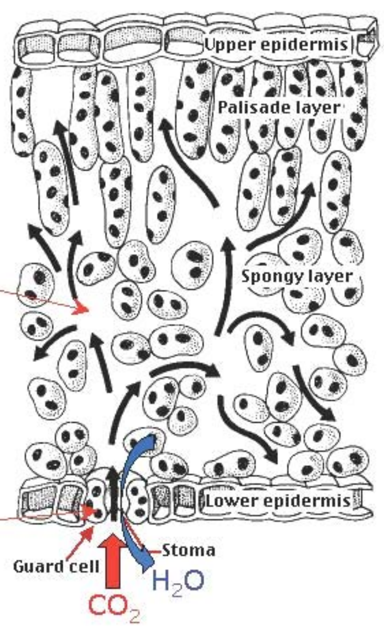
- The question: Why is WA more productive than others?
  - Is it climate, genetics, management, rootstocks, or something else?
  - How can we test this?
- Can climate factors explain the variability in productivity between eastern and western locations?
  - Apply a photosynthesis model scaled to whole-canopy
  - Assume everything else identical including genetics
- Identify dominant climate drivers governing productivity and water use in major apple producing locations
  - Temperature, VPD, total radiation, diffuse radiation
  - Determine the relationships between RUE and climate drivers
  - Determine the relationships between WUE and climate drivers

Research Methods

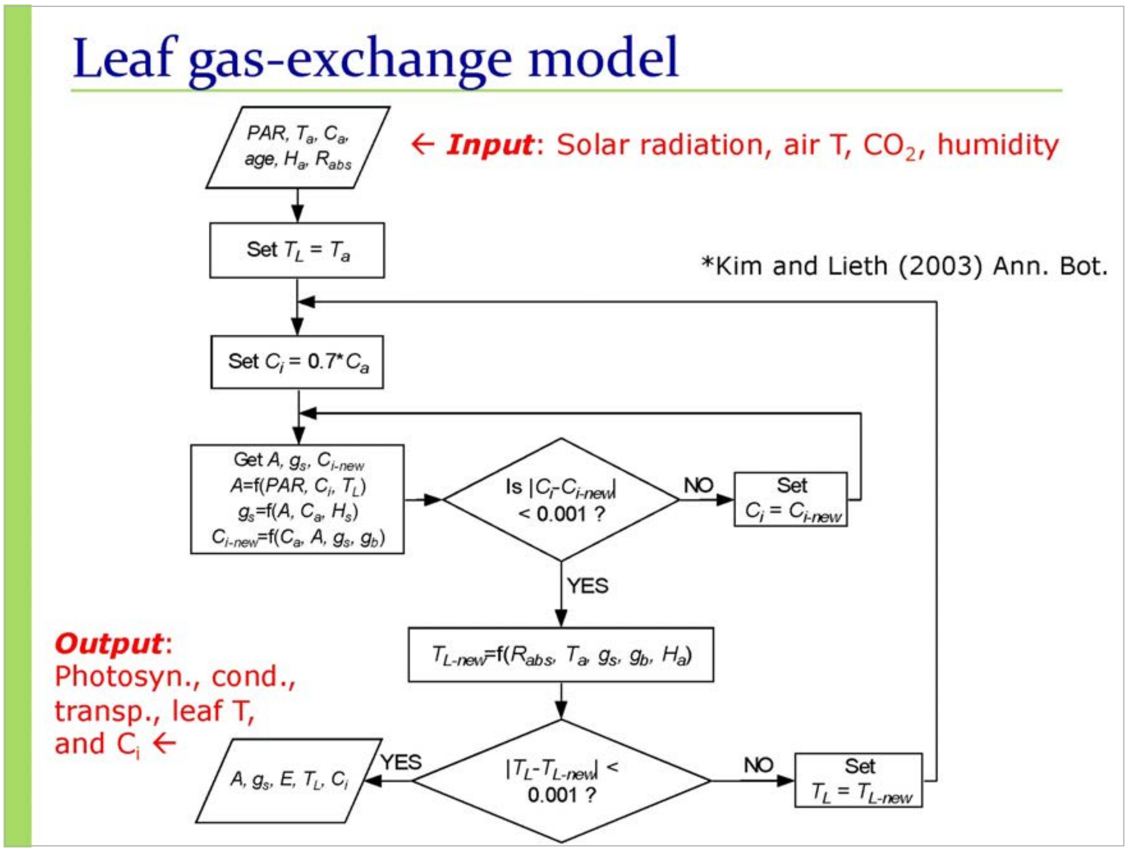
- A computer simulation model combining:
  - Coupled leaf gas-exchange model (Kim and Lieth, 2003)
  - Sun-shade canopy model (de Pury and Farquhar, 1997)
- Test against “independent” whole-tree gas-exchange data from Kearneysville, WV and Wenatchee, WA
- Apply the model with climate data from multiple locations and years in WA, CA, NY, and PA
  - Weather data from WSU AgWeatherNet (WA), CIMIS (CA), and Cornell Univ. NEWA (NY, PA)

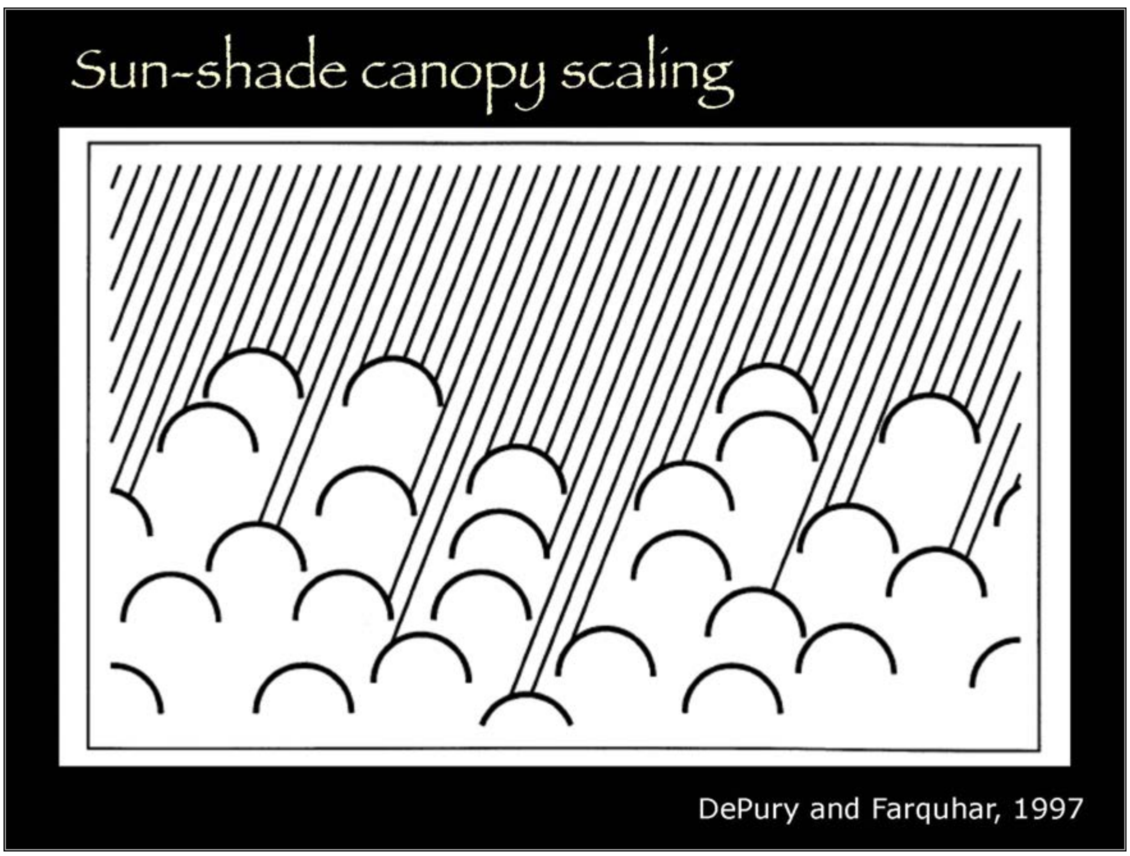
Leaf gas-exchange

- Exchange of CO_2 and water vapor between leaf and atmosphere
- Photosynthesis (*A*)
- CO_2 diffuses into intercellular air spaces through stoma (C_i)
- Water vapor loss: Transpiration (*E*) => Leaf cooling (T_L)
- *A* and *E* are closely linked via stomatal regulation
  - Stomatal conductance (g_s)
- Water use efficiency (*WUE* = *A*/*E*)



(Figure from Kimball’s biology pages)

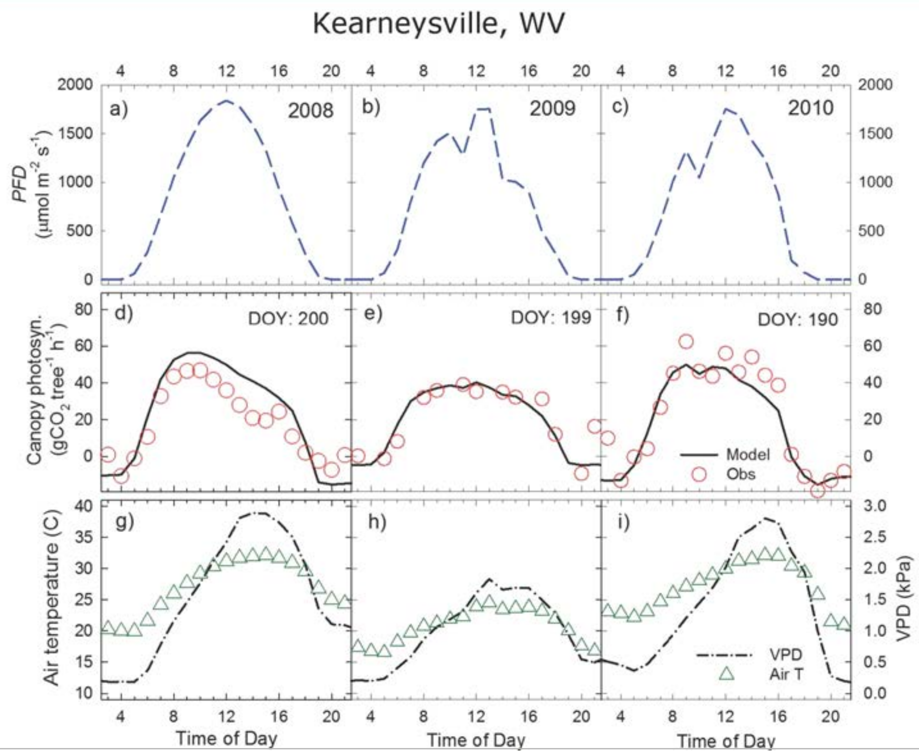

Leaf gas-exchange model
PAR, T_a, C_a, age, H_a, R_{abs}
← Input: Solar radiation, air T, CO_2, humidity
Set $T_L = T_a$
*Kim and Lieth (2003) Ann. Bot.
Set $C_i = 0.7*C_a$
Get A, g_s, $C_{i\text{-}new}$
A=f(PAR, C_i, T_L)
g_s=f(A, C_a, H_s)
$C_{i\text{-}new}$=f(C_a, A, g_s, g_b)
Is $|C_i - C_{i\text{-}new}|$ < 0.001 ?
NO
Set $C_i = C_{i\text{-}new}$
YES
$T_{L\text{-}new}$=f(R_{abs}, T_a, g_s, g_b, H_a)
Output: Photosyn., cond., transp., leaf T, and C_i ←
A, g_s, E, T_L, C_i
YES
$|T_L - T_{L\text{-}new}|$ < 0.001 ?
NO
Set $T_L = T_{L\text{-}new}$


Sun-shade canopy scaling
DePury and Farquhar, 1997

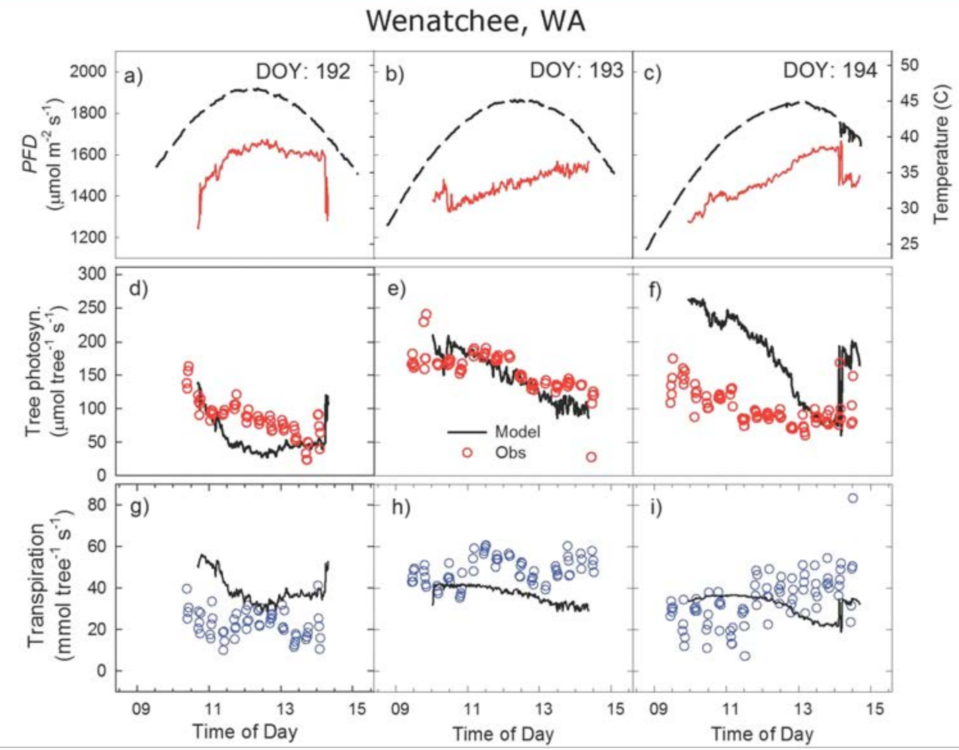
Kearneysville, WV

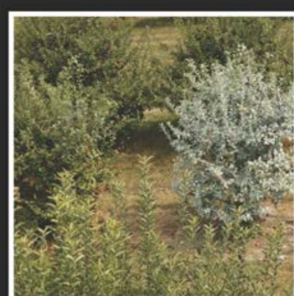
Wenatchee, WA

Model testing with whole-tree gas-exchange data



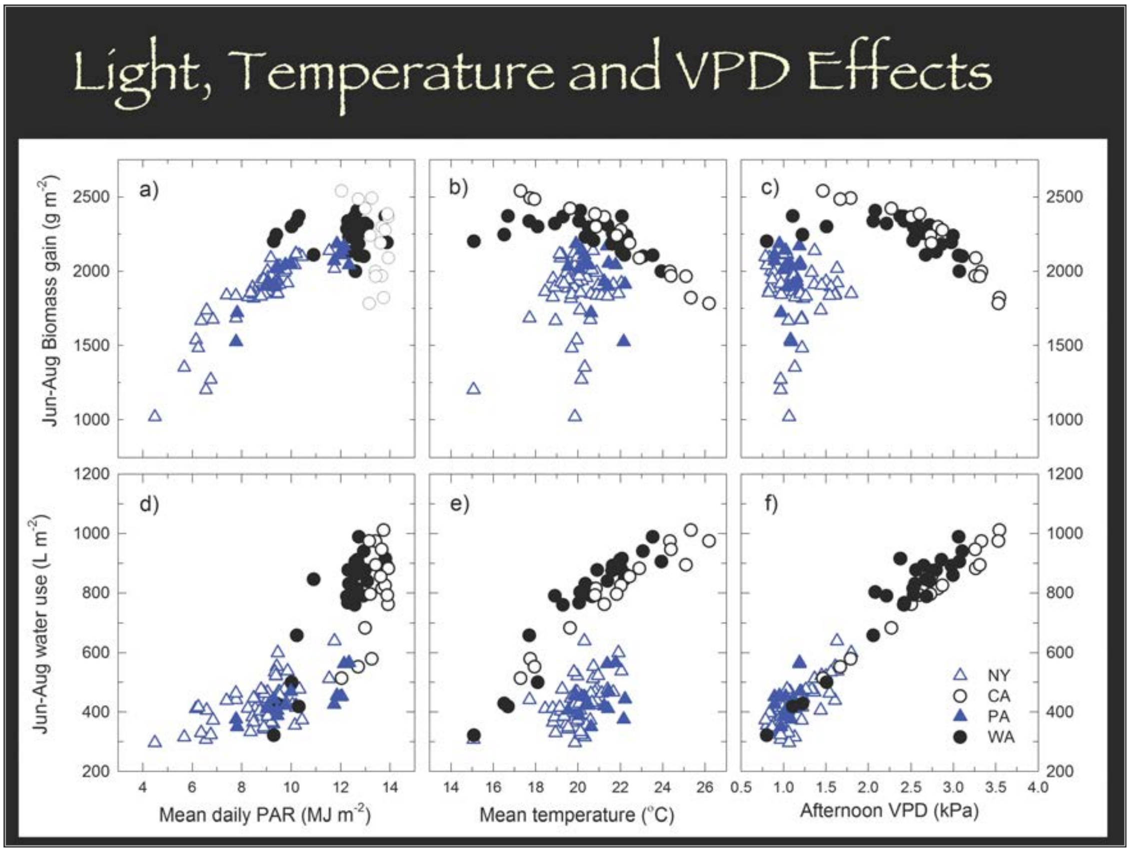
Model testing with whole-tree gas-exchange data

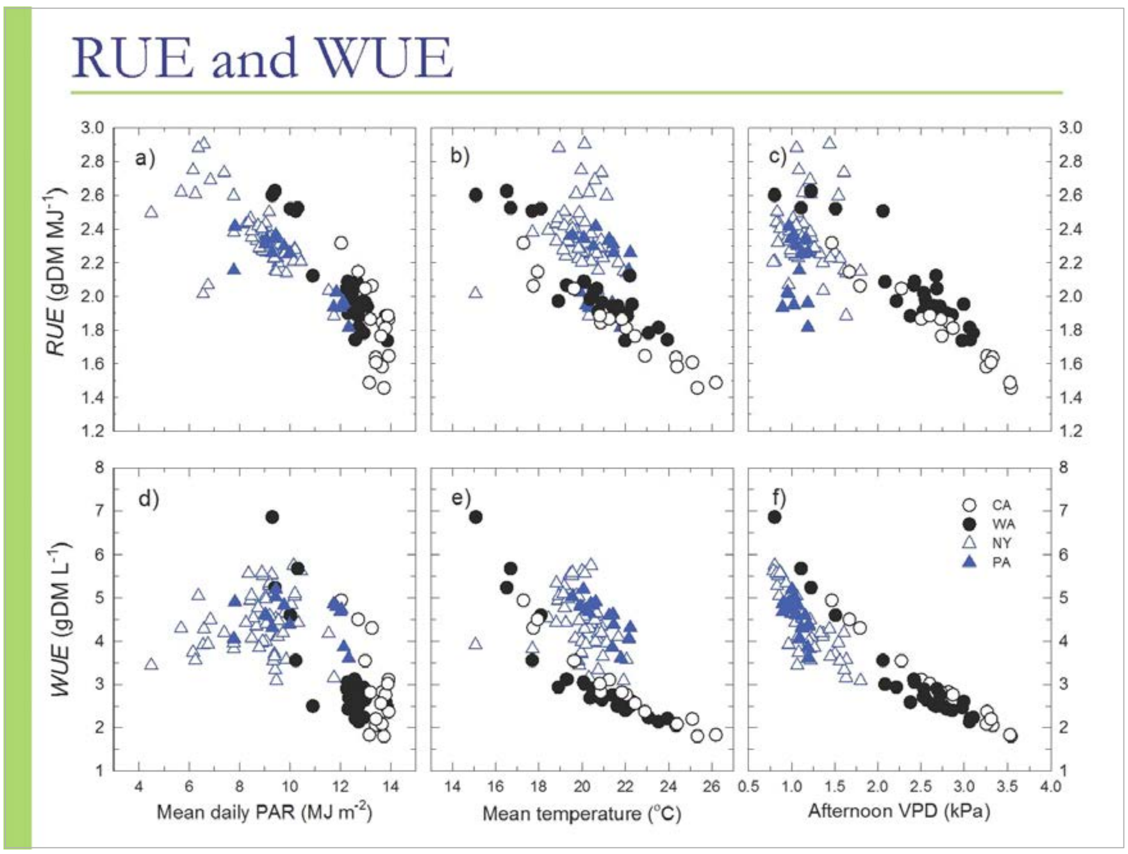




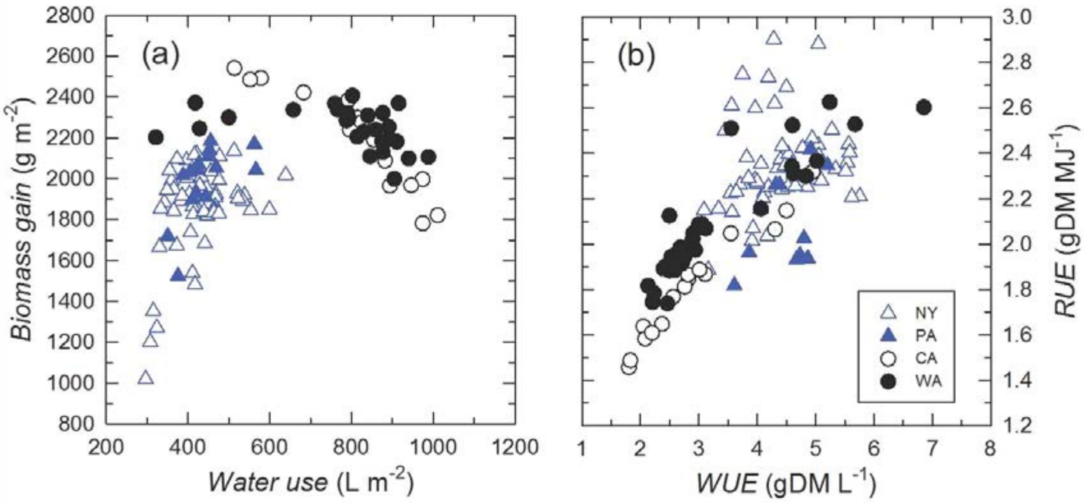
Model Applications

* All results shown hereafter are from model predictions

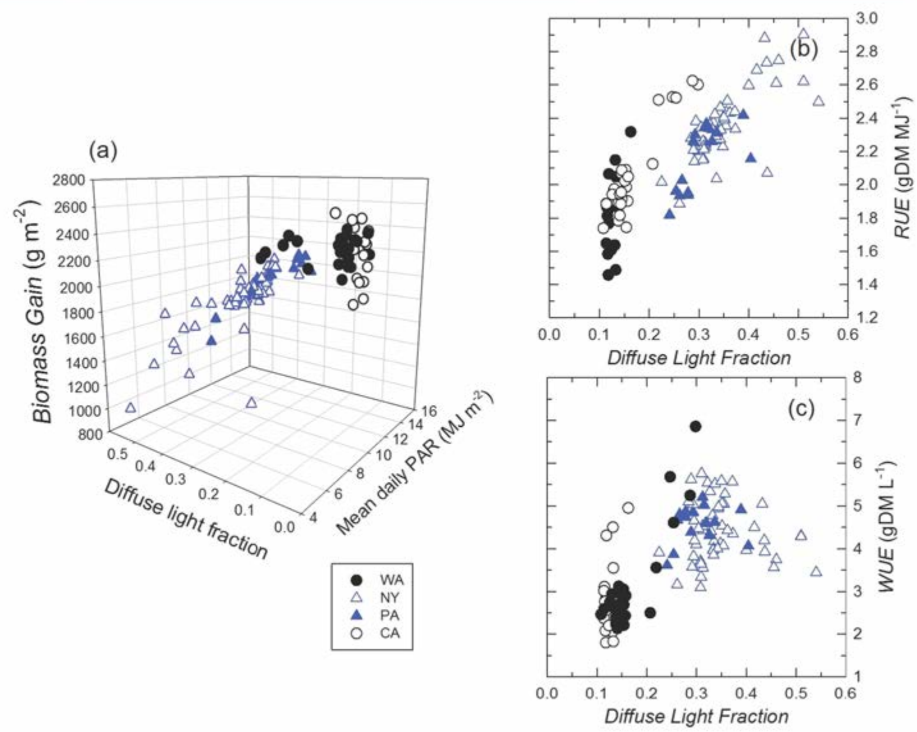

Light, Temperature and VPD Effects
a)
b)
c)
d)
e)
f)
Jun-Aug Biomass gain (g m-2)
Jun-Aug water use (L m-2)
Mean daily PAR (MJ m-2)
Mean temperature (°C)
Afternoon VPD (kPa)
NY
CA
PA
WA


RUE and WUE
a)
b)
c)
d)
e)
f)
RUE (gDM MJ-1)
WUE (gDM L-1)
Mean daily PAR (MJ m-2)
Mean temperature (°C)
Afternoon VPD (kPa)
CA
WA
NY
PA

Carbon gain or water loss?



Diffuse radiation effects



Discussion

- If clonal apple trees are grown in the east and west states, which populations are likely to be:
  - More productive and why?
  - Using more water and why?
  - How much of the differences can be overcome by genetics?
- What were the dominant climate drivers to determine productivity in eastern and western states, respectively?
- What are horticultural, breeding, and management implications?
- How would you test the same question (hypothesis) using an empirical approach?

Acknowledgements

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