Why Scale Matters for Understanding the Ecology of Crop Functional Traits

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Crop Functional Traits for Intensive Agriculture

• Context of this presentation: California Central Valley irrigated row crops
• Intensive agriculture
  – Definition: production system that relies more on mechanized practices, with high input of fertilizers and agrochemicals in large fields and with reduced biodiversity
• Crop functional traits for processing tomatoes
  – Cultivar variation for increasing ecosystem functions
  – Linking ecophysiology with canopy architecture
  – Determinate vs indeterminate growth
Ecology and Cropping Systems

• Use ecology to help solve complex problems in agriculture

• Knowledge-based design
  – Agronomy + ecology = agroecology
  – Farmers’ knowledge and on-farm research
  – Interdisciplinary input (e.g. breeders, molecular biologist, plant physiologists)

• Multi-scale context
  – Space: genes → landscapes
  – Time: now → preparing for future uncertainty

• Social-ecological framework

(Tscharntke et al. 2005; Jackson et al. 2007; Geiger et al. 2010)
Why Scale Matters?

• Crop functional traits have consequences at different scales (e.g., C assimilation, WUE, growth patterns), a few of which will be introduced in this work.

• Agricultural research and implementation programs have rarely considered multiple scales:
  – Complexity
  – Apparent expense
  – Short-term focus
Outline of this Presentation

Cultivar mixtures and effects on ecosystem functions → Population

Cultivar evolution and functional traits → Individual

Genetic basis for cultivar differences → Gene

Functional traits for ecosystem management → Ecosystem
**Ecosystem Functions & Services**

**Provisioning**
- Food (fiber wood, timber)

**Regulating**
- Water cycling
- Nutrient cycling

**Individual**

**Gene**

**Population**

**Cultivar mixtures**

**Cultivar Evolution**

**Morphological Physiological Phenological Traits**

**Water Management**
Cultivar Mixtures and Effects on Ecosystem Functions

Increasing plant biodiversity within the field to:
• Improve nutrient uptake and retention
• Increase productivity
• Decrease effect of pests

Hypothesis
Increasing functional traits can increase sustainability in an organic agroecosystem
• Better use of resources
• Lower disease infestation
• Higher crop performance
Field Evaluations

Location: A 12-year organic farm in Yolo County, California. Tomatoes: ‘Choice cultivar’ is used by the farmer; others varieties used statewide (conventional and organic)
Sampling and Measurements

Plants:
- Canopy light interception
- Biomass: shoots and fruits
- Nutrient analysis of shoots and fruits for N, P and K
- Disease evaluation for *Sclerotium rolfsii* (Southern blight).

Soil (0-15 and 15-30 and 30-60 cm):
- \( \text{NO}_3^- \) and \( \text{NH}_4^+ \)
- Potential mineralizable nitrogen (PMN)
- Microbial biomass carbon (MBC) (0-30 cm only)
- \( \text{CO}_2 \) and \( \text{N}_2\text{O} \) gas emissions from soil surface
Results for Biomass and Growth

- No difference in fruit yield (g m$^{-2}$) between 1cv, 3cv, and 5cv mixtures
- Lower yields in the N-limited winter mustard plots (statistics not shown)
- Cultivar mixtures in winter fallow had consistently higher light interception (statistics not shown)
Results for Soil CO$_2$ and N$_2$O emissions

- Higher CO$_2$ and N$_2$O emissions at the first sampling after inputs added.
- CO$_2$ emissions in fallow monoculture higher than the fallow 3 cv in the last two samplings.
- The high yielding cultivar (choice cultivar of the farmer) in monoculture may have had more roots and more respiration than 3 cv mixture?
Choice Cultivar’s Response to Surrounding Cultivars

- ‘Choice cultivar’ had similar shoot biomass in all treatments

- Exception: Higher shoot and fruit biomass in mid-season, i.e., 3cv mixture at 75 DAP in the N-limited winter mustard plots

- ‘Choice cultivar' had similar tomato yield in the three tomato mixtures
Summary: Cultivar Mixtures and Effects on Ecosystem Functions

• Main results:
  – Cultivar mixtures had little effect on yield, disease, fruit quality, soil parameters or GHG emissions
  – Winter cover crop unexpectedly decreased N availability due to net N immobilization

• Why so little variation among cultivar mixtures?

• Has there been a loss of functional trait diversity during the selection process for high yielding tomatoes in high-input agriculture?
Ecosystem Functions & Services

Provisioning
- Food (fiber wood, timber)

Regulating
- Water cycling
- Nutrient cycling

Cultivar mixtures
Cultivar Evolution
Morphological Physiological Phenological Traits
Water Management
Tomato Cultivar Evolution and Functional Traits

Facts:
• Crop productivity is >3x since 1940s (Gould, 1983)
• Determinate growth habit introduced in the 1960s for mechanized harvest
• No real change in ETc (~648 mm) but 50% gain in yields since 1970s (Hanson and May, 2006)
• Genetic improvement contributes ~50% of the gains in yield from 1970s until 1990s (Grandillo et al. 1999)
• Breeding mostly focused on yield and fruit quality for mechanical harvest of processing tomatoes

Objective: Assess how a suite of traits might be associated with genetic improvement for yield gains under high nutrient and water inputs
Sampling and Measurements

Sampling for traits:
• Morphological
• Physiological
• Phenological

Total of 95 variables in 109 days
• Canopy growth and light interception
• Flowering time, inflorescences, fruit set
• Biomass: leaves, stems and fruits
• Moisture depletion between irrigations
• Leaf gas exchange (Licor-6400)
• $^{13}$C analysis from shoots
• N analysis for leaves, stems and fruits
Results for Photosynthesis and Biomass Allocation

Years of release from left to right are 1930s, 1960s, 1970s and 2000s

*Other fruit= Green, spoiled
Cultivar Evolution as a Suite of Traits

Multivariate statistics:  
- PCA to reduce variables into axes  
- Discriminant analysis to find PCA axes that maximize differences among cultivars

Most important suite of traits (Analytical outcome):  
- Early flowering  
- Low vegetative biomass  
- Concentrated fruit set and ripening  
- High N concentration in aboveground biomass  
- Lower intrinsic WUE  
- Smaller canopies
Summary: Cultivar Evolution and Functional Traits

- A suite of traits accompanied breeding to introduce the agronomic traits for determinate growth habit in the 1960s
- Then, different trait assemblies continued to change with breeding for crop improvement through time
- Was there inadvertent selection for specific traits that provide an advantage for small canopy, early flowering and concentrated fruit set (mechanical harvest)?
Genetic Basis for Cultivar Differences

Genes for determinate, compact growth habit type are closely associated with genes for chloroplasts in leaf veins.

Leaflets of the tomato (*Solanum lycopersicum*) variety M82 and the *Solanum pennellii* introgression lines IL 5-4 (clear veins) and IL 5-5 (obscure veins)

Introgression lines (IL)

Unstained transverse sections of terminal leaflet midribs of tomato cv. Moneymaker and cv. VF36

Jones et al. 2007
IL Sampling and Measurements

- Field study with 6 ILs representing a combination of growth habit and chloroplast presence in leaf veins (Obscure veins).
- Leaf gas exchange
- Chlorophyll content (Lichtenthaler, 1987)
- Stomata counts (Gailing et al., 2008)
- Leaf density
- $\delta^{13}C$ from leaves
- Canopy growth monitoring
- Aboveground biomass: stems, leaves and fruits

Jones et al. 1997
IL Results for Leaf Gas Exchange

- ILs are a tool that help explain trait variation
- Direct comparison of single traits was not possible, e.g. isolate effect of determinate growth from obscure leaf veins
- Overall, ILs with determinate growth and obscure leaf veins:
  - Increased photosynthetic rates and stomatal conductance
  - Decreased water use efficiency
- Trend for higher photosynthetic capacity possibly due to chloroplast presence in leaf veins (obscure veins)
IL Results for Other Leaf Traits

- Not only two traits!
- Determinate/Obscure leaf vein ILs had an accompanying, complex suite of other traits
Summary: Genetic Basis for Cultivar Differences

- Determinate growth habit was accompanied by traits that may contribute to higher C assimilation capacity such as chloroplasts in leaf veins.
- Physiological WUE decreased mainly due to increased stomatal conductance (related to high irrigation inputs?).
- Despite breeding just for determinate, compact growth, other genes may also have inadvertently been selected too.
  - Leaf density, stomata count, chlorophyll and N content
- How important are these traits for planning cropping systems and directing future crop improvement?

How do we combine crop traits with management to increase other ecosystem functions and services besides yield?
Ecosystem Functions & Services

Provisioning:
- Food (fiber, wood, timber)

Regulating:
- Water cycling
- Nutrient cycling

Population

Cultivar mixtures

Cultivar Evolution

Morphological, Physiological, Phenological Traits

Water Management

Individual Gene

Ecosystem
Outline of this Presentation

- Cultivar mixtures and effects on ecosystem functions
  - Population
- Cultivar evolution and functional traits
  - Individual
- Genetic basis for cultivar differences
  - Gene
- Functional traits for ecosystem management
  - Ecosystem
Functional Traits into Agricultural Management

Partial root drying = Alternate furrow irrigation Technique = Practice

• Watering only half of the root system at each irrigation event
• Soil moisture regulation of root to shoot signaling and control of stomatal conductance
• Managing so that yields are not affected by a reduction in water applied, which can increase crop water use efficiency in dry years

Can processing tomatoes be managed with less water? Which traits can help improve ecosystem functions?
Sampling and Measurements

- Two irrigation treatments:
  - Alternate furrow vs. Every furrow
- Cultivars: AB2, CXD255 and Shasta

  - Plant measurements:
    - Leaf gas exchange measurements
    - $\delta^{13}$C from leaves
    - Canopy growth
    - Biomass
    - Fruit quality
  - Field-soil measurements
    - Irrigation estimates
    - Soil moisture EC-5 sensors (Decagon Inc., USA)
    - Soil moisture to a 3 m depth at planting and harvest
Results for Plant Growth and Physiological Water Use Efficiency

- Similar canopy growth with both types of irrigation. Slight decrease with alternate furrow irrigation.
- Two current tomato cultivars both perform well under both irrigations, but cv. CXD255 had higher WUE$_i$ than cv. AB2.
  - In progress: understanding which traits affect WUE
Results for Yield and Applied Water

• Four field trials conducted in grower’s fields
• 3 different soil types

• No yield differences due to the irrigation management
• Alternate furrow irrigation reduced applied water 30%
• Crop WUE was >35% higher in alternate furrow irrigation
• Functional trait hypothesis: Plasticity of root growth + tight stomatal regulation maintains crop water balance, C assimilation with less water resources
Summary: Functional Traits into Agricultural Management

- Processing tomatoes in California have a suite of traits with potential to increase a regulating ecosystem service (water resources) in addition to yield.
- Alternate furrow irrigation can increase crop water use efficiency (yield/applied water).
- Better knowledge of functional traits will underpin new management practices that may facilitate effective adaptation to dry years.
- Combining practices such as alternate furrow irrigation with cultivars and crops with relevant functional traits will provide ‘flexibility’ for crop management under uncertain conditions, e.g. dry years.
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Acknowledgements

• Many people from the Jackson Lab at University of California, Davis (past and current members and visitors)
• Tomato growers, field irrigators, farm advisors, and people from the tomato industry
  • Rominger Brothers Farms
  • Campbells R&D Group in Davis, California
• The Tomato Genetics Resource Center at UC Davis, and especially to Roger Chetelat

Funding from:

– USDA: CSREES 04-51106-02242
– USDA: NIFA SCB09036
– The Western Sustainable Agriculture Research and Education (Western SARE): GW 10-010
– The GA Harris Research Instrumentation Fellowship from Decagon Devices Inc.

Thank you for listening