The Century Experiment: rethinking and redirecting

Kate Scow, Nicole Tautges, Amelie Gaudin and Israel Herrera
Dept of Land Air and Water Resources
Russell Ranch Sustainable Agriculture Facility
Agricultural Sustainability Institute
Challenges & opportunities for California agriculture--Mediterranean agroecosystem

Challenges
- Water scarcity--only winter rainfall, droughts
- Water quality – nutrients/salinity, pesticides
- Soil degradation and loss due to excessive tillage and low organic inputs
- Low soil organic carbon
- Loss of biodiversity

Opportunities
- Deep soils
- Year-round growing season
- Diversity of crops and animal systems
- Irrigation innovation
- Rich social history of agricultural adaptation and innovation
Row crops in Northern California

Irrigated
• Processing tomatoes: high value crop
• Vine seeds, sweet corn, corn, safflower, sunflower, wheat in rotations
• Alfalfa

Rain fed
• Small grains--wheat, oats, barley
• Cover crops

Dynamic!  Substantial changes since start of experiment, e.g. major increase in perennial crops (vineyards, fruit and nut trees)
Russell Ranch Sustainable Agriculture Facility,

- 25 years into a 100 yr experiment
- Commercial-scale, “working farm”—crops grown for income.
- 72 one-acre plots
- By Putah Creek riparian zone: link between natural and agricultural lands

Controlling soil, climate, terrain, time
History

- University purchased Russell Ranch property in 1998 for research. 300+ acres given to Russell Ranch Sustainable Agriculture Facility. Site grew small grains for many years.

- Initial proposal by interdisciplinary team of 19 UCD faculty and stakeholders to investigate “sustainability of agricultural systems”

- Project started 1990 with competitive grant from Federal USDA program (approximately $150,000) and initial commitment of matching funds from College of Agriculture ($500,000 over 4 years).

- Originally LTRAS (Longterm Research Agricultural Sustainability)
Original Question and Approach
What are the relationships between sustainability and external inputs?

- 10 original cropping systems differ in inputs of irrigation water and nitrogen fertilizer. Includes certified organic and inclusion of N-fixing cover crops in some systems.
- 2 yr cropping cycle, both crop phases present
- Farm with “best management practices” (input from extension, farmers)

Sustainability measured by crop yield, profitability, labor, fuel use, resource use efficiency, soil and crop quality (physical, chemical, biological activity). Also soil biodiversity and environmental impact, e.g. leaching, GHG production
<table>
<thead>
<tr>
<th>System</th>
<th>Irrigation</th>
<th>N source</th>
<th>Pesticides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn/tomato organic</td>
<td>Irrigated</td>
<td>Manure + WLCC</td>
<td>Organic</td>
</tr>
<tr>
<td>Corn/tomato mixed</td>
<td>Irrigated</td>
<td>Fertilizer + WLCC</td>
<td>As needed</td>
</tr>
<tr>
<td>Corn/tomato Wheat/tomato conventional</td>
<td>Irrigated</td>
<td>Fertilizer</td>
<td>As needed</td>
</tr>
<tr>
<td>Wheat/fallow Rain fed w/ suppl</td>
<td>WLCC</td>
<td></td>
<td>As needed</td>
</tr>
<tr>
<td>Wheat/fallow Rain fed w/ suppl</td>
<td>Fertilizer</td>
<td></td>
<td>As needed</td>
</tr>
<tr>
<td>Wheat/fallow Rain fed w/ suppl</td>
<td>None</td>
<td></td>
<td>As needed</td>
</tr>
<tr>
<td>Wheat/fallow Rain fed</td>
<td>WLCC</td>
<td></td>
<td>As needed</td>
</tr>
<tr>
<td>Wheat/fallow Rain fed</td>
<td>Fertilizer</td>
<td></td>
<td>As needed</td>
</tr>
<tr>
<td>Wheat/fallow Rain fed</td>
<td>None</td>
<td></td>
<td>As needed</td>
</tr>
</tbody>
</table>
Plots are 0.4 hectare (1 acre):
- Reduces edge effects.
- Plots are basins--limiting soil and water movement
- We farm like commercial farm w/full-scale scale equipment—increases credibility w/farming community

Crops sold to markets: contract w/major tomato processor, grain millers, and forage for horses and dairy (we rely on income!)
Site characterized by sampling and archiving samples at time-zero; repeat sampling and archiving regularly.

Much data publicly available at online data base—worth a discussion.
Century Experiment is experiment itself, but also test bed for hypotheses that build on differences among treatments. Microplots and strips allow flexibility within consistently-managed main plots.

Integrated soil fertility strips in mixed system found winter cover crops can offset 30% of N fertilizer inputs (4 yrs).

Reducing irrigation by 40-60% at 6 weeks before tomato harvest supports same yields and higher solids and brix.
Test beds and playgrounds

Balancing short-term flexibility with long-term consistency: farmers and researchers also have short-term concerns requiring new treatments.

- Test beds or “playgrounds” support new ideas (that resonate with goals of long term experiment)
- Place for innovation!! Promising practices can be incorporated into long term experiment

Balancing long- and short-term interests is essential to survival of long-term sites: new blood, new ideas
Putah Creek Riparian Reserve

- Restored native grasslands
- Organic scale up plots
- Irrigation test bed
- Healthy soils plots
- Biochar plots
- Biodigestate plots
- CC-Deficit Irrigation plots
- Old Kernza Plot
- Manure Application Trial
- Conventional farmer's plot
- Organic scale up plots
- New Kernza Plot
- Restored native grasslands
- Small plots
Changes

Small changes
- Crop varieties, fertility inputs, cover crop mixes, residue management, seeds to transplants
- Equipment improved-reduce tillage, change placement of inputs
- Financial constraints

Larger changes
- Major changes in farm management
- Shift in cropping patterns
- State crises/initiatives: water limitations, nitrogen pollution, dairy CAFOs, soil health
- Global challenges: climate change, sustainable intensification,
- Research interests of new scientists and stakeholders—many with no field experience

May lead to need for new conceptual frameworks and possibly changes in treatments
Research topics on farming systems--based on stakeholder interests

Crop-intensive

Intensive Tillage

Monoculture

More intensively managed

External inputs

Integration with livestock

Reduced tillage

Diversified rotation

Restored

Less managed

Biological farming
Regenerating multifunctional agricultural systems
Two new systems
Alfalfa-alfalfa-alfalfa-T-C-T

Native grassland
Irrigation
Change in irrigation

Originally utilized **furrow** irrigation in tomato-corn and tomato-wheat plots with **surface** water (canals) w/low water pressure. Original flow meters were wrong size and unable to collect precise data.

**Changes:**

**Statewise:** Conventional processing tomatoes switched to currently >90% subsurface drip. Furrow not relevant in conventional. Access to surface water less reliable: some years 0 or reduced water available.

**Russell Ranch:** Access to additional groundwater wells and variable speed pump installed. Regulate water use better and greater pressure permits drip.

Vigorous funding campaign led to gift from Wells Fargo and small grants to obtain infrastructure (pipes and drip tape) and labor costs to install.

Now all irrigated plots (w/exception of alfalfa) are equipped with subsurface drip irrigation.
Water Research at RR
Precision irrigation practices

**Goal:** Test how to improve agricultural water management towards more resource-efficient and sustainable practices in different systems.

Different long term management systems
- (Organic-Mixed-Conventional)
- Irrigation system (SDI - Furrow)
- Crops (tomato-corn, tomato-wheat)
Feedback: Impact of irrigation system on agroecosystem functioning - > interaction with management

- Irrigation design and management
  - Spacial/temporal water availability
  - Aggregation
  - Compaction
  - Salinity
  - pH

Soil physiological properties

- Microbial composition
- Activity
- Soil-born diseases
- In space and time

Soil biological functions

How to manage water for more than just the crop. Trade-offs, synergies. New rotations?

Externalities

System’s ability to adapt to and mitigate agents of climate change
What are trade-offs for soil health of adopting sub-surface drip irrigation in organic?

Could prolonged lack of moisture in non-wetted areas of the soil lead to reduced soil health?

“\(I\) spent decades building up my soil. With a drip system, I am effectively using 10% of it. It does not make sense.\)”

Scott Park, Organic Grower, 1500 acres, 22 fields in Northern California for 24 years. Originally conventional farmer.
Water use

Furrow-irrigated plots had more than 2x the amount of water applied than drip-irrigated plots.

Furrow: 114 cm
Drip: 48 cm

Weeds

~150 person-hours/acre weeding
~20 person-hours/acre weeding

Fruit yields and biomass production

Organic Furrow irrigated
Organic Drip irrigated
Soil services?

- **Large macroaggregates**
  - 2000 – 8000 μm

- **Small macroaggregates**
  - 250 – 2000 μm

- **Microaggregates**
  - 53 – 250 μm

- **Silt and clay**
  - < 53 μm

Providing water to soil as well as plant ensures that soils are more resilient to moisture extremes—regenerates soils.

Also reduction in protected carbon and distribution of microbial biomass.

Changes in community composition.

Relationship to deficit irrigation?
Soil Health
Changes, indicators
"The memories of soil may be most instructive:

‘One way of fostering this long view is through “listening places”—places set aside for patient and oft-repeated measurements, where our observations are melded into those of our predecessors, then handed off as heirlooms to those who follow us.”

Janzen 2016
Soil C Change over 20 years (compared to time zero)

Tomato Systems

Wheat Systems

See Nicole Tautges flash talk
Measured Soil Textural Class: **silt loam**

Sand: 2% - Silt: 83% - Clay: 15%

<table>
<thead>
<tr>
<th>Group</th>
<th>Indicator</th>
<th>Value</th>
<th>Rating</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>physical</td>
<td>Available Water Capacity</td>
<td>0.14</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>physical</td>
<td>Surface Hardness</td>
<td>260</td>
<td>12</td>
<td>Rooting, Water Transmission</td>
</tr>
<tr>
<td>physical</td>
<td>Subsurface Hardness</td>
<td>340</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>physical</td>
<td>Aggregate Stability</td>
<td>15.7</td>
<td>19</td>
<td>Aeration, Infiltration, Rooting, Crusting, Sealing, Erosion, Runoff</td>
</tr>
<tr>
<td>biological</td>
<td>Organic Matter</td>
<td>2.5</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>biological</td>
<td>ACE Soil Protein Index</td>
<td>5.1</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>biological</td>
<td>Soil Respiration</td>
<td>0.5</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>biological</td>
<td>Active Carbon</td>
<td>288</td>
<td>12</td>
<td>Energy Source for Soil Biota</td>
</tr>
<tr>
<td>chemical</td>
<td>Soil pH</td>
<td>6.5</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>chemical</td>
<td>Extractable Phosphorus</td>
<td>20.0</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>chemical</td>
<td>Extractable Potassium</td>
<td>150.6</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>chemical</td>
<td>Minor Elements</td>
<td></td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Overall Quality Score: **51** / Medium

**CORNELL SOIL HEALTH ASSESSMENT**—indicators of soil health tested at Century Experiment

US Study of regional-appropriate indicators and scorings.
Cornell Soil Health Assessment at Russell Ranch - 2017

Scow, Natural Resource Conservation Service

Microbial data coming (sequencing, PLFA)
Multifunctional Agroecosystems

Yield in context
Maize Yields (19 years)

- Conventional
- Mixed
- Organic

Graph showing the comparison of maize yields between conventional, mixed, and organic systems over 19 years (1994-2017).
Building resilience and stability

<table>
<thead>
<tr>
<th>System</th>
<th>Probability of crop failure (&lt;10 percentile)</th>
<th>Probability of High Yield (&gt;90 percentile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic corn/tomato</td>
<td>2.8 % (P=0.0094)</td>
<td>0.9 % (P=0.0020 *)</td>
</tr>
<tr>
<td>Conventional corn/tomato</td>
<td>10.8 %</td>
<td>14.7 %</td>
</tr>
<tr>
<td>Conventional wheat/tomato</td>
<td>16.9 %</td>
<td>17.1 %</td>
</tr>
<tr>
<td>Legume/corn/tomato (mixed)</td>
<td>17.8 %</td>
<td>18.8 %</td>
</tr>
</tbody>
</table>

Based on non parametric models of historical yields - bootstrapping for p values
Long term research provides science for building multifunctional, regenerative systems

- Carbon sequestration
- Soil nutrient provision
- Weed suppression
- Yields and quality

Heatmap of normalized properties

Time period
1= 1994-1997
2= 2002-2005
3=2012-2015

M index based on average of normalized variables from heat map for multifunctionality index

Gaudin, Li, Tautges and Scow
Engagement in Policy
Healthy Soils Initiative
State of California

RR has provided field trips, workshops, inputs on documents, help in outreach

California's Healthy Soils Initiative is a collaboration of state agencies and departments, led by the California Department of Food and Agriculture, to promote the development of healthy soils. A combination of innovative farm and land management practices contribute to building adequate soil organic matter that can increase carbon sequestration and reduce overall greenhouse gases.
Keeping long term experiments funded
Challenge: How to sustain long term funding?

- “Core” funding provides increasingly small portion of annual funds needed for Century Experiment
- Financial pressures: less subsidization by College of field research: investigator must pay more. Shift in culture.
- Cost of farming has gone up. Wages for farm laborers from $12 to $22 per hour. Affects organic system: e.g., weeding
- Equipment!! Replace and keep up or may be irrelevant

- Need consistent funding base for infrastructure and core farm staff--many grants won’t fund
- Need science staff for leading and implementing research, proposal writing--balancing that with farming needs
- New grants help some but usually generate new work

Also need to protect experiment from being terminated by budget cuts!
Some solutions

• Diversify funding base from variety of sources, not just traditional grants
  ■ Internally: income generation from crops and farming for other units
  ■ Endowments and gifts (“Adopt an Acre”); equipment gifts from industry
  ■ Increase recharge rates for investigators, particularly established scientists

• Value-added, branded products from farm to increase visibility
• Working with industry to obtain technology: e.g. instrument plots?

Adopt an acre
Help create an endowment for the Russell Ranch Sustainable Agriculture Facility at UC Davis.
Lessons learned

- Create compelling physical space that provides hub for convergence of researchers, farmers, students, industry, policy makers, hold workshops, trainings, walk about
- Need clear hypotheses and conceptual model, but be flexible
- Keep experiment simple and low cost: # treatments, labor intensiveness
- Anticipate costs for sampling and analysis, archiving
- Local farmers can become strong advocates: share ideas, equipment
- People will come: "serving" them requires staff!!!
- Markets: are important for income and context and industry partners (and potential future research ideas)
- Long-term projects that ignore short-term concerns may not survive.

Threats

- Insufficient Funding—may be temporary w/growing season: need stop-gap
- No champions to lead area of research
- Boredom—must keep science exciting, publications coming, good “stories”
  to use for outreach, engagement

Balance consistency with flexibility:

- Microplots and playgrounds
- Compare systems, not detailed practices.
- Allocate resources to short-term too
Acknowledgements

Research Manager: Nicole Tautges

Scow Microbial Ecology Lab

Undergrads: Tu Thanh Le, Dinh Giang, Evelyn Peña

Russell Ranch farm team