DRAFT

# Proposed New Science Plan for the Century Experiment at Russell Ranch Sustainable Agriculture Facility (2012)

## Background and vision of Russell Ranch at ASI

**The Agricultural Sustainability Institute (ASI)** at **UC Davis** has a **mission** is to ensure access to healthy food and to promote the vitality of agriculture today and for future generations. This is carried out through integrative research, education, communication and early action on big, emerging issues. The Russell Ranch Sustainable Agriculture Facility is a core program of ASI.

Russell Ranch aims to continuously deliver knowledge and tools for sustainable land management practice. Sustainability is understood as increasing agricultural productivity and improving economic viability while minimizing non-renewable energy use, reducing pollution, enhancing the quality of soil, water, air along with that of produce, conserving biodiversity and ensuring the safety and development of farming communities (see further explanation here). We follow strict protocols in the collection and archiving of our soil and plant samples and data measurements. Our database, sample archives and research studies are available for modelling and other research analysis for all interested parties.

Our research design emphasizes a 'systems' approach and is built on a strong interdisciplinary foundation of agricultural, ecological and environmental sciences. Russell Ranch manages each farming system according to best management practices for each system. Best management practices are defined and modified, as needed, based on frequent discussions with local farmers and extension specialists, both individually and at organized workshops and annual meetings.

### Background

Russell Ranch (http://asi.ucdavis.edu/rr), located a few miles from the main UC Davis campus, is a unique 300-acre research facility that focuses on irrigated and dryland agriculture in the Mediterranean climate of California. The original goal of Russell Ranch's 100-year experiment --the Long Term Research in Agricultural Sustainability (LTRAS) also known as the Century Experiment--designed in 1990 and implemented in 1993, was to investigate the effects of external inputs on the sustainability of cropping systems.  Now, 19 years into the experiment, some of the original questions have been answered, and some of the original research priorities have been eclipsed by emerging issues. The design has been modified, and in some cases expanded, to address current global and regional problems, to support shifting faculty research interests, and to be feasible with existing budgetary constraints.

*Current experimental design*: The cropping systems described in the original 1990 proposal to SAREP were designed to study the effect of crop rotation, and degree of reliance on rainfall and legume nitrogen fixation, on resource use efficiency, productivity, soil quality, movement of pollutants, and economic return.  Specific attention was given to study of processes and mechanisms that control changes in soil quality and agroecosystem components. The cropping systems spanned a gradient of external inputs, and were characterized by their carbon, nitrogen and water inputs. The organic system had the highest inputs (of nitrogen, carbon and water) while the unirrigated, unfertilized wheat had the lowest inputs.

Over the last 18 years, additional variables such as irrigation type, rotation length, tillage regime and crop diversity have been investigated and, in some cases, incorporated into the experimental design. In 2003, the Sustainable Agriculture Farming Systems (SAFS) project was moved to Russell Ranch and integrated into the LTRAS experiment. From 2003 to 2007, the plots of the corn/tomato rotation were divided in half to compare standard versus reduced tillage. However, after five years differences between the two treatments (except for fuel use) were minimal and thus the comparison was discontinued. Since 2009, the conventional and low-input treatments have included comparison of furrow and drip irrigation treatments. Thus the original experimental design has been modified, to some degree, over time to respond to new research directions and investigator interests.

**Justification**: The conceptual framework for the New Science plan was defined based on input from recent seminal publications on the food system and sustainability and by seeking input from numerous stakeholders. We aimed to ask broad questions that apply to farming systems throughout the world, but nested into a local context so that the data collected is legitimate. In 2008, the Agricultural Sustainability Institute (ASI) conducted a survey of 165 farmers and 141 university affiliates. Farmland preservation, competition for water, water use efficiency, habitat preservation and soil biodiversity, petroleum dependence and air and water pollution were all among the top 10 highest ranked issues. In a survey of 162 farmers in Yolo County at UC Davis, practices of the most interest to farmers included: reducing on-farm energy usage, conservation tillage, adopting drip or micro-sprinkler irrigation systems, and improving nitrogen use efficiency (Jackson, 2011). Research questions and potential farming systems were discussed with experts (including members of the RR Cropping Systems Committee) at UC Davis.

Reviews of Russell Ranch have also provided input. In 2002, an External Review of the LTRAS project resulted in the following recommendations for modifications of the treatments: 1) expand range of water inputs for the different cropping systems, including incorporating sprinkler or drip irrigation 2) make irrigated wheat a sub-plot of the rainfed wheat plots 3) modify the organic treatment to include both a compost-fertilized and legume-fertilized rotation 4) interact with treatments at the Student Farm and Sustainable Agriculture Farming Systems (SAFS, which researched both inputs and tillage). A twelve year assessment was conducted in 2005 to review progress and solicit ideas for future management. Identified concerns at the meeting included: two year rotations are too simple for disease control, the treatments are not as intensive as commercial agriculture, and a need to review the organic treatment for input levels and other management issues. 4 year rotations were recommended. Additional research questions were selected from a published list of top 100 questions facing global agriculture (Pretty, 2010) and the Agricultural Water Stewardship recommendations by the California Roundtable on Water and Food Supply (AIN, 2011a).

**Research focus and objectives:**

Agriculture is under increasing pressure as the global population rises, as finite resources are increasingly depleted, and as climate systems change. Our overarching research question for the next twenty year phase of the Century Experiment (the 72 main plots at Russell Ranch) is: **Can we increase sustainability as we increase food production?**

Specifically, the five research questions for our experiment will be:

1. How can food production systems be designed to reduce dependence on externally derived resources while maintaining sufficient productivity? [1]

2. What is the tradeoff between provisioning services—i.e. production of agricultural goods such as food, fiber or bioenergy—and regulating services such as natural water purification, soil conservation or carbon sequestration? What are their spatial scales, temporal scales and potential for reversibility? [2]

3. Do agricultural systems differing in biodiversity differ with respect to their resistance and resilience to disturbance (e.g. climate change, drought, tillage)?

4. What are key interactions among energy use, water use and soil inputs in agricultural systems: where are the trade-offs and what are the synergies?

5. What approaches can best increase water use efficiency in irrigated and rainfed agricultural systems? What is the effect of water-efficient and other innovative technologies on local hydrological fluxes, and how do local changes combine and alter water resource availability at larger geographic scales[3] ?

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## Implementation--Proposed New Experimental Design:

**Approach:**

In our conceptual framework, we focus on three major drivers of agricultural production: energy, water and soil resources. Each driver consists of a number of specific components, many of which are relevant to questions that can be addressed at Russell Ranch.

- Water includes: water use (also water quality, water periodicity)
- Energy includes: fossil fuel inputs from tillage fuel, fertilizers and pesticides (also solar energy flux to the system)
- Soil is represented by carbon inputs (kg C / ha)

We reduced each of the three main drivers to a sub-set based on recommendations of the RR Cropping System Committee and literature sources (AIN, 2011b; Jackson, 2011). Though this is a simplification of a complex set of factors, it permits definition of an array of cropping systems that represent different points along the three-dimensional space created by variation in energy inputs, water inputs and land management practices. This design is a first approximation and will be modified, over the course of the experiment, with new information and perspectives.

- Energy inputs are estimated by upstream fertilizer, pesticide and tillage fuel energy costs (Marvinney, 2011; UC ANR cost studies) (MJ/acre/crop).
- Water inputs are estimated by experts and UC ANR cost studies (acre-feet per crop).
- Soil as a driver is represented as total carbon inputs (kg/acre/crop) (estimated based on RR data and the literature). Carbon inputs are a reasonable choice because they are correlated with a number of other relevant soil properties. Carbon inputs can also be assumed to be a first approximation of a more complete “soil index,” encompassing many sustainability indicators, and these will be developed based on researcher and stakeholder feedback.

*Proposed cropping systems*: We then identified a set of potential cropping systems, based on discussions with the RR Cropping Systems Committee, that differ with respect to energy, water use and land use.

We estimated energy use, water use and soil carbon input first for each crop (see Appendix) and then for the rotation as a whole. Table 2 summarizes this information.

We propose a package of one, two and four year rotations. All of the cropping systems will become more intensified (to the degree possible) with respect to production (e.g. less time under fallow) in the proposed cropping systems. The original systems comparison is kept intact, with a conventional, organic and “mixed” system; however sunflower replaces corn from the original rotation. In the “mixed” system, we propose to include a long-term microplot fertility experiment (with different ratios of organic to mineral fertilizer) to study Integrated Nutrient Management (INM). The wheat experiment is reduced from both irrigated and rainfed to adaptive irrigation management, the wheat is grown annually instead of every other year, and an alfalfa/wheat rotation replaces the current rainfed wheat/WLCC rotation. The super biological system in option #1 is a four year rotation with integrated nutrient management and pesticides as needed. The corn-wheat system is a one year reduced-tillage silage rotation. Note that questions will be sometimes be asked at the whole-plot scale and sometimes in microplot comparisons within plots. All plots will undergo the routine ten-year soil sampling (6 samples per plot, 3 meter depth) prior to modification to the new systems.

**Table 1:** Proposed new cropping systems and carbon, water and energy inputs into each system.

| **Proposal: Systems** | **Carbon inputs (kg/ha/crop)** | **Water (acre-feet/crop)** | **Energy (MJ/acre/crop)** |
|---|---|---|---|
| 2 year Tomato/Fallow/Sunflower/Fallow Conventional* | 2150 | 2.8 | 30336 |
| 2 year Tomato/WLCC/Sunflower/WLCC Organic* | 4396 | 3.3 | 13731 |
| 2 year Tomato/WLCC/Sunflower/ WLCC*<br>● INM1: Total N = Conv N+WLCC N<br>● INM2: Total N = Conv N Total N=Mineral N +WLCC N<br>● INM3: Total N = Conv N; Total N = Mineral N + WLCC N + Compost N; P from compost | ● 3700<br>● 3700<br>● 3866 | ● 3.0<br>● 3.0<br>● 3.0 | ● 36102<br>● 24756<br>● 24091 |
| 4 year Super bio, conventional: Tomato/Wheat/Beans/WLCC/ Corn/WLCC for seed/Sunflower/WLCC | 3810 | 2.3 | 18400 |
| 1 year, Reduced-till Corn/wheat | 5000 | 2.3 | 20091 |
| 6 year, Conventional Alfalfa/alfalfa/alfalfa/alfalfa/tomato /fallow/sunflower/fallow | 2350 | 3.6 | 13672 |
| 2 year, Conventional Tomato/wheat* | 1500 | 1.8 | 26467 |
| 2 year, Organic Tomato/corn | 7350 | 4.5 | 16526 |
| 2 year, Rainfed fertilized wheat/fallow | 1000 | 0 | 15570 |

| | | | |
|---|---|---|---|
| 2 year, Rainfed unfertilized wheat/fallow | 750 | 0 | 9031 |
| **Perennial: Native grasses** | 400 | 0 | 2636 |

* Proposed system continues an existing system, with some modifications

To better communicate how the proposed farming systems selected do indeed serve to answer the questions identified in the conceptual model, we “visualize” the farming systems and their differences in Figure 1. The values summarized in the table are plotted in the three-dimensional space representing the three constraints (x=water, y=energy, z=land) thus permitting visualization and selection of a broad range of different cropping systems (Figure 1). Please note that these numbers are simply initial projections (estimates), to describe and differentiate the various systems, and will certainly be modified over the course of the experiment. These initial estimates will be replaced and modified by real data collected during the experiment; biophysical changes in the systems due to management may feedback in needing to adjust some of the inputs and thus change the numbers; and development of new innovations combined with knowledge we gain about each system over time may also lead to changes in management to maximize sustainability (adaptive management).

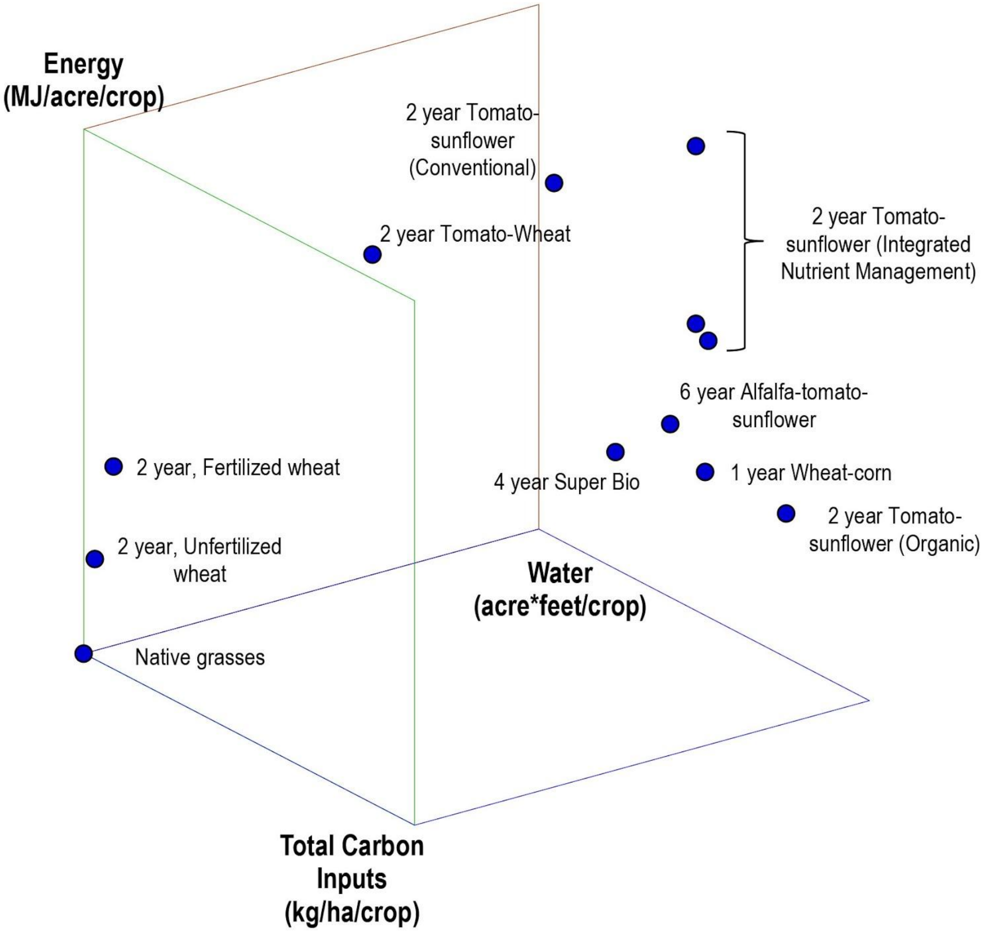

**Figure 1:** The graphical representation of each cropping system in a three dimensional space of energy, water and carbon inputs.

*Costs*: The total annual cost for this option will be an estimated $181,66.83, while the current cropping systems have an annual cost of $188,168.22. The annual cost is the difference between the total cost and the income from the crops, and includes equipment repair, labor, inputs, and overhead (but not research labor). The estimated income assumes that a market will be found for all new crops (alfalfa, sunflower, and dry beans) and also that transportation of the crop is included. Further details of the costs of each cropping system can be found in the Appendix, Table 6 and 7.

The total capital costs needed for new equipment to implement the alfalfa rotation is $26,000 for a planter (capital costs not included on table below). Additionally, growing alfalfa will require the capital costs to plant an 80-acre scale-up field with alfalfa in order to contract with a local swather and baler (estimated costs to RR are $21,954). The capital cost for beans and sunflower is $34,000 for a planter and modified cultivator. The capital cost for the corn-wheat system would require a silage machine, estimated cost is $100,000 (used). Acquisition of new equipment is required for these new systems to go forward.

## Indicators

Development of a meaningful set of indicators to monitor agricultural sustainability is a major research goal for our project. The following research questions on indicators will help to measure progress towards sustainability in different agricultural systems that are appropriate for, and acceptable to, different agroecological, social, economic, and political contexts.

- What are key indicators of system properties/processes? Can early warning systems be developed to predict emerging challenges in disease, nutrient availability, water stress? What indicators will be most effective in detecting thresholds?
- What are different methodologies that integrate understanding of multi-scale processes (cell, organism, community and ecosystem) in order to monitor, predict and mitigate climate change impacts?
- How can information exchange systems be designed to be more efficient and effective, with place-based guidance tools**?**
- Which metrics or combination of metrics (net economic return, economic return including externalities , return proportional to investment, nutritional value, total caloric or total biomass yield, or variation in yields) best asseses the sustainability of an agricultural production system?

The original design of the project included a sampling design set of key indicators representing different attributes of the systems, including information about crops, soil, pest and weeds, economics. Some metrics, including yields and plant and soil elemental content, have been measured on a regular schedule. However, many metrics are not measured on a consistent basis but are dependent upon funding (typically grants). We propose to reevaluate and prioritize the indicators that will be part of the project's core data set or measured on an occasional basis, using stakeholder involvement to prioritize the most important indicators. Increased availability of core funding will permit inclusion of new indicators and permit more frequent measurements.

**Table 3:** Current and proposed indicators and metrics measured at Russell Ranch

| | |
|---|---|
| **Metrics measured on a regular schedule since 1994 (core data):** | Yield of wheat (total biomass, grain yield and moisture), tomatoes (total biomass, fruit yield and moisture), cover crops (total biomass and moisture)<br>Plant elemental content (CNPK)<br>Soil elemental content (CNPKS)<br>(Tractor and equipment data collected annually) |
| **Indicators assessed for some systems and years since 1994 (prioritized in terms of need for more data collection):** | Water use, water use efficiency*<br>Profitability<br>Fuel and energy use*<br>Greenhouse gas emissions (N2O)* |

| | |
|---|---|
| | Weed communities<br>Beneficial and pest insect communities<br>Soil biological communities<br>Water infiltration<br>Food nutritional content<br>Soil compaction<br>Soil inorganic nitrogen content<br>Climatic data*<br>Nutrient balance (CNPKS)*<br>Outreach effectiveness (field day attendance, number of tours given) |
| **Future potential indicators to be assessed on LTRAS plots:** | Nitrogen leaching*<br>Greenhouse gas emissions (CO2,Methane)*<br>Ecosystem service valuation<br>Nitrogen fixed by legumes<br>Impact of knowledge collection in cropping system<br>Energy efficiency index*<br>Above ground diversity*<br>Groundwater level and recharge*<br>Pesticide runoff and residues*<br>Air quality (NOx,SOx, dust emissions)*<br>Water salinity<br>Residual nitrogen in soil<br>Effect on endangered species*<br>Waste generation*<br>Soil heavy metal concentration*<br>Soil erosion* |
| | * = Indicator from OECD Environmental indicator framework |

Many different indicators have been researched at Russell Ranch over the last 18 years (only a small portion are listed above). Defining the core set of indicators to be part of the long-term dataset is essential and will be a major objective of the new science plan.

This set of indicators will be measured in a variety of research areas, allowing for comparison between different farming systems and farming practices.

# Areas of research:

Russell Ranch includes the Century Experiment as well as other research areas and objectives. We include the full list of current and proposed research areas at Russell Ranch below. Researchers are invited to collaborate with Russell Ranch to help implement these areas of research over the next twenty year period.

### Farming systems comparison

The farming systems comparison is the major research area at Russell Ranch (ie. the Century Experiment). Past research on the farming systems have led to many research projects and publications (see a list here: http://russellranch.ucdavis.edu/publications/alpha-temp), most notably on carbon sequestration, greenhouse gas emissions, and nutrional quality of foods produced. The proposed new cropping systems listed above allow key research questions to be answered, including:

1) Can the integrated nutrient management (INM) system get the same yields as conventional by replacing some amount of fertilizer with cover crops and also composted manure to fertilize for phosphorus?

2) What is the interaction of irrigation system with farming system on resource use efficiency and productivity? Can you reduce water use in the organic and INM systems (which have high soil infiltration) by using an overhead or drip irrigation system?
3) Can the super-biological system get higher yields than conventional by having continuous cover, increased use of nitrogen fixation and longer rotations?
4) Can nutritional quality of food be improved through management and what are mechanisms of differences between systems?
5) Can you reduce nitrogen input to a tomato crop in rotation with alfalfa? Can you reduce tillage energy of the overall system by growing perennial crops in rotation with annual crops?
6) Would an annual winter grain rotation be sustainable in a future Central Valley scenario with reduced water reserves? What changes occur in the annual winter grain systems with climate change?
7) What is the productivity of a no-input system? What is impact on soil quality, organic matter, nutrients, pests, weeds, as we continually mine the unfertilized annual wheat system?

**Biodiversity (Hedgerows, native grasses and wildflowers):**

Russell Ranch is initiating a project to increase biodiversity along its farm edges, by planting vegetated swales and canals, hedgerow plantings, forb strip research areas, and native grass research areas. This project is being advised and assisted by a group of on-campus researchers and University staff. Key research questions include:

1) What impact do native grass/forb plantings have on multiple ecosystem services and can we quantify the value? (Ecosystem services can include pollination, pest and weed pressure, soil carbon storage, enhance water holding capacity, erosion control, sequester N to prevent leaching/gas loss, restoration of compacted soils).
2) What combination of management system, forbs and grasses would be most resilient to climate change and compete with agricultural weeds and invasive species over the next 100 years?
3) What grazing regime can maintain and enhance native grasslands (timing, intensity, species of grazer)? Is this economically viable? Does the grazing management change with forbs included in the grassland?

Additionally, Neal Williams and Kimiora Ward are testing mixes of native California wildflowers or their ability to attract native bees without attracting pests. In 2010 they tested several mixtures of annual and perennial wildflowers at low and high diversity, and found that the wildflower mixes attracted up to ten times more native bees than control plots of typical weedy vegetation. In 2010 they trialed seeding the mixes at Russell Ranch with several commonly used farming techniques to develop methods that are accessible to local growers and will ensure successful germination and establishment of the native plants.

**Water: Implications of irrigation and drought**

From 2008-2012, Russell Ranch has studied the effects of drip and furrow irrigation, as well as cover crops, on greenhouse gas emissions, nitrate leaching, nitrogen use efficiency and soil moisture storage. In the future, potential irrigation projects could include a comparison of overhead irrigation with furrow irrigation on row crops, fertigation studies with drip irrigation, especially in organic agriculture, and research on potential mechanisms to reduce nitrate leaching (including nitrification inhibitors and cover crops). Research has also targeted the effects of different moisture regimes (e.g. wet-dry cycles) on nutrient cycling, leaching of nitrogen and carbon, and microbial communities.

Russell Ranch is developing research directions in drought management, including expanding dryland or reduced irrigated agriculture, water harvesting using rainwater tanks and other approaches, and use of low pressure drip systems for perennial crops. Russell Ranch also calls for research to predict the effects of reduced winter precipitation on winter forage crops, through use of high tunnels and other climate simulations.

**Soil Biology - Microbial Communities and Plant Symbiosis**

Soil microbial communities, and plant-microbial symbioses, are crucial for the functioning of all agricultural ecosystems and emerging technologies are facilitating new discoveries about the diversity and activities of microbes in agricultural soils. Extensive research on the biodiversity of soil communities in some of the farming systems shows that long term management has led to divergences in the types of organisms present in, for example, organic versus conventionally managed tomatoes, and in farmed versus unmanaged plots. Russell Ranch launched a campaign in the fall of 2012 to identify the major questions and key gaps in our understanding of how microbes provide services in agriculture and how best to manage soils to promote beneficial and repress detrimental activities of their inhabitants.

Research questions include:

1) How do inputs (fertilizer, organic matter, biological inoculants) and management practices (tillage, herbicide application, fallow periods) affect diversity, community composition and key functions of soil microorganisms?
2) Can nitrogen fixation and nitrogen use efficiency be increased by the use of hormonal signaling compounds to induce nodulation in cover crops and/or alfalfa?
3) How does spatial variation in organic matter and soil infiltration affect microbial populations and communities, and are there microbial hotspots that affect both nitrogen leaching and greenhouse gas emissions?

**Closing the loop - soil amendments and agricultural waste**

Russell Ranch would like to invite research on agricultural application of bioenergy and municipal wastes. Different amendments that could be studied at Russell Ranch include: biochar, biodigester effluent, biosolids, municipal green or food waste, composted animal manure, or other agricultural by-products. Key parameters would be measured to help complete life cycle energy assessments of bioenergy usage and production, as well as long-term impacts on soil properties. Persistence of antibiotics and other chemical residues within these organic wastes will be a key area for study.

A research area dedicated to study the effect of biochar and compost application on tomato and corn yields and soil properties was intiated in 2012. The study was designed as a split-plot experiment, with the ability to have up to 10 treatments within the 4 main plot treatments (biochar, biochar + compost, compost and mineral fertilizer). Research questions that are being asked in this area include:

1) How does biochar affect soil organic carbon sequestration and carbon leaching to deeper soil profiles?
2) How does biochar affect tomato growth properties (yield, flavor, nutritional content)?

**Conservation agriculture and reduced tillage:**

*From 2003 to 2007, the plots of the corn/tomato rotation were divided in half to compare standard versus reduced tillage. However, after 4 years, differences between the two treatments (except for fuel use) were minimal and thus the comparison was discontinued.* There is renewed interest in further investigating the challenges and opportunities of reduced tillage for agriculture in California. The experience of the past experiment at Russell Ranch indicates that undertaking reduced tillage is a substantial shift in cultural practices that requires a period of trial and error, before comparisons between 'control' plots and plots with treatment can be accurately undertaken.

Some of the research questions of interest at Russell Ranch include:

1) What impact does conservation/reduced tillage operations have on soil properties over time?
2) How do conservation/reduced tillage operations interact with the different irrigation options – drip vs. furrow vs. sprinkler/overhead irrigation to ultimately impact crop yields?
3) What impact does increased residue on the soil surface under reduced tillage operations have on multiple ecosystem services and can we quantify the value (including disease, pest and weed pressure, soil carbon storage, water holding capacity, erosion control, soil fertility)?
4) What types of reduced tillage operations are best suited for conditions peculiar to agriculture undertake in the central valley of California?
5) Does undertaking conservation/reduced tillage necessitate increase in herbicide use or can certain mixes of cover crops work effectively to counter weed pressure? As a corollary, can conservation/reduced tillage operations be undertaken under organic systems?
6) What are optimal farm sizes for undertaking reduced/conservation tillage? This can cover the agronomic dimension of residue management as well as an economic dimension related to risk and upfront capital investment required for a shift to conservation/reduced tillage.

**Energy, greenhouse gas emissions and climate change:**

Greenhouse gas emissions from some of the cropping systems have been closely monitored at Russell Ranch. Carbon dioxide and nitrous oxide emissions from organic and conventional, as well as drip and furrow irrigated tomato plots have been investigated extensively (Kallenbach, 2010; Burger, 2005). Soil and greenhouse gas emission measurements have also been incorporated into an ecosystem model, DAYCENT, in order to model climate change mitigation efforts from agriculture (DeGryze, 2010). Russell Ranch would like to encourage more research in this area in the next phase of research. Key research questions include:

1) What is the best mix of internal and external inputs and management system to increase the energy use efficiency of the cropping systems?
2) How does increased temperatures and CO2 levels affect crop production and ecosystem services in long-term agricultural datasets?
3) How can food production be more carbon neutral?

**Integrated livestock-crop production systems:**

Russell Ranch currently only partially integrates animals into the cropping systems with incorporation of chicken manure compost in the organic system. However, Russell Ranch would like to encourage research on an integrated livestock-crop production system. Potential integrated livestock-crop production systems could include: grazing sheep for cover crop incorporation, using animals to replace mowing in native grass systems, and direct grazing of alfalfa for animal feed.

Key research questions could include:

1) What is the life cycle analysis of crops fertilized with manure fertilizers, when including greenhouse gas emissions from animal production, compost production and transportation? How do crops fertilized by direct grazing compare to crops fertilized by off-site manure incorporation?
2) How does nutrient cycling differ from a crop production systems (with either mineral fertilizer, manure based compost or plant-based compost) to an integrated livestock-crop production system?

3) How does spatial deposition of manures affect crop , weed and soil ecology?

## References:

AIN, 2011a. Agricultural Water Stewardship: Recommendations to optimize outcomes for specialty crop growers and the public in California. Ag Innovations Network, California Roundtable on Water and Food Supply. http://aginnovations.org/images/uploads/CRWFS_Water_Stewardship_Recs_electronic.pdf

AIN, 2011b. User's guide to SISC Farm Level Metrics and Calcuator (Beta Version 1.1). Ag Innovations Network, Stewardship Index for Specialty Crops. http://www.stewardshipindex.org/docs/Guide%20to%20SISC%20Metrics.pdf

Collete, L. 2011. "Soil health." Save and grow. FAO Chapter 3. http://www.fao.org/ag/save-and-grow/en/3/index.html

Hayhoe, K., Cayan, D., Field, C.B., Frumhoff, P.C., Maurer, E.P., Miller, N.L., Moser, S.C., Schneider, S.H., Cahill, K.N., Cleland, E.E., Dale, L., Drapek, R., Hanemann, R.M., Kalkstein, L.S., Lenihan, J., Lunch, C.K., Neilson, R.P., Sheridan, S.C., Verville, J.H., 2004. Emissions pathways, climate change, and impacts on California. P Natl Acad Sci USA 101, 12422-12427.

IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

Jackson, Louise, Van R. Haden, Allan D. Hollander, Hyunok Lee, Mark Lubell, Vishal K. Mehta, Toby O'Geen, Meredith Niles, Josh Perlman, David Purkey, William Salas, Dan Sumner, Mihaela Tomuta, Michael Dempsey, and Stephen M. Wheeler (University of California, Davis). 2011. Adaptation Strategies for Agricultural Sustainability in Yolo County, California. California Energy Commission. Publication number: CEC-500-2011-XXX.

Organisation for Economic Co-operation and Development (OECD). "Environmental Indicators for Agriculture: Methods and Results." 2001. OECD Publications, Volume 3.

Pretty, J. et al. The top 100 questions of importance to the future of global agriculture. 2010. International Journal of Agricultural Sustainability. Volume: 8, Issue: 4, Publisher: Taylor & Francis, Pages: 219-236

Sachs, J.et al. 2010. Monitoring the world's agriculture. Nature. Vol. 466, p. 558-560.

Tilman, D. et a. 2002. Agricultural sustainability and intensive production practices. Nature. Vol. 418, p. 671-677.

## Appendix 1: Supporting documentation for estimates

**Table 5:** Water and energy numbers by crop (annual).

| | | Water | | | Fuel | | Energy (from fertilizer and pesticides) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | CONV | INM | ORG | CONV | INM | ORG | CONV | INM1 | INM2 | INM3 | ORG |
| | | Acre-feet | | | MJ/acre | | MJ/acre | | | | |
| | | | | | | | | | | | |
| **Bean** | 1.5 | 2 | 2 | 3273 | 3273 | 3772 | 5551 | 5551 | 5551 | 5551 | 0 |
| **WLCC (total fixed)** | 0 | 0 | 0 | 4600 | 4600 | 4600 | 0 | 0 | 0 | 0 | 0 |
| **Tomato** | 3 | 3.5 | 4 | 7724 | 8826 | 9117 | 31747 | 31747 | 24434 | 23105 | 3059 |
| **Corn (silage)** | 4 | 5 | 5 | 7186 | n/a | n/a | 15601 | tbd | tbd | tbd | tbd |
| **Safflower** | 0.5 | 1 | 1 | tbd | tbd | tbd | tbd | tbd | tbd | tbd | tbd |
| **Sunflower** | 2.5 | 2.5 | 2.5 | 5323 | 6555 | 6913 | 15877 | 15877 | 497 | 497 | 2232 |
| **Wheat** | 0.5 | 1 | 1 | 4988 | 4988 | 4574 | 6568 | 6568 | 4164 | 3004 | 0 |
| **Alfalfa** | 4 | 4 | 4 | 3603 | n/a | n/a | 1133 | n/a | n/a | n/a | n/a |
| **Sorghum** | 3 | 3.5 | 3.5 | 2705 | 2705 | 2803 | 10285 | 10285 | 10285 | 10285 | 2979 |
| **Native grasses** | 0 | 0 | 0 | | n/a | n/a | 2870 | n/a | n/a | n/a | n/a |
| **Wheat fertilized** | 0 | | | 7010 | | | 6538 | | | | |
| **Wheat unfertilized** | 0 | | | 6636 | | | 300 | | | | |

Tbd = to be determined; N/a = Not applicable; not needed for current proposed cropping systems

**Table 6:** Annual cost of each proposed cropping system to Russell Ranch (expense – income)

| | |
|---|---|
| **2 year Conv. Tomato/Fallow/Sunflower/Fallow** | $ 2,962.65 |
| **2 year Organic Tomato/WLCC/Sunflower/WLCC** | $ 3,087.29 |
| **2 year INM Tomato/WLCC/Sunflower/WLCC (Conv N + WLCC)** | $ 3,813.66 |
| **2 year INM Tomato/WLCC/Sunflower/WLCC (Total N = Conv N)** | $ 221.87 |
| **2 year INM Tomato/WLCC/Sunflower/WLCC (Total N = Conv. N; Conv P = Compost P)** | $ 225.07 |
| **2 year, Conv. Tomato/wheat** | $ 1,124.60 |
| **2 year, Close the loop microplots** | $ 882.41 |
| **4 year, Super-bio Tomato/Wheat/Beans/WLCC/ Corn/WLCC for seed/Sunflower/WLCC** | $ 3,880.39 |

| | |
|---|---|
| **6 year, Alfalfa-tomato-sunflower** | $ 106.40 |
| **1 year, Wheat-corn (reduced tillage for silage)** | $ 1,699.37 |
| **2 year, Annual fertilized wheat/fallow** | $ 11,466.16 |
| **2 year, Annual unfertilized wheat/fallow** | $ 11,044.62 |
| **Native grassland** | $ 1,855.13 |
| Fallow plots (21 acres) | $ 18,316.67 |
| Plot margins (56 acres) | $ 12,102.08 |
| Weather station | $ 520.63 |
| Extra acreage (Front fields, conventional) | $ (37,553.99) |
| Extra acreage (Behind the barn, organic) | $ (662.66) |
| Labor | $ 160,363.25 |
| **Total** | $ 181,626.83 |

**Table 7:** Annual costs of current rotations.

| | |
|---|---|
| **2 year rotation, Conv. Wheat-tomato (13 plots)** | $ 5,776.59 |
| **2 year rotation, Mixed Wheat-tomato** | $ 3,195.55 |
| **2 year rotation, Organic Wheat-tomato** | $ 5,337.78 |
| **2 year, Irr Wheat fert./fallow** | $ 5,528.41 |
| **2 year, Irr Wheat unfert./fallow** | $ 5,630.21 |
| **2 year, Rainfed Wheat/legume** | $ 5,329.36 |
| **2 year, Rainfed Wheat fert./fallow** | $ 5,637.53 |
| **2 year, Rainfed Wheat unfert./fallow** | $ 5,624.59 |
| Fallow plots | $ 11,338.89 |
| Plot margins | $ 12,102.08 |
| Weather station | $ 520.63 |
| Extra acreage (conventional) | $ (37,553.99) |
| Extra acreage (organic tomatoes in 2011) | $ (662.66) |

| | |
|---|---|
| Labor | $ 160,363.25 |
| | |
| **Total** | $ 188,168.22 |

## Appendix 2: Research questions

**Table 4:** Additional list of research questions

**1. Land (soil and biodiversity both above and belowground)**:

*Land:*

- How can food production systems be designed to reduce dependence on externally derived N, P and K resources? (Pretty, 2010)
- Can knowledge of spatial variation in soil fertility, etc be used to develop better management strategies? (Pretty, 2010)

*Biodiversity:*

- What is relationship between productivity and biodiversity (and other ecosystem services) and how does this vary between systems and as function of scale? (Pretty, 2010)
- What are gains in resource use efficiency that can be achieved by crop genetic improvement for resistance to abiotic and (via resistance to biotic stresses?) (Pretty, 2010)
- Can native (soil) organisms be better utilized to reduce external inputs, maximize productivity, reduce environmental impacts? (Pretty, 2010)
- How can increasing crop and non-crop biodiversity reduce pests? (Pretty, 2010)
- Are functional groups of organisms and processes below and above ground affected by changing inputs and management practices? What agroecosystem factors govern biodiversity in these systems, and what is consequences of this biodiversity on system properties/behavior?
- How do soil-plant interactions vary over time and space in different systems: what drives these fluctuations? How does it impact nutrient uptake, disease resistance. How can we scale up these interactions to make predictions/management decisions at the field scale?

**2. Energy (fossil fuel and solar derived)**

- How can food production be more carbon neutral?
- What is the impact of replacing food with energy crop production on the environment and socio-economic indicators?

**3. Water (quantity and quality, periodicity)**

- What would be cost of capping water withdrawals for cropping systems to improve environmental conditions?
- What gains can be achieved by crop genetic improvement for water use efficiency? (paraphrased from (Pretty, 2010)
- How does farm water stewardship management impact production and adoption of high water use efficiency practices? (Water)
- How has conversion from flood and furrow to drip and microsprinkler influenced demand for surface water and groundwater? (AINa, 2011)

**4. Integration: Ecosystem Services, Resilience and Resistance, Benchmarks and their Indicators?**

**Ecosystem Services**

- What is best mix of intensification and extensification to deliver increased production, GHG reduction and increase ecosystem services

**Resistance and Resilience:**

- What indicators are most predictive in detecting thresholds of concern and thus increasing the resilience of ag and food system in face of multiple drivers of change?
- Do systems differing in diversity differ with respect to their resistance/resilience to disturbance? (e.g., climate change).

**5. System-specific research questions: (ADAPTIVE QUESTIONS)**

1. Would an annual adaptive irrigation winter grain rotation be sustainable in a future Central Valley scenario with reduced water reserves? What changes occur in the annual winter grain systems with climate change? (Rothamsted pub on UK/AFRICA just showed that temperature not drought has bigger impact on wheat http://www.nature.com/srep/2011/110818/srep00066/full/srep00066.html)
2. Can the integrated nutrient management (INM) system get the same yields as conventional by replacing some amount of fertilizer with cover crops and also composted manure to fertilize for phosphorus?
3. Can the super-biological system get higher yields than conventional by having continuous cover, increased use of nitrogen fixation and longer rotations?
4. Can you reduce nitrogen input to a winter grain in rotation with alfalfa? Can you reduce tillage energy by growing perennial crops in place of annual crops?
5. How far can you take a system in terms of crop production with no inputs. What is impact on soil quality, OM, nutrients, pests, weeds, as we continually mine the unfertilized annual wheat system?
6. Can nutritional quality of food be improved through management: what are mechanisms of differences between systems

(stress? more efficient nutrient uptake, harnessing biologically-mediated enhancements)

**Table 1:** Top priority research questions (to be discussed)

**1. Land (soil and biodiversity both above and belowground)**:

- What benefits can sustainable land management deliver for production and other ecosystem services? What tradeoffs are associated with different management systems? How can costs and benefits be captured in a decision-making tool?

**2. Energy (fossil fuel and solar derived)**

- How can we reduce fossil fuel use and reduce GHG emissions while increasing food production and maintaining/improving the natural ecosystem?

**3. Water (quantity and quality, periodicity)**

- What approaches (operational, agronomic, fertility management, winter rainfall storage) can be developed to increase water use efficiency?

**4. Integration: Ecosystem Services, Resilience and Resistance, Adaptation to Climate Change**

**Ecosystem Service**

- How do the systems compare with respect to their ecosystem services and disservices (soil quality, nitrate leaching, effects on beneficial insects and pests, greenhouse gas emissions)? What processes can be harnessed/manipulated to maximize/conserve ecosystem services (e.g. pollution biodegradation, water efficiency)?

**Resistance and Resilience:**

- How can the resistance and resilience of ag systems be improved with respect to gradual change, increased variability, extreme events (i.e. drought)?

**Adaptation:**

- How can farmers and researchers best work together to develop rapid, adaptive management strategies and information relevant to an unpredictable climate? (Identification and implementation of participatory research methodologies)

## 2) Synthesized questions

### Carbon:

How can we use less energy, less water and sequester more carbon for each system? Which system uses the least energy, water and sequesters the most carbon (per food unit produced)?

What are the effects of increasing carbon inputs on disease, pests, yields, water? (*but duplicated below)

Does increasing carbon inputs change your water, energy, soil properties and yields?

Does managing crops organically change your water, energy, and soil proportional to yield (in comparison to conventional)?

What is the effect of adding recycled organic matter (compost, biochar, biodigester effluent) on yields, soil, economics, water use?

### Water:

Can we increase water use efficiency, capture more winter rainfall and increase nitrogen use efficiency (for example, with cover crops)?

Is there a way to decrease water use in high soil organic matter systems (either through drip or sprinklers or overhead?)

*How does adoption of high water use efficiency practices affect production?

Would an annual adaptive irrigation winter grain rotation be sustainable in a future Central Valley scenario with reduced water reserves? What changes occur in the annual winter grain systems with climate change?

**Nitrogen:**

How much nitrogen does a winter legume cover crop fix at RR?

Do cover crops increase yields in processing tomatoes?

Can you reduce fertilizer use in rotation with a legume cash crop?
Can the integrated nutrient management (INM) system get the same yields as conventional by replacing some amount of fertilizer with cover crops and also composted manure to fertilize for phosphorus?
Can nitrogen fertilizer be replaced by including legume crops (both cover crops and cash crops) in rotations? [*but duplicated below]

**External inputs:**

What is the best mix of intensification and extensification to deliver increased production, GHG reduction and increase ecosystem services?

Can you reduce off-farm inputs and fossil fuel use by incorporating cover crops and compost?

Can you reduce external inputs and increase yields by managing the soil for microbial diversity & higher soil organic matter?

How can food production systems be designed to reduce dependence on externally derived N, P and K resources? (Pretty, 2010) (*but duplicated below)

Nutritional question......rewrite here (I deleted it)

**Synthesis:**

What is the effect of an irrigated summer perennial crop on total productivity, soil, energy and water use as compared to an irrigated summer annual crop (ie. tomatoes, corn, sunflowers or beans)?

What is the effect of an reduced tillage system on on total productivity, soil, energy and water use as compared to a standard tillage system (either tomato - corn [ sunflower?] or tomato-wheat or annual wheat)?

What is the effect of a rainfed winter perennial crop (native grass) on total productivity, soil, energy and water use as compared to irrigated summer perernnial crop (alfalfa) or rainfed winter annual crop (wheat or barley)?

*What are the effects of management and crop choice (reduced tillage, perennial crops, organic amendments, cover crops) on total productivity, soil, energy and water use?
*Can nutritional quality of food be improved through management and what are mechanisms of differences between systems?
**Ecosystem services:**

*How can using ecosystem services help reduce your external inputs and mitigate negative externalities?

How can you quantify ecosystem services (pollination, carbon sequestration) from the native grass system?

What is relationship between productivity and biodiversity (and other ecosystem services) and how does this vary between systems and as function of scale?

Can native (soil) organisms be better utilized to reduce external inputs, maximize productivity, reduce environmental impacts? (Pretty, 2010)

**Resistance and resilience:**

*How can the resistance and resilience of agricultural systems be improved with respect to gradual change, increased variability, extreme events (i.e. drought)?

How long can wheat be grown continuously without added inputs before there is a yield decline?