Russell Ranch Sustainable Agriculture Facility

Agricultural Sustainability Institute

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Research at the Agricultural Sustainability Institute

The Russell Ranch Sustainable Agriculture Facility is a unique 300-acre facility near the UC Davis campus dedicated to investigating irrigated and dry-land agriculture in a Mediterranean climate. Russell Ranch is also a unit of the Agricultural Sustainability Institute (ASI). Among Russell Ranch's ongoing experiments is a 100-year study referred to as Long Term Research in Agricultural Sustainability (LTRAS), which is comprised of 72 one-acre plots. LTRAS is an exploration of the long-term impacts of crop rotation, farming systems (conventional, organic and mixed) and inputs of water, nitrogen, carbon and other elements on agricultural sustainability. Sustainability is indicated by long-term trends in yield, profitability, resource-use efficiency (such as water or energy) and environmental impacts. Key properties monitored include soil physical and chemical properties, such as soil organic carbon and nitrogen, pH, and salinity; biological indicators, such as crop yield, weed occurrence or the composition of the soil microbial community; and economic parameters.

The size, scope and intensity of the research at Russell Ranch make the 300-acre experiment like no other in the world. While acting as an "early warning system" to detect gradual long-term trends that might jeopardize sustainability, the project also provides important short-term contributions to agricultural science at the ASI. An example of this type of research is the recent study on how reduced tillage practices might be incorporated into conventional, organic, and low-input approaches within the long-term experiment.

Currently the cropping systems of the long-term project are being modified to be more flexible and responsive to current trends, while maintaining the integrity of the long-term experiment. New research questions are focused around the core question: "Can we increase sustainability as we increase food production?" Additional projects being discussed include work on other types of farming systems in California including: dairy forage systems, market gardening, woody perennials like orchards and vineyards, native grass and restoration ecology, and "closing the loop" soil amendments. The Russell Ranch site is primarily a research facility, but also supports UC Davis' extension and teaching missions by hosting field days, class field trips, undergraduate interns and graduate student research.

More information is available at our web site: http://russellranch.ucdavis.edu.

Cropping systems and experimental design

The cropping systems at LTRAS are designed to fall along a gradient of increasing irrigation and fertilization intensity. The ten systems are all two-year rotations and include wheat/tomato, wheat/fallow and wheat/legume rotations. The original corn/tomato systems has had both sudangrass and wheat replace corn in different years. There are six one-acre plots per system, three for each of the two phases. From 2003-2007, all one-acre plots of the tomato/corn systems were split in half and reduced tillage treatments were compared to the previous (standard) tillage treatments within each plot. Each plot also contains 40 micro-plots, 15 feet on a side, which allow scientists to test hypotheses on a short-term basis. These micro-plots are outside of the yield measuring area, which is used for long-term data collection.

H_2O N,C

System	Symbol	Irrigation	N Source	Pesticides
Corn/tomato*	OMT	Irrigated	Manure + WLCC	Organic
Corn/tomato*	LMT	Irrigated	Fertilizer + WLCC	As needed
Corn/tomato* Wheat/tomato	CMT CWT	Irrigated	Fertilizer	As needed
Wheat/fallow	IWF	Irrigated	Fertilizer	As needed
Wheat/legume†	IWL	Irrigated	WLCC	As needed
Wheat/fallow	IWC	Irrigated	None	As needed
Wheat/fallow	RWF	Dry land	Fertilizer	As needed
Wheat/legume	RWL	Dry land	WLCC	As needed
Wheat/fallow	RWC	Dry land	None	As needed

Table 1: The 10 cropping systems, with their typical symbol, irrigation type and nitrogen source. *In 2009, sudangrass substituted for corn in corn/tomato rotations and in 2010-2011, wheat substituted for corn. † The irrigated wheat/legume was terminated in 2007.

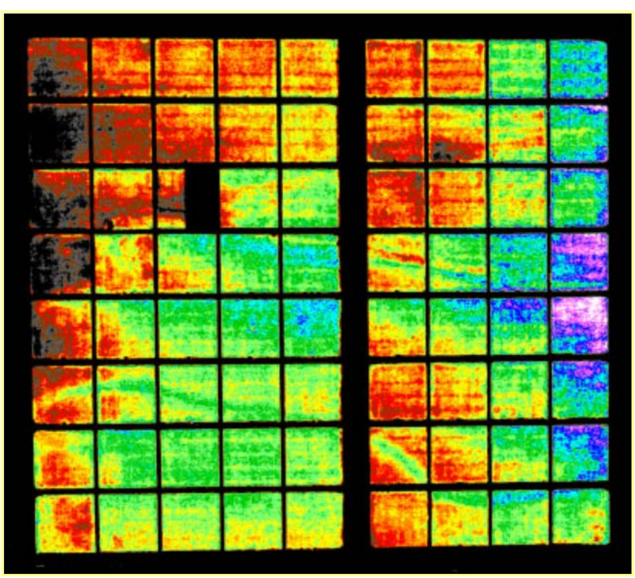


Figure 1: Sudangrass was grown on all plots in 1993 before initiating the cropping system treatments. By using aerial color infrared photography and calculating the Normalized Difference Vegetation Index (NDVI), defined as the difference between the IR and red values for each pixel, initial variability in fertility among the plots was assessed. A white color indicates more complete plant cover and blacker, redder colors indicates less complete plant cover. (Denison, 1996).

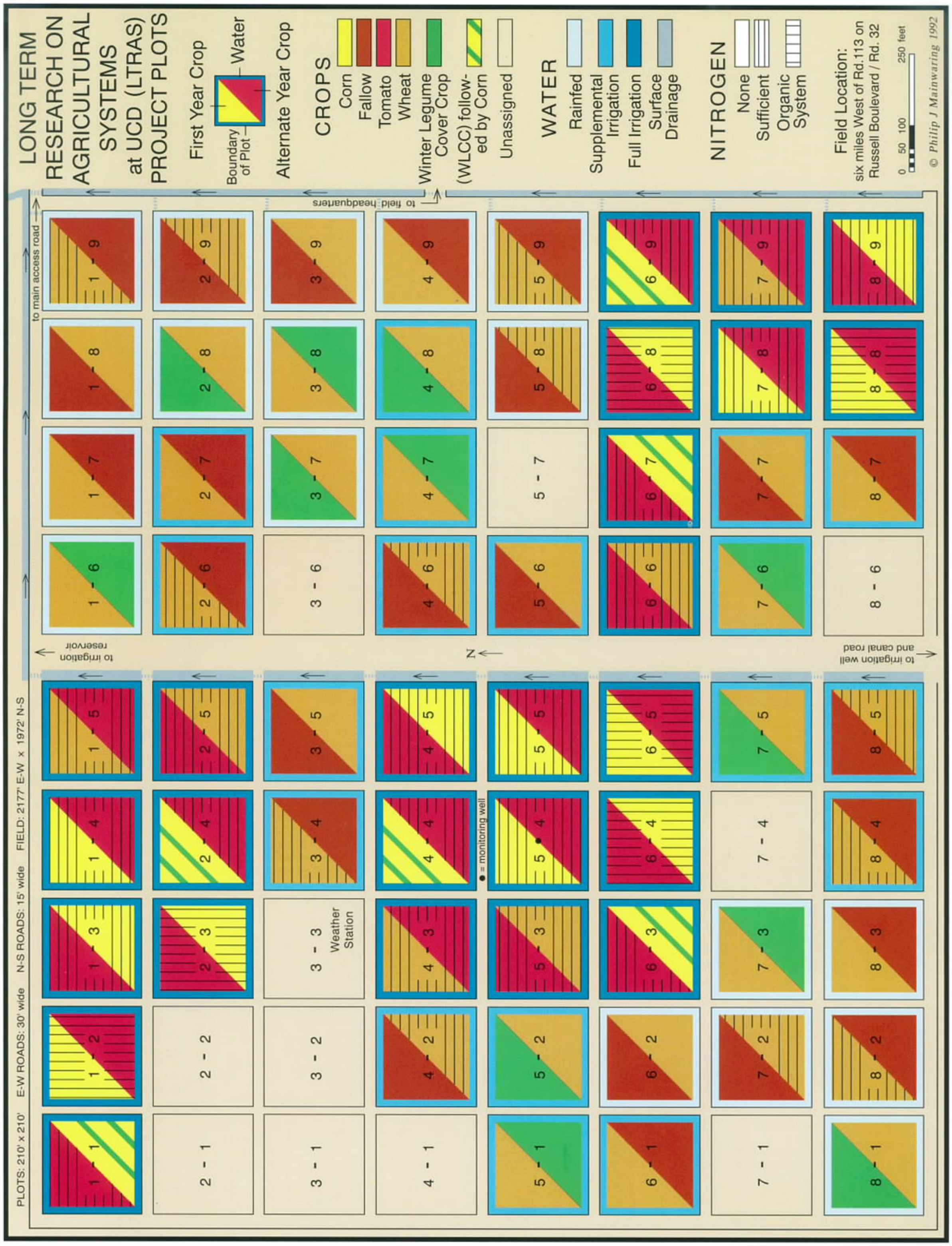


Figure 2: Original plot layout and treatment design for the long-term experiment on agricultural sustainability at the Russell Ranch.

Results from 1994-2011

Yields

Tomato yields in conventional, low-input and organic systems were not significantly different during the first 17 years. Conventional tomato yields were also more variable than organic tomato yields. Part of the reason for low conventional tomato yields in 1999 and 2003 is low soil infiltration.

Corn yields, however, were significantly lower in low-input and organic systems. Corn in the conventional corn-tomato (CMT) system is planted earlier than in the organic corn-tomato (OMT) and legume-corn-tomato (LMT) systems, where winter legume cover crops must be incorporated and break down before planting is possible. Up until 2002, shorter season corn varieties were grown in these systems as well. In particular, grain yields have declined, but not biomass yields, which suggests the hypothesis is insufficient N available to corn crops during the grain-filling stage in these systems.

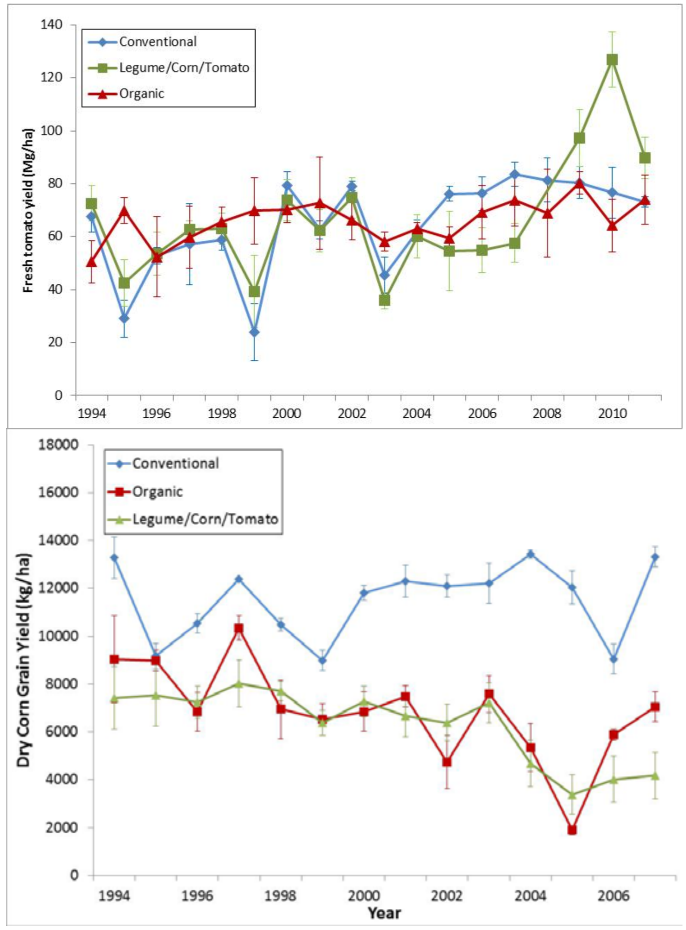


Figure 3: Corn and tomato yields from 1994-2011. Error bars represent standard deviations from three plots.

Figure 4: Measuring soil bulk density. Sam Prentice and a Japanese visitor look on as Joern Sieges takes a sample. Photo by Z. Kabir.

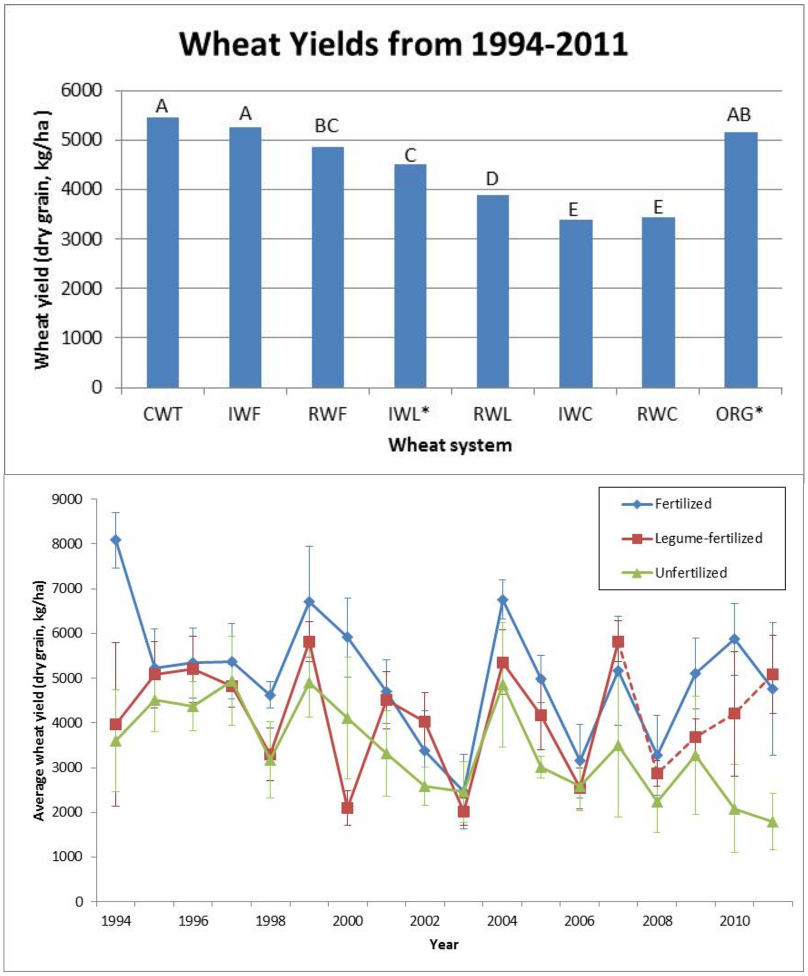


Figure 5: Wheat yields from 1994-2011. *The IWL system ended in 2007; the dashed red line in the second graph represents RWL. Organic wheat (ORG) yields are for 1997, 2008, 2010-11.

A significant interaction exists between fertility and irrigation factors; the wheat yield in the irrigated wheat/legume (IWL) system is significantly higher than the yield in the rainfed wheat/legume (RWL) system. Within the other two fertility treatments (fertilized and unfertilized), there was no significant difference between irrigation treatments. For the rainfed systems, the wheat yields are higher in the fertilized systems the than unfertilized and legume systems. For the irrigated systems, the fertilized and legume systems have higher yields than the unfertilized system.

Year-to-year variation is quite high in the wheat system. Fertilized, legume-fertilized and unfertilized systems had similar yearly yield variations, although fertilized yields were higher. From 2001 to 2003, wheat yields declined, suggesting that none of the systems were sustainable. Switching in 2004 to a single resistant variety in both rain-fed and irrigated plots resulted in a return to average or higher wheat yields for all systems. In 2006, California suffered a statewide wheat rust epidemic, which affected yields at Russell Ranch.

Conservation tillage

Conservation tillage is usually defined as a management practice that maintains at least 30 percent of the soil surface with plant residue cover and reduces soil disturbance. On a national scale, conservation tillage is

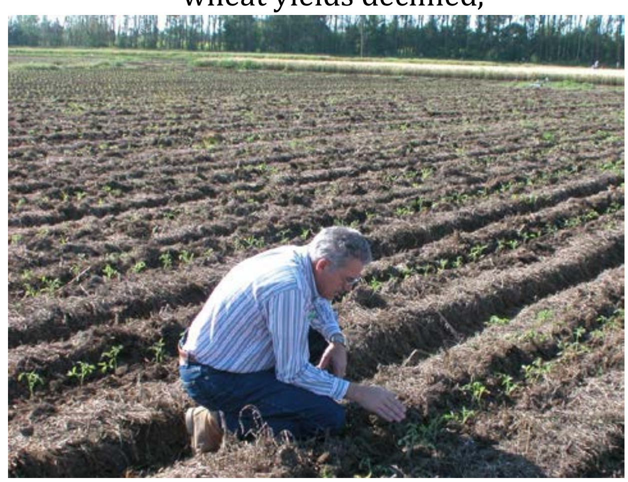


Figure 6: Steve Temple inspecting tomato transplants in a conservation tillage system. Photo by Jeff Mitchell.

used on 41 percent of all land and conservation and reduced tillage combined farm 63 percent of all cropland (Conservation Information Technology Center, 2007). However, in California's Central Valley, conservation tillage practices are used on less than two percent of annual crop acreage (Mitchell et al. 2007).

Researchers at Russell Ranch found that conservation tillage can be used successfully with sub-surface drip irrigation to control weed densities (Sutton et al. 2006). Sub-surface drip practically eliminates the need for herbicides; since no surface water is applied, few weeds germinate. In 2003, treatments with furrow irrigation, standard tillage and herbicides did not have significantly different yields than treatments with drip irrigation and conservation tillage, with or without herbicides. In 2004, drip irrigation resulted in significantly higher yields than furrow irrigation; using herbicides resulted in significantly higher yields than not using herbicides. Furrow irrigated treatments without herbicides resulted in lower tomato yields in both years. These findings suggest that conservation tillage, when paired with sub-surface drip, could reduce the need for herbicides in reduced tillage systems.

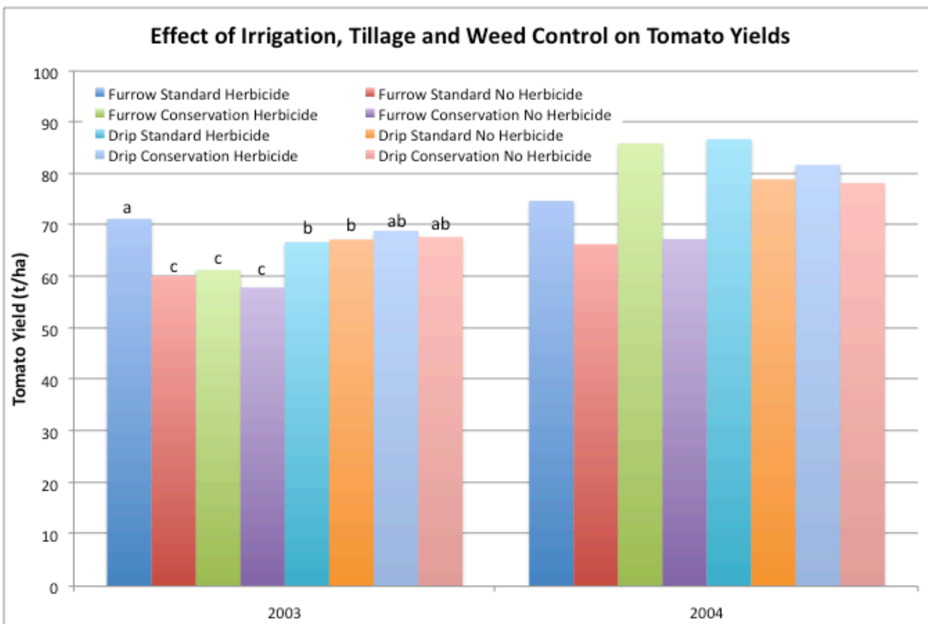


Figure 7: The effect of irrigation (furrow vs. drip), tillage (standard vs. conservation) and weed control (herbicides vs. none) on tomato yield (Sutton, 2006).

Additional information on conservation tillage in California:

The University of California and National Resources Conservation Service (NRCS) Tillage Workgroup has tracked a steady increase in interest in conservation tillage (CT) alternatives over the past eight years. The Workgroup grew from a handful of founding members, including Russell Ranch researchers, to well over 600 affiliates today. In recent years, successful CT innovations have been documented in dairy forage, tomato with cover crop and cotton systems in the Central Valley. The most widespread adoption activity is currently underway in San Joaquin Valley dairies. Up-to-date information on CT in California is available at the CT Workgroup's Web site: http://groups.ucanr.org/ucct.

Water infiltration and runoff

Figure 8: A fallow and cover cropped system during a rain storm at the SAFS project.

In 2003, research was initiated at Russell Ranch to evaluate the economic and environmental effects of different farming practices. A major goal of these studies is to assess the potential of winter cover cropping and conservation tillage to reduce runoff and the associated losses of sediment, nutrients and pesticides in furrow-irrigated systems. Researchers have found that cover crops substantially reduce winter runoff by increasing infiltration. Increased infiltration is also observed the season after cover crop incorporation. By decreasing run-off quantity, cover crops reduce the export of constituents, such as dissolved organic carbon, which is involved in the formation of harmful disinfection by-products in drinking water. Furrow irrigation may not be optimal for organic agriculture because enhanced infiltration leads to high water use and percolation. Research to develop recommendations for best management practices in different seasons, field configurations, and crop types is continuing at Russell Ranch and surrounding farm sites.

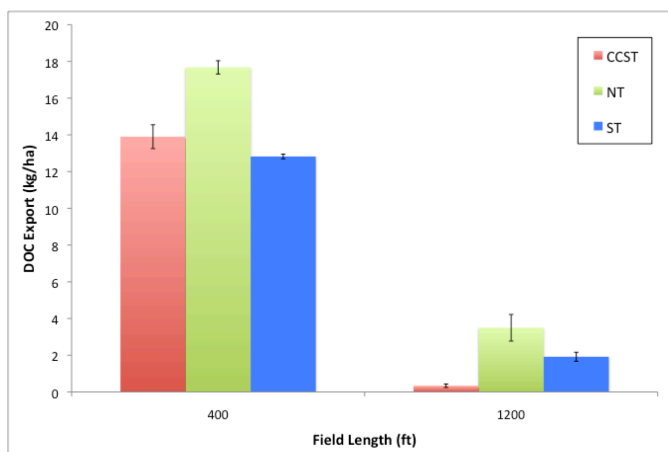


Figure 9: Effect of cover crops and no-tillage practice on dissolved organic carbon export during a 2-day pre-irrigation in 400 and 1200 ft long fields under standard tillage (ST), standard tillage after cover crop incorporation (CC), and no-tillage (NT) (Burger et al. 2008).

Soil organic carbon

The 10 cropping systems received different amounts of carbon input in the form of crop residues, manures and cover crops (Figure 10). The organic corn/tomato rotation (OMT) received the most carbon inputs and the unfertilized, rainfed wheat/fallow (RWC) received the least. Changes in the amount of carbon accumulated or lost on average over the ten-year period from 1994 to 2003 are represented in Figure 12 for all the cropping systems.

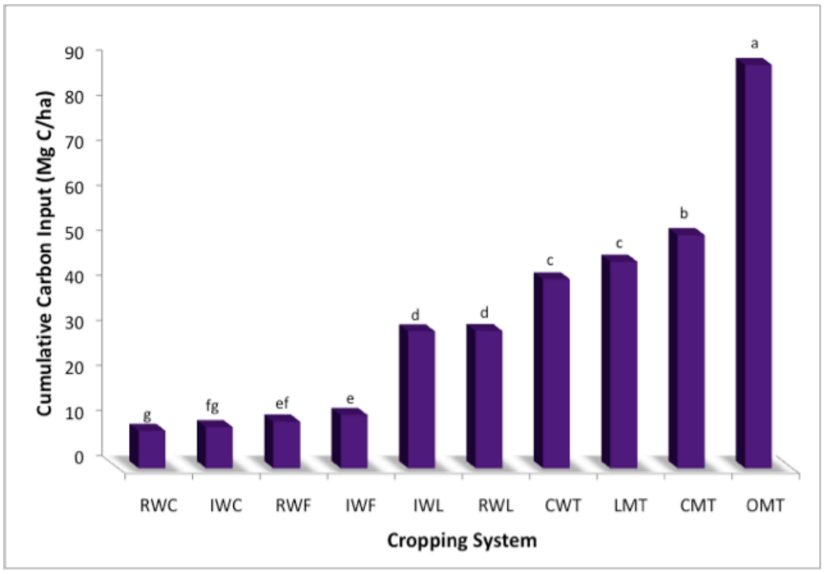


Figure 10: Carbon inputs to the 10 cropping systems (Kong et al., 2005).

Figure 11: Israel Herrera mowing and chopping cover crop for incorporation. Photo taken by Dennis Bryant.

The OMT system had the largest increase in soil organic carbon (SOC). The RWC system showed a decline in SOC while SOC in the other wheat systems was not significantly different. This information is important for assessing the potential for carbon sequestration in California soils.

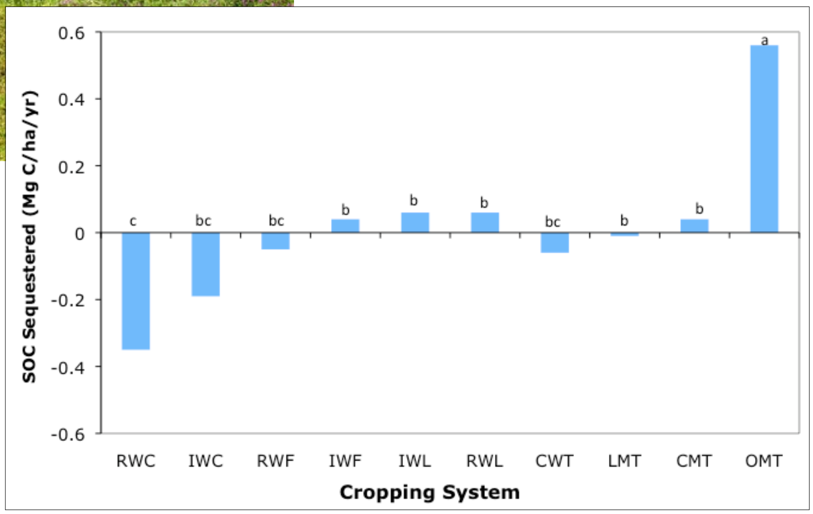


Figure 12: Rate of soil organic sequestration (Kong et al, 2005).

Greenhouse gas emissions

Greenhouse gas emissions from the agricultural sector account for six percent of the total U.S. greenhouse emissions. However, agricultural activities account for 72% of the total U.S. nitrous oxide (N_20) emissions (EPA, 2006). Researchers at Russell Ranch are investigating the effect of different practices and crop systems on greenhouse gas emissions. One important finding is that reducing tillage substantially decreases greenhouse gas emissions through reduced fuel use.

Research at Russell Ranch has shown that winter cover crops increase N_2O emission under furrow irrigation (Fig. 14). Sub-surface drip eliminates the increase in N_2O emission seen with cover crops using furrow irrigation.

Figure 13: Cynthia Kallenbach and Leslie Peacock monitoring greenhouse gases at Russell Ranch. Photo by Dennis Bryant.

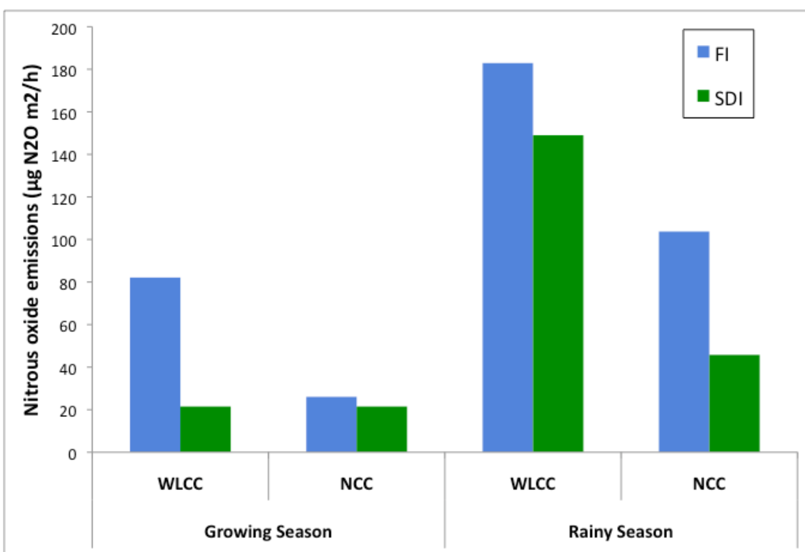


Figure 14: Nitrous oxide emissions by growing season (May to Sept) and the rainy season (Oct to April). WLCC= winter legume cover crop (vetch and pea mix), NCC= no cover crop, FI= furrow irrigation, SDI= subsurface drip irrigation (Kallenbach, 2008).

Research at LTRAS suggests that the conversion to sub-surface drip irrigation from furrow irrigation has the potential to reduce greenhouse gas emissions. This is significant because many studies suggest that planting cover crops can lead to an increase in both CO_2 and N_2O emissions but when managed with sub-surface drip irrigation this effect may be reduced (Kallenbach, 2008).

Soil biology

Soil biology is a major area of investigation at Russell Ranch; topics include linking ecosystem functions to microbial diversity and community composition, and investigations of how management impacts soil food webs.

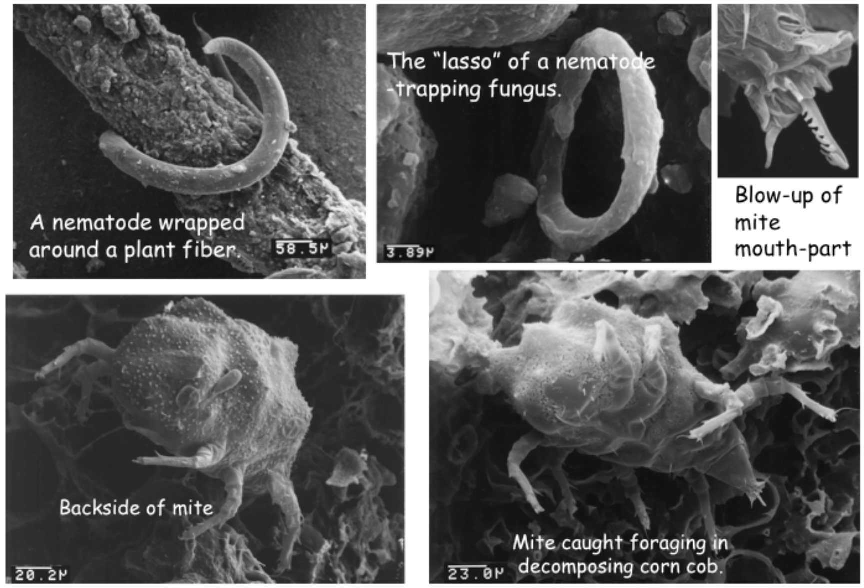


Figure 15: Scanning electron micrographs of nematodes, fungi, and mites. Photo by Mara Johnson.

Researchers have found that nematodes, fungal and bacterial populations are influenced by farming systems and tillage (Minoshima, 2007). Microbial biomass was higher under no-till, continuous cropping compared to standard tillage, fallow systems. However, nematode populations were lowest in no-till, fallow systems, compared to the continuous cropping systems. The accumulation of plant residue on the no-till, continuous cropping surface led to higher soil carbon, when compared to the standard tillage, fallow system. The lack of increase in nematode populations makes researchers suspect that higher trophic levels of nematode communities have disappeared, which reduce the efficiency of nutrient cycling.

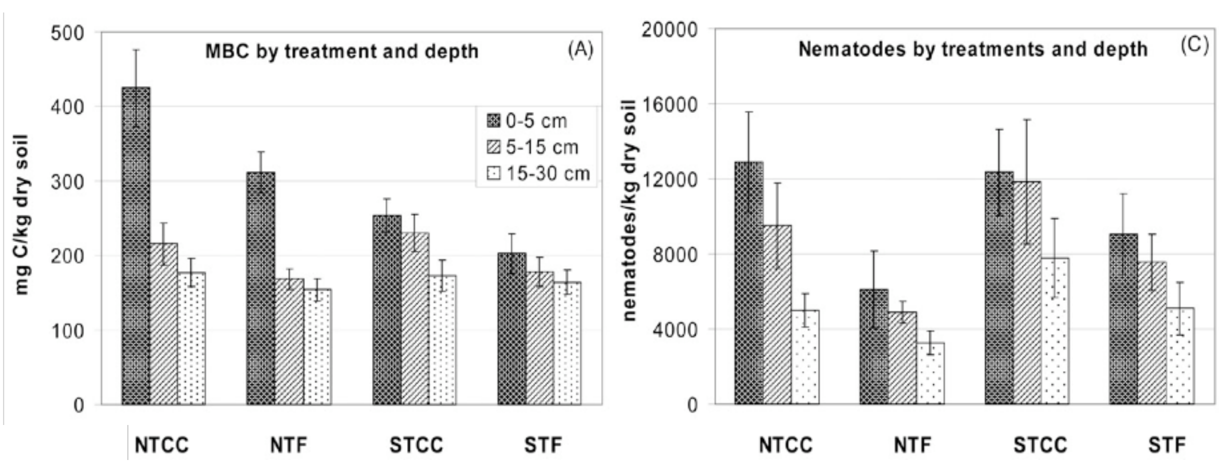
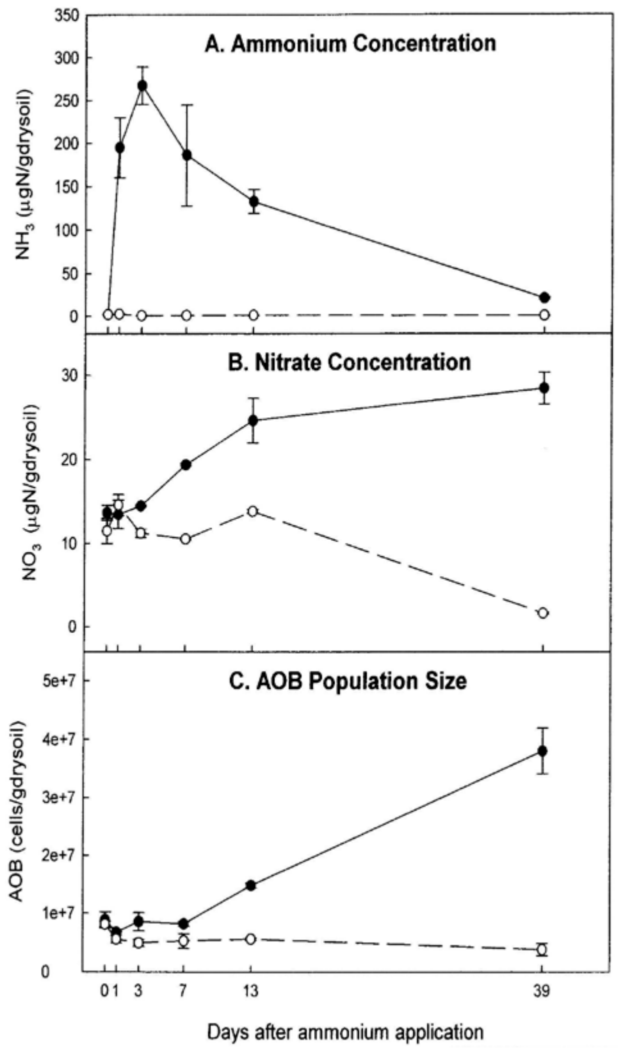


Figure 16: Microbial biomass carbon (MBC) for three different depths in soil and for No-Till, Continuous Cropping (NTCC), No-Till, Fallow (NTF), Standard Till, Continuous Cropping (STCC) and Standard Till, Fallow (STF). Nematode populations for the four systems are shown as well (Minoshima, 2007).



Organic management increases microbial biomass and leads to shifts in microbial community composition when compared to properties under conventional management. Using data from Russell Ranch, we developed a novel quantitative PCR method to determine numbers of bacteria in soil responsible for converting ammonium to nitrite (nitrifiers) (Okano et al. 2004). We found that the population density of nitrifiers was related to the amount of ammonium added to soil and that conversion of ammonium fertilizer to nitrate occurred in consort with the increase of nitrifiers.

Figure 17: Ammonium, nitrate concentrations and ammonium oxiding bacteria (AOB) populations were measured after ammonium was applied to Russell Ranch field soils. The solid line represents plots with ammonium treatment and the dashed line represents plots with no ammonium (Okano et al., 2004).

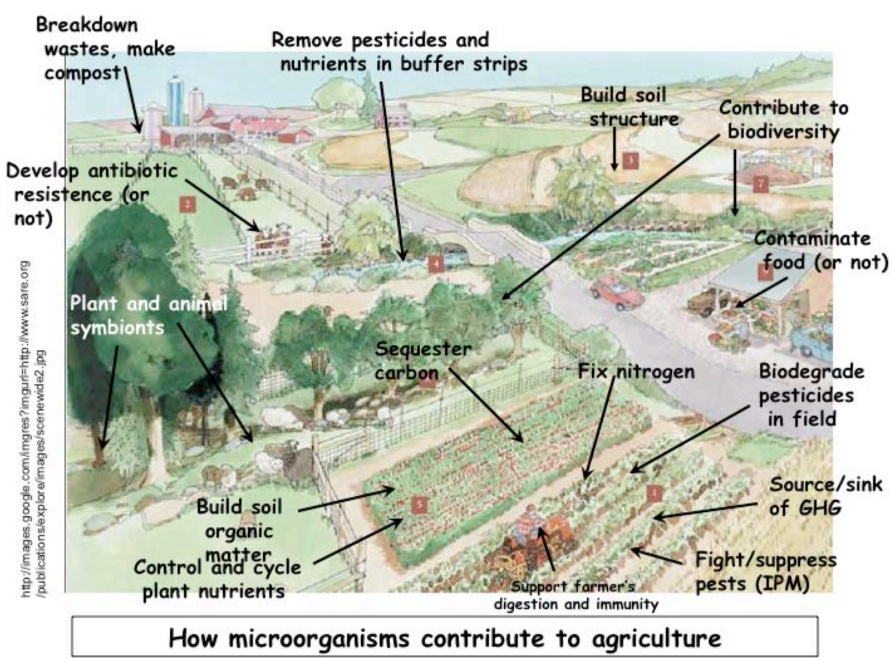


Figure 18: The functions of microorganisms in a soil web. Background image from USDA-SARE.

Human nutrition

Flavonoids, secondary plant metabolites, may impact human health by reducing cardiovascular and other chronic diseases. The three main flavonoids in tomatoes (quercetin, kaempferol, and naringenin) were measured in the organic and conventional tomato/maize systems. Flavonoid content is greater in organic than conventional tomatoes and differences have increased with time (Mitchell et al., 2007). Increases in flavonoid content appear to be correlated with lower amounts of organic nitrogen applied in the last six years to plots at LTRAS compared to the first six years. These results suggest that over-fertilization could reduce flavonoid content, and health benefits of tomatoes.

Figure 19: Patricia Lazicki and Diana Staley assess tomatoes for insect and disease damage. Photo by Z. Kabir.

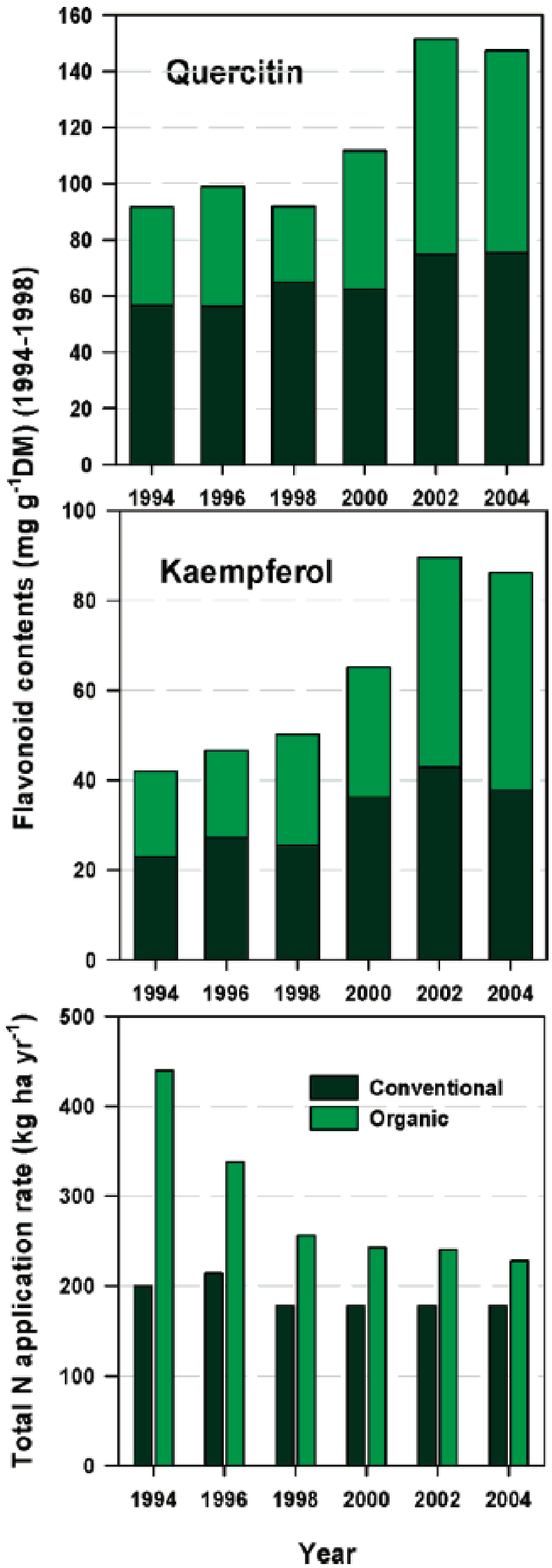


Figure 20: The flavonoid content of conventional and organic tomatoes. The flavonoid content of the organic management treatment is shown as the sum of the conventional and organic management treatments (Mitchell et al., 2007).

Equipment development

Collaborations between Russell Ranch research farming staff and agricultural equipment manufacturers have resulted in creative modifications to existing equipment, focused on reducing energy inputs into California's crop production systems. California's challenging climate variations, soil conditions and water limitations have dramatically increased the awareness and need for greater tillage options. Regional growers have embraced tillage strategies developed at the Russell Ranch by adapting the new operational sequences, modifying existing equipment or purchasing new equipment to accomplish their energy reduction goals. Equipment demonstrations at the Russell Ranch provided growers with various options to deal with crop residue and cover crops in conventional and organic systems, on a diversity of farm scales.

Figure 21: A modified Orthman 1tRIPr performs multiple tasks in a single pass through the field, including; bed center strip-tillage, fertilizer and herbicide application and sweeping crop residue from the furrows as a pre-tomato transplant operation. Photo by Kathy Bryant.

Outreach

Russell Ranch-SAFS has hosted annual field days from 1994-2011 (in 2007 the field day was at a local farm). SAFS field days feature grower panels, tractor demonstrations and presentations of research findings. Also, one to two additional workshops have been hosted each year addressing topics such as conservation tillage and control of runoff. Russell Ranch produced a newsletter three times a year that reaches approximately 1250 recipients, which is no longer currently available. The Russell Ranch and SAFS websites highlight research results, newsletters, press reports and an audio-tutorial presentation on improving agricultural runoff management. Russell Ranch provides a living laboratory for several agronomy and soil science classes on campus and hosts over 400 national and international visitors each year.

Figure 22: Visitors at an equipment demonstration during a Russell Ranch field day view innovative approaches to tillage challenges. Photo by Lyra Halprin.

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