TITLE

The Century Experiment: The first twenty years of UC Davis' Mediterranean agroecological experiment

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METADATA

CLASS I. DATA SET DESCRIPTORS

A. Data set identity

Long-term agroecological data for 11 different cropping systems have been collected as part of the Century Experiment, a core experiment of the Russell Ranch Sustainable Agriculture Facility, part of the Agricultural Sustainability Institute at UC Davis, in north-central California.

B. Data set identification code

DataS1.zip contains twenty-nine .csv data files compressed in a self-extracting zip folder named "RR_2014_datasets.zip." Also included are image files in a .tif format compressed in a self-extracting zip folder named "RR_2014_NDVI_images."

C. Data set description

1. Originators

Includes all authors.

2. Abstract

The Century Experiment at the Russell Ranch Sustainable Agriculture Facility at the University of California, Davis provides long-term agroecological data from row crop systems in California's Central Valley starting in 1993. The Century Experiment was initially designed to study the effects of a gradient of water and nitrogen availability on soil properties and crop performance in ten different cropping systems to measure tradeoffs and synergies between agricultural productivity and sustainability. Currently systems include 11 different cropping systems--consisting of four different crops and a cover crop mixture--and one native grass system. This paper describes the long-term core data from the Century Experiment from 1993–2014, including crop yields and biomass, crop elemental contents, aerial-photo-based Normalized Difference Vegetation Index data, soil properties, weather, chemical constituents in irrigation water, winter weed populations, and operational data including fertilizer and pesticide application amounts and dates, planting dates, planting quantity and crop variety, and harvest dates. This data set represents the only known long-term set of data characterizing food production and sustainability in irrigated and rainfed Mediterranean annual cropping systems.

D. Key Words

agroecology, California, carbon, crop rotations, crop yield, long-term agricultural systems comparison, nitrogen, resilience, soil, sustainability, irrigation, xeric.

CLASS II. RESEARCH ORIGIN DESCRIPTORS

A. Overall project description

1. Identity

The Century Experiment: UC Davis's long-term irrigated agroecological experiment.

2. Originator

College of Agricultural and Environmental Sciences, UC Davis, 1993, including all authors.

3. Period of Study

1993–present

4. Objectives

Monitoring long-term agricultural changes (crop and soil properties) in 11 cropping systems.

5. Abstract

The Russell Ranch Sustainable Agriculture Facility (RRSAF) is a 120-ha facility near the University of California, Davis (UC Davis) campus dedicated to investigating irrigated and dryland agriculture in a Mediterranean climate and is a core unit of the Agricultural Sustainability Institute at UC Davis. The RRSAF houses a study designed for a 100-year duration, referred to as the “Century Experiment”, and formerly called the Long Term Research in Agricultural Systems (LTRAS). Initiated in 1993, the Century Experiment is comprised of 72 0.4-ha plots including 10 different replicated cropping systems. Cropping systems were designed to compare resource-use efficiency, productivity, environmental effects, and economic return from cropping systems that differ in crop rotation and degree of reliance on rainfall and fertilizer nitrogen (McGuire et al. 1998, Denison et al. 2004).

The RRSAF conducted a stakeholder review in 2012 to evaluate the cropping systems and research questions represented in the Century Experiment, which resulted in the New Science Plan (Scow et al. 2013). The overarching research question for the Century Experiment is, “Can we increase sustainability as we increase food production?” The Century Experiment focuses on three major resources that limit the sustainability of agricultural production: energy, water, and carbon. Additional research questions include:

- How can food production system design reduce dependence on externally derived resources while maintaining economic sustainability?

- What are the trade-offs among provisioning services – e.g., production of agricultural goods such as food, feed, fiber or bioenergy - and regulating services such as nutrient recycling and C storage?

- Is there a consistent relationship between the biodiversity of agricultural systems and their resistance and resilience to disturbance (e.g., climate change, drought, tillage)?

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

- What approaches can best increase water use efficiency in irrigated and rainfed agricultural systems? What is the effect of different irrigation methods on local and larger scale hydrological fluxes?

6. Sources of funding

The College of Agricultural and Environmental Sciences, UC Davis and the Agricultural Sustainability Institute, UC Davis provide annual sources of funds. Other funds are obtained from competitive grants, endowments, and gifts to Russell Ranch.

B. Specific subproject description

1. Site description

The RRSAF is located in the city of Davis, Yolo County, in the heart of California's Central Valley. The facility includes the Century Experiment (begun in 1993), scale-up fields, and associated experiments surrounding the Century Experiment. The Century Experiment is laid out in a grid of 72 0.4-ha plots, with the plots labeled as column-row (e.g., plot 1-1 to 1-9…8-1 to 8-9), where the columns run north to south and the rows west to east.

a. Site type

The RRSAF is located in an area that was originally oak savannah and perennial grassland, which have been replaced, for the most part, by annual row crops [*Solanum lycopersicum* (tomato), *Zea mays* (corn), *Helianthus annuus* (sunflower)], *Citrullus lanatus* (watermelon), and perennial crops [*Prunus dulcis* (almonds), *Juglans regia* (walnuts), *Prunus domestica* (prunes), *Medicago sativa* (alfalfa)]. Two soil types are present at RRSAF: Yolo silt loam (fine-silty, mixed nonacid, thermic Typic Xerorthents) and Rincon silty clay loam (fine, montmorillonitic, thermic Mollic Haploxeralfs) (NRCS 2013).

b. Geography

Each plot within the Century Experiment has a concrete monument installed 1.2 m to the south and 1.2 m to the west of the southwest corner of the first bed, buried to a depth of 0.6 m. The monument of plot 1-1 is at 38.5447'N, 121.8783'W and the monument of plot 8-9 is at 38.5403'N, 121.8714'W [using EPSG:4326 (WGS84) spatial reference system].

c. Habitat

The Century Experiment is bordered by the Putah Creek Riparian Reserve to the south. Three fields managed by RRSAF lie to the north (conventional scale-up fields: front field west is 3.4-ha and front field east is 2.9-ha) and east (organic scale-up field is 2-ha) of the Century Experiment, and are used for larger scale experiments (Fig. 1). From 1995–1997 both conventional scale-up fields were planted in oats, and the east organic field was planted in corn in 1998 and tomatoes in 1999. From 1999–2011, both conventional scale-up fields were fallow. The conventional scale-up fields have been in a conventional corn-tomato rotation since 2010 for the front field east and since 2011 for the front field west. The organic scale-up field was planted in tomatoes from 2000–2001, and was fallow from 1994–1999 and 2001–2009, and an organic tomato-WCC-corn-WCC rotation since 2010 (WCC = winter cover crop). On the south border of the Century Experiment, an *Asclepias fascicularis* (milkweed) experiment was initiated in fall of 2013. Beyond the milkweed experiment, the Putah Creek Riparian Reserve is an oak savannah grassland. On the west border, a native wildflower strip was initiated in Fall 2010.

d. Geology, landform

The RRSAF is located in an alluvial plain in the Putah Creek watershed, which contains soil deposited from what is now the Berryessa Reservoir. The geology of the Berryessa reservoir includes the Great Valley Complex (from the Cretaceous-Jurassic period), Sonoma Volcanics (Volcanic breccia and tuff breccia from the Pliocene-Miocene era) and Quaternary surface deposits (Holocene and late Pleistocene) (Shlemon et al. 2000, Wagner et al. 2011).

e. Watersheds, hydrology

Though the RRSAF is part of the Putah Creek watershed, any surface water allocations come from Clear Lake and the Cache Creek Diversion Dam. The site is at an elevation of 28.3 m and was land-levelled in 1991.

f. Site history

The RRSAF tract was previously owned by William O. Russell (1867–1943) who farmed wheat, barley, alfalfa, walnuts, and almonds, and raised cattle. In 1990, the tract was sold to UC Davis by his children, William Russell and Charlotte Russell-Ham. UC Davis faculty and staff planned a long-term experiment in 1991 and laser-leveled the site in preparation. In July 1992 and May 1993, irrigated unfertilized *S. vulgare* (sudan grass) hay was planted throughout the Century Experiment area to determine variation in the baseline productivity of the soils (see Class II, Section B, Subsection 2, Part C, under the header "Initial productivity asssessment"). Three blocks were designated on the site based on intrinsic productivity and treatments were randomly assigned within these blocks (Block One: Plots 1-1 through 2-5, 2-8 through 3-5, 4-1 through 4-2, 5-1 through 5-2, and 6-1; Block Two: Plots 2-6 through 2-7, 3-6, 4-3 through 4-8, 5-3 through 5-6, 6-2 through 6-5, 7-1 through 7-4, and 8-1 through 8-3; Block Three: Plots 3-7 through 3-9, 4-9, 5-7 through 5-9, 6-6 through 6-9, 7-5 through 7-9, and 8-4 through 8-9; see Fig. 2). Three plots with significantly lower yields (2-1, 3-1, and 4-1; Fig. 2), likely due to topsoil removal during leveling, were excluded from the original experimental design, and are used for other experimental manipulations (Denison et al. 2004).

g. Climate

The RRSAF has a Mediterranean climate with monthly average minimum temperatures varying from 2.9°C during the coldest month (December) to monthly average maximum temperatures of 33.7°C during the warmest month (July). Mean annual rainfall is 440 mm (UC Davis weather station, described below in Class II, Section B, Subsection 2, Part C, under the header "Weather data").

2. Experimental or sampling design

a. Design characteristics

The Century Experiment was originally designed with ten cropping systems, including a comparison of two "sub-experiments": i) conventional and organic tomato-corn rotations (CMT and OMT, respectively) and a legume-corn-tomato (LMT) rotation with mineral fertilizer and cover crops (Fig. 2, Table 1), and ii) a wheat factorial experiment with fertilizer application and irrigation as the two main factors, including both wheat-fallow and wheat-legume rotations where the "legume" is a WCC. A conventional wheat-tomato (CWT) system provides a link between the two sub-experiments.

The Century Experiment cropping systems were established with three randomized, replicate 0.4-ha plots for each phase (i.e., crop) of each two-year rotation, for a total of six replicates of each cropping system. Thus, each crop has a simultaneous "entry point" or "phase" (defined as the crop in place during the first year a crop rotation starts). Having each phase of the rotation present each year means that weather or disease variations are seen by each crop every year and makes detection of differences in treatment comparisons possible much sooner, as well as earlier detection of time-dependent trends, a principal reason for long-term research (Kaffka 2006).

The alfalfa-corn-tomato (AMT) system is the only system that does not have a two-year rotation: it is a six-year rotation for which only two phases of the six potential phases are represented in a given year. Alfalfa is grown for three years, followed by a three-year tomato-corn-tomato rotation, or vice-versa (tomato-corn-tomato following by three years of alfalfa). All field operations use full-scale agricultural equipment identical or similar to equipment used by local commercial farming operations, and is either owned by RRSAF, leased from UC Davis facilities, or borrowed from local farmers. Our goal is to closely replicate management practices typical in California's Central Valley and hence have greater relevance for collaborating farmers.

b. Permanent plots

The Century Experiment consists of 72 spatially isolated 0.4-ha plots. In 1991 when the site was laser-leveled, the plots were installed with raised berms around the perimeters to prevent runoff and erosion between plots. Each plot contains a central 0.2-ha area, where there are no manipulations of the long-term treatment. Areas of 208.9 square m on the west and east sides of each plot (Fig. 3) can be divided into forty microplots of 20.9 square m each, or four microstrips of three beds, for short-term research experiments and more destructive sampling (e.g., root excavation, non-radioactive isotopic tracer experiments): data from microplots and microstrips are not included in this paper, but many publications may be browsed at http://asi.ucdavis.edu/programs/rr/publications/russell-ranch-publications.

As in other long-term experiments (Jenkinson 1991, Paustian et al. 1992), changes have been made to some of the practices and systems in the Century Experiment to adaptively manage the plots in accordance with changes in agricultural practices in California (e.g., due to replacement of original with more disease-resistant crop varieties). **Most of the original treatments have been maintained as initially conceived, with small modifications (as described) in management or varieties when changes were necessary due to improved innovations** (Fig. 4, Table 2). In 1999, three of the previously unassigned plots were converted into a transitional organic corn-tomato rotation (TR) to monitor changes during the transition from conventional to organic management (Martini et al. 2004). The treatment for that system was then managed according to the same practices as the OMT system, however, its management history was different (e.g., initiated in 1999 rather than 1994, fully converted to organic by 2000, and certified organic by 2001).

In 2007, the irrigated wheat-legume (IWL) rotation was terminated and fallowed through 2012. These six plots were converted into the AMT rotation in 2013. Also in 2012, a native grassland treatment was created by seeding a native grass mix [*Stipa cernua* (nodding needlegrass), *Poa secunda* (pine bluegrass), *Vulpia microstachys* (three week fescue), *Elymus multisetus* (squirreltail), *Melica californica* (California oniongrass), and *Stipa pulchra* (purple needlegrass)] into three unassigned plots previously used for other experiments. Herbicides were applied initially to reduce annual weed pressure; since 2015, no herbicides have been used.

There have been other changes to the long-term rotations, some due to unavoidable budget cuts to RRSAF (Table 3). These changes include the following: 1) wheat replaced corn in all corn-tomato rotations from 2009–2012; 2) the LMT system lay fallow for both entry points in 2008; 3) *Sorghum bicolor* ssp. *drummondii* replaced corn in the OMT system, and the CMT system lay fallow in replicates that would otherwise have been planted in corn in 2008; 4) *S. x drummondii* replaced corn in the CMT, OMT, and LMT systems in 2009; and 5) the LMT system was planted with a WCC after tomatoes from 1994–2003, and after tomatoes and corn from 2004–2007 and 2013–2014 (also see data set plot_system.csv for description of planned and actual planting and harvest operations).

From 2003–2007, plots in all corn-tomato systems were split into west and east halves, and the treatments of conservation tillage or standard tillage were randomly assigned to one half of each plot (West = beds/rows 1-21, East = beds/rows 22-42; Figs. 3, 5). Conservation tillage equipment used included a conservation tillage planter, a conservation tillage transplanter that transplanted in strip tilled rows, and a modified Orthman 1tRIPr row unit (Orthman Manufacturing, Inc., Lexington, NE), that performed 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. The conservation tillage data is not included in this paper (see Kong et al. 2009 for details on that experiment), and all data included from the 2003–2007 period are from the standard tillage treatment.

The OMT system received chicken manure compost from Foster Farms (Livingston, CA) and is planted with a WCC. Starting in 1993, the WCC planted each fall was 90 kg/ha of *Pisum sativum* (Magnus peas) and 45 kg/ha of *Vicia villosa* (lana vetch). In 2006, the WCC mix changed to 90 kg/ha *Vicia faba* (bell bean), 22.5 kg/ha lbs *V. villosa*, and 28 kg/ha *Avena sativa* (oats) per 0.4-ha plot for all systems with cover crops. The LMT system received mineral fertilizer and was planted with a WCC. The CMT and CWT systems received only mineral fertilizer, as did the irrigated wheat-fallow (IWF) and rainfed wheat-fallow (RWF) systems. The IWL and rainfed wheat-legume (RWL) systems rotated annual winter wheat with a WCC (note, IWL was discontinued in 2012, replaced by AMT in 2013), and generally received no mineral fertilizer. However, the

RWL system received a phosphorus and potassium fertilizer in 2013. The irrigated wheat-control (IWC) and rainfed wheat-control (RWC) systems that generally receive no mineral N fertilizer also received supplemental phosphorus and potassium fertilizer in 1999 and 2013. All wheat systems were harvested for grain and the wheat straw was generally returned to the soil as an input after straw samples were collected. All systems received pesticides as needed; conventional systems received conventional pesticides, while organic systems received only pesticides approved by the Organic Materials Review Institute (Eugene, OR).

Crop varieties changed as varieties became out-of-date with agricultural practices at the time. New wheat varieties were introduced three times throughout the experiment as *Pucinia striiformis* (wheat rust) resistance was compromised. Decisions were based on visual observations of wheat rust, and discussion with the Crop Protection Advisor and local farmers. Tomato varieties changed twice since the beginning of the experiment as seed or transplants were no longer available for some tomato varieties as they were phased out of farming in the area. Initially, the corn variety for the OMT and LMT systems was a short-season variety (NC 4616). From 2003–2007, the CMT and LMT systems were planted in a Roundup Ready® variety (ST7570RR) and the OMT system was planted in the same variety without the Roundup Ready® gene (ST7570). In 2013, the OMT system was replanted due to poor germination of the corn seed lot.

All corn-tomato rotations receive summer irrigation, while irrigated wheat rotations receive supplemental irrigation in early spring (Jan–March) in years with low precipitation in the spring season. Note the CWT system is also fully irrigated in years when tomato is planted. Crops are planted in beds and all irrigated systems received furrow-flood irrigation through 2014, with some exceptions. In November 2012, all irrigated cover crop rotations were sprinkler irrigated, and in November 2013, only the WCC in the LMT rotation received sprinkler irrigation. Prior to tomato transplanting from 2010–2012, the OMT and LMT systems were sprinkler-irrigated due to a dry spring. In 2013, all tomato rotations received sprinkler pre-irrigation due to a dry winter. As of 2015 all corn and tomato crops have subsurface drip irrigation (SSDI), as does wheat in the CWT system. Wheat in all other systems is irrigated by furrow-flood, and alfalfa by check-flood. The OMT system is irrigated by SSDI in half of the plot, and furrow-flooded in the other half.

All the plots in the Century Experiment are irrigated with groundwater supplied by two pumps (Floway, 125 HP; General Electric, Fairfield, CT). These pumps were converted to variable frequency drives in winter of 2012. Though water input was a key variable in the original experimental design, accurate measurement of water was not possible due to problems with the types of flow meters initially installed. Irrigation data thus are not included in this data set, with the exception of the water quality data. The main tool in deciding irrigation in controlled flood systems was probing the soil and using a soil feel test. Furrow irrigation in its nature is not precise, so applications of water based on evapotranspiration were difficult, if not impossible. Other logistical complications include the scale and configuration of the experimental plots, which prevents drainage. Unlike most flood irrigation systems, the experimental plots were designed to retain all inputs in, including water, which makes control and rate of water applications challenging. For this reason, it was impossible to measure water in for the entirety of the experiment. However, starting in 2015, new meters were installed on some plots in the Century Experiment, with the goal to instrument all plots with functional meters within several years.

c. Data collection period and frequency

The database was designed to allow for direct entry of raw data after collection in the field so as to minimize the amount of processing before data entry, and to allow data to be double-checked quickly and accurately. When relevant, data set terms are identified and designated as such using controlled vocabulary from the Food and Agriculture Organization of the United Nations Thesaurus (AGROVOC 2016) or the National Oceanic and Atmospheric Administration (NOAA 2016) glossary.

<u>Initial productivity assessment:</u>

In July of 1992 and May 1993 a uniform crop of sudan grass (*Sorghum vulgare*) was grown on all plots to assess initial plot productivity (see Denison et al. 1996); yield data are only reported for 1993.

<u>NDVI imaging:</u>

The plots were imaged on July 11, 1993 prior to harvest from an altitude of 1,220 m.

<u>Soil sampling:</u>

Soil samples were collected at least every ten years beginning in 1993, and more often as needed for other experiments (see Fig. 5).

- Initial soil samples: Soil samples for texture and pH analyses were taken in May 1992. Four soil cores (3-cm diameter) were taken per plot to a depth of approximately 2 m using a Giddings probe (see Fig. 5, 1992 LTRAS locations) (Giddings Machine Company, Windsor, CO). Each core location was 16.7 m inwards from the edge of the plot (e.g., Location 1 is 16.7 m north of the southern edge of the plot, and 16.7 m east of the western edge of the plot). In July 1992, soil samples were collected during neutron probe installation in the southwest corner of each plot for analysis of particle size, organic matter content, hydraulic conductivity, and moisture. Samples were collected in 8.25-cm inner diameter and 6-cm long soil cores at two depths (0–25 and 25–50 cm). Soil samples were collected in corn-tomato systems to assess organic matter from 0–30 cm in March 2012.

- Archival soil samples: Decadal soil samples were collected during the fall in 1993, 2003, and 2012. In 1993, soils were sampled at depths of 0–15, 15–30, 30–60, 60–100, and 100–200 cm. In 2003 and 2012, soils were sampled at depths of 0–15, 15–30, 30–60, 60–100, 100–150, 150–200, 200–250, and 250–300 cm. In 1993, soil samples were taken at 10 locations and composited to make two samples per plot (an east and a west) as well as one composited sample for the entire plot. In 2003 and 2012, soil samples were taken at six locations. In 2003 and 2012, soil cores (3-cm diameter) were taken from each plot using a Giddings probe and three were composited to make two samples per plot, an east and a west sample per plot. These samples were composited across the entire plot for 2012 analyses.
- Other soil samples: In 1995 and 1999, soil samples were collected to 1 m with a Giddings probe (3-cm diameter). In 1995, the following soil depths were collected: 10–22, 22–34, 34–46, and 46–58 cm. In 1999, the following soil depths were collected: 0–7.5, 7.5–15, 15–22.5, 22.5–30, 30–37.5, 37.5–45, and 45–52.5 cm. In both 1995 and 1999, all samples were compiled to make one composited sample for the entire plot. In 1999, soil samples were collected from plots 1-2, 1-4, 2-2, 2-4, 4-3, 4-4, 5-5, 5-7, 6-5, 6-9, 7-4, 7-8, 7-9, and 8-8; samples were not collected in all plots due to inclement weather.

Soil samples from 1994–1999 for nitrate and ammonium analyses were taken with a 19-mm diameter soil probe at 0–15, 15–30, 30–45, and 45–80 cm depths. Four to 20 samples from each soil layer per plot (more samples from the topsoil and fewer from deeper layers) were composited in plastic bags. Four soil cores were collected per plot from 10–58 cm with a depth increment of 12 cm in September 1995.

In April 2003, soil cores were collected from the 0–15-cm layer of all three replicate plots of one phase of each of the 10 original cropping systems. Five soil cores were collected at 15-m intervals along a north–south transect of each replicate plot. Cylindrical cores were either pushed into the soil surface by hand or, when the soil surface was less friable, the core was pounded to a 15-cm depth with a mallet and wood block to distribute the pressure evenly across the core surface.

Soil samples were collected in November 2007 to 100 cm using a GeoProbe (sleeve diameter =3.8 cm; GeoProbe, Salina, KS) and divided into four segments: 0–15, 15–30, 30–60, and 60–100 cm.

Yield sampling:

It was not always possible to collect complete yield data sets due to climatic or management issues. In 1995, plots were flooded and the wheat crop was damaged in certain areas and wheat yields were only reported for undamaged strips through the plot. Starting in 1996, drainage ditches were installed each winter on the northern edge of each plot to reduce flooding. From 2010–2011 the OMT and LMT systems were planted as wheat-tomato systems, and in 2012, these systems had very low wheat yields due to weed pressure and the wheat was not harvested for grain. Instead, all biomass was harvested for hay and these data were not included.

Biomass and archive sampling:

As part of the long-term experiment, archival samples were collected annually for all crops grown at the RRSAF in all cropping systems (biomass samples were not regularly taken in the native grass system).

Weather data:

A weather station is located in a 0.4-ha plot (plot 3-3) within the Century Experiment in irrigated, mowed turf grass, and is maintained by U.C. Davis. The weather station was maintained from 1993–2001, and there was a gap in maintenance until 2009. A new weather station was installed and became operational on 10 May 2009.

Weed measurements:

Winter weed populations were measured in the wheat factorial experiment plots in some years from 1994–2008; in plots that were split by tillage treatment from 2004–2007, only the standard tillage treatment sides were monitored.

Water sampling:

Water samples were taken in some years from two groundwater pumps at the site (identity of the pump is indicated in data set).

Compost sampling:

Compost samples were taken with a soil sample probe from at least ten different locations in the pile of compost soon after it was delivered to Russell Ranch. Samples were collected at the time of compost application in most years between 1994–2014.

Operation records:

Each operation (e.g., fertilizer application, pesticide application, harvest, and planting) performed by a tractor was recorded on hand-written logs, entered into the database, and double-checked. Plot, date, tractor, equipment, number of passes (number of times there is a passage of a tractor over a specified area), type of operation, and any material inputs into the plot were recorded. Pesticides were designated as being aerially sprayed (operation type “Spray”) or incorporated into the soil (operation types “Perfecta,” “Mulch_Beds” or “Incorporate”).

3. Research methods

a. Field and laboratory methods and instrumentation:

Initial productivity assessment:

Sudan grass was harvested with commercial swathers and rakers and allowed to dry in the field (see Denison et al. 1996). Yield was measured by weighing four bales per plot, one at each corner of the plot, counting the number of bales per plot and multiplying for total biomass (fresh weight, not oven dried) Yield data are only reported for 1993.

NDVI imaging:

The plots were imaged with a Maurer P-2 camera with a 76-mm lens covered with a yellow filter. Shutter speed was 1/500 second and the film used was 70-mm Kodak Aerochrome 2443 (Denison et al. 1996) (Kodak, Rochester, NY). The 70-mm transparencies were scanned with a slide scanner. The resulting TIF-format computer file has a spatial resolution of 1,200 x 1,200 pixels, with 24 bits per pixel (8 bits x 3 colors). The scanned image was processed using the software package Image Pro for Windows (Media Cybernetics, Silver Spring, MD). First, the scanned image was aligned with four ground reference points to correct for differences in the flight path of the airplane and facilitate comparisons among photos from different dates. Then the Image Pro software was used to calculate the NDVI, defined as the difference between the IR and red values for each pixel, divided by their sum [NDVI = (IR-red)/(IR+red)], where IR is 0.7–0.9 microns and red is 0.6–0.7 microns. The NDVI values for all pixels in each 0.4-ha plot were averaged. The NDVI index was measured for each aerial image taken of the Century Experiment with the same protocol from 1994–2002.

Soil sampling and analysis:

May 1992 soil samples were examined with a hand lens for horizon depth; grade, size and soil structure; Munsell color notations for dry and moist soil; and textural determination by manual feel in a dry, moist, and wet state (Munsell 2000). Soil pH was determined using a Hellige-Truog reaction kit (Orbeco-Hellige, Inc., Sarasota, FL) for each horizon. Soil horizon nomenclature was based on Master horizons and subdivisions (Fitzpatrick 1967).

On July 1992 soil samples, particle size analysis was conducted by measuring the physical proportions of three sizes of primary soil particles--sand, silt, and clay--using the hydrometer method (Sheldrick and Wang 1993). Organic matter was measured with the Walkley-Black method (Nelson and Sommers 1982). Saturated hydraulic conductivity was measured using the constant head method (Klute and Dirksen 1986). Saturated water retention was measured by soil saturation and calculation of water content by oven-drying a sub-sample (Gardner 1986). Organic matter was measured on March 2012 samples in corn-tomato systems by loss upon ignition (Storer 1984).

Archival soil samples from 1993, 2003, and 2012 and samples taken in 1995 and 1999 were air-dried and ground to 2 mm with a mortar and pestle. To prepare for total carbon (C) and nitrogen (N) analysis, soil samples were pulverized with a mortar and pestle for analysis. Particle size analysis was conducted on 1993 and 2012 samples using the hydrometer method (Sheldrick and Wang 1993).

Bulk density was determined on subsamples (approximately 15 g) of air-dried soils in some plots in 1992, 1995, 1999, 2003, 2007, and 2012 following the procedure described in Blake and Hartge (1986). For bulk density measurements in 2003, all debris (mainly gravel) larger than 2 mm was sieved, weighed and included in final weight. For bulk density measurements in 1995, 1999, 2007, and 2012 all debris (mainly gravel) larger than 2 mm was discarded and not included in the final weight. The total weight of the debris for all samples in the 2012 sampling was less than 1% of the total weight and deemed negligible for bulk density calculations.

Approximately 5 g subsamples (dry weight) of soil samples taken in 1994–1999 were extracted with 25 ml of a 2 M KCl solution (modified from Keeney and Nelson 1982). Total inorganic-N and ammonium-N concentrations were analyzed using a permeable membrane analyzer (Carlson et al. 1990). Nitrate-N was calculated as the difference between the total N and ammonium-N. A second subsample was weighed wet, dried at least for 24 h at 110^{o}C, and then weighed dry. Volumetric soil water content was calculated on a dry weight basis. Bulk density was determined on four soil cores per plot from September 1995 samples (Hasegawa et al. 1999).

Total soil C and N content was measured on 1993, 2003, and 2012 archived soil samples by a dynamic flash combustion system coupled with gas chromatographic (GC) separation and thermal conductivity detection (TCD) systems (AOAC 1997) using a Costech Elemental Analyzer (Valencia, CA). Extractable phosphate was measured with the Olsen method (Olsen and Sommers 1982, Prokopy 1995a). Sulfate sulfur was measured by extraction (Schulte and Eik 1988), with the procedure modified to eliminate activated C, followed by determination of S by inductively coupled plasma atomic emission spectrometry (ICP-AES). Exchangeable potassium was also determined by ICP-AES (Loku 1991). Elemental data were expressed as percent for N and C, and as ppm for P, S, and K.

Field-moist soil samples from April 2003 were gently broken apart, passed through an 8-mm sieve and >8 mm material (e.g., gravel and residues) was weighed and recorded. Gravimetric water content was determined on a dry subsample of the <8 mm sieved soil (~10g); samples were deemed free of carbonates via a fizz test (Harris et al. 2001). Bulk density was calculated by dividing the oven-dry weight of 8 mm-sieved soil by the volume of the core corrected for the volume of gravel. Bulk densities were determined for the individual soil cores and the five soil cores from each plot were composited to estimate average bulk density for each field plot.

November 2007 samples were measured for bulk density and sieved to 4 mm for ammonium, nitrate, and moisture analyses. Subsamples (~20 g) of soils were oven-dried at 105^{o}C for 24 hours to determine moisture content. Ammonium and nitrate concentrations were measured following Doane and Horwath (2003) and Miranda et al. (2001).

<u>Biomass and archive sampling:</u>

Crops were sorted into different plant parts (e.g., tomatoes as fruit and vine; corn as grain, stalk, and cob; and wheat as grain and stalk) and archived long-term in glass vials at room temperature. The plot, year, and sample type were recorded on the jar and on a paper tag stored inside the jar following the Rothamsted archival procedure (Blake et al. 2000, Poulton 2003). For archival samples, tomato samples were taken from manually harvested red tomato samples. Archived wheat and corn samples were randomly sampled from the bins of mechanically harvested grain. Archived cover crop and alfalfa samples were randomly subsampled from each manually plant biomass harvested sample.

Manual harvests were used to establish total aboveground biomass measurements. Corn manual harvests were taken from a 1.52 square m plot area from four rows approximately half way through the row (35 m north of the southern edge of the plot), selected to be representative of the plot. Grain was removed from the cob with a corn thresher (International Harvester, Warrenville, IL), and grain, cob, and stalk fresh weights were recorded.

Manual harvests of tomato were taken from a 3.04 square m plot area in four rows approximately half way through the row (35 m north of the southern edge of the plot), selected to be representative of the plot. Tomato fruit was shaken onto a tarp to separate fruit from vine and then manually sorted into red and green fruit. Both fruit and vine fresh weights were recorded.

From 1994–1997 "manual" harvests of wheat straw were measured by counting mechanically-harvested wheat bales for the entire plot. From 1998–1999 wheat straw manual harvests were taken from a 27.9 square m plot area. From 2000-2011, wheat straw manual harvests were taken from a 3.04 square m plot area in each of two rows approximately half way through the row (35 m north of the southern edge of the plot), selected to be representative of the plot. From 2012-2014, wheat straw manual harvests were taken from a 0.914 square m plot area in each of the same two rows. From 2015 on, wheat straw manual harvests were taken from a 4.65 square m plot area in each of the same two rows (although these data are not included in this dataset, as they occurred after 2014). Wheat grain was mechanically harvested throughout the experiment. Through 2012, wheat grain and stalk were manually separated by cutting the grain head from the stalk and fresh weights of the wheat grain and stalk were recorded, but from 2013 and on, were mechanically separated by stripper header.

The WCC manual harvests were taken from a 4.65 square m plot area in the week before incorporation from two rows approximately halfway through the row (35 m north of the southern edge of the plot), selected to be representative of the plot. Starting in 2013 when the AMT system was implemented, alfalfa manual harvests of biomass were collected at each alfalfa cutting using the same protocol as for the WCC manual harvests

In 1993, the sudan grass crop was mowed, air-dried in the field, and baled. Yield measurement was taken by weighing four bales per plot in each four corners of the plot and counting the total number of bales. Bales were weighed as air dry weight (no oven dried weights were taken). In 2008 and 2009, sudan grass harvests were performed identically to WCC manual harvests, and the sudan grass crop was sampled prior to plowing under at every harvest and no hay was removed from the plots. The species of sudan grass planted in years following the initial planting was *S. bicolor* ssp. *drummondii*.

All crop archive samples were oven-dried at 62^{o}C and ground with a Thomas Model 4 Wiley® Mill (Thomas Scientific, Swedesboro, NJ) and Foss Tecator

Cyclotec sample mill (Foss, Eden Prairie, MN) before storage. Tomato fruit was cut into quarters and dried on aluminum foil covered trays for at least three days to ensure that most moisture was removed. With the exception of corn stalks, all grain and biomass samples were dried in brown paper bags for at least three days and measured to ensure that most moisture was removed. Corn stalks were dried in burlap bags for at least seven days and measured to ensure that most moisture was removed. Fresh and dry weights of the dried samples were measured to calculate moisture content. Crop archive samples were pulverized with a mortar and pestle before total C and N analysis.

Crop nutrient analysis:

For selected samples from 1994–1998, total C and N concentrations were analyzed with a modified, automated Dumas combustion method using a Carlo Erba NA-1500 elemental analyzer (Thermo Fisher Scientific, Waltham, MA) (Pella 1990). From 2009 and on, selected archived crop samples were sub-sampled for nutrient analysis. Total C and N content of tomato, corn, wheat, and WCC archive samples were measured by a dynamic flash combustion system coupled with GC separation and TCD systems (AOAC 1997). Phosphorus content (PO_4-P) of the archived samples was measured by automated Flow Injection Analyzer (Lachat Instruments, Milwaukee, WI) (Prokopy 1995b). Sulfate-sulfur (SO_4-S) and soluble potassium (Total K) content were determined by ICP-AES (Littlefield et al. 1990, Jones 2001, U.S. EPA 2001).

Soluble carbohydrates (glucose, sucrose, fructose) of the tomato fruit were measured by high performance liquid chromatography (HPLC) with mass selective detection (Johansen et al. 1996). Total nonstructural carbohydrates and starch were measured by enzymatic hydrolyzation and HPLC with mass selective detection (Smith 1969). Samples of fresh red tomato fruit were analyzed annually by the Processing Tomato Advisory Board (see www.ptab.org). The color of the tomato fruit and soluble solids was measured by blending the tomato fruit and using a digital refractometer (Bellingham & Stanley RFM 110 and RFM 190, Kent, UK). The pH of the tomato fruit (“pH - PTAB”) was measured from the same blended sample with a Fisher Accumet AB150 pH meter (Fisher Scientific, Pittsburgh, PA).

Weather data:

The weather station datalogger (CR800; Campbell Scientific, Logan, UT) recorded weather data daily and hourly, and these were summarized as daily weather reports. A HMP45C sensor (Vaisala Inc., Louisville, CO) measured air temperature and relative humidity. A Campbell Scientific 024A MetOne wind direction sensor and MetOne wind speed sensor measured wind speed and direction (Gilhousen 1987). Two

Campbell Scientific CSI 107 soil temperature probes measured soil temperature at 0.3-m and 0.9-m depths. A TE525WS rain gauge (Texas Electronics, Dallas, TX) measured rainfall. A Campbell Scientific Li-Cor Li200X pyranometer measured sun and sky radiation in the range of 400 to 1100 nm. A Campbell Scientific Kipp & Zonen NR Lite Net Radiometer measured net radiation in the spectral range of 200 to 100,000 nm. Dew point was measured by the datalogger (Park and Park 2011).

Weed measurements:

Weed seedlings were counted and identified by species in most years from 1994–2008 in the winter period between Dec 1st and March 15th of the subsequent year. Weed seedlings were counted in two to five quadrats in each plot, with quadrat size varying from 0.5–93.75-square m, depending on weed density. Weed species was recorded with the Bayer/WSSA 5 letter codes (WSSA 2016). All weed data collection was supervised by Dr. Robert Norris.

Water analyses:

Samples were collected from irrigation water after the groundwater well pump was operated for at least 15 min. Samples were analyzed at the UC Davis Analytical Laboratory for B, Ca, K, Mg, Na, P, and S by ICP-AES (U.S. EPA 2001). Sodium adsorption ratio was measured after determining Ca, Mg, and Na concentrations (U.S. Salinity Laboratory Staff 1954). Electrical conductivity was measured using a pH electrode (Clesceri et al. 1998). Nitrate-nitrogen (NO_3-N) (Clesceri et al. 1998, Knepel 2003), chloride (Diamond 1994), bicarbonate (HCO_3^-), carbonate (CO_3^{2-}) (Clesceri et al. 1998), and ammonium-nitrogen (NH_4-N) (Hofer 2003) were determined. Total dissolved solids were determined by gravimetric analysis (Clesceri et al. 1998).

Compost analyses:

Compost samples were collected most years between 1994–2014 with a soil sample probe from at least ten different locations in the compost pile at the time of compost application, frozen, and then thawed directly before analysis. From 1994–2014, total C and N of the compost sample were analyzed by a dynamic flash combustion system coupled with GC separation and TCD systems (AOAC 1997). From 2001–2009, additional properties of the compost samples were analyzed by the UC Davis Analytical Laboratory. Concentrations of the elements K, P, S, B, Mg, Ca, Zn, Mn, Fe, and Cu were determined by ICP-AES and (Meyer and Keliher 1992, Sah and Miller 1992). Electrical conductivity and pH were measured on slurry samples using ratios of 1:5 sample:deionized water (Wolf 2003).

From 2011–2014, chemical properties of compost samples (other than total C and N, see above) were analyzed by Denele Analytical (Gavlak et al. 2005). Extractable K, Ca, Mg, and Na were analyzed by ICP-AES (Knudsen et al. 1982), as were extractable Zn, Mg, Fe and Cu (Lindsay and Norvell 1978). Extractable B was measured by spectrophotometry (Bingham 1982, Mahler et al. 1984, Horneck et al. 1989). Organic matter was measured by loss upon ignition (Storer 1984). Total N was measured by combustion using a Leco CHN-1000 (Leco Corporation, St. Joseph, MI) or automated resistance furnace (Sheldrick 1986, Yeomans and Bremmer 1991).

b. Instrumentation

See Class II, Section B, Part 3, Subsection a, above.

c. Taxonomy and systematics

Biological specimens requiring taxonomic identification were not collected for archive.

d. Permit history

Not applicable.

e. Legal and organizational requirements

Not applicable.

4. Project personnel

See names and addresses of originators listed in Class I, Section C, Part 1.

Currently, the Director of the Russell Ranch Sustainable Agriculture Facility is Kate Scow and the Director of the Agricultural Sustainability Institute is Tom Tomich. Current staff include: Kristina Wolf, Israel Herrera, Luis Loza, Martin Loza, and Everardo Aguila. Current researchers include but are not limited to: Amelie Gaudin, Daniele Zaccaria, Will Horwath, Martin Burger, Wendy Silk, Jan Hopmans, Helen Dahlke, Mark Lundy, Daniel Geisseler, Neal Williams, Louie Yang, Emilio Laca, Chris van Kessel, Tim Hartz, Gene Miyao, Howard Ferris, Randy Dahlgren, Anthony O'Geen, Graham Fogg, Maria Teresa Carrillo-Cobo, and Daoyuan Yang (all UC Davis), Gabriel Maltais Landry, and Peter Vitousek (Stanford University), and Adina Paytan (UC Santa Cruz). Past directors of the Century Experiment included Montague Demment (1991–1992), R. Ford Denison (1993–2002), and Stephen Kaffka (2002–2007).

CLASS III. DATA SET STATUS AND ACCESSIBILITY

A. Status

1. Latest update

The data span the period of 1992–2014. The database is updated annually.

2. Latest Archive date

December 2014

3. Metadata status

The metadata are complete and up-to-date.

4. Data verification

Field data were manually recorded on paper datasheets and entered into an Access database. Data entries were checked for typographical and other data-entry errors.

B. Accessibility

1. Storage location and medium

The original Access™ database (.accdb) file is stored on a server hosted by the College of Agricultural and Environmental Sciences, which is backed up weekly. Data is downloaded to an open access website annually: http://asi.ucdavis.edu/programs/rr/data. Russell Ranch is in the process of upgrading the online open access database. The modified database is estimated to be publicly accessible by June 2017; currently data requests may be made manually via the same website.

2. Contact person

Kate Scow, 1315 Plant and Environmental Sciences, Agricultural Sustainability Institute, One Shields Avenue, Davis, CA 95616. Queries regarding the data set can be directed to kmscow@ucdavis.edu.

3. Copyright restrictions

None

4. Proprietary restrictions

None

5. Costs

None.

CLASS IV. DATA STRUCTURAL DESCRIPTORS

A. Data set files

The complete set of data files includes: crop yield, biomass and moisture data (corn_harvests_all.csv, tomato_harvests_all.csv, wheat_harvests_all.csv, alfalfa_harvests_all.csv, sudangrass_harvests_all.csv), cover crop biomass and moisture (wcc_harvests_all.csv), crop elemental content (corn_analyses_all.csv, tomato_analyses_all.csv, wheat_analyses_all.csv, wcc_analyses_all.csv), soil properties [bulk density (soil_bulkdensities_all.csv), texture (soil_textures_all.csv), soil particle distribution (soil_particle_distribution_all.csv), total N and C (soil_total_CN_all.csv), soil organic matter (soil_organic_matter_all.csv), nitrate and ammonium (soil_extracts_N_all.csv), phosphorus, sulfur, and potassium (soil_extracts_PKS_all.csv), and soil hydraulic properties (soil_hydraulic_properties_all.csv)], weather (weather_all.csv), winter weed populations (weed_measurements_all.csv), water elemental content (water_analyses_summary.csv), fertilizer and compost application amounts and dates, and compost analyses (operations_fertilizers.csv, operations_compost.csv, compost_analyses_summary.csv), pesticide application amounts and dates (operations_pesticides.csv), planting dates, planting quantity, and crop variety (operations_planting.csv), harvest dates and equipment (operations_harvest.csv), and planned and actual planting and harvest data by plot, year, and system (plot_system.csv). These data sets are contained in the self-extracting zip file named RR_2014_datasets.zip. NDVI data are contained in the file ndvi_all.csv, and all ndvi .tif image files in the zip file RR_2014_NDVI_images.zip.

1a. Identity 1: corn_harvests_all.csv

2a. Size: This 26 KB file contains the complete corn harvest records for the period 1994–2014 (280 entries). Each row consists of 10 cells, described below in Section B.

3a. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4a. Header information: See variable names in Class IV, Section B, Part 1.

5a. Alphanumeric attributes: Mixed.

6a. Special characters/fields: Missing data denoted as " ".

7a. Authentication procedures: Not applicable.

1b. Identity 2: tomato_harvests_all.csv

2b. Size: This 43 KB file contains the complete tomato harvest records for the period 1994–2013 (535 entries). Each row consists of 11 cells, described below in Section B.

3b. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4b. Header information: See variable names in Section B.

5b. Alphanumeric attributes: Mixed.

6b. Special characters/fields: Missing data denoted as " ".

7b. Authentication procedures: Not applicable.

1c. Identity 3: wheat_harvests_all.csv

2c. Size: This 38 KB file contains the complete wheat harvest records for the period 1994–2013 (538 entries). Each row consists of 8 cells, described below in Section B.

3c. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4c. Header information: See variable names in Section B.

5c. Alphanumeric attributes: Mixed.

6c. Special characters/fields: Missing data denoted as " ".

7c. Authentication procedures: Not applicable.

1d. Identity 4: alfalfa_harvests_all.csv

2d. Size: This 5 KB file contains the complete wheat harvest records for 2013–2014 (78 entries). Each row consists of 6 cells, described below in Section B.

3d. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4d. Header information: See variable names in Section B.

5d. Alphanumeric attributes: Mixed.

6d. Special characters/fields: Missing data denoted as " ".

7d. Authentication procedures: Not applicable.

1e. Identity 5: sudangrass_harvests_all.csv

2e. Size: This 8 KB file contains the complete sudan grass harvest records for the period 1993–2009 (87 entries). Each row consists of 7 cells, described below in Section B.

3e. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4e. Header information: See variable names in Section B.

5e. Alphanumeric attributes: Mixed.

6e. Special characters/fields: Missing data denoted as " ".

7e. Authentication procedures: Not applicable.

1f. Identity 6: wcc_harvests_all.csv

2f. Size: This 48 KB file contains the complete WCC harvest records for the period 1994–2014 (632 entries). Each row consists of 7 cells, described below in Section B.

3f. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4f. Header information: See variable names in Section B.

5f. Alphanumeric attributes: Mixed.

6f. Special characters/fields: Missing data denoted as " ".

7f. Authentication procedures: Not applicable.

1g. Identity 7: corn_analyses_all.csv

2g. Size: This 33 KB file contains the corn grain, stalk and cob analysis for chemical composition for the period 1994–2007 (576 entries). Each row consists of 7 cells, described below in Section B.

3g. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4g. Header information: See variable names in Section B.

5g. Alphanumeric attributes: Mixed.

6g. Special characters/fields: Missing data denoted as " ".

7g. Authentication procedures: Not applicable.

1h. Identity 8: tomato_analyses_all.csv

2h. Size: This 104 KB file contains the tomato fruit and vine analysis for chemical composition for the period 1994–2013 (1743 entries). Each row consists of 7 cells, described below in Section B.

3h. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4h. Header information: See variable names in Section B.

5h. Alphanumeric attributes: Mixed.

6h. Special characters/fields: Missing data denoted as " ".

7h. Authentication procedures: Not applicable.

1i. Identity 9: wheat_analyses_all.csv

2i. Size: This 52 KB file contains the wheat grain and stalk analysis for chemical composition for the period 1994–2008 (895 entries). Each row consists of 7 cells, described below in Section B.

3i. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4i. Header information: See variable names in Section B.

5i. Alphanumeric attributes: Mixed.

6i. Special characters/fields: Missing data denoted as " ".

7i. Authentication procedures: Not applicable.

1j. Identity 10: wcc_analyses_all.csv

2j. Size: This 45 KB file contains the WCC data for chemical composition for the period 1994–2011 (823 entries). Each row consists of 7 cells, described below in Section B.

3j. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4j. Header information: See variable names in Section B.

5j. Alphanumeric attributes: Mixed.

6j. Special characters/fields: Missing data denoted as " ".

7j. Authentication procedures: Not applicable.

1k. Identity 11: soil_bulkdensities_all.csv

2k. Size: This 242 KB file contains the soil bulk density from 1992–2012 (4452 entries). Each row consists of 8 cells, described below in Section B.

3k. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4k. Header information: See variable names in Section B.

5k. Alphanumeric attributes: Mixed.

6k. Special characters/fields: Missing data denoted as " ".

7k. Authentication procedures: Not applicable.

1l. Identity 12: soil_textures_all.csv

2l. Size: This 223 KB file contains the soil textural data from 1992 soil samples (1892 entries). Each row consists of 20 cells, described below in Section B.

3l. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4l. Header information: See variable names in Section B.

5l. Alphanumeric attributes: Mixed.

6l. Special characters/fields: Missing data denoted as " ".

7l. Authentication procedures: Not applicable.

1m. Identity 13: soil_particle_distribution_all.csv

2m. Size: This 29 KB file contains the soil particle size analysis data from 1992–2012 soil samples (392 entries). Each row consists of 9 cells, described below in Section B.

3m. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4m. Header information: See variable names in Section B.

5m. Alphanumeric attributes: Mixed.

6m. Special characters/fields: Missing data denoted as " ".

7m. Authentication procedures: Not applicable.

1n. Identity 14: soil_total_CN_all.csv

2n. Size: This 165 KB file contains the soil total C and N concentrations from 1993–2003 (2183 entries). Each row consists of 8 cells, described below in Section B.

3n. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4n. Header information: See variable names in Section B.

5n. Alphanumeric attributes: Mixed.

6n. Special characters/fields: Missing data denoted as " ".

7n. Authentication procedures: Not applicable.

1o. Identity 15: soil_organic_matter_all.csv

2o. Size: This 9 KB file contains the soil textural data from 1992–2012 soil samples (101 entries). Each row consists of 8 cells, described below in Section B.

3o. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4o. Header information: See variable names in Section B.

5o. Alphanumeric attributes: Mixed.

6o. Special characters/fields: Missing data denoted as " ".

7o. Authentication procedures: Not applicable.

1p. Identity 16: soil_extracts_N_all.csv

2p. Size: This 347 KB file contains the soil nitrate and ammonium concentrations from 1993–2007 (3486 entries). Each row consists of 9 cells, described below in Section B.

3p. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4p. Header information: See variable names in Section B.

5p. Alphanumeric attributes: Mixed.

6p. Special characters/fields: Missing data denoted as " ".

7p. Authentication procedures: Not applicable.

1q. Identity 17: soil_extracts_PKS_all.csv

2q. Size: This 27 KB file contains the soil phosphorus, potassium and sulfur concentrations from 1993–2012 (512 entries). Each row consists of 8 cells, described below in Section B.

3q. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4q. Header information: See variable names in Section B.

5q. Alphanumeric attributes: Mixed.

6q. Special characters/fields: Missing data denoted as " ".

7q. Authentication procedures: Not applicable.

1r. Identity 18: soil_hydraulic_properties_all.csv

2r. Size: This 10 KB file contains the soil hydraulic property data from 1992 soil samples (126 entries). Each row consists of 8 cells, described below in Section B.

3r. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4r. Header information: See variable names in Section B.

5r. Alphanumeric attributes: Mixed.

6r. Special characters/fields: Missing data denoted as " ".

7r. Authentication procedures: Not applicable.

1s. Identity 19: weather_all.csv

2s. Size: This 540 KB file contains the weather data from 1993–2014 (5299 entries). Each row consists of 28 cells, described below in Section B.

3s. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4s. Header information: See variable names in Section B.

5s. Alphanumeric attributes: Mixed.

6s. Special characters/fields: Missing data denoted as " ".

7s. Authentication procedures: Not applicable.

1t. Identity 20: weed_measurements_all.csv

2t. Size: This 423 KB file contains the weed species counts from 1994–2008 (2732 entries). Each row consists of 53 cells, described below in Section B.

3t. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4t. Header information: See variable names in Section B.

5t. Alphanumeric attributes**:** Mixed.

6t. Special characters/fields: Missing data denoted as " ".

7t. Authentication procedures: Not applicable.

1u. Identity 21: water_analyses_summary.csv

2u. Size: This 1 KB file contains the water elemental analysis from 1992–2014 for two wells supplying water to the Century experiment (9 entries). Each row consists of 19 cells, described below in Section B.

3u. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4u. Header information: See variable names in Section B.

5u. Alphanumeric attributes: Mixed.

6u. Special characters/fields: Missing data denoted as " ".

7u. Authentication procedures: Not applicable.

1v. Identity 22: ndvi_all.csv

2v. Size: This 154 KB file contains the aerial infrared image names and calculated NDVI from 1993–2002 (2898 entries). Each row consists of 6 cells, described below in Section B.

3v. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files. Actual .tif image files are stored in a self-extracting zip file named "RR_2014_NDVI_images.zip".

4v. Header information: See variable names in Section B.

5v. Alphanumeric attributes: Mixed.

6v. Special characters/fields: Missing data denoted as " ".

7v. Authentication procedures: Not applicable.

1w. Identity 23: operations_fertilizers.csv

2w. Size: This 87 KB file contains the fertilizer applications including dates, products and quantities for 1993–2013 (883 entries). Each row consists of 11 cells, described below in Section B.

3w. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4w. Header information: See variable names in Section B.

5w. Alphanumeric attributes: Mixed.

6w. Special characters/fields: Missing data denoted as " ".

7w. Authentication procedures: Not applicable.

1x. Identity 24: compost_analyses_summary.csv

2x. Size: This 7 KB file contains the compost elemental analysis from 1994–2013 (163 entries). Each row consists of 5 cells, described below in Section B.

3x. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4x. Header information: See variable names in Section B.

5x. Alphanumeric attributes: Mixed.

6x. Special characters/fields: Missing data denoted as " ".

7x. Authentication procedures: Not applicable.

1y. Identity 25: operations_pesticides.csv

2y. Size: This 167 KB file contains the pesticide applications including dates, products and quantities for 1994–2014 (1590 entries). Each row consists of 11 cells, described below in Section B.

3y. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4y. Header information: See variable names in Section B.

5y. Alphanumeric attributes: Mixed.

6y. Special characters/fields: Missing data denoted as " ".

7y. Authentication procedures: Not applicable.

1z. Identity 26: operations_planting.csv

2z. Size: This 169 KB file contains the planting operations including dates, equipment, material and quantities for 1993–2013 (1121 entries). Each row consists of 12 cells, described below in Section B.

3z. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4z. Header information: See variable names in Section B.

5z. Alphanumeric attributes: Mixed.

6z. Special characters/fields: Missing data denoted as " ".

7z. Authentication procedures: Not applicable.

1aa. Identity 27: operations_harvest.csv

2aa. Size: This 108 KB file contains the harvest operations including dates and equipment for 1994–2013 (949 entries). Each row consists of 9 cells, described below in Section B.

3aa. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4aa. Header information: See variable names in Section B.

5aa. Alphanumeric attributes: Mixed.

6aa. Special characters/fields: Missing data denoted as " ".

7aa. Authentication procedures: Not applicable.

1bb. Identity 28: operations_compost.csv

2bb. Size: This 12 KB file contains the compost applications for 1994–2013 (252 entries). Each row consists of 5 cells, described below in Section B.

3bb. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4bb. Header information: See variable names in Section B.

5bb. Alphanumeric attributes: Mixed.

6bb. Special characters/fields: Missing data denoted as " ".

7bb. Authentication procedures: Not applicable.

1cc. Identity 29: plot_system.csv

2bb. Size: This 372 KB file contains the planned and actual planting and harvest operations for each harvest year, plot, and system for 1993–2014 (1474 entries). Each row consists of 20 cells, described below in Section B.

3bb. Format and storage mode: Data are stored in a .csv file (comma delimited), which is compressed into a self-extracting zip file with other data files.

4bb. Header information: See variable names in Section B.

5bb. Alphanumeric attributes: Mixed.

6bb. Special characters/fields: Missing data denoted as " ".

7bb. Authentication procedures: Not applicable.

B. Variable information

1a. Identity 1: Data in the file corn_harvests_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	Description	Unit
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an "E" or "W" if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	
date	The date (month/day/year) of the corn mechanical harvest	
dry_stalk_wt_kg.ha	Stalk biomass weight from manually harvested plot	kg/ha
dry_grain_wt_kg.ha	Grain weight from manually harvested plot	kg/ha
dry_cob_wt_kg.ha	Cob weight from manually harvested plot	kg/ha
dry_total_biomass_kg.ha	Total biomass weight from manually harvested plot	kg/ha
corn_mh_fresh_yield_kg.ha	Fresh (wet) weight of corn grain from mechanically harvested strip; for plots in which "E" and "W" dry sample weights are recorded, this value is duplicated	kg/ha

	in each row for each plot	
corn_mh_dry_yield_kg.ha	Dry weight of corn grain from mechanically harvested strip; for plots in which “E” and “W” dry sample weights are recorded, this value is duplicated in each row for each plot	kg/ha
corn_grain_moisture_.	Moisture content of mechanically harvested grain; for plots in which “E” and “W” dry sample weights are recorded, this value is duplicated in each row for each plot	%

1b. Identity 2: Data in the file tomato_harvests_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an “E” or “W” if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	
date	The date (month/day/year) of the tomato mechanical harvest	
tomato_hh_red_fresh_yield_Mg.ha	Tomato red fruit weight (fresh) from manually harvested plot	Mg/ha
tomato_hh_green_fresh_yield_Mg.ha	Tomato green fruit weight (fresh) from manually harvested plot	Mg/ha

tomato_hh_vine_fresh_yield_Mg.ha	Tomato vine weight (fresh) from manually harvested plot	Mg/ha
tomato_hh_vine_dry_yield_Mg.ha	Tomato vine weight (dry) from manually harvested plot	Mg/ha
tomato_mh_fresh_yield_Mg.ha	Fresh (wet) weight of tomato fruit from mechanically harvested strip	Mg/ha
tomato_mh_dry_yield_Mg.ha	Dry weight of tomato fruit from mechanically harvested strip	Mg/ha
tomato_fruit_moisture_.	Moisture content of manually harvested tomatoes; for plots in which "E" and "W" harvest data are recorded, this value is duplicated in each row for each plot	%
tomato_vine_moisture_.	Moisture content of manually harvested tomato vine; for plots in which "E" and "W" harvest data are recorded, this value is duplicated in each row for each plot	%

1c. Identity 3: Data in the file wheat_harvests_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an "E" or "W" if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	

date	The date (month/day/year) of the wheat mechanical harvest.	
wheat_hh_dry_grain_yield_kg.ha	Wheat dry grain yield from manually harvested plot; when “E” and “W” samples were harvested for some dates and plots, they are reported here on separate rows	kg/ha
wheat_mh_fresh_grain_yield_kg.ha	Wheat grain yield weight (fresh) from mechanically harvested plots; for plots in which “E” and “W” Wheat_hh_dry_grain_yield_kg/ha samples were taken, this value is generally duplicated in each row for each plot	kg/ha
wheat_mh_dry_grain_yield_kg.ha	Wheat grain yield weight (dry) from mechanically harvested plots; for plots in which “E” and “W” Wheat_hh_dry_grain_yield_kg/ha samples were taken, this value is generally duplicated in each row for each plot	kg/ha
wheat_grain_moisture_.	Moisture content of mechanically harvested grain; for plots in which “E” and “W” Wheat_hh_dry_grain_yield_kg/ha samples were taken, this value is generally duplicated in each row for each plot	%
comments_moisture	Comments on wheat grain moisture data collection	

1d. Identity 4: Data in the file alfalfa_harvests_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**

plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an “E” or “W” if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	
date	The date (month/day/year) of the alfalfa harvest	
alfalfa_fresh_yield_kg.ha	Alfalfa fresh yield from manually harvested plot	kg/ha
alfalfa_dry_yield_kg.ha	Alfalfa dry yield from manually harvested plot	kg/ha
alfalfa_moisture_.	Alfalfa moisture content from manually harvested plot; moisture data was composited across “E” and “W” sides of the plot, and values are duplicated on both rows	%

1e. Identity 5: Data in the file sudangrass_harvests_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an “E” or “W” if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	
Date	The date (month/day/year) of the sudan grass harvest	

fresh_sudangrass_yield_kg.ha	Sudan grass fresh yield from manually harvested plot	kg/ha
dry_sudangrass_yield_kg.ha	Sudan grass dry yield from manually harvested plot	kg/ha
sudangrass_moisture_.	Sudan grass moisture content from manually harvested plot	%
comments	Comments on data collection	

1f. Identity 6: Data in the file wcc_harvests_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an “E” or “W” if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	
date	The date (month/day/year) of the WCC incorporation	
wcc_fresh_yield_kg.ha	WCC fresh yield from manually harvested plot	kg/ha
wcc_dry_yield_kg.ha	WCC dry yield from manually harvested plot	kg/ha
wcc_moisture_.	WCC moisture content from manually harvested plot; for some dates, moisture data was composited across “E” and “W” sides of the plot, and moisture values are duplicated on both rows	%

comments	Comments on WCC manual harvest data collection; notes referring to "Loc X dirt" mean a dirt clod of the specified weight in grams was in the sample but was removed to ensure proper weight and moisture calculations

1g. Identity 7: Data in the file corn_analyses_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9	
system_name	Cropping system name	
date	The date (month/day/year) when the corn was sampled	
corn_part	Corn part analyzed (grain, stalk, cob)	
corn_analysis	Type of chemical composition analysis conducted (described in sampling methods above)	
analysis_value	Analysis value of corn analysis described in column E	
units	The units for the analysis value in column F	

1h. Identity 8: Data in the file tomato_analyses_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	Variable Description	Unit
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an “E” or “W” if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	
date	The date (month/day/year) when the tomatoes were sampled	
tomato_part	Tomato part analyzed (fruit or vine)	
tomato_analysis	Type of chemical composition analysis (described in sampling methods above)	
analysis_value	Analysis value of tomato analysis described in column E	
units	The units for the analysis value in column F	

1i. Identity 9: Data in the file wheat_analyses_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	Variable Description	Unit
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an “E” or “W” if applicable to designate the east or west side of the plot (e.g., 4-3W is the	

	west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	
date	The date (month/day/year) when the wheat was sampled	
wheat_part	Wheat plant part analyzed (grain or stalk)	
wheat_analysis	Type of chemical composition analysis (described in sampling methods above)	
analysis_value	Analysis value of wheat analysis described in column E	
units	The units for the analysis value in column F	

1j. Identity 10: Data in the file wcc_analyses_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an “E” or “W” if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	
date	The date (month/day/year) when the WCC was sampled	

wcc_part	Cover crop plant part analyzed (plant)	
wcc_analysis	Type of chemical composition analysis (described in sampling methods above)	
analysis_value	Analysis value of analysis described in column E	
units	The units for the analysis value in column F	

1k. Identity 11: Data in the file soil_bulkdensities_all.csv are organized laterally in rows with variables in columns. Each row of the data represents one determination of soil moisture content for each date, plot, location and each depth of soil. Where multiple values occur for the same plot, date, and depth, the same sample was analyzed multiple times to determine method variability. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an “E” or “W” if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	
date	The date (month/day/year) when the soil sample was taken	
depth_top_cm	Depth from soil surface to the top of the soil sample	cm
depth_bottom_cm	Depth from soil surface to the bottom of the soil sample	cm

core_diameter	Diameter of soil core used for bulk density measurement	cm
residue_gravel_wt_g	Weight of residue gravel in soil sample in grams	g
bulk_density_g.cm3	Soil bulk density	g/cm^3

1l. Identity 12: Data in the file soil_textures_all.csv are organized laterally in rows with variables in columns. Each row of the data represents one soil textural observation for each soil sampling location and each depth of soil from soil samples taken in 1992. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an "E" or "W" if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	
date	The date (month/day/year) when the soil sample was taken	
soil_location_description	Description of soil sample location (ltras_1992_location_1 … ltras_1992_location_4)	
depth_top_cm	Depth from soil surface to the top of the soil sample	cm
depth_bottom_cm	Depth from soil surface to the bottom of the soil sample	cm
date_analyzed	Date when soil textural sample was analyzed	

horizon_number	Soil horizon number starting from the soil surface, typically ranging from 1–10
horizon_name	Soil horizon is named according to the nomenclature described in the methods above
dry_hue_scale	Scale from 1–10 for hue in Munsell color notation for a dry soil sample
dry_hue	Hue in Munsell color notation for a dry soil sample
dry_value	Value in Munsell color notation for a dry soil sample
dry_chroma	Chroma in Munsell color notation for a dry soil sample
moist_hue_scale	Scale from 1–10 for hue in Munsell color notation for a moist soil sample
moist_hue	Hue in Munsell color notation for a moist soil sample
moist_value	Value in Munsell color notation for a moist soil sample
moist_chroma	Chroma in Munsell color notation for a moist soil sample
texture	Soil texture by manual determination
pH	pH of soil horizon
comments	Any additional comments

1m. Identity 13: Data in the file soil_particle_distribution_all.csv are organized laterally in rows with variables in columns. From the soil samples from 1992–2012, each row of the data represents one observation for each plot and each depth of soil. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an "E" or "W" if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	
date	The date (month/day/year) when the soil sample was taken	
soil_location_description	Description of soil sample location (e.g., ltras_1992_location_1, SW soil sampling location, or whole_plot_compilation; see Fig. 5 for 1992 soil sample locations)	
depth_top_cm	Depth from soil surface to the top of the soil sample	cm
depth_bottom_cm	Depth from soil surface to the bottom of the soil sample	cm
sand_.	Sand in the soil sample	%
silt_.	Silt in the soil sample	%
clay_.	Clay in the soil sample	%

1n. Identity 14: Data in the file soil_total_CN_all.csv are organized laterally in rows with variables in columns. From 1993–2003, each row of the data represents one year of observation for each plot and each depth of soil. Where multiple values occur for the same plot, date and depth, the same sample was repeatedly analyzed to determine method variability. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an “E” or “W” if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	
date	The date (month/day/year) when the soil sample was taken	
soil_location_description	Description of soil sample location (whole_plot_compilation, west_side_compilation, or east_side_compilation; see Fig. 5 for soil sampling locations)	
depth_top_cm	Depth from soil surface to the top of the soil sample	cm
depth_bottom_cm	Depth from soil surface to the bottom of the soil sample	cm
total_nitrogen_.	Total soil N determined by combustion (see methods above)	%
total_carbon_.	Total soil C determined by combustion (see methods above)	%

1o. Identity 15: Data in the file soil_organic_matter_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an “E” or “W” if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row)	
system_name	Cropping system name	
date	The date (month/day/year) when the soil sample was taken	
soil_location_description	Description of soil sample location (e.g., ltras_1992_location_1, whole_plot_compilation; see Fig. 5 for soil sample locations)	
depth_top_cm	Depth from soil surface to the top of the soil sample	cm
depth_bottom_cm	Depth from soil surface to the bottom of the soil sample	cm
organic_matter_.	Organic matter	%
methodology	Methodology used to measure organic matter (see methods above)	

1p. Identity 16: Data in the file soil_extracts_N_all.csv are organized laterally in rows with variables in columns. Variables in the.csv file are:

Column/Variable Name	Variable Description	Unit
plot	Plot number: Each plot is indicated by 1-1 through 8-9	
system_name	Cropping system name	
date	The date (month/day/year) when the soil sample was taken	
soil_location_description	Description of soil sample location (e.g., whole plot compilation, safs_location_2007_1 through safs_location_2007_5; see Fig. 5 for soil sample locations)	
depth_top_cm	Depth from soil surface to the top of the soil sample	cm
depth_bottom_cm	Depth from soil surface to the bottom of the soil sample	cm
ammonium_ppm	Extractable soil ammonium (see methods above); negative or zero values may reflect values below the instrument's minimum detection limit	ppm
nitrate_ppm	Exchangeable soil nitrate (see methods above); negative or zero values may reflect values below the instrument's minimum detection limit	ppm
methodology	Method of measuring soil ammonium and nitrate (either Doane and Miranda, or Keeney and Nelson, see methods above)	

1q. Identity 17: Data in the file soil_extracts_PKS_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9	
system_name	Cropping system name	
date	The date (month/day/year) when the soil sample was taken	
depth_top_cm	Depth from soil surface to the top of the soil sample	cm
depth_bottom_cm	Depth from soil surface to the bottom of the soil sample	cm
phosphorus_ppm	Extractable soil phosphate measured with Olsen method (see methods above)	ppm
potassium_ppm	Exchangeable soil potassium (see methods above)	ppm
sulfur_ppm	Soil sulfate sulfur measured by extraction (see methods above)	ppm

1r. Identity 18: Data in the file soil_hydraulic_properties_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1	

	through 8-9	
system_name	Cropping system name	
date	The date (month/day/year) when the soil sample was taken	
soil_location_description	Description of soil sample location (e.g., ltras_1992_location_1, SW soil sampling location; see Fig. 5 for soil sample locations)	
depth_top_cm	Depth from soil surface to the top of the soil sample	cm
depth_bottom_cm	Depth from soil surface to the bottom of the soil sample	cm
saturated_hydraulic_conductivity_cm_hr	Saturated hydraulic conductivity	cm/hr
saturated_water_retention_cm3_cm3	Saturated water retention	cm^3/ cm^3

1s. Identity 19: Data in the file weather_all.csv are organized laterally in rows with variables in columns. Each row of the data represents the average, maximum, or minimum weather observation over one day, as specified below. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
date	The date (month/day/year) when the weather data was taken	

day_of_year	The day of year (from 1 to 365/366, with January 1st = 1)	
rain..mm.	Depth of rain per day	mm
air.temp.max..C.	Maximum daily air temperature	^oC
air.temp.min..C.	Minimum daily air temperature	^oC
air_t_avg_c	Average daily air temperature	^oC
soil.temp.max..C.	Maximum daily soil temperature at 0.3 m below soil surface	^oC
soil.temp.min..C.	Minimum daily soil temperature at 0.3 m below soil surface	^oC
soil_t_avg_c	Average soil temperature at 0.3 m below soil surface	^oC
solar_W.m2	Average daily solar radiation in Watts per square m (see methods above)	W/m^2
solar_MJ.day.m2	Total daily solar radiation in Megajoules per day per square m (see methods above)	$MJ/day/m^2$
RH_avg	Average relative humidity	%
RH_max	Maximum relative humidity	%
RH_min	Minimum relative humidity	%
dew_pt_avg	Average daily dew point	^oC

horizontal_wind_speed_km.hr	Mean horizontal wind speed	km/hr
wind_direction_mrad	Unit vector mean wind direction in milliradians	mrad
daily_max_wind_km.hr	Daily maximum wind speed	km/hr
time_of_max_wind	Time of max wind with the first two digits as the hour and the last two as the minute, in the 24-hour clock (ie. 1234 is 12:34)	
direction_max_wind_mrad	Direction of max wind in milliradians	mrad
yearly_rain	Cumulative depth of rain per year	mm
solar_radiation_avg_W.m2	Net average solar radiation (see methods above)	W/m^2
daily_ET0	Evapotranspiration rate per day	mm/day
wind_run_km	Amount of wind passing daily (speed of wind multiplied by time)	km
vapor_pressure_avg_kpa	Average vapor pressure in Kilopascals	KPa
soil_t_depth_max_c	Maximum soil temperature at 0.9 m depth	^{o}C
soil_t_depth_min_c	Minimum soil temperature at 0.9 m depth	^{o}C
soil_t_depth_avg_c	Average soil temperature at 0.9 m depth	^{o}C

1t. Identity 20: Data in the file weed_measurements_all.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	Variable Description	Unit
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an “E” or “W” if applicable to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid and the 3rd row); note, in years when plots were split by tillage treatment (standard vs. conservation tillage) only the standard side of the plot was monitored	
system_name	Cropping system name	
date	The date (month/day/year) when weed observation occurred	
winter weed year	Year for which winter weed populations were monitored; if monitored at the end of the calendar year (e.g., 12/31/1993), the winter weed year is the following calendar year (e.g., 1994)	
quadrat	Number of quadrat within plot; in years when plots were split, only the standard tillage side was monitored, and quadrats within the conservation tillage area were not monitored and are not included in this data set	
AMSIN	Number of *Amsinckia intermedia* (coast fiddleneck) observed within quadrat	
ANTCO	Number of *Anthemis cotula* (mayweed) observed within quadrat	

AVEFA	Number of *Avena fatua* (wild oats) observed within quadrat
CAPBP	Number of *Capsella bursa-pastoris* (shepherd's purse) observed within quadrat
CENSO	Number of *Centaurea solstitialis* (yellow starthistle) observed within quadrat
CHEAL	Number of *Chenopodium album* (lambsquarters) observed within quadrat
CLAPE	Number of *Claytonia (Montia) perfoliata* (miner’s lettuce) observed within quadrat; note, in some years CLAPE observations were combined in the CLNCM weed category, as noted in the comments column
CLNCM	Number of *Calandrinia ciliata* (desert rock purslane; redmaids) observed within quadrat
CONAR	Number of *Convolvulus arvensis* (field bindweed) observed within quadrat
CVCCA	Number of *Cuscuta campestris* (dodder) observed within quadrat
CYPES	Number of *Cyperus esculentus* (yellow nutsedge) observed within quadrat
ECHCG	Number of *Echinochloa crus-galli* (barnyardgrass) observed within quadrat
EPIPC	Number of *Epilobium paniculatum* (panicled willow

	herb) observed within quadrat
ERIBO	Number of *Conyza bonariensis* (flax-leaved fleabane) observed within quadrat
ERICA	Number of *Conyza canadensis* (horseweed) observed within quadrat
HRYGL_HRYRA	Number of *Hypochaeris radicata* (common cat's ear) *Hypochaeris glabra* (smooth cat's ear) observed within quadrat
KICEL	Number of *Kickxia elatine* (sharppoint fluvellin) observed within quadrat
LACSE	Number of *Lactuca serriola* (prickly lettuce) observed within quadrat
LAMAM	Number of *Lamium amplexicaule* (henbit) observed within quadrat
LOLMU	Number of *Lolium multiflorum* (Italian ryegrass) observed within quadrat
MALPA	Number of *Malva parviflora* (little mallow) observed within quadrat
MATMA	Number of *Matricaria matricarioides* (pineapple weed) observed within quadrat
MEDPO	Number of *Medicago polymorpha* (California burclover) observed within quadrat
MEUOF	Number of *Melilotus officinalis* (yellow

	sweetclover) observed within quadrat
PHACA	Number of *Phalaris canariensis* (canarygrass) observed within quadrat
PICEC	Number of *Picris echioides* (bristly ox-tongue) observed within quadrat
POANN	Number of *Poa annua* (annual bluegrass) observed within quadrat
POLAV	Number of *Polygonum aviculare* (common knotweed) observed within quadrat
RUMCR	Number of *Rumex crispus* (curly dock) observed within quadrat
SENVU	Number of *Senecio vulgaris* (common groundsel) observed within quadrat
SINAR	Number of *Sinapis arvensis* (wild mustard) observed within quadrat
SLYMA	Number of *Silybum marianum* (milk thistle) observed within quadrat
SOLNI	Number of *Solanum nigrum* (black nightshade) observed within quadrat
SONOL	Number of *Sonchus oleraceus* (common sowthistle, prickly) observed within quadrat
STEME	Number of *Stellaria media* (common chickweed) observed within quadrat

tomato	Number of *Lycopersicon esculentum* (tomato) volunteers observed within quadrat	
VERPG	Number of *Veronica peregrina* (purslane speedwell) observed within quadrat	
VETCH	Number of *Vicia villosa* (vetch) observed within quadrat	
XANST	Number of *Xanthium strumarium* (cocklebur) observed within quadrat	
wheat	Number of *Triticum aestivum* (wheat) volunteers observed within quadrat	
other	Number of other weed species observed	
width..m.	Width of quadrat	m
length..m.	Length of quadrat	m
area..m2.	Area of quadrat	m^2
other_species_comments	Comments on other species observed	
comments	Comments on data collection	
total_weeds	Total number of individual weed species observed within quadrat	
population_density	Density of all weed species in the surveyed area	weeds/m^2

1u. Identity 21: Data in the file water_analyses_all.csv are organized laterally in rows with each row of the data representing one water sampling per well. Variables are in columns. Variables in the Excel .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
date	The date (month/day/year) when the water sample was taken	
well_name	Well sampled at Russell Ranch	
NO3.N_ppm	Nitrate (NO_3^-)-N in irrigation water	ppm
Na_Soluble_meq.L	Sodium (Na^+) in irrigation water	meq/L
Ca_Soluble_meq.L	Calcium (Ca^{2+}) in irrigation water	meq/L
Mg_Soluble_meq.L	Magnesium (Mg^{2+}) in irrigation water	meq/L
CO3_meq.L	Carbonate (CO_3^{2-}) in irrigation water	meq/L
HCO3_meq.L	Bicarbonate (HCO_3^-) in irrigation water	meq/L
Cl_meq.L	Chlorine (Cl^-) in irrigation water	meq/L
PO4_ppm	Soluble phosphate (PO_4^{3-}) in irrigation water	ppm
K_ppm	Potassium (K^+) in irrigation water	ppm
SO4_ppm	Sulfate (SO_4^{2-}) in irrigation water	ppm
B_ppm	Boron (B) in irrigation water	ppm

TDS_ppm	Total dissolved solids	ppm
NH4.N_mg.L	Ammonium (NH_4^+)-N in irrigation water	mg/L
EC_ds.m	Electrical conductivity (EC) of irrigation water in deciSiemens (dS) per m	dS/m
pH	pH of irrigation water	
SAR	Sodium adsorption ratio	

1v. Identity 22: Data in the file ndvi_all.csv are organized laterally in rows. From 1993–2002, each row of the data represents one aerial photograph of each plot. Variables are in columns. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9	
system_name	Cropping system name	
date	The date (month/day/year) when the aerial photograph was taken	
ndvi_value	Average NDVI value for all pixels within the plot; NDVI is calculated based on the description in the methods section above	
image_attached	Yes or No, based on whether an Infrared scan for all plots is included in the images zip file	

file_name	File name of attached image, if any (format is RR_YEAR_MONTH_DAY.TIF)

1w. Identity 23: Data in the file operations_fertilizers.csv are organized laterally in rows. From 1993–2013, each row of the data represents one fertilizer application for each plot. Variables are in columns. Variables in the Excel .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9	
system_name	Cropping system name	
date	The date (month/day/year) when the crop was fertilized	
crop_fertilized	Crop in the rotation that was fertilized	
material_applied	Fertilizer applied to the crop	
fertilizer_brand	Trademark of fertilizer applied	
total_applied_material_kg.ha	Total weight of fertilizer applied	kg/ha
nitrogen_applied_kg.ha	Weight of nitrogen applied	kg/ha
potassium_applied_kg.ha	Weight of potassium applied (as K_2O)	kg/ha
phosphorus_applied_kg.ha	Weight of phosphorus applied (as PO_4)	kg/ha
sulfur_applied_kg.ha	Weight of sulfur applied (as SO_4)	kg/ha

1x. Identity 24: Data in the file compost_analyses_summary.csv are organized laterally in rows. Each row of the data represents one analysis of a compost sample for the compost that was applied uniformly in the transitional and organic corn-tomato systems. Variables are in columns. Variables in the Excel .csv file are:

Column/Variable Name	Variable Description	Unit
year	The year when the compost was applied and the compost sample was taken	
compost_analysis_parameter	Type of chemical composition analysis (described in sampling methods above)	
analysis_value	Analysis value of compost analysis described in column B	
units	Units of value in column C	
analytical_lab	The analytical lab performing the analysis (either UC Analytical Lab, Denele Analytical, or In-house Costech, see methods above)	

1y. Identity 25: Data in the file operations_pesticides.csv are organized laterally in rows, with each row of the data representing one pesticide application for each plot. Variables are in columns. Variables in the .csv file are:

Column/Variable Name	Variable Description	Unit
plot	Plot number: Each plot is indicated by 1-1 through 8-9	
system_name	Cropping system name	

date	The date (month/day/year) when the pesticide was applied	
crop_applied	Crop in the rotation that was treated with pesticides	
method_application	Method of pesticide application (spray, incorporate, mulch or combined fertilizer and pesticide application)	
number_of_passes	Number of passes for pesticide application	
material_applied	Pesticide applied to crop	
additional_description	Additional description of pesticide (trademark, organic certification)	
EPA_registration_number	Registration number with the Environmental Protection Agency (EPA)	
material_quantity	Quantity of pesticide applied to crop	
material_units	Units (amount per unit area) of pesticide application	

1z. Identity 26: Data in the file operations_planting.csv are organized laterally in rows with variables in columns. Variables in the Excel .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9	
system_name	Cropping system name	

date	The date (month/day/year) when planting was performed	
crop_planted	Crop in the rotation that was planted	
operation_type	Type of planting operation (transplant, seed or seed and fertilize)	
tractor	Tractor used to plant crop	
equipment	Equipment used to plant crop (if equipment is integrated into the tractor then “no equipment” is listed)	
number_of_passes	Number of passes for planting	
material_planted	Material that was planted	
additional_description	Additional description (variety, organic)	
material_quantity	Amount of planting material planted	
material_units	Units of planting material	

1aa. Identity 27: Data in the file operations_harvest.csv are organized laterally in rows with variables in columns. Variables in the Excel .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9 and then an “E” or “W” to designate the east or west side of the plot (e.g., 4-3W is the west side of plot 4-3, which is in the 4th column of the plot grid	

	and the 3rd row)
system_name	Cropping system name
date	The date (month/day/year) when the harvest was performed
harvest.year	Year of harvest operation
crop_harvested	Crop in the rotation that was harvested
description_harvest	Description of harvest performed
tractor	Tractor used to harvest crop
equipment	Equipment used to harvest crop (if equipment is integrated into the tractor then “no equipment” is listed)
number_of_passes	Number of passes for harvest

1bb. Identity 28: Data in the file operations_compost.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
plot	Plot number: Each plot is indicated by 1-1 through 8-9	
system_name	Cropping system name	
Date	The date (month/day/year) when the harvest was	

	performed
compost_applied_wet_weight	Quantity of moist compost applied to crop
material_units	Units (amount per unit area) of compost application

1cc. Identity 29: Data in the file plot_system.csv are organized laterally in rows with variables in columns. Variables in the .csv file are:

Column/Variable Name	**Variable Description**	**Unit**
Plot	Plot number: Each plot is indicated by 1-1 through 8-9	
new_system_name	Cropping system name as of 2014	
new_system_name	Original cropping system name as assigned in 1993	
main_crops	Main cash crops planted in plot	
harvest_year_rotation_order_(even_odd)	Planned harvest rotation order (even-odd years)	
harvest_year	Year of operation	
crop_A_planned	Early season (spring) crop planned for planting in plot; may differ from crop_A_planted	
crop_A_planted	Early season (spring) crop planted in plot; may differ from crop_A_planned	

crop_A_date_planted	Date, or range of dates, for planting of crop A	
crop_A_planned_harvest	Crop planned for harvest in early season (spring/summer) in plot; may differ from crop_A_harvested	
crop_A_harvested	Crop harvested in early season (spring/summer) in plot; may differ from crop_A_planned harvest	
crop_A_date_harvested	Date, or range of dates, for harvest of crop A	
crop_B_planned	Late season (fall) crop planned for planting in plot; may differ from crop_B_planted	
crop_B_planted	Late season (fall) crop planted in plot; may differ from crop_B_planned	
crop_B_date_planted	Date, or range of dates, for planting of crop B	
crop_B_planned_harvest	Crop planned for harvest in late season (fall) in plot; may differ from crop_B_harvested	
crop_B_harvested	Crop harvested in late season (fall) in plot; may differ from crop_B_planned harvest	
crop_B_date_harvested	Date, or range of dates, for harvest of crop B	
Century_Experiment_Core	Is this plot/system part of the core of the Century Experiment in the given year?	Y/N
anomalies	Description of changes to system or data	

collection

CLASS V. SUPPLEMENTAL DESCRIPTORS

A. Data acquisition

1. Data forms or acquisition methods

Paper field sheets (1993–present) and subsequent entry into an Access database.

2. Location of completed data forms

The original paper field sheets collected between 1993–2014 were stored in the Plant and Environmental Sciences Building (room 1315) in notebooks. Copies of the field sheets were stored in the Agricultural Sustainability Institute's Robbins Hall Annex and Russell Ranch Analytical Laboratory in the Plant and Environmental Sciences Building (both at 1 Shields Avenue, Davis, CA 95616). Electronic copies were archived on the Agricultural Sustainability Institute's cloud storage drive at ucdavis.box.com.

3. Data entry and verification procedures

The original data were recorded by hand onto paper field sheets (1993–present). The data were entered into a Lotus Database file (.dbf) until 2002, and then transferred to and entered into an Access Database file (.accdb) after that period. All data entries were checked against field sheets for each observation period to check for typographical and data-entry errors.

B. Quality assurance and quality control procedures

Data for the period 1993–2011 were double-checked when transferred into the Access database from previous years of data. Since 2012, all data were entered annually at the end of the field season and double-checked after entry. We then computed yearly averages, compared with the historical records, and investigated outliers. If any irregularities were found, we searched original field sheets and lab notebooks and interviewed field personnel to determine and correct the error, when possible.

C. Related material

Not applicable.

D. Computer programs and data processing algorithms

Not applicable.

E. Archiving

1. Archival procedures

For descriptions of the archival process for physical soil and plant samples, see Class II, Section A, Subsections 2 and 3. Physical archival samples were housed in locked facilities at on the U.C. Davis campus (1 Shields Avenue, Davis, CA 95616) and at Russell Ranch (Kinsella Lane, Davis, CA 95616).

2. Redundant archival sites

Not applicable.

F. Publications and results

A variety of articles have been published over the 20+ years of experiments being conducted at Russell Ranch. Many of these publications investigate very specific parameters and responses to experimental treatments, and are only fractional subsets – or data sources outside the realm – of the core data presented in this data paper. A list of publications using these and other related data sets can be found at: http://russellranch.ucdavis.edu/publications.

LITERATURE CITED

AGROVOC. 2016. AGROVOC Multilingual agricultural thesaurus. Food and Agriculture Organization, Washington, DC, USA. Available online at: http://aims.fao.org/vest-registry/vocabularies/agrovoc-multilingual-agricultural-thesaurus (accessed 23 Nov 2016).

[AOAC] AOAC International. 1997. AOAC official method 972.43, microchemical determination of carbon, hydrogen, and nitrogen. In: Official methods of analysis of AOAC International, 16th ed., pp. 5–6. AOAC International, Arlington, VA, USA.

Bingham, F. T. 1982. Boron. In: Methods of soil analysis, Part 2. Chemical and microbiological properties. Page, A. L., R. H. Miller, and D. R. Keeney (Eds.) Agronomy Monograph no. 9, 2nd ed., pp. 431–448. ASA and SSSA, Madison, WI, USA.

Blake, G. R., and K. H. Hartge. 1986. Bulk density. In: Methods of soil analysis, Part 1. Physical and mineralogical methods. Klute, A. (Ed.) Agronomy Monograph no. 9, pp. 363–375. American Society of Agronomy-Soil Science Society of America, Madison, WI, USA.

Blake, L., K. W. T. Goulding, C. J. B. Mott, and P. R. Poulton. 2000. Temporal changes in chemical properties of air-dried soils and their interpretation for long-term experiments. *European Journal of Soil Science* 51:345–353.

Carlson, R. M., R. I. Cabrera, J. L. Paul, J. Quick, and R. Y. Evans, 1990. Rapid direct determination of ammonium and nitrate in soil and plant tissue extracts. *Communications in Soil Science & Plant Analysis* 21:1519–29.

Clesceri, L. S., A. E. Greenberg, and A. D. Eaton. 1998. Standard methods for the examination of water and wastewater, 20th ed. American Public Health Association, Washington, DC, USA.

Denison, R. F., D. C. Bryant, and T. E. Kearny. 2004. Crop yields over the first nine years of LTRAS, a long-term comparison of field crop systems in a Mediterranean climate. *Field Crops Research* 86:267–277.

Denison, R. L., R. Miller, D. Bryant, A. Abshahi, and W. Wildman. 1996. Image processing extracts more information from color infrared aerial photos. *California Agriculture* 50:9–13.

Diamond, D. 1994. Determination of chloride by flow injection analysis colorimetry. QuikChem Method 10-117-07-1-B. Lachat Instruments, Milwaukee, WI, USA.

Doane, T. A., and W. R. Horwath. 2003. Spectrophotometric determination of nitrate with a single reagent. *Analytical Letters* 36:2713–2722.

Fitzpatrick, E. A. 1967. Soil nomenclature and classification. *Geoderma* 1:91–105.

Gardner, W. H. 1986. Water content. In: Methods of soil analysis, Part 1. Physical and mineralogical methods. Klute, A. (Ed.) Agronomy Monograph no. 9, 2nd ed., pp. 493–544, 2nd ed. American Society of Agronomy-Soil Science Society of America, Madison, WI, USA.

Gavlak, R. G., D. A. Horneck, and R. O. Miller. 2005. Plant, soil and water reference methods for the Western region, 3rd ed. Western Region Extension Publication 125, WCC-103 Publication, Corvallis, OR, USA.

Gilhousen, D. B. 1987. A field evaluation of NDBC moored buoy winds. *Journal of Atmospheric and Oceanic Technology* 4:94–104.

Harris, D., W. R. Horwath, and C. van Kessel. 2001. Acid fumigation of soils to remove carbonates prior to total organic carbon or carbon-13 isotopic analysis. *Soil Science Society of America Journal* 65:1853–1856.

Hasegawa, H., J. M. Labavitch, A. M. McGuire, D. C. Bryant, and R. F. Denison. 1999. Testing CERES model predictions of N release from legume cover crop residue. *Field Crops Research* 63:255–267.

Hofer, S. 2003. Determination of ammonia (Salicylate) in 2M KCl soil extracts by flow injection analysis. QuikChem Method 12-107-06-2-A. Lachat Instruments, Loveland, CO, USA.

Horneck, D. A., J. M. Hart, K. Topper, and B. Koepsell. 1989. Methods of soil analysis used in the soil testing laboratory at Oregon State University. Agricultural Experiment Station, Oregon State University, Corvallis, OR, USA.

Jenkinson, D. S. 1991. The Rothamsted long-term experiments: are they still of use? *Agronomy Journal* 83:2–10.

Johansen, H. N., V. Glitso, and K. E. B. Knudsen. 1996. Influence of extraction solvent and temperature on the quantitative determination of oligosaccharides from plant materials by high-performance liquid chromatography. *Journal of Agricultural and Food Chem*istry 44:1470–1474.

Jones, Jr. J. B. 2001. Extraction of Cl, NO_3, PO_4, K, and SO_4 from plant tissue. In: Laboratory guide for conducting soil tests and plant analysis. Jones Jr., J. B. (Ed.) pp. 228–229. CRC Press, Boca Raton, FL, USA.

Kaffka, S. 2006. The design of LTRAS and data analysis. Available online at: http://asi.ucdavis.edu/programs/rr/publications/designofltras-dataanalysis.pdf. Russell Ranch, University of California, Davis, USA.

Keeney, D. R., and D. W. Nelson. 1982. Nitrogen-inorganic forms. In: Methods of soil analysis, Part 2. Chemical and microbiological properties. Page, A. L., R. H. Miller, and D. R. Keeney (Eds.) Agronomy Monograph no. 9, 2nd ed., pp. 643–698. American Society of Agronomy-Soil Science Society of America, Madison, WI, USA.

Klute, A., and C. Dirksen. 1986. Hydraulic conductivity and diffusivity: laboratory methods. In: Methods of soil analysis, Part 1. Physical and mineralogical methods. Klute, A. (Ed.) Agronomy Monograph no. 9, 2nd ed., pp. 687–734. American Society of Agronomy-Soil Science Society of America, Madison, WI, USA.

Knepel, K. 2003. Determination of nitrate in 2M KCl soil extracts by flow injection analysis. QuikChem Method 12-107-04-1-B. Lachat Instruments, Loveland, CO, USA.

Knudsen, D., G. A. Peterson, and P. F. Pratt. 1982. In: Methods of soil analysis, Part 2. Chemical and microbiological properties. Page, A. L., R. H. Miller, and D. R. Keeney (Eds.) Agronomy Monograph no. 9, 2nd ed., pp. 225–246. American Society of Agronomy-Soil Science Society of America, Madison, WI, USA.

Kong, A. Y., S. J. Fonte, C. van Kessel, and J. Six. 2009. Transitioning from standard to minimum tillage: Trade-offs between soil organic matter stabilization, nitrous oxide emissions, and N availability in irrigated cropping systems. *Soil and Tillage Research* 104:256–262.

Lindsay, W. L., and W. A. Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal* 42:421–428.

Littlefield, E. S., R. O. Miller, and R. M. Carlson. 1990. Determination of sulfate-sulfur in plant tissue by inductively coupled plasma spectrometry. *Soil Science & Plant Analysis* 21:1577–1586.

Loku, L. W. 1991. Inductively coupled plasma atomic emission spectrometry for the analysis of soil extracts prepared on ion-exchange resins. *Analyst* 116:601–603.

Mahler, R. L., D. V. Naylor, and M. K. Fredickson. 1984. Hot water extraction of boron from soils using sealed plastic pouches. *Communications in Soil Science and Plant Analysis* 15:479–492.

Martini, E. A., J. S. Buyer, D. C. Bryant, T. K., Hartz, and R. F. Denison. 2004. Yield increases during the organic transition: improving soil quality or increasing experience? *Field*

Crops Research 86:255–266.

McGuire, A. M., D. C. Bryant, and R. F. Denison. 1998. Wheat yields, nitrogen uptake, and soil moisture following winter legume cover crop vs. fallow. *Agronomy Journal* 90:404–410.

Meyer, G. A., and P. N. Keliher. 1992. An overview of analysis by inductively coupled plasma-atomic emission spectrometry. In: Inductively coupled plasmas in analytical atomic spectrometry. Montaser A., and D.W. Golightly (Eds.) pp. 473-516. VCH Publishers, New York, NY, USA.

Miranda, K. M., M. G. Espey, and D. A. Wink. 2001. A rapid, simple spectrophotometric method for simultaneous detection of nitrate and nitrite. *Nitric oxide* 5:62–71.

Munsell. 2000. Munsell soil color charts. Revised. Washable ed. Munsell Color, New Windsor, NY, USA.

Nelson, D. W., and L. E. Sommers. 1982. Total carbon, organic carbon and organic matter. In: Methods of soil analysis, Part 2. Chemical and microbiological properties. Page, A. L., R. H. Miller, and D. R. Keeney (Eds.) Agronomy Monograph no. 9, 2nd ed., pp. 539–579. American Society of Agronomy-Soil Science Society of America, Madison, WI, USA.

[NOAA] National Oceanic and Atmospheric Administration, 2016. NOAA's national weather service – glossary. National Oceanic and Atmospheric Administration, National Weather Service, Washington, DC, USA. Available online at: http://www.crh.noaa.gov/glossary.php (accessed 28 Nov 2016).

[NRCS] Natural Resources Conservation Service. 2013. Web soil survey. United States Department of Agriculture, Washington, DC, USA. Available online at: http://websoilsurvey.nrcs.usda.gov/ (accessed 27 Oct 2016).

Olsen, S. R., and L. E. Sommers. 1982. Phosphorus. In: Methods of soil analysis, Part 2. Chemical and microbiological properties. Page, A. L., R. H. Miller, and D. R. Keeney (Eds.) Agronomy Monograph no. 9, 2nd ed., pp. 403-430. ASA and SSSA, Madison, WI, USA.

Park, D. H., and J. W. Park. 2011. Wireless sensor network-based greenhouse environment monitoring and automatic control system for dew condensation prevention. *Sensors* 11:3640–3651.

Paustian, K., W. J. Parton, and J. Persson. 1992. Modeling soil organic matter in organic-amended and nitrogen-fertilized long-term plots. *Soil Science Society of America Journal*. 56:476–488.

Pella, E. 1990. Combustion gas analyzer method for total carbon and total nitrogen. *Elemental Organic Analysis* 1:1–16.

Poulton, P. R. 2003. Practical considerations for the sampling and storage of soils and crops from long-term experiments. (Condensed English version of paper published in Russian). In: Progress in the long-term trials methodology and the mathematical methods of experimental data processing. Semenov, V. A., L. K. Shevtsova, and V. A. Romanenkov (Eds.) pp. 239–257. All Russian Research Institute for Fertilizers and Agricultural Soil Science after D. N. Prianishnikov, Agroconsult, Moscow, Agriculture and the Environment Division, Rothamsted Experimental Station, Harpenden, Herts, UK.

Prokopy, W. R. 1995a. Phosphorus in 0.5 M sodium bicarbonate soil extracts. QuikChem Method 12-115-01-1-B. Lachat Instruments, Milwaukee, WI, USA.

Prokopy, W. R. 1995b. Phosphorus in acetic acid extracts. QuikChem Method 12-115-01-1-C. Lachat Instruments, Milwaukee, WI, USA.

Sah, R. N., and R. O. Miller. 1992. Spontaneous reaction for acid dissolution of biological tissues in closed vessels. *Analytical Chem*istry 64:230–233.

Schulte, E. E., and K. Eik. 1988. Recommended sulfate-sulfur test. In: Recommended chemical soil test procedures for the North Central Region. W.C. Dahnke (Ed.) Bulletin No. 499 (revised), pp. 17–19. North Dakota Agriculture Experiment Station, Fargo, ND, USA.

Scow, K. M., E. T. Torbert, and T. P. Tomich. 2013. New science plan for the Century Experiment at the Russell Ranch Sustainable Agriculture Facility. Agricultural Sustainability Institute, University of California, Davis, USA. Available online at: http://asi.ucdavis.edu/programs/rr/about/russellranch-newscienceplan-revised2012.pdf (accessed 29 Nov 2016).

Sheldrick, B. H. 1986. Test of the LECO CHN-600 Determinator for soil carbon and nitrogen analysis. *Canadian Journal of Soil Science* 66:543–545.

Sheldrick, B. H., and C. Wang. 1993. Particle-size distribution. In: Carter, M. R. (ed), Soil Sampling and Methods of Analysis, pp. 499-511. Canadian Society of Soil Science, Lewis Publishers, Ann Arbor, MI.

Shlemon, R. J., T. Horner, and J. Florsheim. 2000. Quaternary geology of the Sacramento area. Sacramento section guidebook for March 2000 field trip. Association of Engineering Geologists, Sacramento, CA, USA.

Smith, D. 1969. Removing and analyzing total nonstructural carbohydrates from plant tissue. Research Bulletin Vol. 41. College of Agricultural and Life Sciences, University of

Wisconsin, Madison, WI, USA.

Storer, D. A. 1984. A simple high sample volume ashing procedure for determining soil organic matter. *Communications Soil Science and Plant Analysis* 15:759–772.

U.S. EPA. 2001. Method 200.7, trace elements in water, solids, and biosolids by inductively coupled plasma-atomic emission spectrometry. Rev. 5.0 U.S. Environmental Protection Agency, Washington, DC, USA.

U.S. Salinity Laboratory Staff. 1954. Choice of determinations and interpretation of data. In: Diagnosis and improvement of saline and alkali soils. L. A. Richards. (Ed.) USDA Agricultural Handbook 60, pp. 25–26. U.S. Government Printing Office, Washington, DC, USA.

Wagner, D. L., G. J. Saucedo, K. B. Clahan, R. J. Fleck, V. E. Langenheim, R. J. McLaughlin, A. M. Sarna-Wojcicki, J. R. Allen, and A. L. Deino. 2011 Geology, geochronology, and paleogeography of the southern Sonoma volcanic field and adjacent areas, northern San Francisco Bay region, California. *Geosphere* 7:658–683.

Wolf, N. 2003. Determination of manure electrical conductivity (EC). In: Recommended methods of manure analysis. Peters, J. (Ed.) Cooperative Extension Publication A 3769, pp. 50–51. University of Wisconsin, Madison, WI, USA.

[WSSA] Weed Science Society of America. 2016. Composite list of weeds. Weed Science Society of America, Lawrence, KY, USA. Available online at: http://wssa.net/wssa/weed/composite-list-of-weeds/ (accessed 10 Nov 2016).

Yeomans, J. C., and J. M. Bremmer. 1991. Carbon and nitrogen analysis of soils by automated combustion techniques. *Communications Soil Science and Plant Analysis* 22:843–850.

TABLES AND FIGURES

Figures

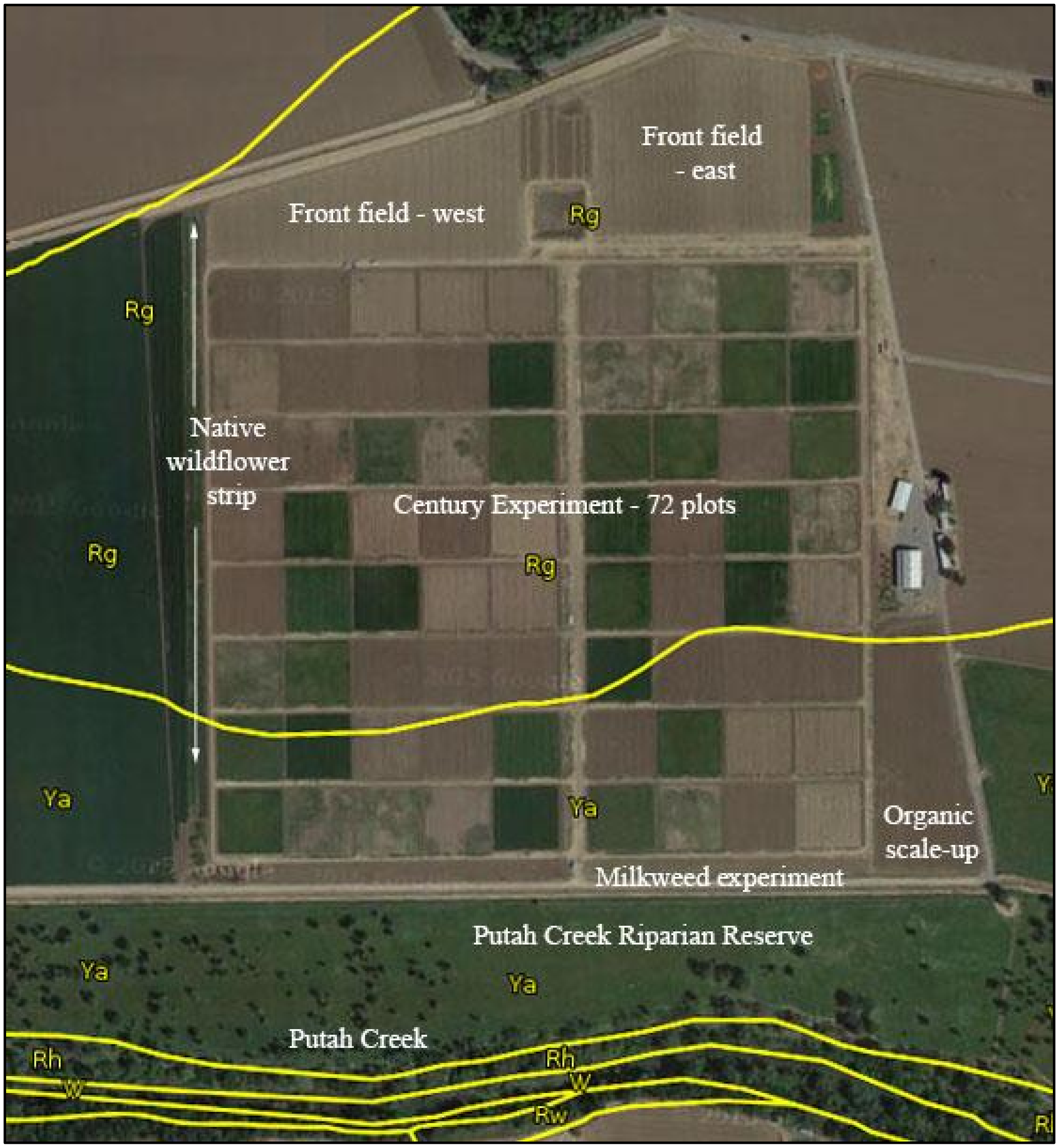

Figure 1. Aerial view of the Century Experiment, scale-up fields, and Putah Creek Riparian Reserve. The different soil types are indicated in yellow (Rg = Rincon silty clay loam, Ya = Yolo silt loam, Rh/Rw = riverwash, W = water).

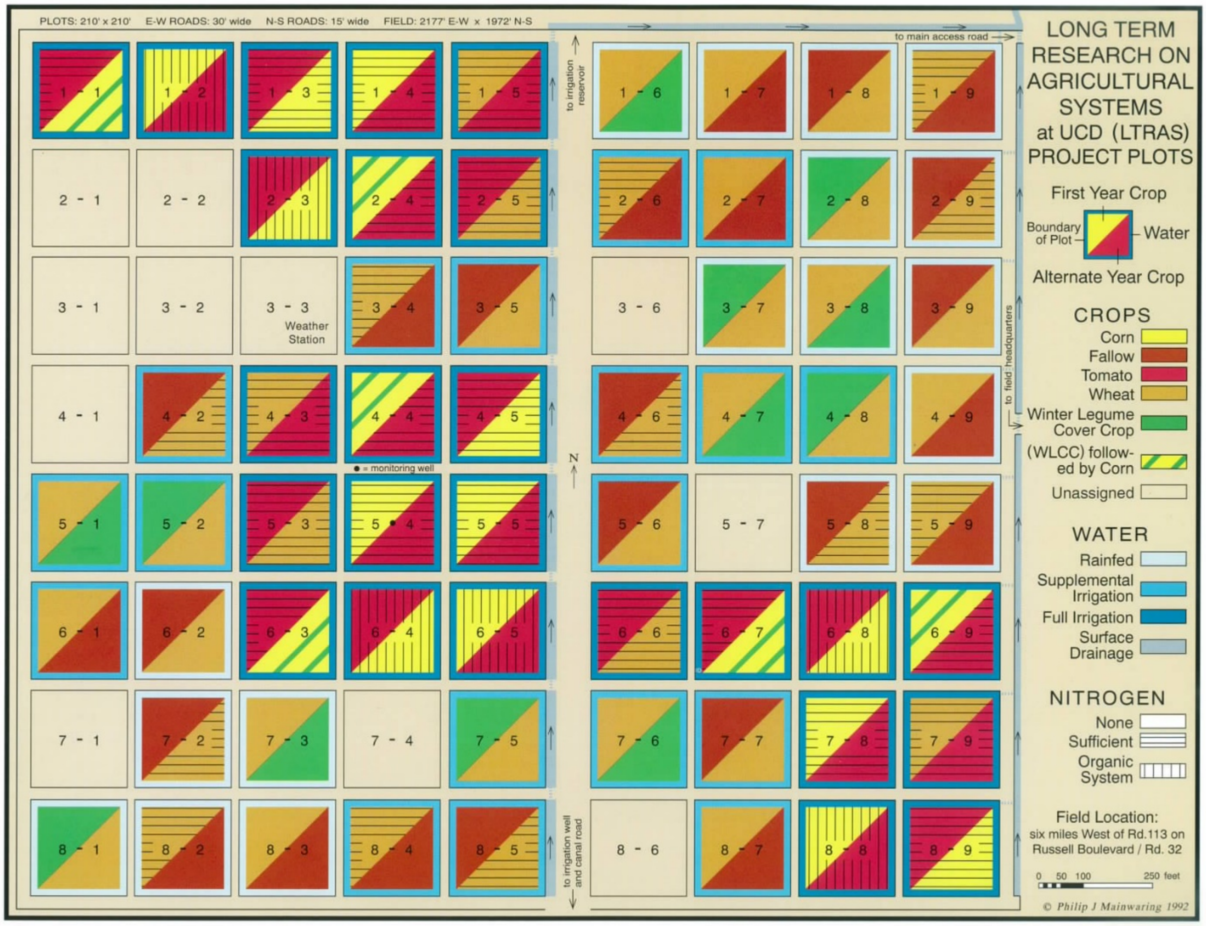

Figure 2. Original plot map of the Century Experiment designed in 1992.

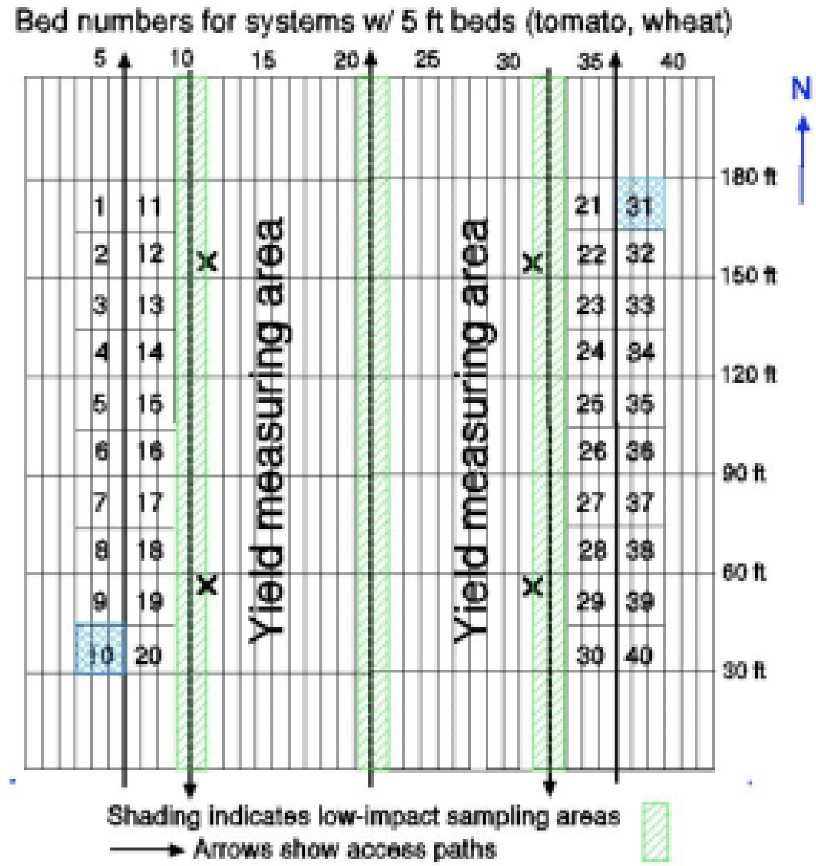

Figure 3. Microplot design in each 0.4-ha plot in the Century Experiment.

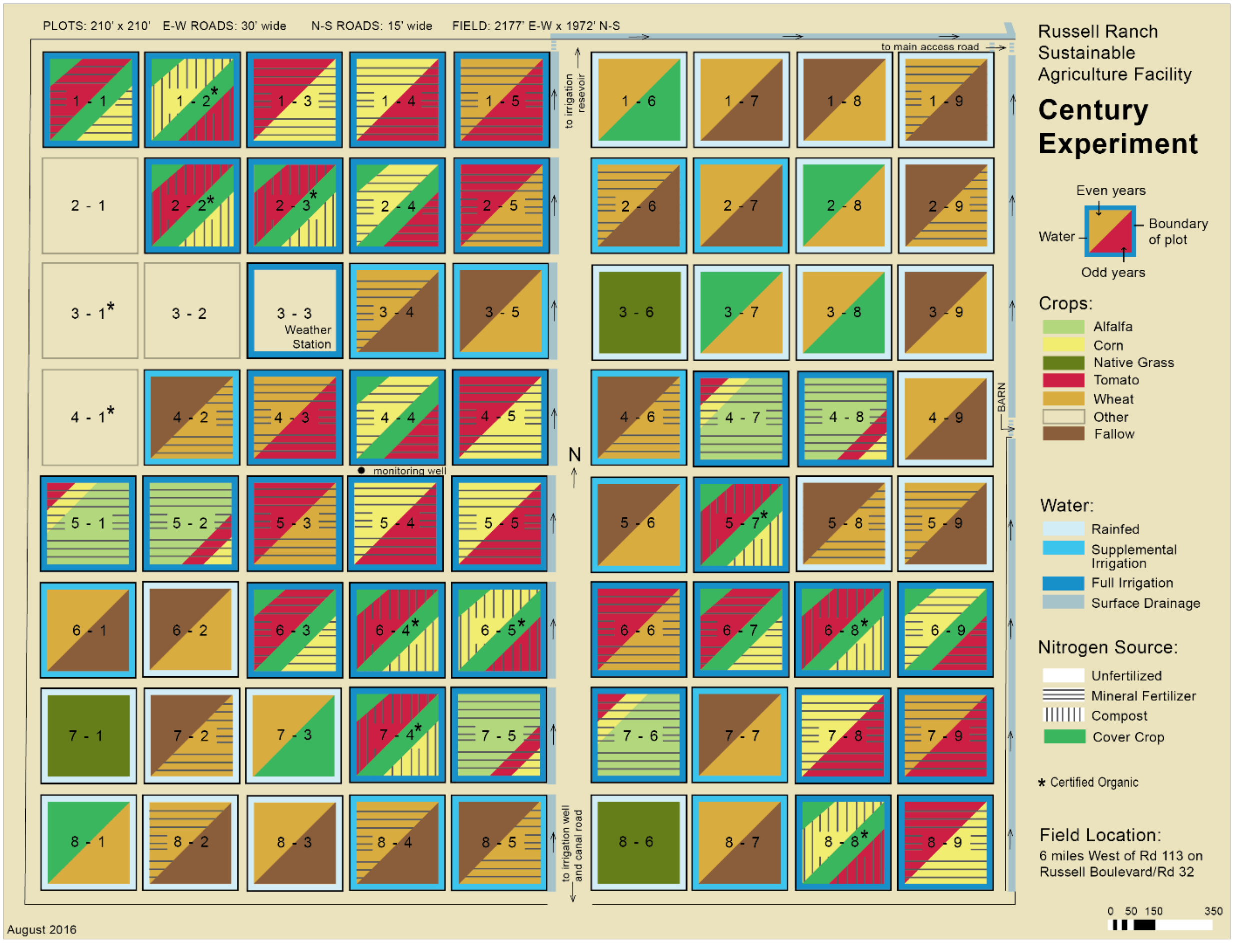

Figure 4. Current plot map of the Century Experiment, 2016.

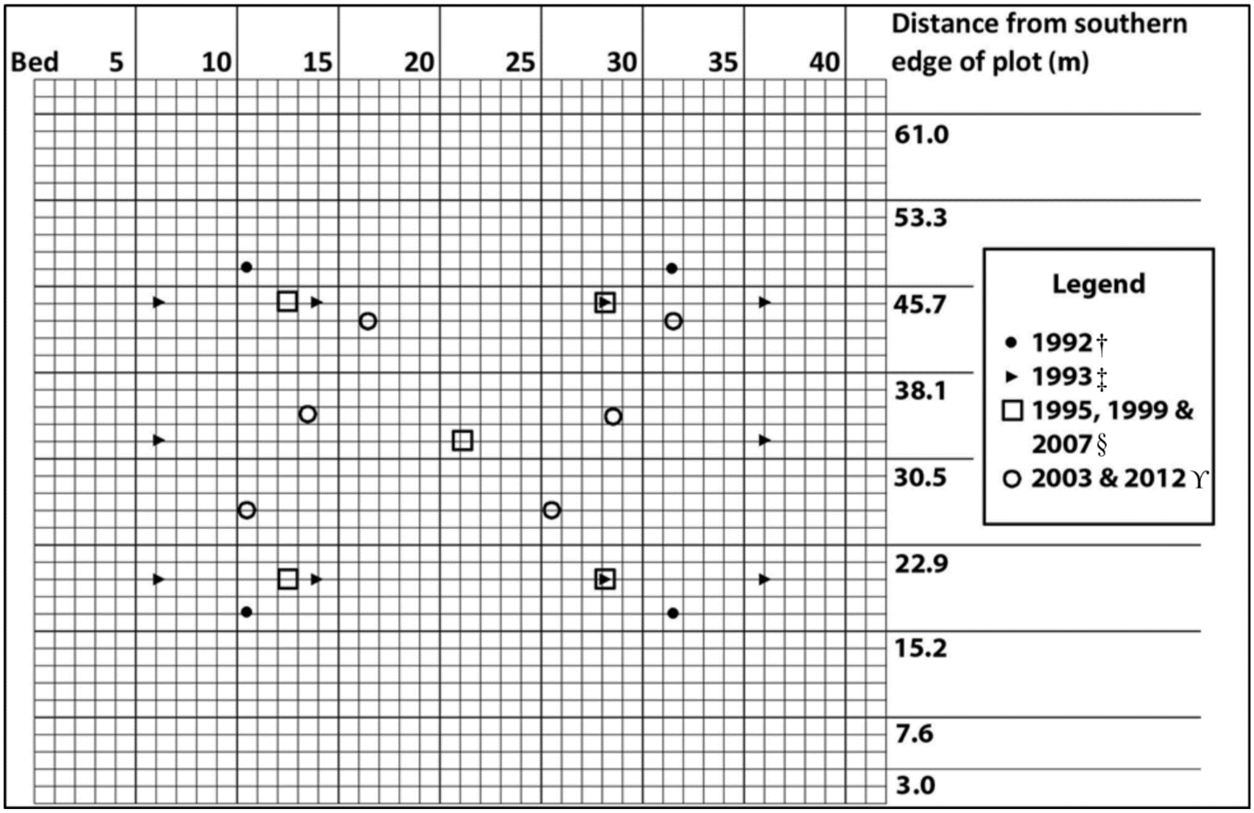

Figure 5. Soil sampling locations within each 0.4-ha plot from 1992–2012 in the Century Experiment.

Soil_location_descriptions in different data sets and quadrant locations within a plot can include:

† ltras_1992_location_1…4: 1 = SW, 2 = NW, 3 = NE, 4 = SE

‡ east/west/whole_plot_compilation: 5 samples on E side and 5 on W, with samples compile from each side; also one sample for whole plot compilation

§ safs_location_1…5: 1 = SW, 2 = middle of plot, 3 = NE, 4 = NW, 5 = SE

ϒ ltras_locations_1…6: 1 = SW, 2 = central W, 3 = NW, 4 = SE, 5 = central E, 6 = NE

Tables

Table 1. Original cropping systems for the Century Experiment

System	System Code	Irrigation	Fertilizer Source	Pesticides
Conventional Wheat-Tomato	CWT	Irrigated	Mineral Fertilizer	As needed
Conventional Corn-Tomato	CMT	Irrigation	Mineral Fertilizer	As needed
Legume-Corn-Tomato	LMT	Irrigated	Mineral Fertilizer + WCC	As needed
Organic Corn-Tomato	OMT	Irrigated	Compost + WCC	Organic
Wheat-Fallow	IWF	Irrigated	Mineral Fertilizer	As needed
Wheat-Fallow	IWC	Irrigated	None	As needed
Wheat-Fallow	RWF	Dry land	Mineral Fertilizer	As needed
Wheat-Fallow	RWC	Dry land	None	As needed
Wheat-Legume	IWL	Irrigated	WCC	As needed
Wheat-Legume	RWL	Dry land	WCC	As needed

Table 2. Current cropping systems for the Century Experiment

System	System Code	Irrigation	Fertilizer Source	Pesticides
Alfalfa-Corn-Tomato	AMT	Irrigated	Mineral Fertilizer	As needed
Conventional Wheat-Tomato	CWT	Irrigated	Mineral Fertilizer	As needed
Conventional Corn-Tomato	CMT	Irrigated	Mineral Fertilizer	As needed

Legume-Corn-Tomato	LMT	Irrigated	Mineral Fertilizer + WCC	As needed
Native Grass	NG	Dry land	None	None
Organic Corn-Tomato	OMT	Irrigated	Compost + WCC	Organic
Transitional Corn-Tomato	TR	Irrigated	Compost + WCC	Organic
Wheat-Fallow	IWF	Irrigated	Mineral Fertilizer	As needed
Wheat-Fallow	IWC	Irrigated	None	As needed
Wheat-Fallow	RWF	Dry land	Mineral Fertilizer	As needed
Wheat-Fallow	RWC	Dry land	None	As needed
Wheat-Legume	RWL	Dry land	WCC	As needed

Table 3. Changes to the cropping systems in the Century Experiment over time

System	Year	Crop rotation
Alfalfa-Corn-Tomato	2013–2014	alfalfa-corn-tomato
Conventional Corn-Tomato	1994–2007	corn-tomato
Conventional Corn-Tomato	2008	fallow-tomato
Conventional Corn-Tomato	2009	sudan grass-tomato
Conventional Corn-Tomato	2009–2012	wheat-tomato
Conventional Corn-Tomato	2013–2014	corn-tomato
Conventional Wheat-Tomato	1994–2014	wheat-tomato
Irrigated Wheat-Control	1994–2014	wheat-fallow
Irrigated Wheat-Fallow	1994–2014	wheat-fallow
Irrigated Wheat-Legume	1994–2007	wheat-WCC
Irrigated Wheat-Legume	2007–2012	fallow
Legume Corn-Tomato	1994–2007	corn-tomato-WCC
Legume Corn-Tomato	2008	fallow-WCC
Legume Corn-Tomato	2009	sudan grass-WCC or wheat-tomato-WCC
Legume Corn-Tomato	2010–2012	wheat-tomato-WCC
Legume Corn-Tomato	2013–2014	corn-tomato-WCC
Native grass	2013–2014	native grass
Organic Corn-Tomato	1994–2007	corn-tomato
Organic Corn-Tomato	2008–2009	sudan grass-tomato
Organic Corn-Tomato	2009–2012	wheat-tomato
Organic Corn-Tomato	2013–2014	corn-tomato

Rainfed Wheat-Control	1994–2014	wheat-fallow
Rainfed Wheat-Fallow	1994–2014	wheat-fallow
Rainfed Wheat-Legume	1994–2014	wheat-WCC
Transitional Corn-Tomato	1994	fallow
Transitional Corn-Tomato	1995–1999	Conventional corn-tomato-wheat
Transitional Corn-Tomato	2000–2007	Organic corn-tomato
Transitional Corn-Tomato	2008	Organic wheat
Transitional Corn-Tomato	2009	Organic sudan grass
Transitional Corn-Tomato	2010–2012	Organic wheat-tomato
Transitional Corn-Tomato	2013–2014	Organic corn-tomato

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