Trade-Offs of 20 Years of Management on Sequestration, Stabilization, and Stratification of Soil Organic Matter

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Introduction

- Intensive agriculture has depleted soil organic matter (SOM) from ~225 Pg carbon (C) pre-cultivation to ~111-170 Pg C today[1,2]. Adopting best management practices has potential to sequester 0.9-2.9 Pg C per year[3,4].
- Mediterranean ag systems are some of the most diverse, productive, and economically valuable in the world, yet there is a paucity of data on impact of management on C sequestration (SCS)[5,6]. ~75% of Mediterranean soils are under-saturated with less than 2% SOM[7,8] and may have high potential for SCS[9]. Average sampling depth in Mediterranean limited to 25.7 cm[7].
- 46 to 63% of SOM found from 30-100cm, where affect of climate on SOC turnover is muted and role of texture and mineralogy enhanced[10,11,12]. SOM at 1m or deeper has been found to be vulnerable to changes in land use and cover[13,14] Practices that encourage movement of C into the subsoil may lead to greater stabilization in organo-mineral complexes and longer turnover times of SOM[15,16].
- Accurate evaluation of trends in soil C balances can take 20-50 years[17,18]. Long-term experiments are necessary to validate models that predict SCS potential of management systems and inform carbon-credit trading policy[19,20].

We hypothesize that 1) management systems that return more carbon to the soil (via aboveground inputs and belowground biomass/exudates) will sequester more SOC with time, and 2) irrigated systems will sequester more SOC, stratified to greater depths.

Methods

Experimental Design: Russell Ranch Sustainable Agricultural Facility in Davis, CA

- RCBD – 3 blocks based on intrinsic productivity (NDVI imaging)
- 72 – 1 acre plots under 10 different management systems – each with two sets of 3 replicates representing opposing crop rotations or entry points (see Map)

Soil Sampling

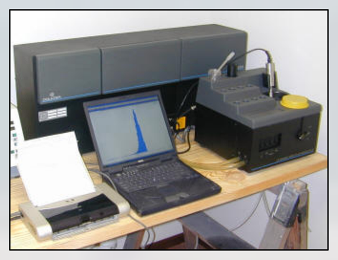
- Soil cores taken from 10 locations in Sept. 1993, 6 in 2012, using a 4.7 cm diameter Giddings probe
- Depth increments: 0-15cm, 15-30cm, 30-60cm, 60-100cm, 100-200cm (100-150cm, 150-200cm in 2012)
- Composited, air-dried, sieved to <2mm, and archived.
- Bulk Density - Measured length & depth of core at time of sampling, weighed air-dried samples in lab

Carbon/Nitrogen Analysis

- Visible plant material removed
- Ball milled to a fine powder
- Carbonate removal - 1g soil reacted with 10mL HCl (100-200cm only)
- Samples analyzed (2x) for C and N content with Costech Elemental Analyzer (ECS4010)
- Concentrations converted to mass using BD and depth of sampling increment

Textural Analysis:

- 0.2g of <2mm soil (2x) shaken for 16 hours with 50g/L $(NaPO_3)_6$
- Sonicated for 30 seconds and run 4x through Beckman Coulter LS-230 Laser Particle-Size Analyzer[21]



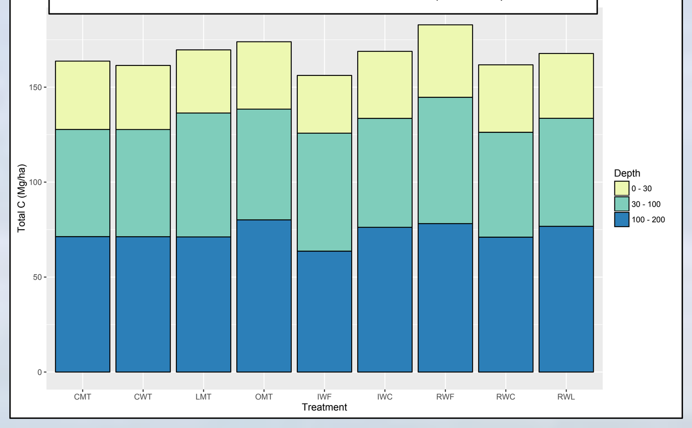
Objectives

To identify management practices that 1) improve long-term, on-farm sustainability; maximizing yield/profit while reducing resource use and environmental impact, and 2) Maximize SCS, especially at depth.

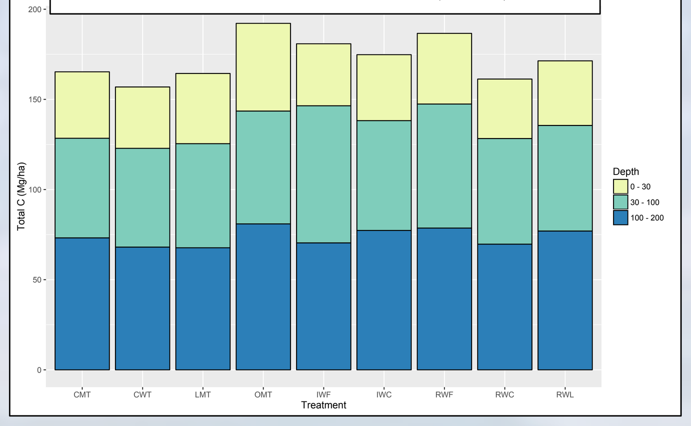
Results

- On average 21.3% of SOC was found from 0-30cm, 35.5% from 30-100cm, 43.3% from 100-200cm (78.8% below 30cm)

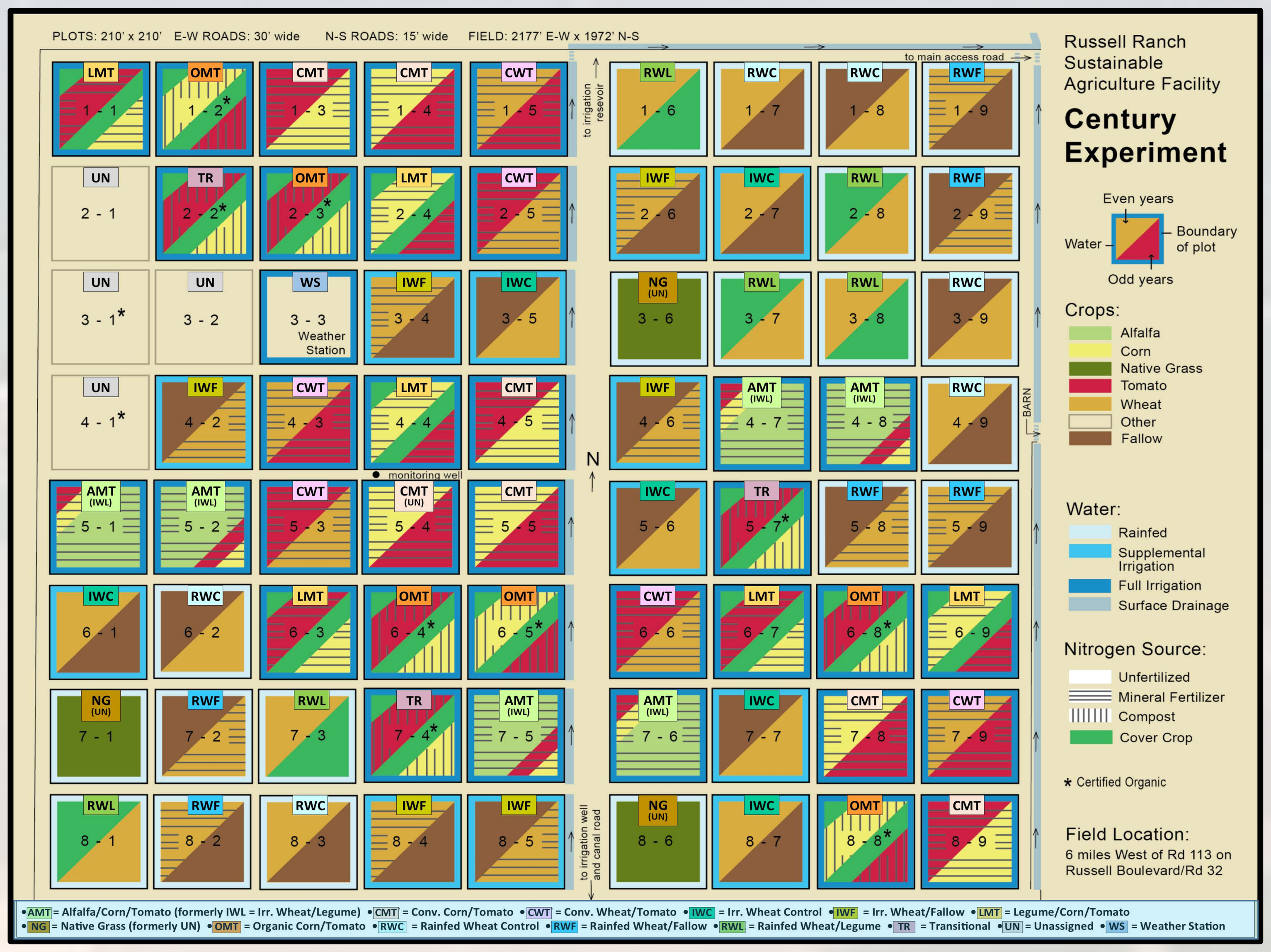
Stratification of Carbon (1993)



Stratification of Carbon (2012)



- All wheat systems (except CWT) exhibited similar SOC increases from 30-100cm, averaging 8.22% across systems
- OMT increased C at all depths with a 37% ↑ from 0-30cm
- LMT ↑ 17% from 0-30cm, but gains were offset with a 11% ↓ from 30-100cm



Results (cont.)

Depth Weighted Sums

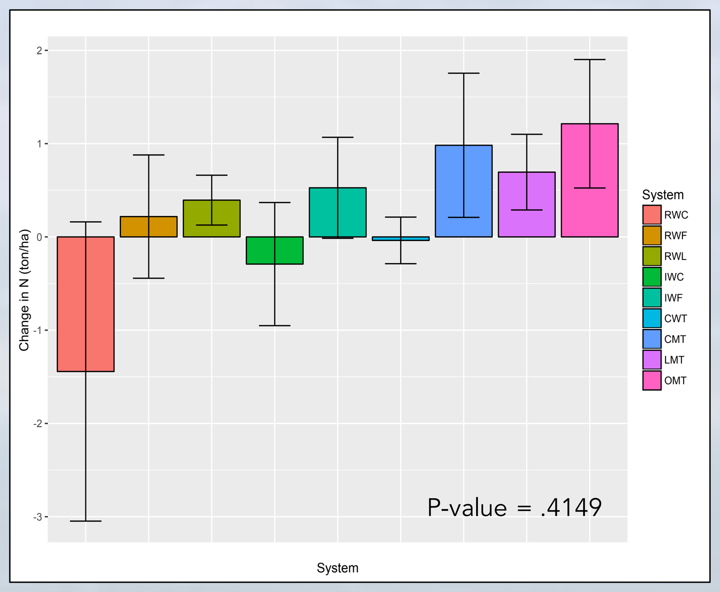
Analysis of SOC change from 0-200cm showed:

- Significant losses of -7.05 Mg/ha of SOC in RWC systems
- Significant accumulation of 18.3 Mg/ha SOC in OMT systems

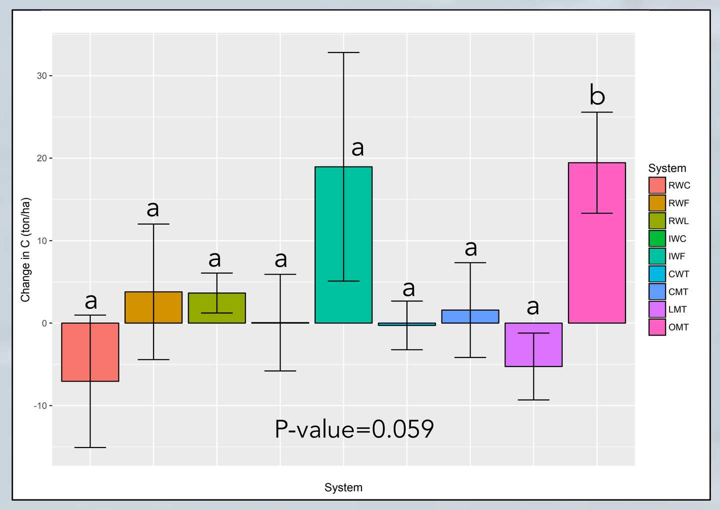
Change in Nitrogen

- No significant correlations were found between treatments and change in N from 0-200cm
- From 0-100cm, there is a significant loss of N in IWC, RWF, and CWT and significant increase in OMT, P-value=0.038

Change in Nitrogen over 20 years (0-200 cm)



Loss/Accumulation of Carbon (0-200 cm)



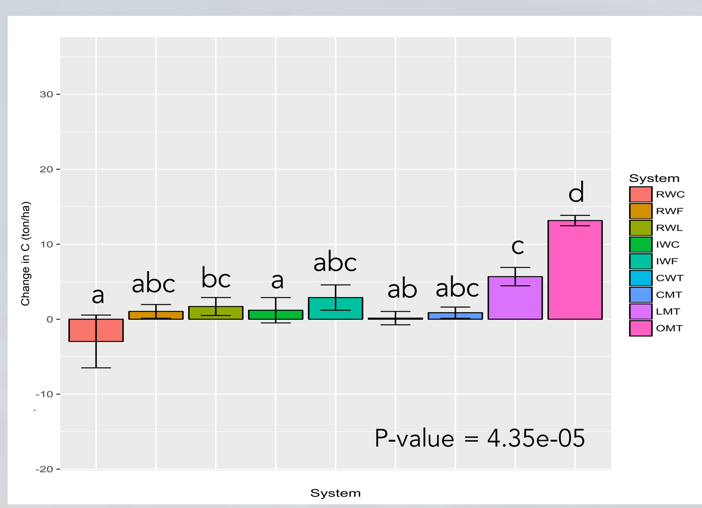
A Case for Depth

From 0-200cm, only the OMT is significantly different from other systems; whereas from 0-30cm, most treatments are significantly different from one another.

C Input Conversion

- Increase in SOC was found to correlate with cumulative C inputs with an overall SOC conversion rate of ~18.2%‡
- Analysis in 2003 showed a 7.6% conversion rate, but only included top 0-10cm[22]

Loss/Accumulation of Carbon (0-30 cm)



Input Conversions

- Crops manually harvested seasonally
- Conversions as per Kong et al., 2005
- Compost C/N analyzed via dynamic flash combustion with GC

Total Inputs by Management System

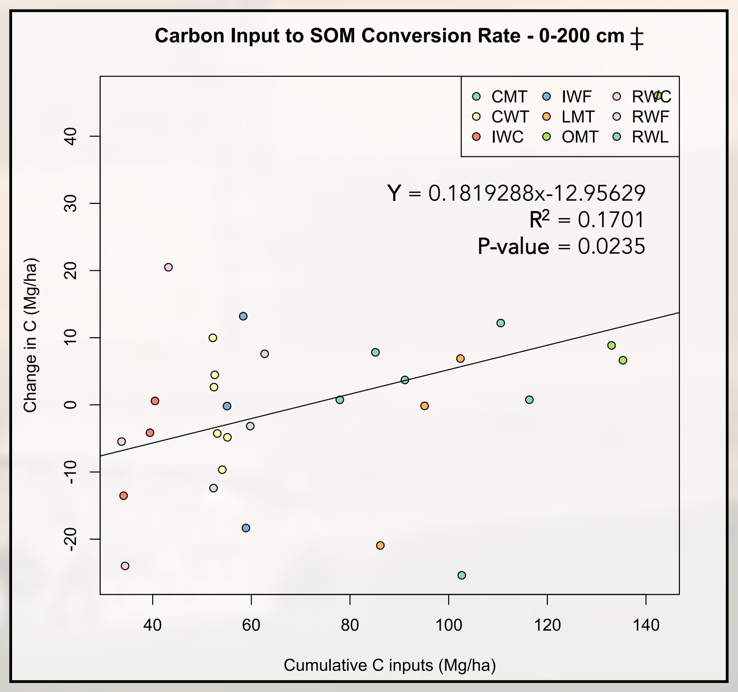
Carbon Inputs | Nitrogen Inputs | △ SOC

H_2O ↑

	Root-C	Residue-C	Compost	Nitrogen Inputs	△ SOC
OMT	30.8 Mg/ha	91.4 Mg/ha	13.1 Mg/ha	1.30 Mg/ha*	19.7 Mg/ha
LMT	26.0 Mg/ha	71.3 Mg/ha	0.00 Mg/ha	1.57 Mg/ha	-5.26 Mg/ha
CMT	31.1 Mg/ha	81.0 Mg/ha	0.00 Mg/ha	3.53 Mg/ha	1.57 Mg/ha
CWT	10.7 Mg/ha	42.6 Mg/ha	0.00 Mg/ha	3.18 Mg/ha	-0.27 Mg/ha
IWF	11.1 Mg/ha	50.4 Mg/ha	0.00 Mg/ha	1.46 Mg/ha	18.9 Mg/ha†
IWC	6.7 Mg/ha	30.5 Mg/ha	0.00 Mg/ha	0.0 Mg/ha	0.33 Mg/ha
RWF	10.3 Mg/ha	46.9 Mg/ha	0.00 Mg/ha	1.04 Mg/ha	3.79 Mg/ha
RWL	13.1 Mg/ha	68.7 Mg/ha	0.00 Mg/ha	0.00 Mg/ha	3.64 Mg/ha
RWC	6.6 Mg/ha	30.4 Mg/ha	0.00 Mg/ha	0.00 Mg/ha	-7.05 Mg/ha

Future Work

- 16S Sequencing on each plot/depth
- Fourier Throughput Infrared Spectroscopy – preliminary work shows variation in functional groups across treatments
- Fe/Al-oxide extractions
- Micronutrient analysis of soil and crop using X-Ray Fluorescence Spectroscopy
- Olsen P, NH_4OAc-exchangeable K, $Ca(H_ePO_4)_2$ extractable S



Full Model: Change in Carbon ~ Cumulative C inputs * clay + irrigation + Baseline C in 1993 + Baseline N in 1993
$R^2 = 0.5226$ **P-value** = 0.00974

Conclusions

- Treatment did not exert a significant effect on SOC accumulation/loss in any system, but the Organic Maize Tomato, which accumulated significantly more C than all other systems except IWF†.
  - Trends do indicate, however, that lower input systems (less irrigation, less fertilizer, less C inputs, fewer crops in rotation) have a propensity to lose C in the long-term.
- Change in N highly variable from 100-200cm, no significant trend. Trends indicate low input systems are mining N leading to losses over time.
- When only sampling up to 30cm (as most SOM research currently does) the significant correlations shift slightly, which may indicate that we are overlooking the big picture with superficial sampling.
- When considering up to 200cm, the variation increases drastically, suggesting we may have to reconsider our sampling approach (i.e. more sampling locations) to capture heterogeneity of SOC at depth.
- The application of composted chicken manure seems to have a disproportionately greater impact on the conversion of C inputs to SOM than both residue and root-C inputs.
- Overall, Organic Management systems, which refrain from applying biocides and return large amounts of C inputs back to the soil, providing readily available food for soil organisms, has a significant impact on a soil's ability to sequester carbon.

* Nitrogen from composted poultry manure application
† Standard Error of 13.86
‡ Only includes 1 set of replicates -- textual analysis still in progress

References

See Handout

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