UC DAVIS RUSSELL RANCH SUSTAINABLE AGRICULTURE FACILITY

2018 RESEARCH PROGRESS REPORT

Edited By: Nicole Tautges, Emily Woodward, Asha Sharma, and Kate Scow

UC DAVIS AGRICULTURAL SUSTAINABILITY INSTITUTE

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FACILITY OVERVIEW

The Russell Ranch Sustainable Agriculture Facility is a unique 300-acre facility located a few miles west of the core UC Davis campus. Research at Russell Ranch is dedicated to investigating the impacts and benefits of particular agricultural practices on productivity, resource use efficiency, and soil health within irrigated and dryland agricultural systems in California's Mediterranean climate.

Researchers at Russell Ranch focus on complex agronomic, ecological, and economic questions about large-scale agriculture. Testing these questions requires years of study in order to detect long-term trends. The experiments at the Ranch look at the combination of particular management practices and crop rotations that comprise a cropping system, and how sustainable those systems are on both spatial and temporal scales. Director Kate Scow, Facility Manager Israel Herrera, and Research and Data Manager Nicole Tautges work together to develop ways to measure and compare inputs, like water and nitrogen, and to investigate outputs beyond yield, such as economic return and ecosystem impacts. While Russell Ranch is primarily a research facility, faculty and staff work together to encourage students and the wider community to get involved through field days, class field trips, undergraduate internships and graduate student research. Russell Ranch has also formed collaborations with other research institutions in the state of California and both nationally and internationally, as well as strong working partners with agricultural industry organizations and California growers.

Russell Ranch studies big issues in agriculture, including:

- Drought and water management
- Soil health
- Nutrient cycling
- Agroecosystem biodiversity, including the development of new crops
- Sustainable pest management
- Crop nutritional quality

THE CENTURY EXPERIMENT

Russell Ranch is the home to the Century Experiment, where 72 one-acre plots are being used for a 100-year-long mega-experiment in agricultural systems. Unlike most other long-term agricultural cropping systems studies, Russell Ranch is located in a region with a Mediterranean climate, meaning that most of the rain falls between November and April and little rain is received during the summer, a drought period accompanied by high temperatures. The Mediterranean climate type stretches across the western U.S., all the way north through central Washington State and Montana, and south to southern CA and New Mexico. The Mediterranean climate provides prime conditions for production of many crops, as the dry period limits disease and pest damage, but also causes water stress in crops during the summer and necessitating irrigation to grow healthy crops. We use irrigation systems at a large scale similar to those used by field crop growers in California, so that our findings scale up and are applicable to large farms throughout the state of California and the western United States.

Within the Century Experiment each of the systems are replicated six times across the 72 acres. These systems are complemented by ongoing studies that compare drip and furrow irrigation systems.

1. TOMATO ROTATIONAL SYSTEMS

The rotational tomato plots are on a 2-year rotation, either involving tomato one year and corn the next, or a tomato–wheat rotation. On these plots, the Russell Ranch researchers compare organic, conventional, and hybrid (i.e., a mix of both organic and conventional management practices) cropping systems. The organic experiments use organically approved composted chicken manure donated by Foster Farms, along with cover crops, as the primary fertility inputs. The conventional experiments use synthetic fertilizers. The hybrid experiments use a combination: synthetic fertilizers with the addition of cover crops. Recently, researchers at the Ranch have added another rotation system to the mix: a tomato–corn–tomato–alfalfa–alfalfa–alfalfa rotation that will examine potential benefits for soil of reduced disturbance and savings on fertilizer for tomatoes following alfalfa.

2. WHEAT AND FALLOW STUDIES

These plots allow researchers to compare rainfed wheat growth in different systems ranging from no fertilizer input, to cover cropped, to conventional systems using synthetic fertilizer. Some of the systems receive supplemental water via irrigation in winter. These systems yield results that inform our understanding of efficient and responsible resource use in dryland (i.e., non-irrigated) agricultural lands, which are important but highly sensitive ecosystems in the Mediterranean Western U.S.

AT THE RANCH IN 2018: CELEBRATING RESEARCH MILESTONES

Russell Ranch is heading into the quarter century milestone of our Century Experiment this year, on the verge of completing 25 years of research on tomato-corn rotations under organic, conventional and mixed management regimes, and wheat-fallow rotations with winter cover crops. We also have completed four years of research in studying the effects of biochar, and biochar interactions with compost amendments, in agricultural soils in tomato-corn rotations. Research into biochar effects on crops and soils will continue in 2019.

Research continues on deficit irrigation, an area of great emphasis in the past few years at Russell Ranch. Deficit irrigation is a new practice used in tomatoes to lower the amount of water applied to plants in the last six weeks of tomato growth, and shows promise to increase water use efficiency while possibly increasing tomato fruit quality. Past collaborations with PowWow Energy and UC Davis department of Plant Sciences researcher Dr. Amélie Gaudin have indicated that irrigation can be reduced by up to a third in the final six weeks of tomato growth, without decreasing yields. Ongoing research on this topic is focusing on developing models and tools that improve deficit irrigation planning by using tomato crop canopy characteristics. Researchers hope that this new practice can increase water savings even further (especially when paired with the subsurface drip irrigation practices already used by tomato growers).

A new cropping systems specialist, Nicole Tautges, joined the team in fall of 2017 to contribute to agronomic and long-term research at Russell Ranch, and to build more collaborations with the wide variety of researchers from UC Davis—and beyond—who come to conduct research at the Ranch. Dr. Tautges is thrilled to continue building Russell Ranch's unique research program. A new project scientist, Emily Woodward, also joined the team in summer of 2018 to contribute to environmental research at Russell Ranch. Dr. Woodward is looking forward to researching the interplay between agriculture and the environment within this unique long-term system.

RESEARCH COLLABORATIONS

Russell Ranch is a hub for cutting-edge research at UC Davis. Our team invites researchers from the UC system and other universities and organizations to leverage our unique experimental plots and facilities to conduct innovative research in agroecosystems. In 2018, the list of collaborations with researchers includes work on anaerobic carbon-sequestering microsites in soils with scientists from Stanford, investigation of tomato-mycorrhizal associations with scientists from UC Berkeley, and assessment of soil health indicators with NRCS, among others. We also take great pride in our continued collaborations with our industry partners, which include the Morning Star Company, Tule Technologies, Foster Farms, TerrAvion, and more.

OUTREACH & EDUCATION

Our 25th annual Russell Ranch field day on the theme of “Increasing Farm Resilience through Healthy Soils & Water Management,” examined how soil health-building management practices can decrease water use and increase cropping systems’ resistance to climatic and pest pressures. The field day brought together 120 university researchers, industry professionals, students, growers and other attendees. We also collaborated with the California Dept. of Food and Agriculture to host a Biochar Field Day at Russell Ranch, attended by 110 biochar researchers and industry partners. Russell Ranch was also a popular field trip spot for UC Davis courses where students could get their hands dirty and compare soil qualities across different management systems, from organic to conventional. Russell Ranch encourages field trips for courses at UC Davis and beyond to take advantage of our facility as a living laboratory for agriculture.

By T. Becker, M. Leinfelder-Miles, and M. Lundy, UC Davis

OBJECTIVES

Despite corn being an important crop in California, current models and crop coefficients for nitrogen (N) uptake and evapotranspiration (ET) for corn have been developed in regions that have different soil types, overall climate, and that have utilized different irrigation techniques from California. This project seeks to develop an N uptake curve relative to cumulative ET for corn in California, relate that curve to canopy and leaf reflectance values measured in real-time by proximal sensing devices, and determine if those proximal sensing values can be used to indicate crop N deficiency in real-time. If corn N uptake patterns correspond consistently to patterns of cumulative seasonal crop water demand across heterogeneous growing environments, real-time crop N demand can be estimated as a function of real-time and cumulative seasonal crop water demand. The combination of real-time canopy and leaf reflectance values from proximal sensing devices can be used to estimate crop N uptake either directly or as a function of cumulative seasonal crop water demand.

APPROACH AND METHODS

To explore these hypotheses, an experiment was carried out at Russell Ranch during the summer of 2018. It consisted of five treatments combining three irrigation rates (25%, 50%, and 100% ET) and three nitrogen fertilizer rates (25 lb/acre, 105 lb/acre, 210 lb/acre UAN-32) across four replications. To calculate nitrogen uptake, seven in-season biomass harvests were conducted. Yield and nitrate concentration will be used to determine total N uptake across treatments. ET will be estimated using local weather data, soil moisture, Leaf Area Index (LAI), and canopy temperature measured using infrared radiometers. Three-foot deep soil samples were taken every 7-10 days to determine moisture and nitrogen content in increments of one foot. Drone generated multispectral aerial images were taken weekly and will be used to calculate indices such as NDVI, GRVI, and OSAVI. NDVI was also measured using a handheld Greenseeker device, and total chlorophyll was measured using an ATleaf on a weekly basis.

KEY FINDINGS

The treatments were found to have an effect on silage yield (R5 growth stage). The 210 lb N/acre fertilizer rate in combination with an irrigation rate of 100% of ET yielded 17460 kg/ha, whereas the 25 lb N/acre treatment with the same amount of water yielded only 15400 kg/ha. Also, the treatment with 210 lb N/acre but only 25% of ET irrigation only produced 13952 kg/ha (Fig. 1). This shows that water stress can reduce vegetative growth more than nitrogen stress. Irrigation treatments were discontinued on July 14th. At that point, the 25% ET irrigation treatment had used 8.9 inches of water, and the 100% ET irrigation treatment had used 16.3 inches of water (Fig. 2). Considering that the 16.3 inches represents the ideal water use, the low water treatment experienced a deficit of 7.4 inches.

SIGNIFICANCE AND FUTURE STEPS

Further work involves determining nitrogen concentration of all biomass samples and generating a nitrogen uptake curve. Soil moisture data needs to be completed and used with canopy temperature readings, local weather station data, and LAI to more accurately determine ET. The previously mentioned indices will be assessed for their ability to predict yield and N uptake patterns across the treatments. The goal is to translate the information gained from this experimental effort into decision support information that will help growers to make informed, real-time decisions about how their crop is likely to respond to added nitrogen. Data relating cumulative ET and N uptake will enable growers to utilize practices that combine water and nitrogen applications and plan their N applications for periods of rapid N uptake by the crop. This will ensure maximum efficiency of nitrogen and water by the crop and help minimize nitrogen leaching to the environment.

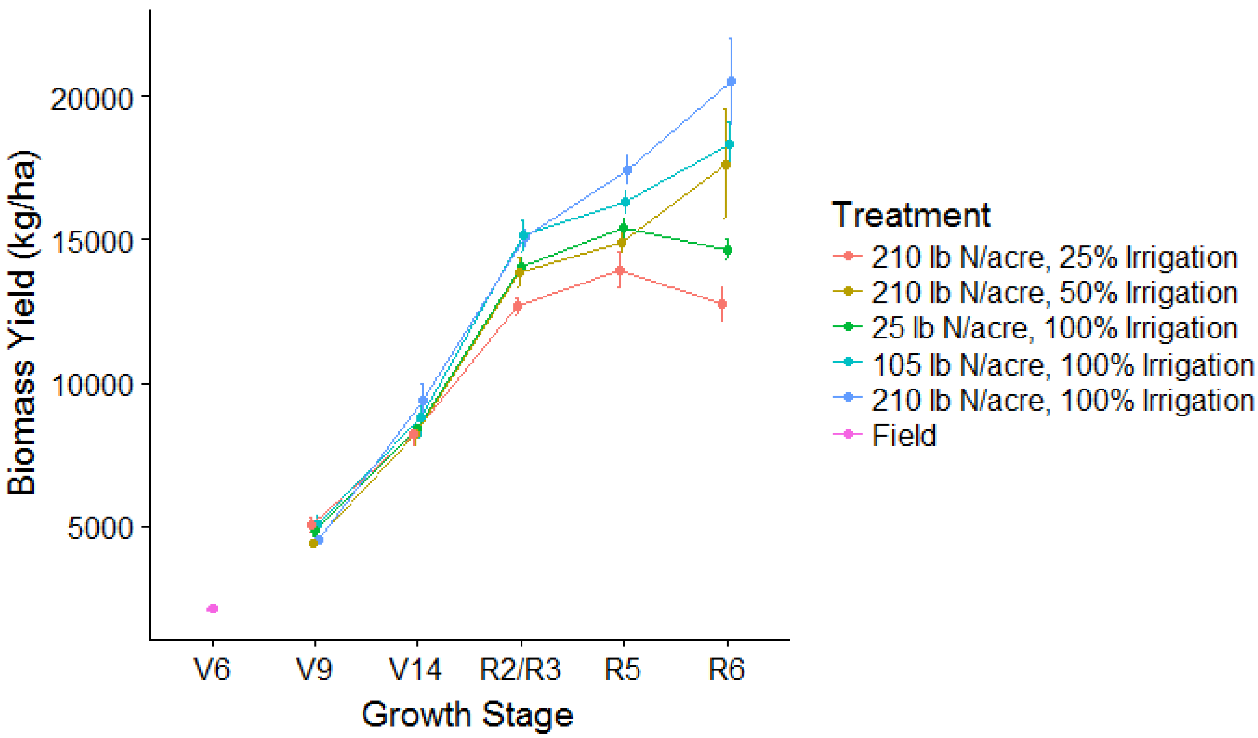


Figure 1: Biomass yield for all five treatments at six growth stages in corn. The first harvest was before treatments were started and represents a starting point for all treatments.

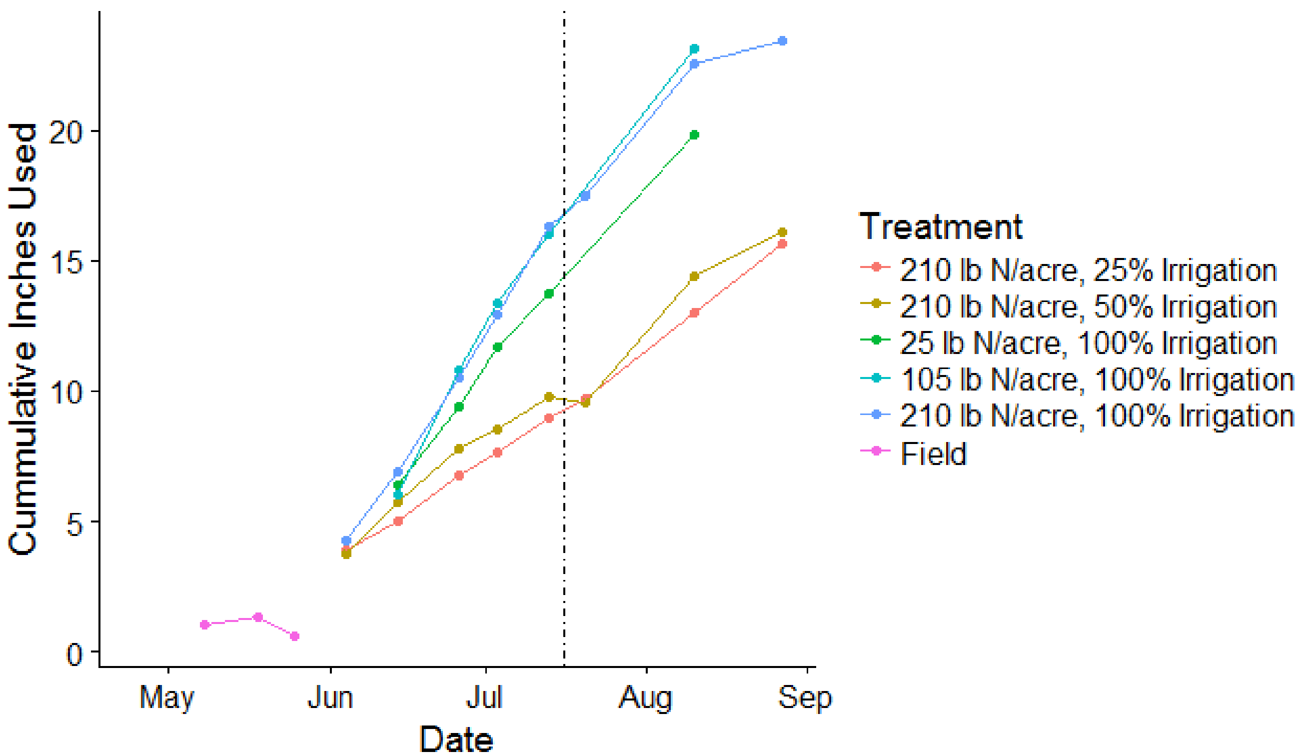
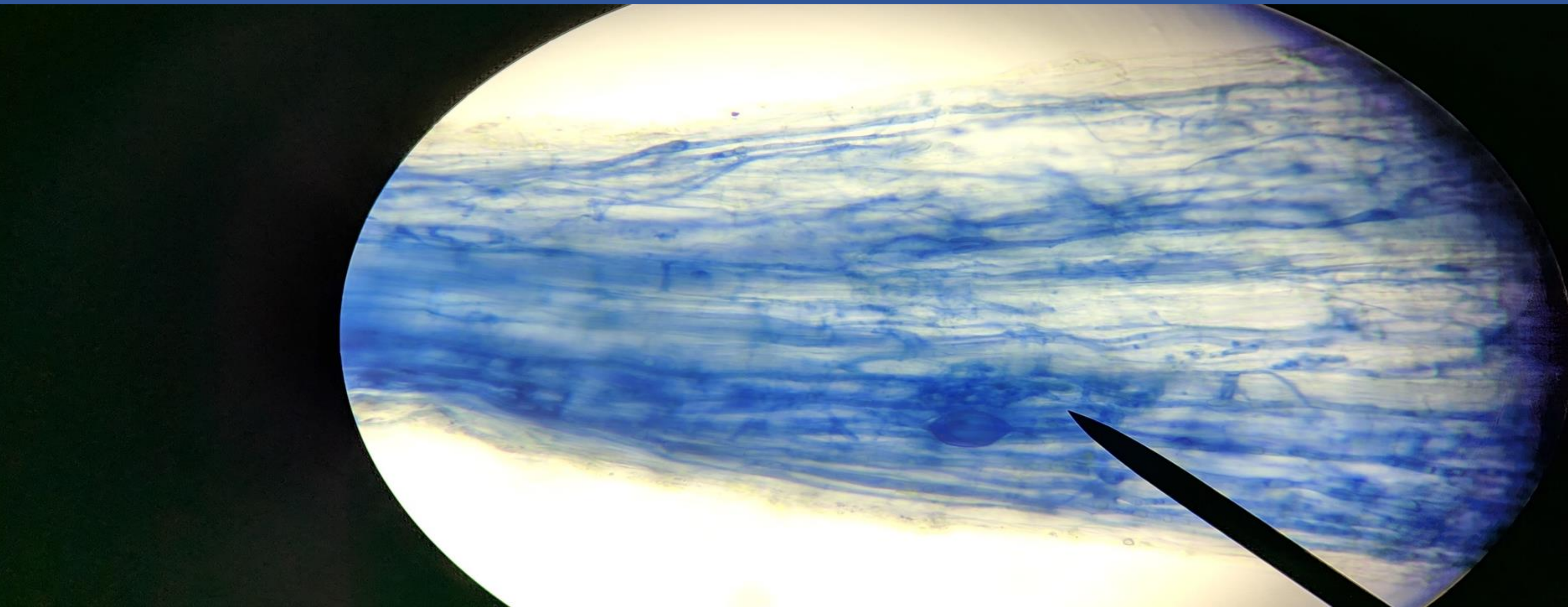


Figure 2: Crop water use for corn estimated using soil moisture and added irrigation at Russell Ranch. The dotted vertical line represents when water treatments were terminated, and all treatments received 100% of ET. The line represented by "Field" was before treatments were started and serves as a baseline for all treatments.



By S.F. Bender and T.M. Bowles, UC Berkeley

INTRODUCTION

The arbuscular mycorrhizal symbiosis is an ancient, mutually beneficial association between Glomeromycota fungi and most of land-plants. Arbuscular mycorrhizal fungi (AMF) are known to provide a range of benefits to plants, including enhanced nutrition and growth, and enhanced resistance to environmental stress, such as drought or pathogen attacks. Moreover, they have been proposed to be major players in soil N cycling, enhancing decomposition of plant litter and immobilizing and transferring mineralized N to associated host plants. AMF associate with a wide range of agricultural crops. However, agricultural practices, such as tillage, additions of agrochemicals, or high loads of fertilizers have been shown to exert negative effects on AMF communities in agricultural fields, reducing their abundance and diversity. Agricultural management systems with increased periods of roots being present in soil, e.g. through cover cropping, have been shown to promote the abundance and diversity of AMF. Moreover, cropping systems with reduced inputs of synthetic fertilizers and pesticides can exert positive effects on AMF communities.

OBJECTIVES

This project aims to test the contribution of abundant and diverse AMF communities, as shaped by long-term agricultural management, to crop yield plant nutrition and nutrient cycling in tomato cropping systems.

We hypothesized that:

- Crop-rotations comprising cover crops have more abundant and diverse AMF communities compared to rotations without cover crops. Similarly, rotations with reduced or no synthetic fertilizer and pesticide inputs will show higher abundance and diversity of AMF than cropping systems with purely synthetic inputs.
- More diverse and abundant AMF communities enhance overall soil nutrient cycling and promote soil microbial communities involved in organic matter breakdown. Decomposition and plant nutrient supply from decomposing plant material will, therefore, be higher in systems comprising richer AMF communities
- An interruption of the AMF-plant symbiosis will negatively affect yields, the decomposition of plant litter and on plant uptake of litter-derived nutrients. Negative effects will be stronger in cropping systems hosting a more abundant and diverse AMF community as compared with systems of lower AMF abundance and diversity. Effects on overall soil nutrient cycling will also be more pronounced.

APPROACH AND METHODS

We planted two different tomato genotypes in 4 long-term crop rotations, differing in management strategy, at the Russell Ranch Century Experiment: the rmc-mutant with highly reduced mycorrhizal colonization and its wildtype progenitor (76R), which forms regular AMF symbioses (Table 1). Planting the rmc-mutant tomato genotype effectively mutes the AM fungal symbiosis and allows to assess the contribution of AM fungal communities to ecosystem functioning in-situ, when compared to the 76R genotype.

To look at the effects of different AM fungal communities on soil nutrient cycling, we installed in-growth cylinders in soil, allowing AMF hyphae but not plant roots to pass, filled with 15N-labeled plant material.

We monitored plant biomass, nutrient contents, and tomato yield in dependence of the mycorrhizal status of the plants. DNA was extracted from roots and soil samples to investigate AM fungal community composition in the different systems. AM fungal abundance in roots was assessed by microscopy.

Table 1: Characteristics of cropping systems at the Russell Ranch Century experiment used in the study

Rotation	Winter Cover Crops	Fertilization	Plant Protection
Alfalfa/Corn/Tomato (AMT)	yes	synthetic	conventional
Conventional Corn/Tomato (CMT)	no	synthetic	conventional
Legume/ Corn/Tomato (LMT)	yes	reduced synthetic	conventional
Organic Corn/ Tomato (OMT)	yes	organic	organic

KEY FINDINGS

Tomato yield was lowest in the organic (OMT) system and highest in the Alfalfa-Corn-Tomato rotation (AMT). Muting the AM fungal symbiosis reduced tomato yields in all systems, except for OMT. The biggest effect of AMF on tomato yield was observed in the AMT-system, where rmc-plants had 33% lower tomato fresh yield than 76R.

SIGNIFICANCE AND FUTURE STEPS

Muting AMF functioning caused yield reductions in all but one system investigated. These results show that AM fungal communities significantly support tomato yields. However, long-term agricultural management affects the ability of AMF to provide benefits. Further analyses will reveal, whether differences in AM community composition and/or AMF abundance are responsible for the observed effects and which particular management characteristics are likely to cause the observed differences in AM fungal functioning. The findings imply that crop yields, nutrient use efficiency, and overall sustainability of tomato systems can be enhanced by management practices that support AM fungal communities.

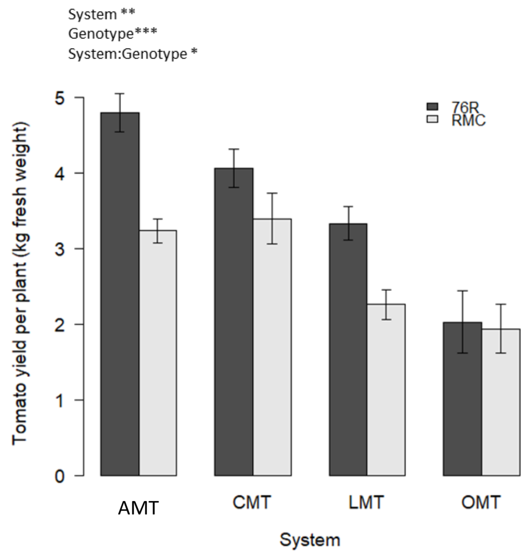


Figure 1: Tomato fresh yield per plant from rmc-(light grey), and 76R-(black) tomato plants grown in four different management systems at Russell Ranch.

By N. Bogie, T.A. Ghezzehei, and A.A. Berhe, UC Merced

INTRODUCTION

As the climate changes, many regions face water scarcity. As a result of water scarcity and with improved irrigation technology, new methods are being implemented that significantly reduce the amount of water used to grow crops. However, we still don't know how these new high efficiency irrigation methods, such as subsurface drip irrigation (SDI), or other conservation agricultural measures, such as cover cropping will affect the cycling and stabilization of organic matter in the changing California climate. Therefore, this study aims to investigate carbon cycling as it relates to soil structure (aggregation) and hydro-physical properties.

OBJECTIVES

Research Questions:

- What are the short-term (1year) and near-term (2+ year) effects of a winter legume cover crop in conjunction with deficit SDI on soil aggregate stability in a tomato-corn rotation?
- What are the short-term (1year) and near-term (2+ year) effects of a winter legume cover crop on carbon stock and distribution within the water stable aggregate hierarchy?

- What are the short-term (1year) and long-term (20+ year) effects of a winter legume cover crop on water retention and hydraulic conductivity of the crop rooting zone?

APPROACH AND METHODS

In this study we investigated the effects of cover cropping on the aggregate structure and the cycling of SOM in a long-term agricultural experiment at Russell Ranch. The study site was recently (2015) switched to SDI. Furthermore, we investigated short-term (one season, 2016-2017) and longer-term effects of cover cropping on plots that were under furrow irrigation from 1993-2014 and SDI since 2015. We measured water stable soil aggregation using wet sieving, and then performed C and N analysis, including stable isotopes, on bulk soils and fractions at four depths: 0-10 cm, 10-20 cm, 20-30 cm, and 30-50 cm. We also measured bulk density, water retention, and saturated hydraulic conductivity on cores collected at a 15 cm depth.

KEY FINDINGS

In the short-term plot, the presence of a cover crop (CC) reduced water stable macro-aggregates at 0-10 cm depth. In the 0-10 cm depth range, there were significant ($p = 0.02$) differences in the 250-2000 µm fraction, which were 13% higher in the no cover crop (NC) treatment than the cover crop (CC) treatment (data not shown). This shows that the cover crops can lead to the breakup of soil aggregates in the short-term. By the second sampling, during tomato growth, there was no significant difference between the two treatments.

Accompanying the short-term differences in aggregation at the March 2017 sampling during cover crop growth, there were significant differences in δ13C and δ15N in the upper 30 cm of the profile and the zone with the most differences was in the 0-10 cm depth range (Fig. 1). At 0-10 cm in the 250-2000 μm fraction with a value of -25.38 ‰ the δ13C of CC was 0.25 ‰ lower than the NC treatment ($P = 0.01$). In the 53-250 μm fraction CC was also lower, with a value of -25.28 ‰ ($P = 0.06$). At 10-20 and 20-30 cm the significant differences were in the >2000 μm fraction with δ13C values 1.08 ($P = 0.02$) and 0.38 ($P = 0.06$)

higher in the NC in the 10-20, and 20-30 cm depths, respectively. In the short-term plots we found no differences in bulk density, water retention, or hydraulic conductivity (data not shown).

The presence of cover crops, even in the short-term, causes the isotopic signature of the soil organic matter (SOM) to change even in the smallest aggregate size classes. This would indicate that new SOM, likely as belowground input, is being incorporated into micro-aggregates (< 250 μm). Micro-aggregates are typically thought to contain mineral associated SOM that is not easily respired. These results support recent research, however, suggesting that belowground inputs derived from root biomass and/or exudates can destabilize some mineral associated OM. We do not see significant changes to the quantity of C that is held in aggregate fractions under cover crop regimes (Fig. 2). Although previous work at Russell Ranch shows that increasing biomass inputs to the plots builds soil C over time, there were no differences in C stock between the mixed and conventional tomato-corn plots, which correspond to the CC and NC treatments studied here, respectively.

SIGNIFICANCE AND FUTURE STEPS

This research is ongoing, and we will continue to analyze C and N data from aggregate fractions in the long-term plots that were sampled in 2017. Additionally, we are investigating changes to soil hydraulic properties below the plow layer (37.5 cm depth) to see if the long-term management of these plots with cover crops and organic treatments has changed the deep drainage characteristics of the Rincon silty clay loam and the Yolo silt loam soils.

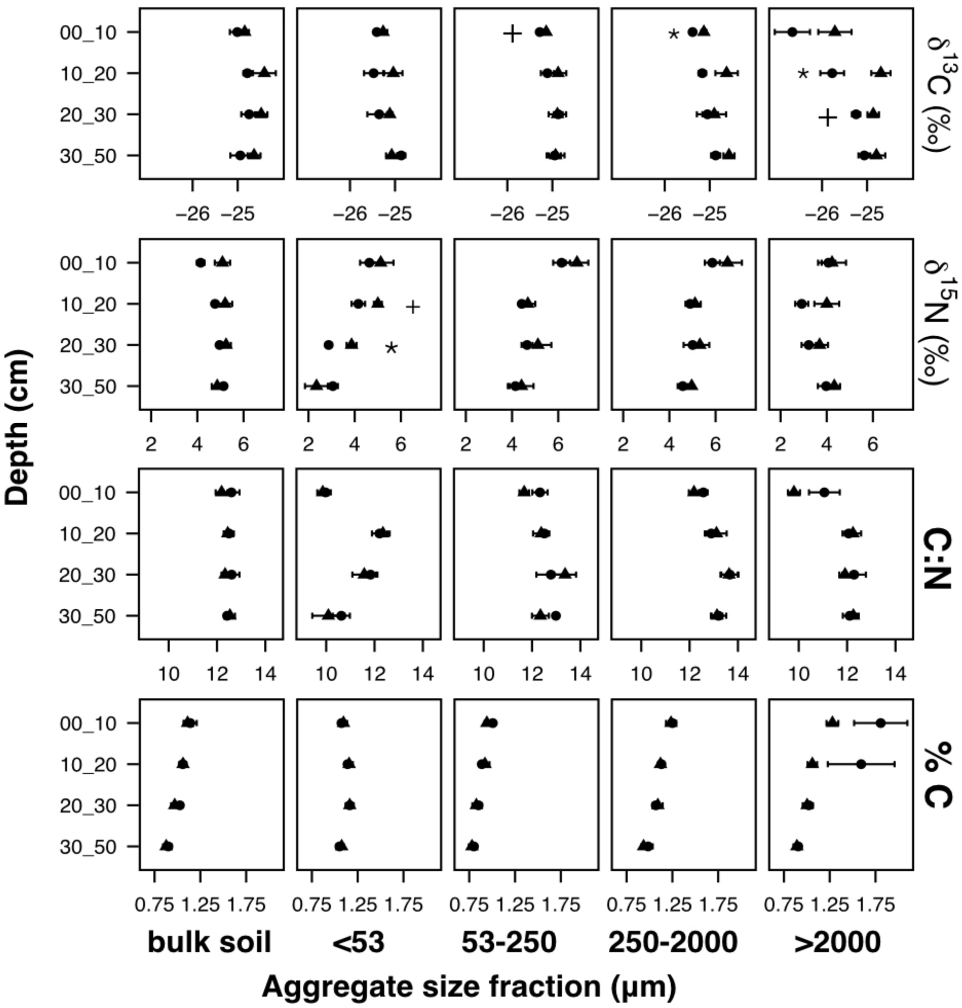


*Figure 1: C and N stable isotope ratios, C:N and % C of aggregate size fractions and bulk soil at four depths. * indicates significance difference between treatments within depths at P < 0.05, + indicates significance at P < 0.10.*

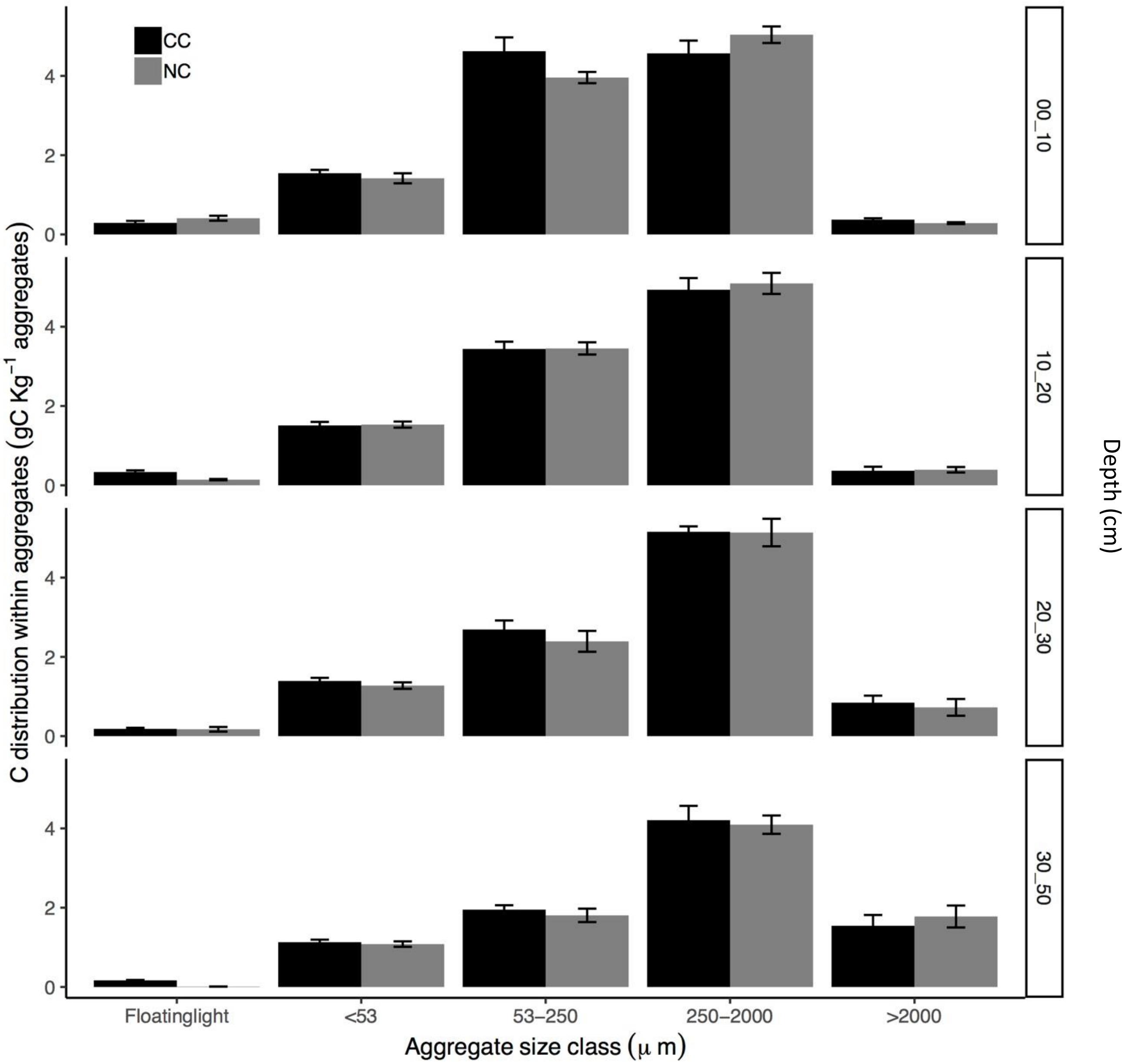


Figure 2: C distribution within aggregates at four depths in short-term plot, no significant differences found (P<0.05).

By A. Boyce, UC Davis

OBJECTIVES

- Investigate the feasibility of crude and modified biochar to function as a biosorbent and retain nutrients within different soil systems.
- Assess the variation in the sorption and desorption capacity of biochar for selected macronutrients (i.e. nitrate and phosphate) as a stand-alone sorbent and in combination with soils over varying timescales.
- Develop an empirical biochar model that can be integrated into established soil nutrient and crop production mechanistic models and/or simulators.
- Determine which physiochemical properties and pyrolysis production parameters are the most statistically significant in impacting the nutrient retention performance of biochar within soils.

APPROACH AND METHODS

Miscible displacement column experiments are being conducted on soils amended with superior performing crude and modified biochars. Two contrasting soils with similar mineralogy and textural class (i.e. silt loam) but differing organic matter content (i.e. Low = 1-2% and High = 5-6%) were sampled from plots under respective conventional and organic cultivation at Russell Ranch. The objective is to evaluate performance in a range of soil types. Soil physical properties (e.g. bulk and particle density, total porosity, particle size distribution etc.) and chemical properties (e.g. EC, pH, total carbon, NPK content, CEC etc.) have been determined. Columns will be uniformly packed with soils with biochar amendment (0, 1, and 5% on a dry weight basis), and will be slowly wetted with a $CaCl_2$ background solution. Following saturation, flux will be maintained by a peristaltic pump. Once steady-state pore velocity is achieved a pulse input of a conservative, non-reactive tracer (e.g. iodide, I-, or bromide, Br-) will be applied and eluted with the $CaCl_2$ solution. Tracer concentrations in outflow samples collected at regular time intervals will be measured using ion chromatography. Tracer breakthrough curves (BTCs) will be constructed using relative concentration (C/Co) as a function of pore volume (V/Vo). Breakthrough curves will be analyzed using the physical equilibrium convective dispersive equation (CDE) assuming one-dimensional, steady-state flow in a homogeneous soil.

HYDRUS software will be used to solve the CDE for appropriate boundary conditions by means of inverse fitting of the resulting tracer BTCs (Simunek et al., 2005). A mixed 50:50 nitrate and phosphate nutrient solution of set concentration (e.g. 100 mg L-1) will be eluted through the column at a set flow rate. Effluent solutions will be collected at intervals and analyzed for pH, Total C, TKN, NO_3^- , Total P and PO_4^{3-}. Transformation products or metabolites of nutrients will not be included in this transport model. The pore-water velocity and dispersity coefficients originally estimated for the tracer will be used as inputs values for nutrient BTCs, so that their respective retardation factors (Rf) and dispersion coefficients (D) may be estimated. Exhausted columns (i.e. C/Co = 0.98) will be regenerated with the background solution and re-run for several continuous cycles.

SIGNIFICANCE AND FUTURE STEPS

In order to develop a long-term performance profile of biochar amended soil, the expected outcomes of this proposed project are twofold. 1) To increase the ability of researchers to predict the effects of pyrolysis production schemes on a biochar's ability to increase nitrogen and phosphorus retention in soils while allowing these nutrients to be also bioavailable and 2) to develop a biochar model that interfaces with established soil nutrient and crop production mechanistic models. The primary limitation of this proposed research is that field or greenhouse studies are not considered within the scope of work. Therefore, changes in crop yields or plant health will not be directly evaluated in response to biochar amendment and will only be inferred from project results. This project could, however, inform subsequent investigations intended to directly measure any predicted benefits of biochar additions.

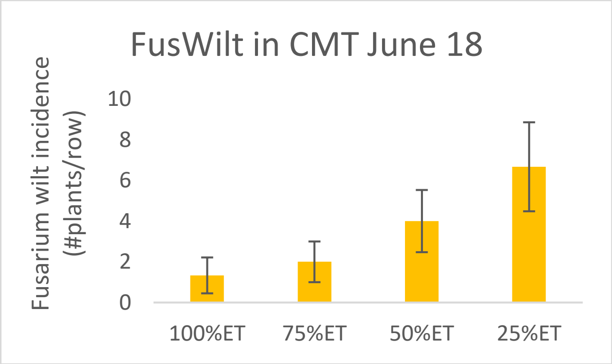
By J.D. Castillo and A. Gaudin, UC Davis

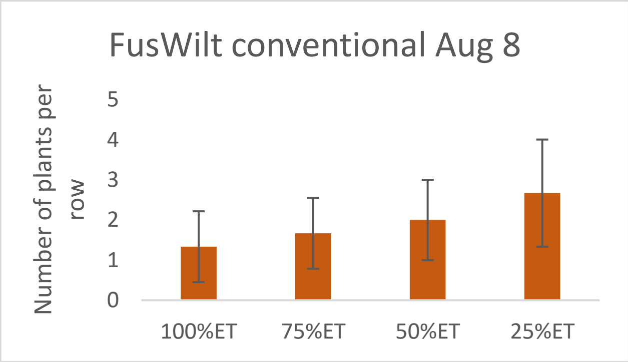
OBJECTIVES

Evaluate how the implementation of deficit irrigation in conventional and organic tomato production affects pathogen community dynamics. The project was funded for one year.

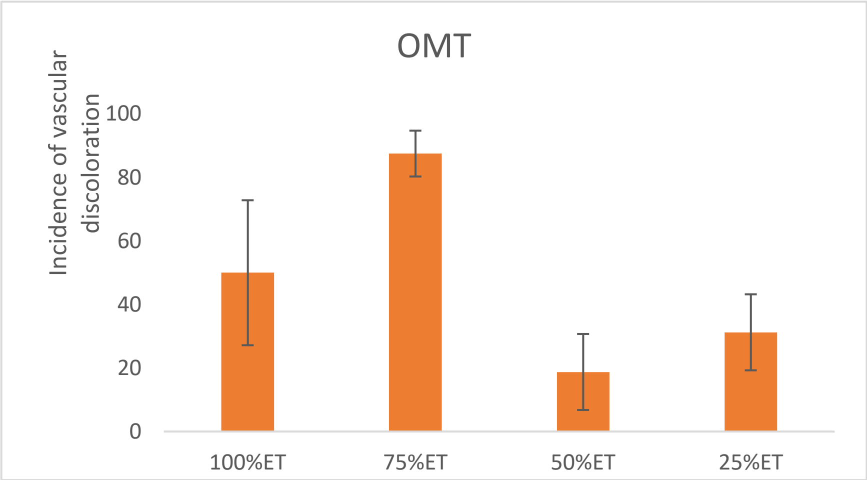
KEY FINDINGS

Based on visual rating, deficit irrigation increased the incidence of Fusarium wilt. This was only evaluated in the conventional plots due to high levels of other diseases in the organic plots.

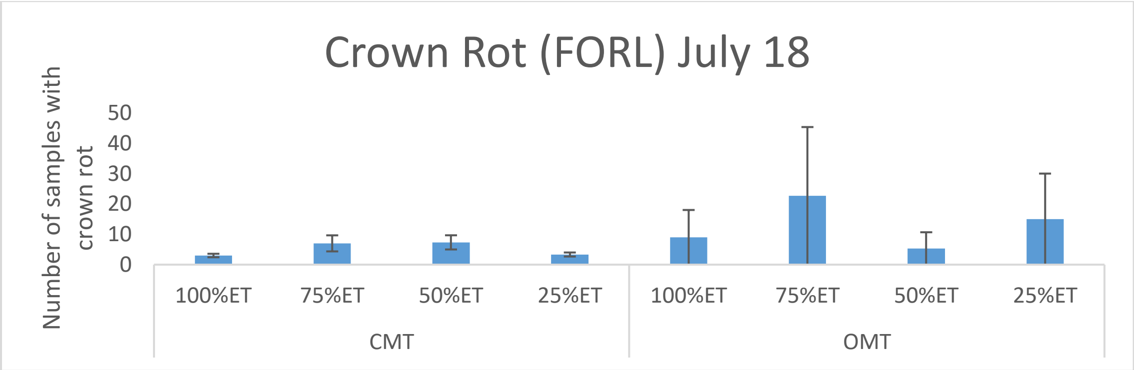


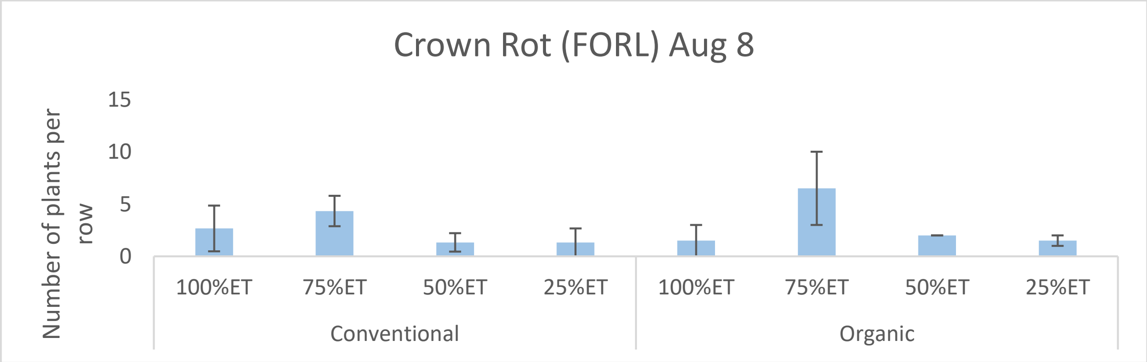


Based on end of season assessment of vascular wilt in 4 plants / row, reductions in water input significantly increased the incidence of Fusarium wilt (P for DI treatment in OMT = 0.03) (based on analysis of organic plots—there was a similar but not significant effect in the conventional plots).

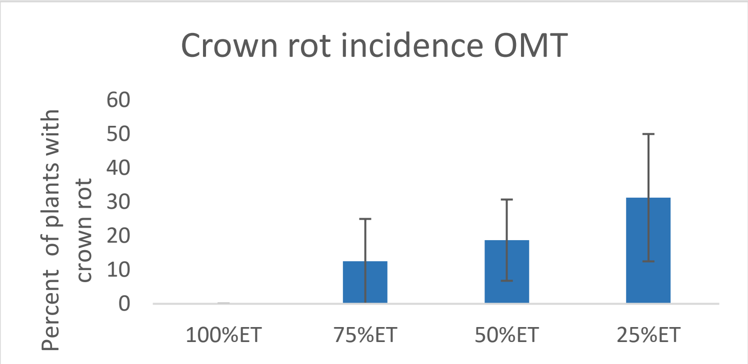


Based on visual rating of whole rows, crown rot levels were reduced under deficit irrigation. This effect was relatively consistent between CMT and OMT treatments and between dates.

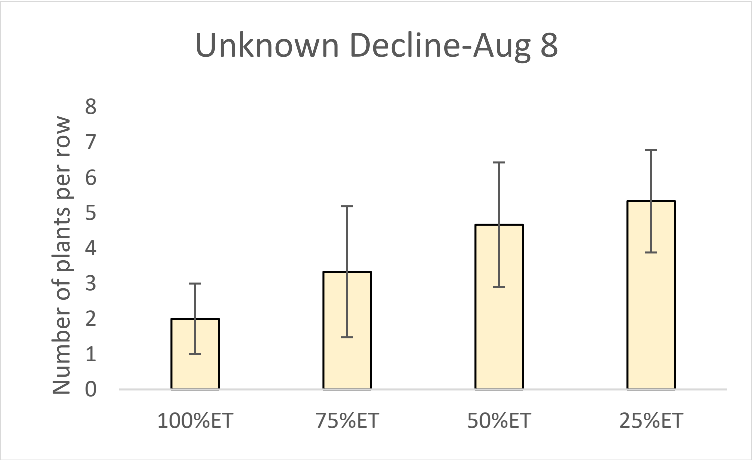




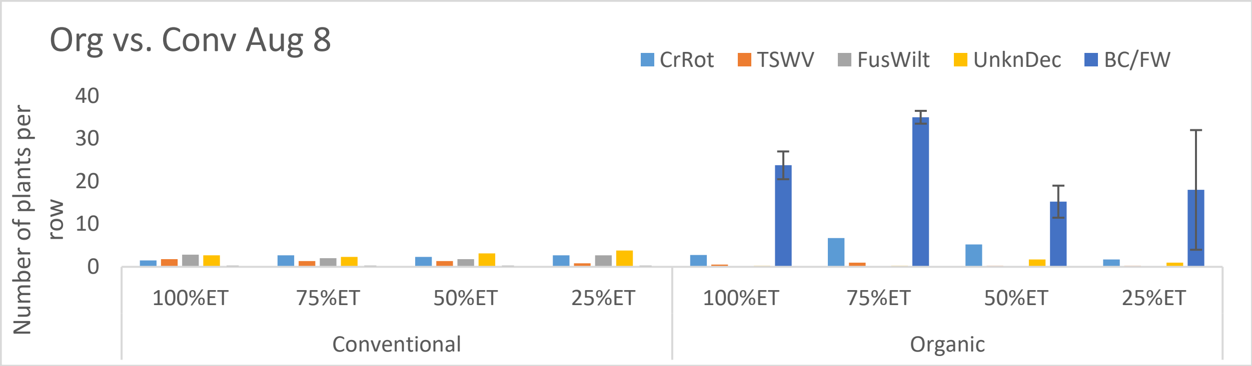
There was a similar pattern when we evaluated presence of crown rot in 4 plants / row based on destructive analysis at the end of the season.

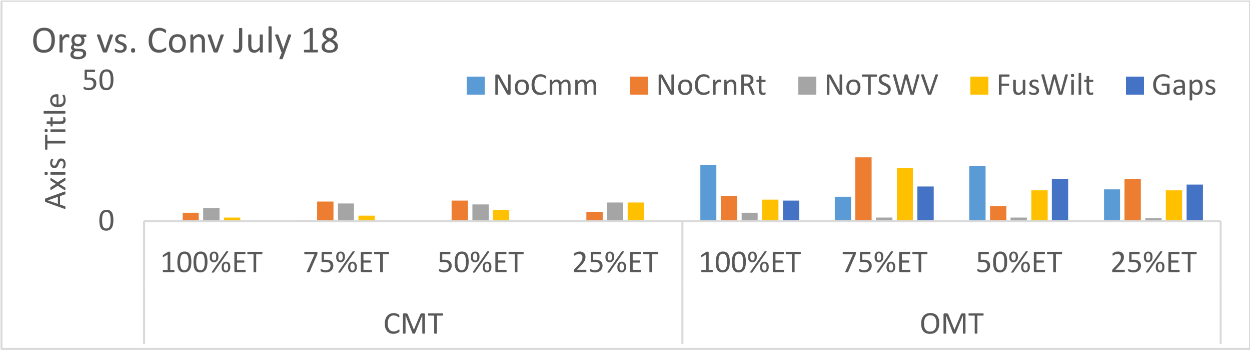


We also observed an unknown decline primarily in the conventional plots (shown below). The patterns were patchy, consistent with a biotic disorder. There was no internal necrosis and no clear causal agents were recovered. The incidence of the decline consistently increased with increasing irrigation deficit.



There was an overall trend in which diseases were higher in the organic plot vs. conventional. This included bacterial canker (Cmm), Crown rot, and Fusarium wilt. There were also far more gaps, indicating issues with post-transplant mortality. Of note, the most effected organic plot (2-3) was excluded from August 8 analysis due to very high levels of Cmm (~25-60plants/row).


Org vs. Conv Aug 8
CrRot
TSWV
FusWilt
UnknDec
BC/FW
Number of plants per row
40
30
20
10
0
100%ET
75%ET
50%ET
25%ET
100%ET
75%ET
50%ET
25%ET
Conventional
Organic


Org vs. Conv July 18
NoCmm
NoCrnRt
NoTSWV
FusWilt
Gaps
Axis Title
50
0
100%ET
75%ET
50%ET
25%ET
100%ET
75%ET
50%ET
25%ET
CMT
OMT

By M. Cooley, USDA ARS Albany

INTRODUCTION

Consumption of contaminated produce accounts for nearly half of the outbreak-associated foodborne illnesses in the United States, and leafy vegetables are associated with more illness than any other produce commodity. Produce can become contaminated at any point in the production chain. O157:H7 is a serotype of Escherichia coli and is an enteric pathogen that produces shiga toxin and can cause life threatening hemorrhagic colitis and, in very severe cases, hemolytic uremic syndrome and death. Hundreds of different serotypes of E. coli can be isolated from agricultural environments, but the majority of human illnesses are caused by a group of 6 clinically important serotypes. Shiga toxin-producing E. coli (STEC) exposure results in an average of 4,000 illnesses per year (28% of all foodborne illnesses) in the United States.

Preharvest contamination of fresh produce can occur for a variety of reasons. The primary source of STEC in agricultural environments is domestic ruminants, with cattle as the largest source. Nevertheless, the feces of many different animals harbor STEC, including representatives of all animal phyla. The accidental or intentional deposition of manure in fields of fresh produce is a major concern. Concerns over intentional application, as an amendment, is somewhat alleviated by proper composting of the manure. However, several research articles still point to the potential risk to produce from manure amended soils.

In contrast, agronomic research has expounded on the benefits of organic amendments, not only for the health and wellbeing of people (primarily from lack of exposure to herbicides and pesticides), but also to the soil itself. Healthy soil produces healthy crops and is sustainable with careful management of the land. One of the characteristics of healthy soil is a rich, diverse population of microorganisms.

Survival of human pathogens on the produce farm is of concern, especially in close proximity to the edible portion of the plant. Lettuce is a widely consumed produce, grows close to the ground and is implicated in several outbreaks each year. Enteric pathogens can survive on this plant. However, to do so they must compete with endogenous microflora for living space, water and nutrients.

OBJECTIVES

We hypothesized that competition of STEC is more likely to occur in organically maintained soil. Furthermore, we expect that poor survival of STEC in soil will also reduce the amount of STEC present in the phyllosphere; the edible portion of the lettuce plant.

APPROACH AND METHODS

All experiments were performed on Romaine lettuce grown in a growth chamber. Soil was collected 2015-2018 from 3 different plots at Russell Ranch that were maintained as organic, mixed, or conventional. In general, soil was collected at 3 different intervals during the growing year; just prior to the cover crop, just prior to turning in the cover crop, and just prior to planting the cash crop (tomato). Soil was collected 2-10 cm below the soil surface. Prior to planting of lettuce, soil microbial activity was assayed by the fluorescein diacetate (FDA) method of Adam and Duncan (2001).

STEC serotypes used in these experiments represent the 6 clinically important serotypes (O26, O103, O111, O121, O145, O157). The STEC strains were made rifampicin resistant and each were used to inoculate Romaine lettuce seed. Inoculum level on the seed was typically 104-105 CFU/seed. Inoculated seed was planted in each of the 3 soils from Russell Ranch and covered with a thin layer (approx. 3-5 mm) of the same soil. The aerial portion of the plants were harvested at 6 days after planting with sterile scissor and forceps. Nine plants were pooled to represent one sample and 6 samples were taken for each treatment and time point.

In later experiments (3rd year), soil amendments were added to the soil following the suggestion of the manufacturer. Two proprietary formulations were used, Compost Tea (Growing Solutions, Inc) and VESTA (SOBEC Corp.). Both are manure-based liquids suggested to enhance the soil structure and/or microbial content. Compost Tea was applied by uniformly mixing the product into the bulk soil prior to planting. VESTA was applied as a spray to the surface of the soil after bed formation and prior to planting. Application rate was 25 gallon/acre.

KEY FINDINGS

Microbial activity as assayed by FDA method varied considerably from year to year and plot to plot (Figure 1). The average activity in organic soil was greater than both mixed and conventional soils. Furthermore, even though the value of microbial activity varied considerably with time, microbial activity in organic soil was always significantly higher than mixed and conventional soil at every sample point, with the exception of mixed soil, sampled just before turn in of the cover crop. In these exceptional cases the microbial activity in mixed soil was higher than organic soil.

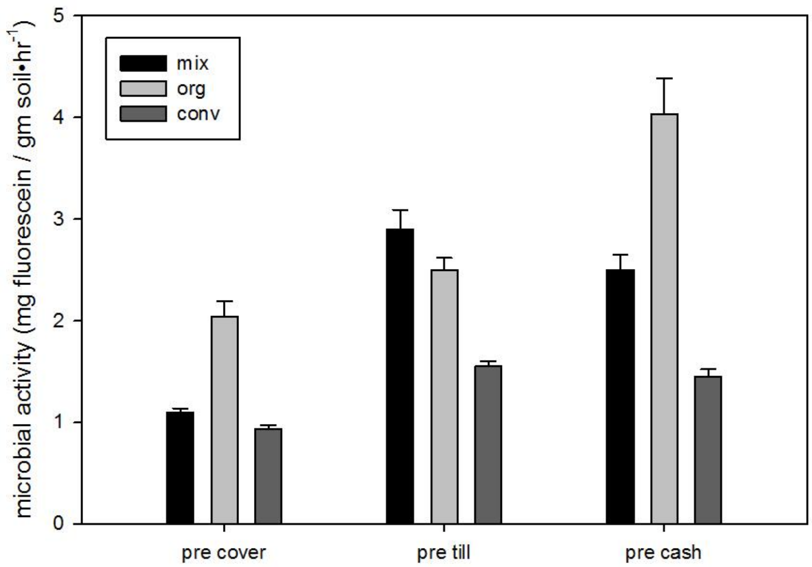
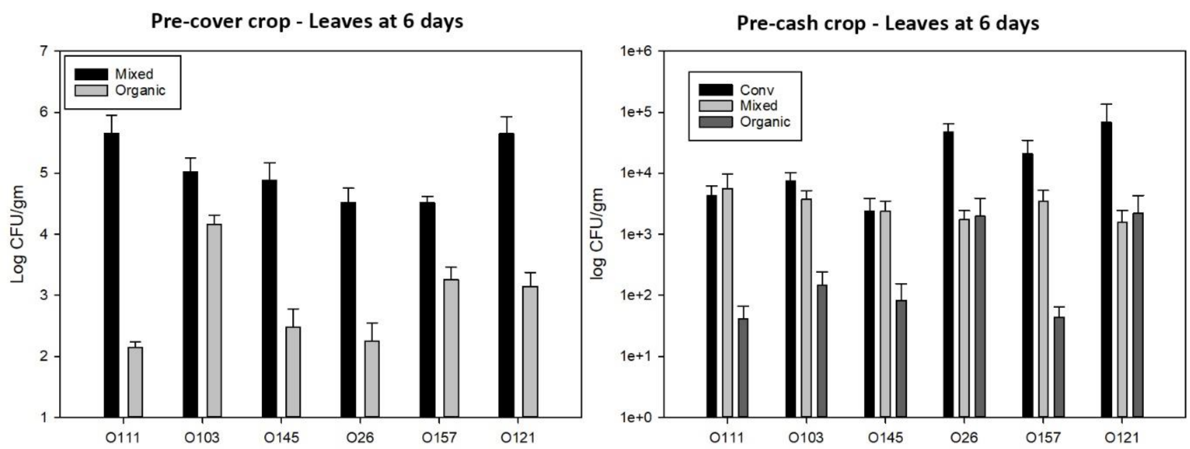


Figure 1. Microbial activity in different soils and field conditions.

Pathogen survival was monitored by rifampicin resistant colony count of bacteria present on the aerial portion of the lettuce plants as they grew from organic, mixed, or conventional soil. The assay was conducted on day 6, primarily because the pathogens become unculturable beyond this time frame (data not shown). Data for all 6 serotypes is shown in Figure 2. Behavior of the serotypes was different dependent on the soil type, but also on the field conditions when the soil was collected. Organic soil, collected prior to cover crop, suppressed all serotypes strongly as evidenced by 1 to 3 orders of magnitude reduction at day 6. Conventional soil was not used during this first experiment. All six serotypes were also significantly restricted in lettuce grown on organic soil collected prior to planting the cash crop. Additionally, O26 and O121 were suppressed in mixed soil compared to conventional soil.

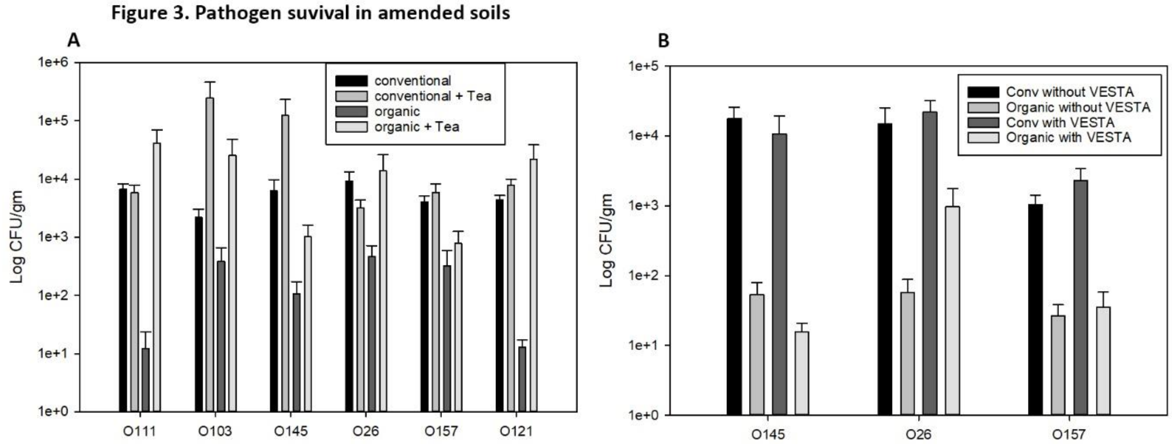
Since a correlation has been demonstrated between enhanced microbial activity in organic soil and reduced pathogen survival on lettuce, additional soil amendments that may promote microbial activity were tested. A Compost Tea from Growing Solutions was tested by incorporating the tea into organic and conventional soil prior to planting (Figure 3A).

Figure 2. Survival of select serovars on lettuce leaves



As seen before, the pathogens were suppressed in un-amended organic soil compared to un-amended conventional soil. However, the addition of Compost Tea either had no effect (eg. conventional soil + Tea for O111, O26 and O157) or promoted the pathogen (eg. organic soil + Tea for O111, O103, O26 and O121). Similarly, VESTA application as a spray produced no significant effect on pathogen survival (Figure 3B).

Figure 3. Pathogen suvival in amended soils



SIGNIFICANCE AND FUTURE STEPS

This research consistently demonstrates the suppression of a small collection of clinically important enteric pathogens on young lettuce plants with organic soil collected from Russell Ranch. A demonstration of pathogen suppression re-enforces the motivation for maintenance of proper soil health. However, broad conclusions are pre-mature because there are many different types of soil and, consequently, many different types of organic soil, each of which are likely to have different microflora. Nevertheless, these preliminary results suggest that a more complex microflora is more likely to suppress enteric pathogens. Testing of more soils will better support this conclusion.

Additionally, there are many different pathogens that could be tested, i.e., other strains of these same serotypes may behave differently, primarily because competition in these complex environments probably involves several biochemical pathways. Also, other species should be included in future studies, for example, Salmonella and Listeria, both of which commonly contaminate produce. Nevertheless, with further investigations, it is not unlikely that we will discover pathogens that will compete effectively with the indigenous microflora in this soil used here. However, with different soils, or amendments to these soils, competing flora can be discovered.

It is somewhat disappointing that the two soil amendments from Growing Solutions and SOBEC Corporation failed to improve the STEC suppression. This failure is likely due to the length of time between application of the amendment and the end of the experiment. Further experiments will be conducted to test this possibility. Also soil samples from all these experiments have been retained for further examination using metagenomics via 16S and whole genomic sequencing. With this information we expect to see specifically which microflora are responsible for pathogen suppression and what conditions may support their growth.

By K. Diederich and M. Lundy, UC Davis

INTRODUCTION

There has been a growing interest in perennial grain production due to its novelty and recent studies showing the ecological benefits associated with the cultivation of Kernza™, a perennial wheatgrass. Although these benefits may appear promising, particularly with regard to Kernza's potential to sequester soil carbon, studies comparing this crop to annual wheat have lacked a good control for the effect of tillage. Furthermore, there has yet to be adequate research published on how this perennial grain performs in Mediterranean environments. In December 2017 we implemented a split-plot randomized complete block design with plant species (annual wheat and Kernza) and tillage (till and no – till annual wheat) as a whole-plot treatment, irrigation as a subplot treatment, and nitrogen fertilization (0 to 150 kg N/ha) as a sub-sub plot treatment. This design allows us to answer questions regarding Kernza's productivity and the mechanisms behind its potential contribution to soil ecosystem services while controlling for tillage.

OBJECTIVES

Research Questions:

- Is Kernza a practical crop choice for specialty grain growers interested in improving soil health, and/or growers interested in implementing Kernza on marginal landscapes in the Central Valley of California?
- Is the quantity and lability of soil carbon and nitrogen a function of plant type and its associated plant community, tillage, water, nitrogen fertilization, or a combination of factors, and how does this vary with depth
- Is carbon sequestration on a Yolo loam in a Mediterranean environment a function of plant type, tillage, water, nitrogen fertilization, or a combination of factors?
- Do plant species type and tillage select for soil microbial functional genes that are linked to carbon cycling (i.e. carbon fate and allocation), and if so, how does this correlate with the system's measured stable carbon stocks?

Hypotheses:

- Biomass and grain yields of Kernza will be lower than those observed in the Midwest and Northeast U.S.A. but will be suitable for use on marginal land or as specialty crops. Soil health metrics will show improvements in soil health over the course of three years in all Kernza treatments relative to all no-till and tilled annual wheat.
- Based off a recent study that suggests Kernza increases investments in root production in highly enriched areas, and carbon from root turnover contributes 30-80% of organic C inputs in soil, it's anticipated that the irrigated and non-irrigated Kernza treatments that receive 100 kg of N/ha will have the greatest quantity of total and labile soil N and C, particularly within the top 0-30 cm of soil.
- Soil carbon sequestration will predominantly be function of plant species and tillage and will positively correlate with the frequency of microbial functional genes linked to carbon cycling. Kernza cultivation will select for functional genes that demonstrate

potential to degrade complex substrates, produce osmolytes, protect against desiccation, and maintain cellular integrity – all of which have been suggested to result in potential soil C sequestration. Irrigated and moderate N (100 kg N/ha) Kernza treatments are anticipated to accumulate the most stable carbon at a depth of 0-240 cm.

APPROACH AND METHODS

To answer the first question, grain yield, aboveground biomass yield, and harvest index will be assessed in all treatments, and soil from one replicate of each sub-sub plot treatment will be sent to Cornell to be analyzed in the comprehensive Cornell Soil Health Assessment Lab after the second year of production. For the second question, POXC, PMN, TC, TN, NH_4^+, NO_3^-, qPCR and PLFA total lipids in the irrigated and non-irrigated treatments that receive 0 and 100 kg N/ha and the fallow will be analyzed. To address the third and fourth question, culture-independent shotgun metagenomic analyses will be used to assess the frequency of functional genes linked to carbon cycling. Soil organic carbon (SOC) stocks (0-243 cm) will be tracked annually and compared to baseline samples taken in 2017. SOC stocks and microbial analyses will be conducted on the fallow and the irrigated and non-irrigated treatments that received 0 and 100 kg N/ha.

KEY FINDINGS

Agronomic and soil data is currently being analyzed, as it was collected in late summer and fall of 2018; preliminary data is provided in the figures below.

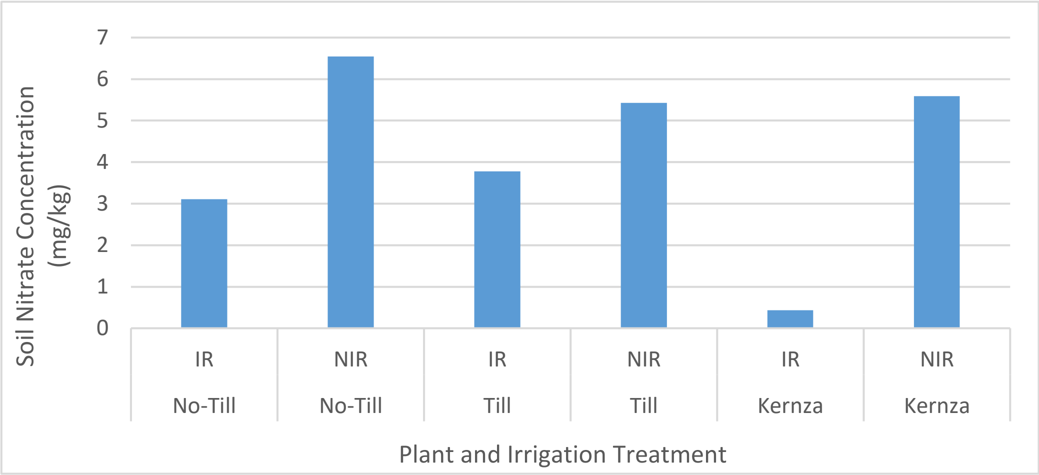


Figure 1. Soil nitrate concentrations as determined by KSO_4^- extraction within the top 0-6 inches of soil that received 0 lb N/ha as affected by plant type and irrigation treatments during the 2018 growing season.

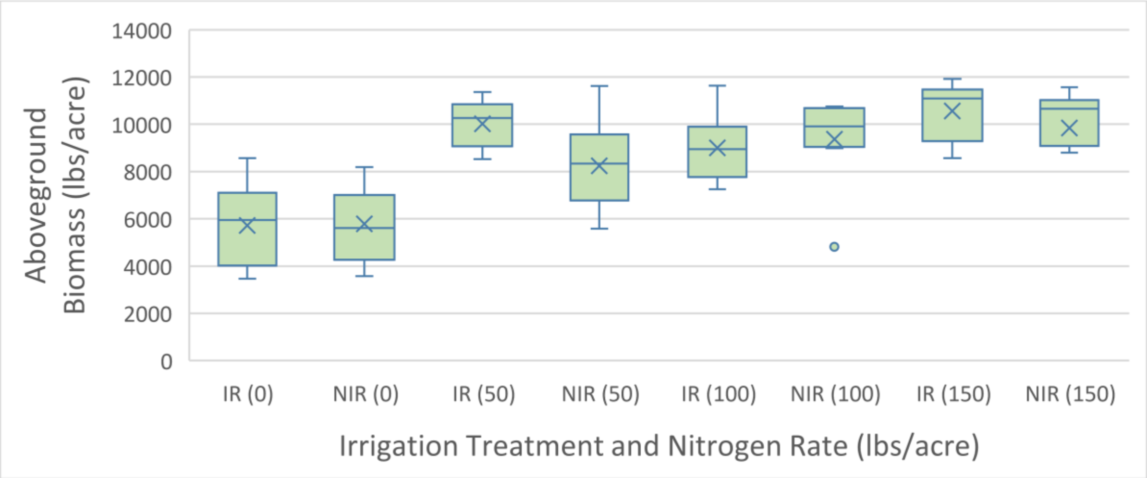


Figure 2: Aboveground biomass of annual wheat (tilled and no-till) as affected by nitrogen fertilization (0-150 lb N/ac) and irrigation (IR=irrigated; NIR=non-irrigated) during the 2018 growing season.

By A. Gaudin, C. Casteel, R. Vannette, R. Blutnell, J. Schmidt, T. Bowles, and F. Bender, UC Davis and UC Berkeley

INTRODUCTION

Numerous ecological and agricultural studies show that organic farming practices can significantly increase soil health and plant nutrient balance while decreasing incidence of plant pathogens and insect pests. Decreased insect populations on long-term organic farms have largely been attributed to increased herbivore biodiversity and numbers of beneficial insects, such as predators. However, the role of rhizosphere microbes as shaped by management on these interactions has largely been ignored, despite increasing evidence that root associated microbiomes can regulate higher trophic interactions and substantially reduce attractiveness to insect pests. Induced systemic resistance is emerging as an important mechanism by which rhizosphere microbes and endophytes can prime the whole plant for enhanced defense against a broad range of pathogens and insect herbivores. We sampled leaf and rhizosphere soil from the conventional-mixed and organic tomato fields to elucidate impacts of organic management and soil health building practices in general on induced systemic resistance pathways and attractiveness to beet leafhoppers (Circulifer tenellus) carrying the Beet Curly Top Virus (BCTV). We also took advantage of an experiment lead by

Tim Bowles to further investigate the role of AMF and their diversity and abundance in mediating resistance to beet leafhoppers.

OBJECTIVES

Research Questions:

- To what extent does management increase constitutive and induced systemic resistance and what is the impact on plant attractiveness to beet leafhoppers carrying the BCTV?
- What is the role of rhizosphere microbes and AMF in mediating this process and how does that vary with management?

Hypotheses:

- By fostering soil microbial communities, organic management practices increase beneficial soil-plant interactions which improve constitutive and/or induced systemic resistance pathways to decrease BCTV pressure.
- SA/JA-mediated defenses observed in previous experiments are primarily induced by AMF and AMF colonization regulates basal levels of host defense metabolites.

APPROACH AND METHODS

We sampled the organic and conventional long-term treatments of the Century experiment during the 2016 and 2017 growing season. Insect populations were sampled three weeks after transplanting with ten sweeps up and down the plots within an eight-row boundary along a transect. Rhizosphere soil was collected and soil slurries were prepared and autoclaved or left untreated for lab experiments. The soil slurries were added to sterile soil with tomato seeds twice a week in a greenhouse. Three weeks after seedling emergence, a choice bioassay was performed. Tomato branches were also collected from the conventional and organic locations three weeks after transplanting to the field and immediately used for choice bioassays. Avirulent beet leafhoppers (*Circulifer tenellus)* were collected and starved for two hours prior to the experiment. A cage was constructed that allowed an organic tomato leaf to be sealed in one end and a conventional leaf in the other. Developmentally similar leaves were selected to standardize the assay. Five avirulent beet leafhoppers were introduced in the center of the cage equidistant to both leaves and kept in the dark for two hours. Their preference was then recorded. Each experiment was repeated 18 times. Developmentally similar true leaves from tomato plants were also sampled to determine hormone contents via HPLC. Composited dried and homogenized soil and plant samples were analyzed for soil chemical properties. DNA from rhizosphere soil samples was extracted and sequenced to characterize bacterial and fungal communities. Binomial distributions were used to determine the impact of treatments on insect choice. Analysis of variance (ANOVA) were performed to determine the impact of farm management on insect populations, survival, phytohormones levels, plant nutrition and soil properties. Mantel tests were conducted to identify correlations among plant, soil, and microbial variables.

KEY FINDINGS

We demonstrate that organic fields had lower pest populations compared to conventional sites and that differences were due partially to increased plant resistance. Beet leafhoppers consistently prefer to settle on conventionally grown tomato plants rather than organically grown plants at Russell Ranch and in a survey across 3 other paired sites in Yolo county (Figure 1).

Organic management altered plant defense hormones and rhizosphere microbial communities have a significant impact on plant attractiveness to leafhoppers. Microbiome sequencing and transgenic approaches coupled with multi-model inference show that changes in plant resistance were dependent on salicylic acid accumulation in the plant and rhizosphere microbial communities (Figure 2, Figure 3).

Shifts in leaf nutrient composition or nutrient imbalances might also be involved as organic management often decreases N and P in tissues.

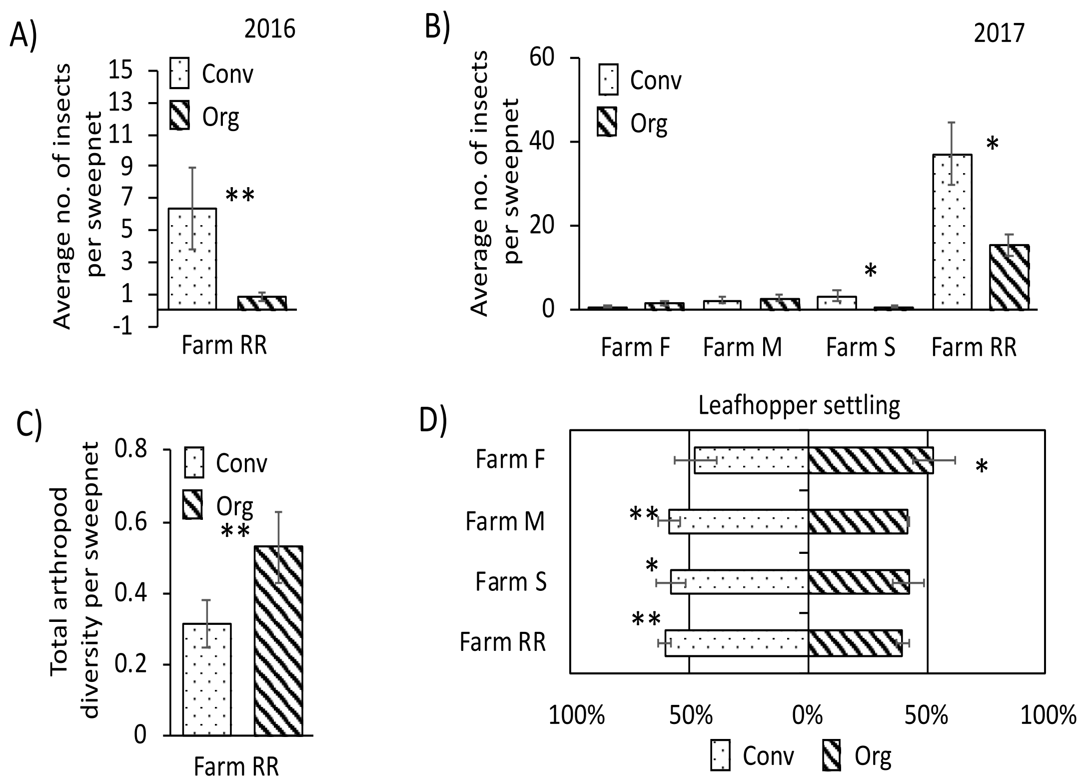


*Figure 1: Organic management practices reduced insect populations and preference in processing tomatoes. (A) The number of insects collected in sweepnets on organic and conventional plots of tomato at Russell Ranch (Farm RR) in 2016. (B) The number of insects collected in sweepnets on organic and conventional plots at Farm RR and three commercial processing tomato farms (Farm F, M, and S) in 2017. (C) Combined arthropod diversity across all sites in 2017. D) Leafhopper settling preference for leaves collected from Farm RR and three commercial processing tomato farms (Farm F, M, and S) in 2017. (mean ± SE; N= 6 for A and B, C, N= 24 for C and N=18 for D). Stars represent significant differences; *P<0.1, **P<0.05).*

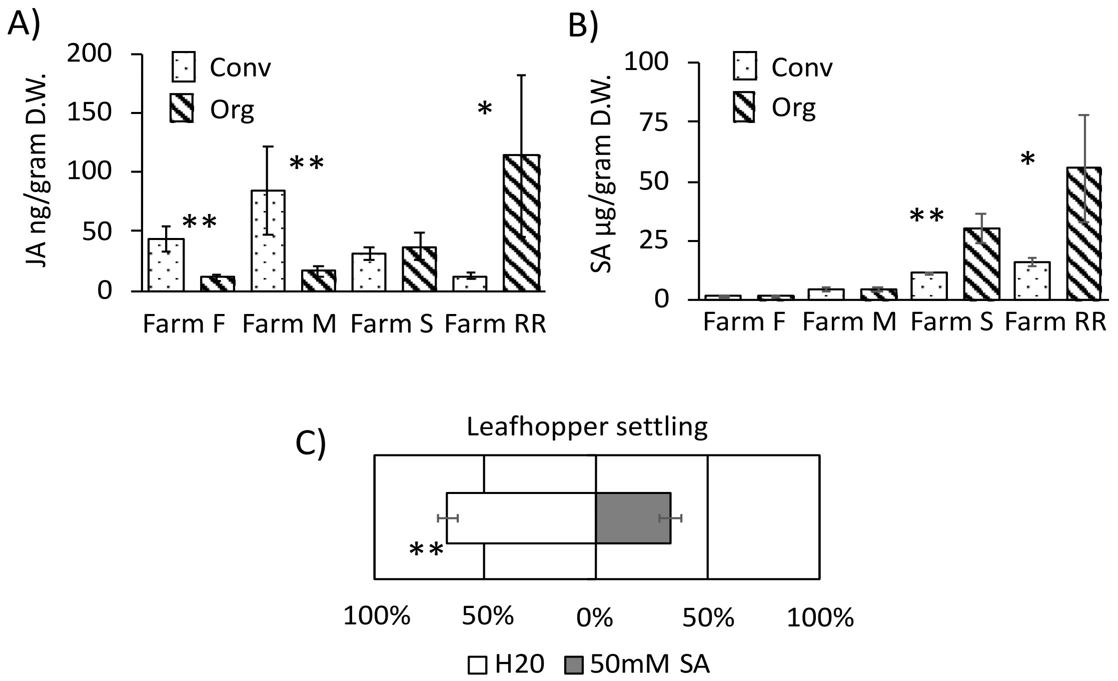


*Figure 2: Organic management practices altered plant defense hormones. (A) Jasmonic acid (JA) and (B) salicylic acid (SA) content in tomato leaves from organic and conventional plots at Farm RR and three commercial processing tomato farms (Farm F, M, and S). (C) Leafhopper settling preference for leaves induced with 50 mM of SA or with water as a control. (mean ± SE; N= 6-12 for A and B, N= 12 for C). Stars represent significant differences; *P<0.1, **P<0.05, ***P<0.001).*

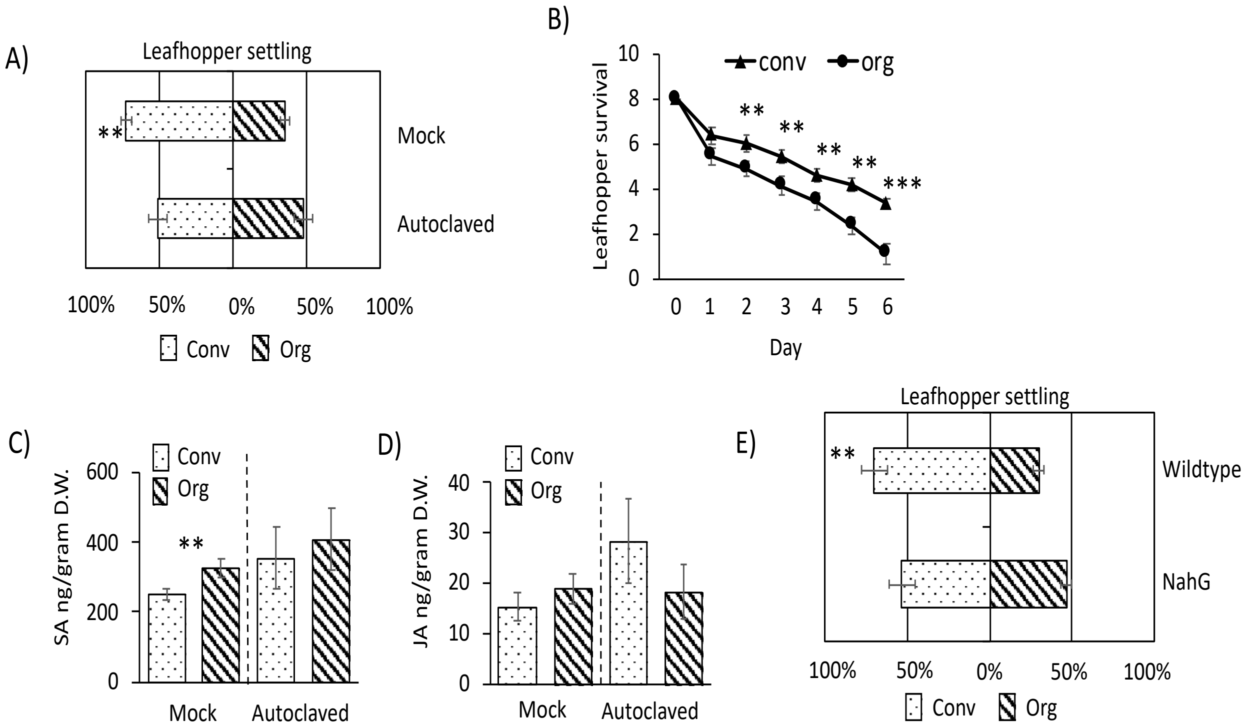


*Figure 3: Rhizosphere biota drives differences in leafhopper populations, preference, and plant resistance. (A) Leafhopper survival on tomatoes grown with a soil slurry prepared from conventional and organic plots from Farm RR. (B) Leafhopper settling preference for tomatoes grown a soil slurry prepared from conventional and organic grown rhizosphere soils from Russell Ranch that was untreated or autoclaved. (C) Jasmonic acid and (D) salicylic acid content of leaves from tomatoes grown a soil slurry prepared from conventional and organic plots from Farm RR that was untreated or autoclaved. (E) Leafhopper settling preference for leaves from Wt and NahG cultivars grown in conventional and organic soil slurries. (mean ± SE; N= 8-9 for A, N= 36 for B, N= 6-9 for C, D, E; Stars represent significant differences; *P<0.1, **P<0.05).*

SIGNIFICANCE AND FUTURE STEPS

These results suggest that novel and more sustainable pest management strategies can be developed through soil health management. Our manuscript has been conditionally accepted in PNAS pending successful revisions. Experiments related to the role of AMF in regulating these trophic interactions are still being analyzed but interesting trends are emerging.

By A. Gaudin, J. Schmidt, and V. Brisson, UC Davis

INTRODUCTION

The impacts of management practices are often monitored on bulk soil, but uncertainties remain as to how this translate to rhizosphere community and functions involved in efficient nutrient cycling and uptake. Maize is known to recruit certain core microbial taxa across environments. However, little is known about the degree to which a core microbiome is observed across different agricultural management systems. Can maize recruit management-system-specific microbial taxa to the rhizosphere? How does that impact adaptation to different systems? If so, maize grown in organically managed systems could select an increased abundance of taxa involved in organic matter mineralization and N cycling or stimulate the expression of the responsible genes, potentially increasing nutrient availability in these systems. Alternatively, if the abundance and activity of organic-matter-mineralizing and N-cycling taxa are conserved across management systems, nutrient availability in the rhizosphere is likely less responsive to plant-microbe feedbacks and must be manipulated through bulk soil management.

OBJECTIVES

Research questions:

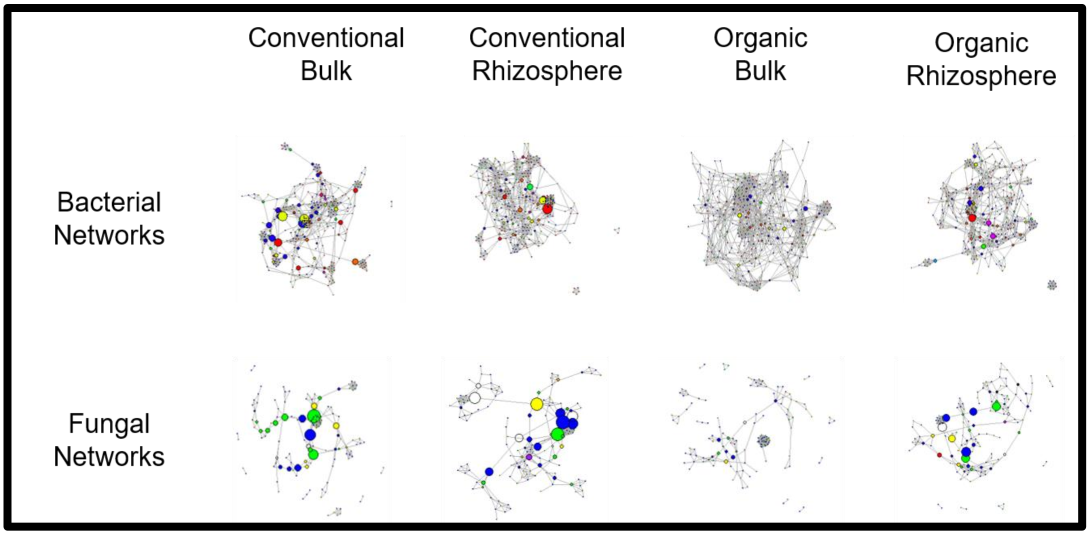
- Can maize recruit management-system-specific rhizosphere microbes (i.e. high plasticity in recruitment), or is recruitment constant across all management systems (i.e. a core microbiome)?
- Similarly, does stimulation of microbial N cycling in the rhizosphere vary by system (upregulation of organic N mineralization in organic systems, upregulation of ammonia- and nitrate-cycling genes in conventional systems), or is it constant?

Hypotheses:

- Rhizosphere microbial community composition will be more similar than bulk soil community composition but will be significantly different between conventional and organic systems, supporting the plasticity in recruitment hypothesis.
- Microbial genes related to organic N mineralization (apr, npr) and ammonification (amoA) will be upregulated to a greater degree in the organic system than the conventional system. An increase in the abundance of these genes may be observed in both rhizospheres as compared to bulk soil, but the overall abundance will be greater in the organic system.
- Similarly, microbial genes related to denitrification (nirK, nirS, nosZ) will be upregulated to a greater degree in the conventional system.

APPROACH AND METHODS

During peak N uptake in summer 2017, bulk soil and rhizosphere samples were collected from the maize plots of the maize-tomato rotation in the Century Experiment at Russell Ranch. Samples were sent for sequencing (16S and ITS2 regions) at Argonne National Laboratory. Differential abundance analysis was used to identify taxa whose abundance differed between environments (bulk/rhizosphere x conventional/organic) and indicator species analysis was used to identify taxa unique to each environment. Co-occurrence networks were constructed for each environment and network topology was compared.



Differential abundance analysis revealed larger differences due to management than the rhizosphere effect (below left: bacteria; right: fungi; CB = conventional bulk; CR = conventional rhizosphere; OB = organic bulk; OR = organic rhizosphere).

KEY FINDINGS

A rhizosphere/management interaction was observed for bacterial co-occurrence networks. In the conventional system, the rhizosphere network was less connected, less dense, and less centralized, but the opposite was true in the organic system. Fungal networks were less dense, connected, and centralized in the rhizosphere in both management systems.

SIGNIFICANCE AND FUTURE STEPS

N-cycling gene abundance is still being measured using qPCR by a collaborator at the University of Illinois – Champaign-Urbana. This data will allow us to link observed shifts in rhizosphere community composition and co-occurrence patterns to functional outcomes. Thus far, plant selection appears to be far weaker than the effects of management system even in the rhizosphere, underscoring the importance of sustainable bulk soil management to maximize beneficial plant-microbe interactions.

By A. Gaudin, J. Schmidt, and V. Brisson, UC Davis

INTRODUCTION

Human selection has changed modern maize dramatically as compared to its wild ancestor, teosinte (Zea mays ssp. parviglumis), and it has become clear that domestication and breeding may have had profound effects belowground. Environmental shifts during agricultural intensification, changes in maize genetics, and genotype-by-environment interactions have imposed selective pressures on not only the host plant itself, but also on its associations with the rhizosphere microbiome. Given that the soil microbial community influences plant health and productivity, it is important to understand the impact of potential changes on plant-microbe interactions and the implications for developing sustainable agroecosystems.

OBJECTIVES

Research questions:

- How have diversity, composition, and function of rhizosphere bacterial and fungal communities changed over the course of maize domestication and breeding?
- Have shifts in maize-microbe interactions resulted in decreased adaptation to organic agroecosystems, which rely to a greater

degree on microbial processes such as mineralization of organic matter?

Hypotheses:

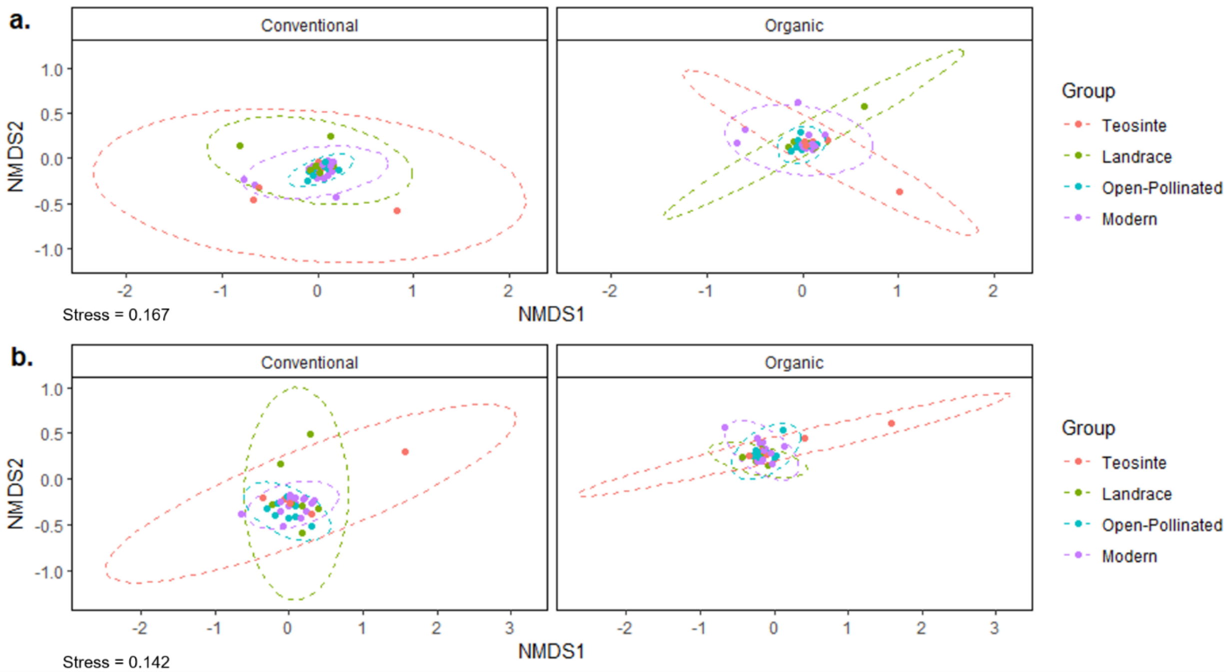
- Diversity, composition, and function of microbial communities will be affected to a greater degree by soil management history (conventional vs. organic) than maize genetic group, but domestication and breeding will nonetheless have significant effects.
- Domestication and breeding will cause directional shifts in rhizosphere diversity and composition, such that teosinte will be most similar to landraces and most distinct from modern maize. In line with the "genetic bottleneck" hypothesis proposed elsewhere4, we will see decreased diversity in the modern maize rhizosphere as compared to teosinte.
- A genotype-by-management interaction will be observed for plant nutrition and biomass: modern maize will perform relatively better in the conventional soil than the organic soil, and the converse will be true for teosinte. Significant effects of maize genetic group on microbial community composition in both soils will support a link between microbial communities and plant outcomes.

APPROACH AND METHODS

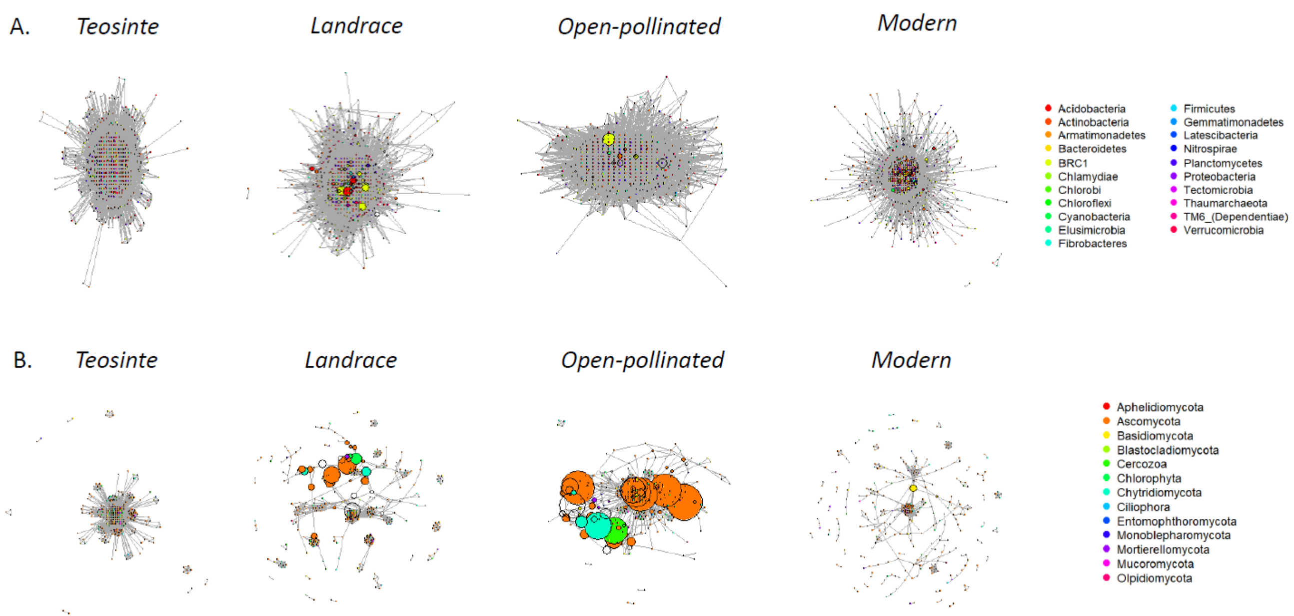
In fall 2016, topsoil was collected from the upper 10 cm of the conventional and organic plots of the Century Experiment corn-tomato rotation at Russell Ranch. Soil was thoroughly homogenized and used to fill 5-gallon pots for a greenhouse experiment. Seeds of 12 maize genotypes representing a domestication/selection gradient (2 teosinte, 2 landrace, 3 open-pollinated parents of modern elite germplasm, 5 modern hybrids) were germinated, transplanted, and grown for 6 weeks under controlled conditions. Shoots were dried, weighed, and submitted for complete macro- and micronutrient analysis. Rhizosphere soil was collected and microbial communities (16S V4-5 and ITS2 regions) were sequenced at the DOE Joint Genome Institute. Nitrogen-cycling gene abundance was measured for 7 genes using qPCR and metagenomic sequencing provided a comprehensive profile of microbial community functions for one teosinte and one modern genotype in both soils.

Differential abundance, indicator species, and co-occurrence network analyses were used to assess unique and shared taxa for each genetic group in both soils.

KEY FINDINGS



Permutational multivariate analysis of variance revealed the significant effects of soil, compartment, and genetic group on bacterial and fungal community composition. Soil management history accounted for the greatest proportion of variation (6-18%) in bacterial and fungal communities, with only ~2% of variation attributable to maize genetic group. Indicator species analysis identified more shared taxa between the modern and open-pollinated rhizospheres than any other pair of genetic groups, and network analysis showed that the modern maize rhizosphere has far fewer positive co-occurrences than other genetic groups.



SIGNIFICANCE AND FUTURE STEPS

These results support our hypothesis that human selection has had profound effects on belowground interactions. However, shifts in rhizosphere microbial community composition have been non-linear and have not resulted in decreased diversity. The functional implications of these changes remain to be understood and are the focus of ongoing qPCR analysis and bioinformatic analysis of sequenced metagenomes. We intend to link differences in community composition between the soils to plant outcomes to determine whether specific taxa are strongly linked to plant performance in either soil.

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By D. Geisseler and J. Rodrigues, UC Davis

OBJECTIVES

The core assumption of the research is that healthy soils provide an environment for soil microorganisms and plants that minimizes stress. A decrease in soil health thus measurably increases stress indicators.

APPROACH AND METHODS

Soil and plant samples were taken from the conventional and organic corn-tomato plots twice in spring/early summer. Soil physicochemical parameters that are commonly used in soil health indices were quantified. Metagenomic analyses of soil microorganisms with a focus on stress related genes and high throughput sequencing of the 16S rRNA genes as a proxy for microbial community changes have been performed. Crop growth and yield were measured to assess plant performance. Furthermore, stress-related physiological responses of plants (e.g. hormone levels and photosystem II activity) were measured.

KEY FINDINGS

This is the first year of the study. Under both crops, the organic soil had a higher total carbon content, higher microbial biomass and higher microbial activity than the conventional soil. These results strongly suggest that the organic soil is heathier.

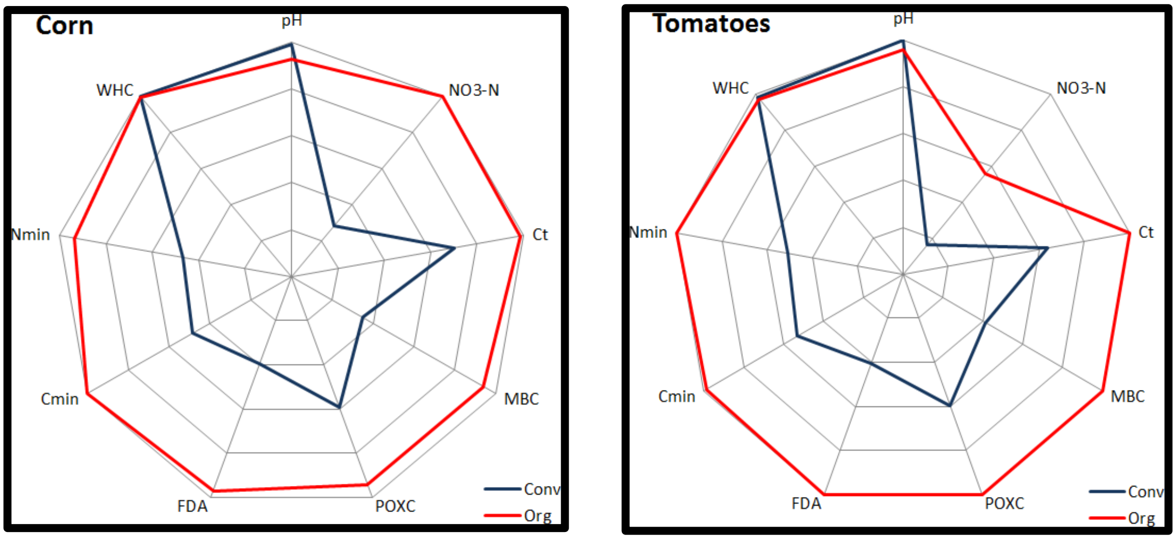

Figure 1: Soil chemical and biological properties. Samples were taken pre-plant. The axes are normalized, with the highest value taken as 1. For abbreviations see Table 1.

Table 1: Soil health measurements included in Figure 1.

Abbrev.	Measurement	Abbrev.	Measurement
pH	pH	FDA	Fluorescein diacetate hydrolysis activity
NO3-N	Residual soil nitrate-N	Cmin	C respired after 24 hours incubation
Ct	Total carbon	Nmin	N mineralized after 4 weeks incubation
MBC	Microbial biomass carbon	WHC	Water-holding capacity
POXC	Permanganate-oxidizable C		

Did the healthier organic soil result in heathier plants? Not in the case of the tomatoes. The organic tomatoes were more stressed than the conventional ones (Figure 2). This was likely the result of increased disease pressure in the organic treatments. In contrast, the organic corn plants experienced less stress than the conventional plants throughout the season. However, the corn results need to be interpreted with care, as the organic corn needed to be replanted.

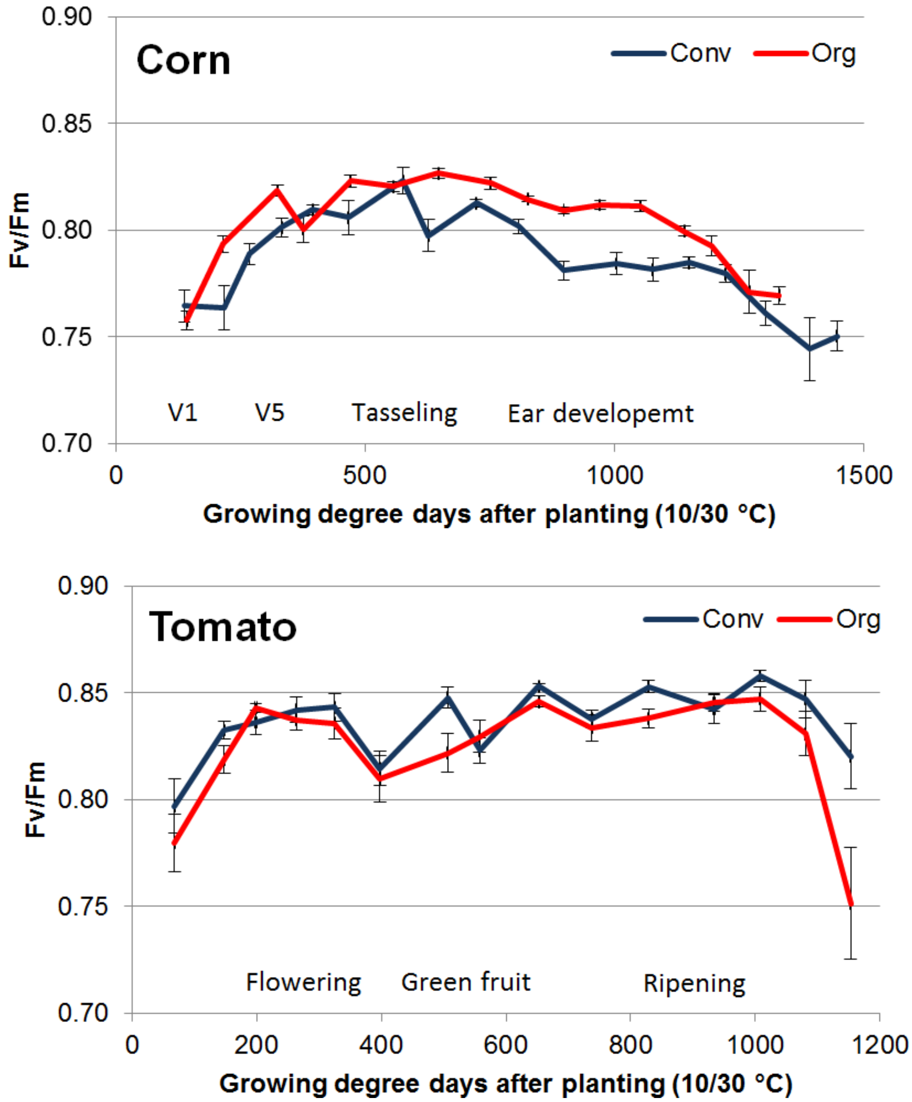

Figure 2: Chlorophyll fluorescence was measured as an indicator of biotic and abiotic stress. Shown in the graph is the maximum quantum efficiency of photosystem II photochemistry (Fv/Fm). Stress can decrease the Fv/Fm ratio. Unstressed leaves generally have values of about 0.83.

SIGNIFICANCE AND FUTURE STEPS

The project shall improve the understanding of the effects of crop management practices on soil health, microbial communities, and plants. Ultimately, the results shall lead to a better stewardship of the soil as a natural resource.

The soil health assessment, microbial metagenomic analyses and plant hormone analyses are currently being completed on the samples taken in 2018. The study shall be repeated in 2019 in the same plots.

By D. Griffin and K. Scow, UC Davis

INTRODUCTION

Understanding the effects of drought and wet-dry cycling on microbial communities could provide the basis for designing management practices that more effectively manage below-ground biota and their processes that conserve carbon and tighten nutrient cycles. Most of the current knowledge, however, is based soils obtained from natural systems such as grasslands and tested under laboratory conditions. In agricultural soils, management of irrigation dramatically alters the availability and distribution of water and could cause similar effects seen with changing precipitation patterns in grasslands.

Subsurface drip irrigation (SDI) has been widely adopted in California's Mediterranean agroecosystems, particularly in processing tomato (Solanum lycopersicum L.) systems. Though SDI provides obvious agronomic benefits, it wets only a small portion of the soil leaving the majority of the soil volume dry throughout the growing season. This is in contrast to furrow irrigation (FI), where furrows between beds are flooded periodically and wet up the entire bed.

These management systems provide a real-world case for comparisons of continuously wet, continuously dry, and fluctuating moisture conditions and their effects on soil microorganisms. Additionally, fields with contrasting fertility management and organic matter input histories (organic vs. conventional) allow us to assess the effects of SDI in systems with different organic C contents and reliance on microbial processes for nutrient availability.

OBJECTIVES

Our first objective was to evaluate the effects of three treatments—organically-managed FI (Org-FI), organically-managed SDI (Org-SDI), and conventionally-managed SDI (Conv-SDI)—on microbial biomass and extractable carbon and nitrogen dynamics, microbial community structure bacterial and archaeal diversity at various lateral and vertical areas within tomato beds. Our second objective was to compare the effects of the fertility and irrigation management treatments on crop yields and system costs.

APPROACH AND METHODS

In a field experiment conducted at the Russell Ranch Sustainable Agriculture Facility, soil samples were collected throughout the processing tomato growing season from transplanting (May) until harvest (August) at three depths (0-15, 15-30, 30-45 cm) and three distances from bed center (10, 25, 45 cm; Fig. 1). Dissolved organic C and inorganic N (NO3--N and NH4+-N) were extracted with potassium sulfate, as was MBC after chloroform fumigation. Microbial community structure and diversity were evaluated through phospholipid fatty acid analysis (PLFA) and 16S rRNA gene sequencing. Crop yields and vegetation biomass were measured through machine and hand harvest.

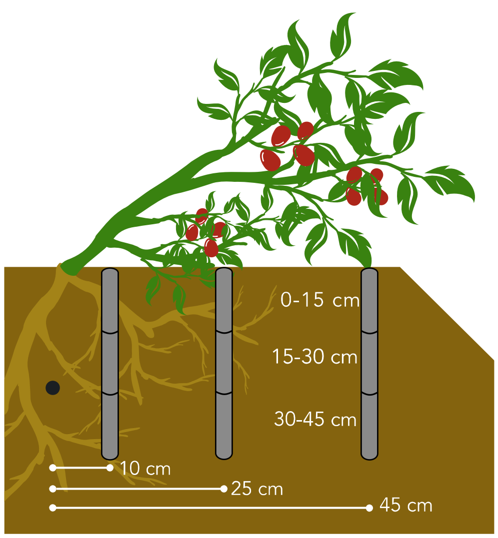

Figure 1: Sampling design scheme. Two sets of these cores were taken at randomly selected locations in each plot at four sampling time points.

KEY FINDINGS

- In August, Org-SDI at the bed edge (45 cm distance) had lower MBC:DOC and MBC:inorganic N ratios than Org-FI, indicating a decoupling of C and N cycles from reduced microbial uptake.
- Conv management had consistently lower DOC concentrations than Org.
- Community composition at the bed edge diverged between SDI and FI, favoring Actinobacteria in the former and Acidobacteria and Gemmatimonadetes (previously associated with dry conditions) in the latter (Fig. 2).
- Lipids associated with arbuscular mycorrhizal (AM) fungi were greater in Org-FI at the bed edge.
- In all treatments, the dry areas of the bed had the highest alpha diversity indices (Shannon and Chao1). Response to SDI was similar between Org and Conv, though Conv had lower MBC, DOC, and relative abundance of Proteobacteria and fungal lipids.
- Though tomato fruit yields were higher in Org-FI than Org-SDI, costs were greatest in the FI system to due hand weeding labor required (Fig.3).

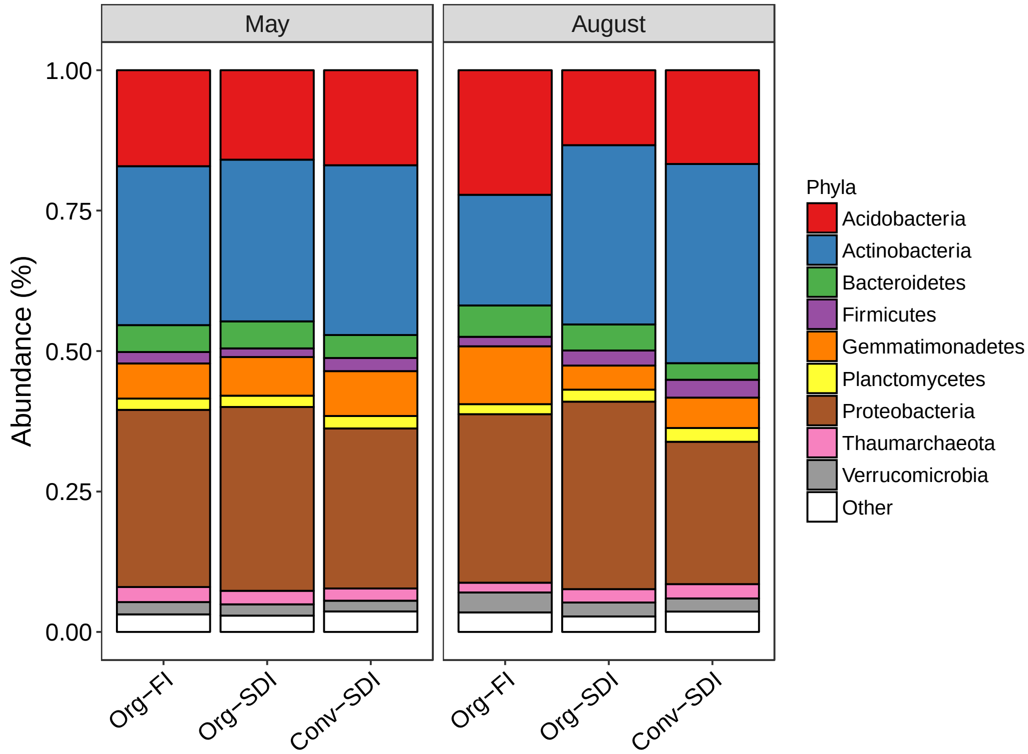

Figure 2: Relative abundance of major phyla at the surface (0-15 cm) and bed edge (45 cm distance) in May and August. "Other" represents the sum of all phyla that represented less than 1% relative abundance.

SIGNIFICANCE AND FUTURE STEPS

Our spatial investigation into the effects of SDI and FI in organic and conventional tomato systems puts mechanisms described in extensive wet-dry cycling and drought literature in a field context. We found that continuously dry and wet-dry cycling niches created at the bed edge in SDI and FI, respectively, do indeed change microbial community composition and disrupt C and N cycling dynamics. Continuously dry surface soils in Org-SDI had lower MBC than Org-FI, and at the bed edge showed a drop in MBC:DOC and MBC:inorganic N ratios, indicating that uptake of these resources to support biomass growth is reduced, likely from diffusion limitations. This decoupling of C and N pools leaves these elements more vulnerable to loss from the system during the first winter rain event, an important question for a future study. Rewetting of SDI surface soils with winter rain after months of remaining dry may actually create extended, more severe wet-dry cycles than those in Org-FI.

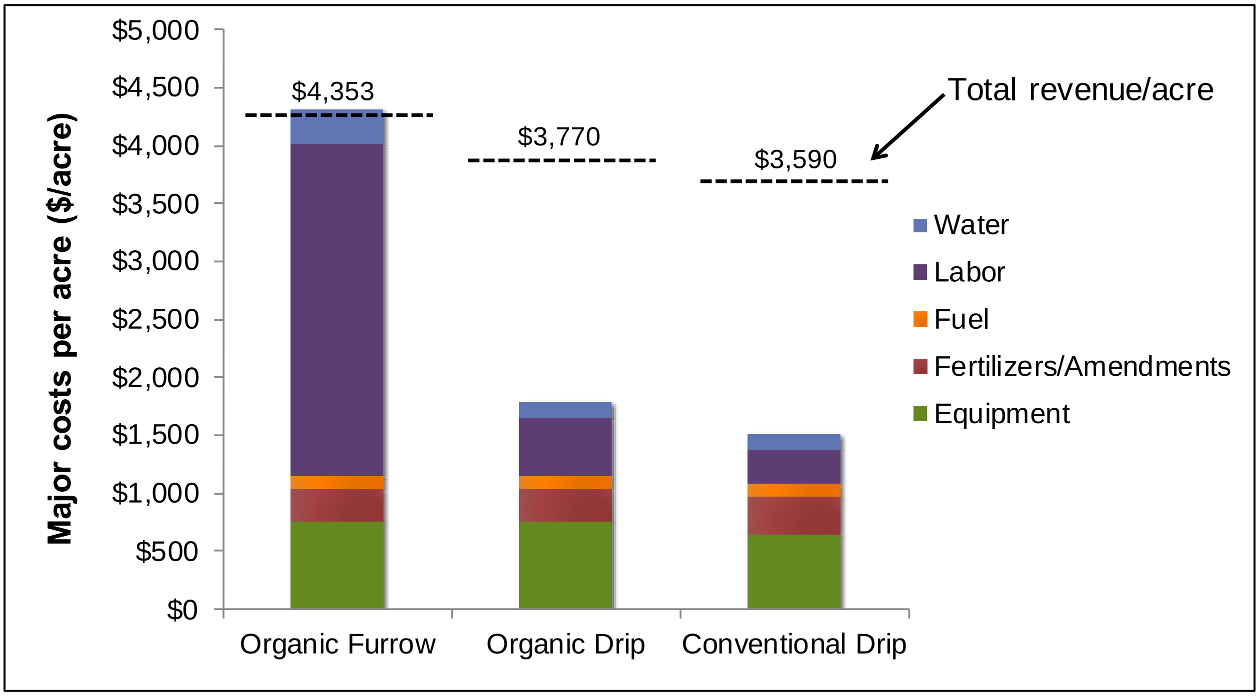

Figure 3: Major costs (bars) and revenue (dotted line) associated with each management system.

Knowing how phylogenetic diversity or shifts in microbial community composition influence soil health and biogeochemical cycling could provide valuable insights into how to most effectively and sustainably manage farms. Greater phylogenetic diversity may, but not always, indicate greater functional diversity. Networks of soil microbes interact to decompose organic matter, cycle nutrients, create compounds that build soil aggregates, and control pathogens; the redundancy of these important functions is key to their resilience in changing conditions (Kibblewhite et al., 2008). However, stresses such as desiccation can reduce functioning of even diverse microbial communities. While organisms like gram-positives and spore-forming bacteria may become more abundant (Naylor and Coleman-Derr, 2018), these organisms may still shut down metabolism with desiccation or be limited by substrate diffusion and accessibility (Schimel, 2018). In future studies, it will be important to assess whether communities in surface soils adapt to desiccation after multiple years under SDI (here in the first year) and whether divergence of microbial communities between irrigation systems is long-term or reset by winter rains.

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By M. Li, M. Burger, and A. Gaudin, UC Davis and CDFA

INTRODUCTION

Deficit irrigation in the second half of the growing season provides opportunities to increase soluble solids concentration in processing tomatoes while decrease water inputs. Our deficit irrigation experiment in 2017 applied four water treatments to conventional tomatoes starting at 73 days after transplanting. Results showed that water saving deficit irrigation regimes up to 50% ET increased soluble solids concentrations without negatively affecting tomato yields and that NDVI might be a good decision-making tool to determine the onset of deficit irrigation. In 2018, the deficit irrigation treatment was expanded to organic management tomato systems to optimize decision tools for both conventional and organic systems. Organic systems at Russell Ranch likely have higher water holding capacity coupling with a more diverse, connected microbial pool, which may allow tomatoes to more dynamically resist/adapt to lower deficit regimes compared to conventional systems. We are also comparing rhizosphere microbial communities and activities in a single genotype (G) under deficit irrigation (E) in organic and conventional systems (M) to provide critical insight into the relative contribution of plant and management to building agroecosystem resilience and the ecological interactions involved (GxExM).

OBJECTIVES

Research questions:

- When and which tool can be used to guide the application of end-of-season deficit irrigation to maximize soluble solids concentration without causing significant yield loss?
- Do organic systems respond differently to deficit irrigation? Are they more resilient?
- How does that translate to rhizosphere community composition, activity and function?

Hypotheses:

- We hypothesize that the normalized difference vegetation index (NDVI) could be a potential decision-making tool to guide the application of deficit irrigation since it is closely related to canopy evapotranspiration (ET) rates.
- We hypothesize that crops in the organic system will be more resistant to water stresses induced by deficit irrigation than the conventional system in terms of plant growth, yield, and rhizosphere microbial community activity, due to the enhanced water holding capacity and high diversity of microbes in the organic system.

APPROACH AND METHODS

In the 2018 season, four deficit treatments (25%, 50%, 75%, and 100% ET) were applied one week after the NDVI reached the plateau (56 days after transplanting) in both organic and conventional tomato systems. Irrigation water was adjusted for different treatments based on ET data from Tule on a daily basis. Soil moisture conditions were monitored using the Watermark soil sensors. The mid-day stem water potential and canopy temperature were measured to monitor plant stress levels on a weekly basis. Rhizosphere and bulk soils were collected three and six weeks after the onset of deficit irrigation for microbial community composition and enzyme activity analyses.

KEY FINDINGS

Deficit irrigation increased tomato brix level by up to 0.76° than the fully irrigated treatment without causing a yield loss in the organic system. However, although increased brix by up to 0.61°, all deficit irrigation treatments resulted in significant yield losses in the conventional system (Figure 1). Applying deficit irrigation up to 25% ET one week after the NDVI plateau has the potential to increase the concentration of soluble solids of processing tomatoes without influencing yields in organic systems.

Water stresses as monitored by stem water potential (SWP) indicated that plants started to show differences among treatments after 2~3 weeks of deficit irrigation in both organic and conventional systems.

Tomato plants were more resistant to water stress in the organic relative compared to the conventional system. After 6 weeks of deficit irrigation, SWP in the 75% and 50% ET treatments did not differ from the full irrigation in the organic systems, whereas only the 75% ET treatment maintained the same SWP level as the full irrigation treatment in the conventional system (Figure 2).

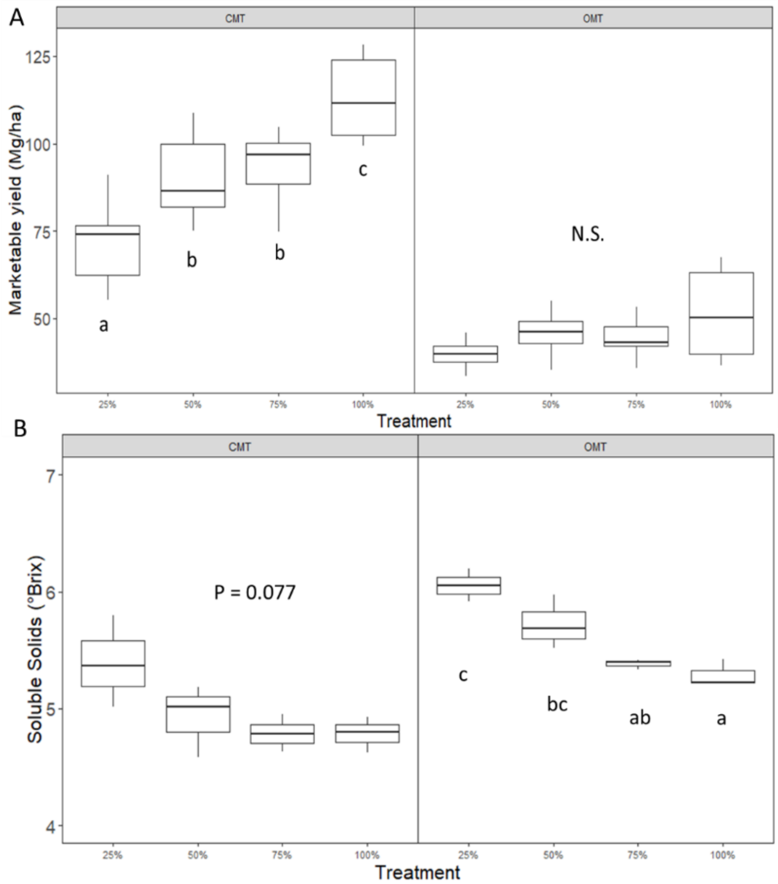


Figure 1: Tomato yields (A) and soluble solids concentration (B) under four irrigation treatments in the organic (OMT) and conventional (CMT) systems. Letters represent differences among treatments at the 0.05 significance level.

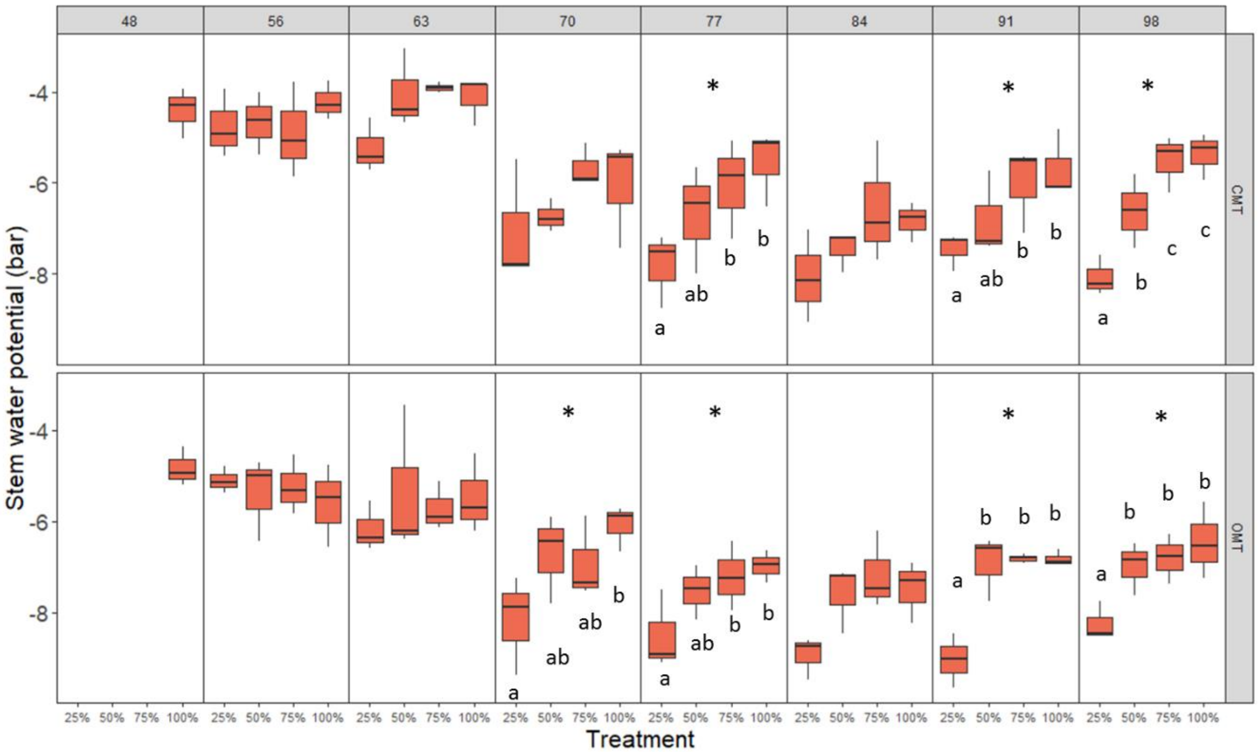


Figure 2: Mid-day stem water potential measurements under four irrigation treatments in the organic (OMT) and conventional (CMT) systems. Stars indicate significant differences among treatments at the 0.05 significance level.

SIGNIFICANCE AND FUTURE STEPS

Rhizosphere microbial community composition and activity (enzymes) being measured will allow us to understand the link between rhizosphere microbial processes and the plant outcomes as influenced by deficit irrigation. These samples are still in process, and the data will be available in spring, 2019.

By M. Li, C. Peterson, N. Tautges, K. Scow, and A. Gaudin, UC Davis

INTRODUCTION

To be sustainable and resilient, agriculture must rely on management practices which build agroecosystem's capacity to supply and harness critical ecosystem services. This project centers around mining the long-term datasets available for the tomato rotation to provide critical insight into the long-term effects of management on provision of multiple ecosystem services and their linkages with productivity and sustainability of irrigated cropping systems. We first developed a systematic, resilience-centric framework emphasizing multiple aspects of yield dynamics (i.e., long-term yield trends, yield stability, yield resistance and potential). We then moved beyond yields as metrics of success by quantifying provision of multiple ecosystem services and shifts in multifunctionality over time in these systems.

OBJECTIVES

Research questions:

- How have organic and cover crop practices influenced tomato and maize yield trends relative to the conventional system over 24 years of management?

- What is the impact of long-term organic, cover cropping, and conventional management on temporal stability and resilience of maize and tomato yields?
- How does management impact long-term provision of multiple ecosystem services (multifunctionality) and, based on past research, what are the potential underlying mechanisms?

Hypotheses:

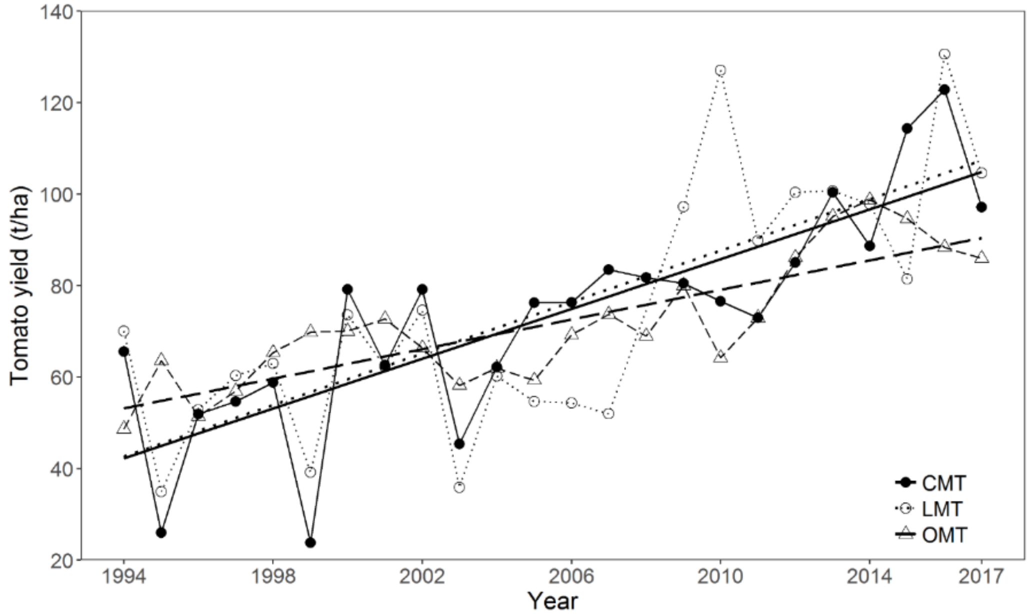
- We hypothesized that due to enhanced ecosystem services such as soil quality and soil-water relations, long-term organic and cover cropped management systems would show increased crop yields over time and comparable performance to conventional systems in absolute crop yields.
- Long-term organic and cover cropping practices can increase system resilience relative to conventional systems in the form of enhanced yield stability and reduced yield losses under adverse environmental conditions.
- Long-term organic systems provide more ecosystem functions that can be harnessed to improve agricultural sustainability over time.

APPROACH AND METHODS

Yield trends of maize and tomato over 24 years were analyzed using linear mixed-effects models with cropping system and year as fixed effects, and cropping system nested within block as random effects. Likelihood ratio tests were conducted to choose the most parsimonious models based on tests of different random structures and temporal autocorrelation of residuals. For maize, yield patterns were analyzed separately for the periods 1994-2007 and 2012-2017, due to the missing data. Four yield stability metrics per system were calculated and compared for both maize and tomatoes: 1) yield range, 2) coefficient of variation (CV), 3) yield variance, and 4) Finlay-Wilkinson (FW) regression slope. Tomato yield potential was calculated using two metrics: 1) probability of low and high yields based on frequency distributions, and 2) minimum and maximum yield potential. The yield potential of maize was not analyzed due to small sample size (n=19) and missing data.

KEY FINDINGS

- In tomatoes, long-term organic management maintained comparable productivity to conventional management while significantly increasing resilience in the form of yield stability and resistance (Figure 1; Table 1; Table 2).
- Cover cropping provided extra opportunities to increase tomato yield potential under optimum environmental conditions (Table 2).
- In maize, on the other hand, organic management resulted in 36% lower yields and reduced yield stability relative to the conventional system, indicating the need for crop-specific technological innovations tailored to organic agriculture (Figure 1; Table 1).
- We are refining our models to quantify multidimensional ecosystem functions, including productivity, soil carbon sequestration, energy use efficiency, nutrient retention and biodiversity.



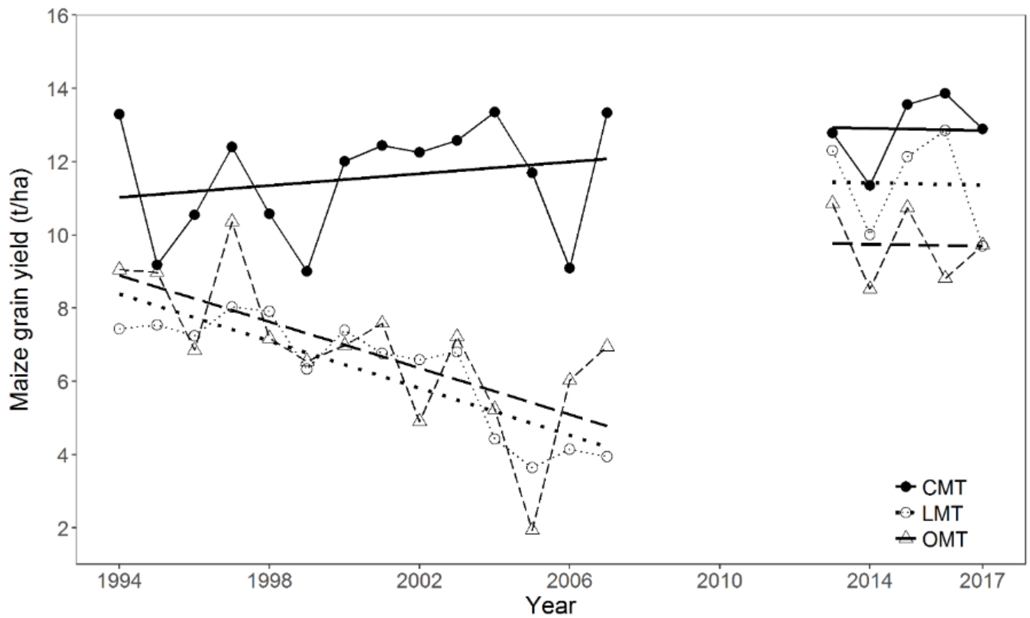


Figure 1: Mean yields of tomato (left) and maize (right) in conventional maize-tomato (CMT), legume-maize-tomato system (LMT), and organic maize-tomato (OMT) for 1994-2017. Letters represent significant differences among systems at the 0.05 significance level.

Table 1. Yield stability parameters and ranks for tomato and maize yields of conventional maize-tomato (CMT), legume-maize-tomato (LMT), and organic maize-tomato (OMT) systems for 1994-2017. Numbers in parentheses represent ranks of three systems using four yield stability methods. Letters represent significant differences among systems at the 0.05 significance level. CV, coefficient of variation. FW slope, Finlay and Wilkinson regression slope.

Crop	System	Yield stability parameters				Rank
		Yield range	CV [a] (%)	Yield variance	FW slope [b]	
Tomato	OMT	50.04 (1)	0.14 a (1)	10.23 a (1)	0.23 (1)	1
	CMT	99.07 (3)	0.20 ab (2)	14.83 ab (2)	1.17 (2)	2
	LMT	95.68 (2)	0.28 b (3)	21.19 b (3)	1.60 (3)	3
Maize	CMT	4.86 (1)	0.12 a (1)	1.47 b (2)	1.13 (2)	1
	LMT	9.20 (3)	0.15 b (2)	1.13 a (1)	0.71 (1)	2
	OMT	8.92 (2)	0.20 b (3)	1.54 b (3)	1.16 (3)	3

Table 2. The probabilities of obtaining high and low tomato yields and the minimum and maximum tomato yield potential of conventional maize-tomato (CMT), legume-maize-tomato (LMT), and organic maize-tomato system (OMT). Stars represent significant differences from the random distribution (P < 0.05) based on left-tail tests (probability of low yield) and right-tail tests (probability of high yield) over 5000 iterations.

System	Probability of low yield (<10 percentile)	Probability of high yield (>90 percentile)	Minimum yield potential	Maximum yield potential
OMT [a]	3.8 % *	2.1 %	52.47	96.42
CMT	12.4 %	16.6 %	37.76	119.90
LMT	19.2 %	22.3 % *	24.02	125.54

By E. Manaigo and B. Houlton, UC Davis

OBJECTIVES

- We are working at Russell Ranch to uncover pathways to reduce global greenhouse gas (GHG) emissions using enhanced weathering of agro-minerals, or rock pulverized to 10-150um. We employ two approaches to determine the GHG reduction potential of enhanced weathering and to study how rock-derived nutrients are retained in crop and soil.
- Our first research question asks how pulverized silicates, basalt and wollastonite, and calcium sulfate, or gypsum, impact CO2 and N2O emissions, and the crop and soil retention of rock derived Si, Mg, Mn, Fe, and S.
- Our second question aims to quantify the rate that these minerals dissolve in order to determine the pace at which crops and soil gain access to the nutrients. We will also estimate CO2 consumption by the weathering process based on mass loss from buried mesh bags.

Basalt weathering reaction:

Mg2SiO4 + 4CO2 + 4H2O ⇒ 2Mg2+ + 4HCO3- + H4SiO4

Wollastonite weathering reaction:

CaSiO3 + 2CO2 + 2H2O ⇒ 2Ca2+ + 4HCO3- + H4SiO4

Gypsum weathering reaction:

CaSO4 + 2H2O ⇒ Ca2+ + SO42- + 2H2+

According to their chemical weathering reactions, basalt and wollastonite exhibit a 4:1 and 2:1 CO2 consumption ratio respectively. This process reduces net CO2 emissions as it requires twice or four times as much CO2 as mineral substrate. Although gypsum's weathering reaction does not directly consume CO2, we expect lower net CO2 emissions as carbonates form. Mineral weathering lowers pH, therefore reducing denitrification potential and lowering N2O emissions. We expect Si, Mg, Mn, Fe, Ca, and S to be retained in crop and soil because these essential nutrients are removed during harvest at a faster rate than they are returned.

We expect gypsum to have the most rapid dissolution rate, followed by wollastonite then basalt.

Table 1: Wollastonite and Basalt are silicates with CaSiO3 and SiO2 structures. Gypsum is an insoluble salt.

Wollastonite	45% CaO, 50% SiO, 5% remainder: MgO, FeO, AlO, NaO, MnO
Basalt	48% SiO2, 14% Al2O3, 10% Fe2O3, 10% CaO, 6.5% MgO
Gypsum	CaSO4

APPROACH AND METHODS

To 30ft x 3ft plots of corn in organic, amended with cover crop residues and composted chicken manure, and conventional plots that receive only synthetic fertilizer, we applied wollastonite and gypsum at 8 t/ha and basalt at 40 t/ha (see section heading photo). We will observe soil properties (pH, aggregate stability, and soil moisture) and use a Picarro Analyzer to measure CO2 and N2O emissions in treated plots and in a control. We will use elemental analysis to quantify rock-derived Si, Mg, Mn, Fe, Ca, and S in soil and crop. In January, we will fill polyester bags with about 10g of mineral and bury the bags about 6 inches below the surface in the same plots as research question 1. We will withdraw bags several times a year for 2 years and assess mass loss. We use elemental composition analysis to measure the proportion of Mg:Ca:Si remaining in the sample compared to unweathered samples to infer weathering rate and CO2 consumption.

SIGNIFICANCE AND FUTURE STEPS

Agriculture is responsible for a significant proportion of global GHG emissions, but agriculture may also be an avenue for significant global GHG reduction. Agro-minerals have been used since the early 19th century as they contain nutrients that crops require for growth and development and renew cultivated soils by returning nutrients removed during harvest. They may also increase potential C sequestration by supporting aggregate stability. We know that mineral weathering consumes CO2, but questions regarding the time scale of dissolution of these mineral additives, net GHG reduction, and long-term soil and crop impacts remain. Our study employs 3 minerals in particular, wollastonite, gypsum, and basalt (fig.1) According to Beerling et al. 2018, Basalt applied to 2/3 of the most productive US cropland soils at rates of 10–30 t/ha/yr could extract 0.5–4 PgCO2/yr by 2100. According to RCP4.5, with an application rate 1-5 kg/m2/yr, agro-minerals could remove 30–300ppm CO2 from the air by 2100. These model projections demonstrate the potential for agro-minerals to be pivotal in stabilizing atmospheric CO2.

Next quarter we will continue this study by beginning GHG emissions assessments and deploy mesh bags.

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By A. Mandel, R. Hijmans, A. Ghosh, T. Parker, S. Mabanta, E. Hurry, and A. Rose, UC Davis

OBJECTIVES

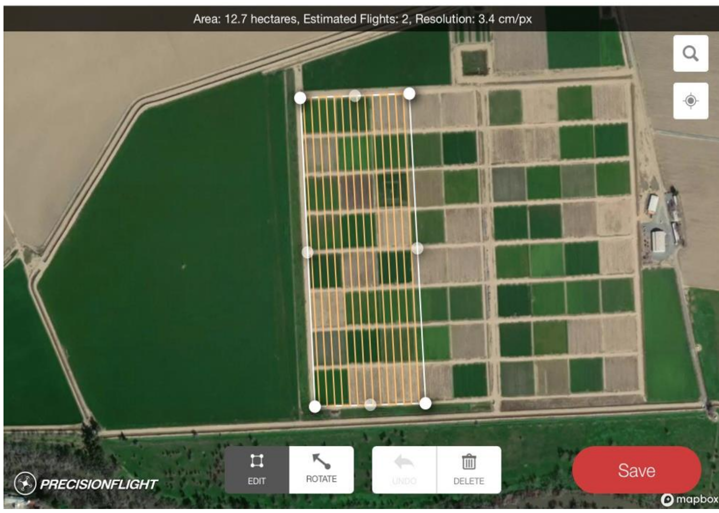
- Comparison of commonly available multispectral sensors (5 bands) and platforms (fixed wings vs multi- rotor) for agricultural applications.
- Crop yield monitoring.
- Identification of narrow-band hyperspectral wavelengths and vegetation indices for crop mapping and growth monitoring.
- Estimation of various soil properties and map field scale variability of soil properties.

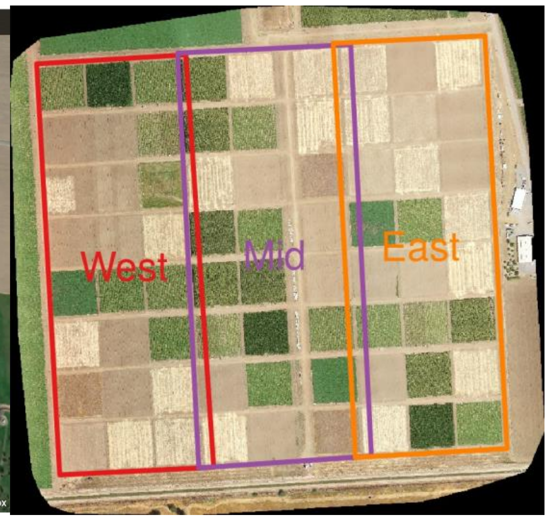
The majority of the work in 2018 focused on objective 1, to compare and optimize data collection with common multi-spectral sensors. Now that significant data collection has been done, we can now begin work on objectives 2 and 4 once we obtain in field measurements from other projects at Russell Ranch. Objective 3 is currently delayed as initial testing of our hyperspectral sensor has demonstrated immense challenges in data collection and processing.

APPROACH AND METHODS

In 2018 we conducted flights on 17 separate days at Russell Ranch. All the flights were over the Century Experiment plots. To accommodate flying all 72 acres+ (plots & paths) the flight was divided into 3 parts. This flight plan was the result of optimization between the aircraft flying time, mission planner optimization, preferred pilot location, and lowest possible altitude above ground level (AGL).

Flights are approximately 20-24 minutes at 80m AGL, with an average speed of 8.5 m/s. Flights were conducted between 10am and 2pm. Before each flight images are captured of the multi-spectral calibration panels.

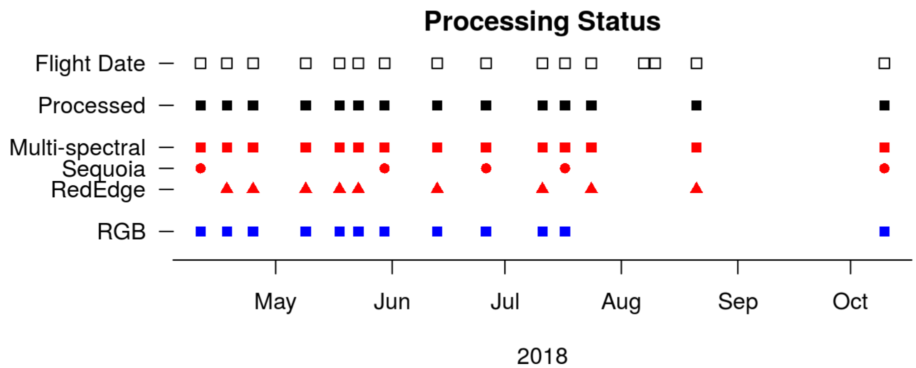


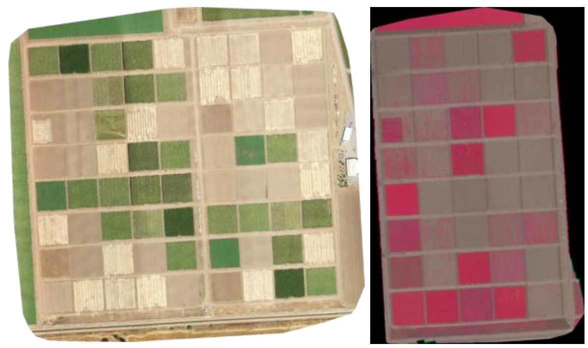


Hardware Type	Name	Bands	Average GSD
Multi-spectral	Parrot Sequoia	4 Band (G,R,RE,IR)	0.082
Multi-spectral	Micasense Rededge	5 Band (B,G,R,RE,IR)	0.055
Color	DJI X3	RGB	0.036
Color	Parrot Sequoia	RGB	0.037

Two different data processing software are used; Pix4d (https://www.pix4d.com/product/pix4dmapper- photogrammetry-software) and Photoscan (http://www.agisoft.com/). We are currently evaluating the difference in output products between the software. Current processing takes 1 to 4 hours, per camera, per flight.

RGB data is combined from all 3 flights into 1 large mosaic per day. Multi-spectral data is processed as 3 separate flights. We've made sure that each plot is 100% within a single flight to make analysis easier and data more consistent



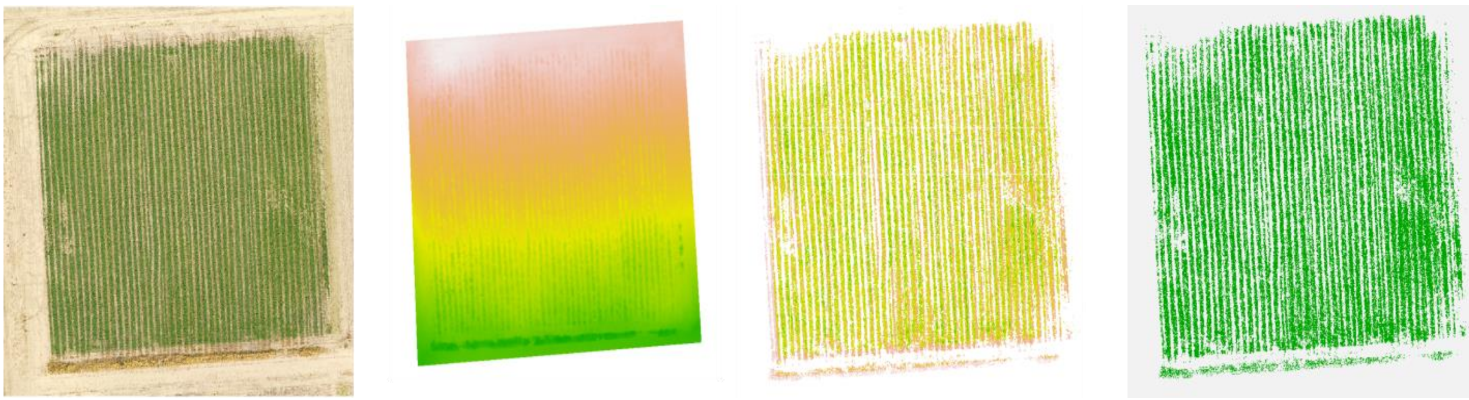


KEY FINDINGS

The primary results for 2018 are the defining of flight operations methods mentioned in the methods, along with the processed data from the flights conducted this year. Processed data is now available to any researchers who request it. It should be of interest to researchers who work at Russell Ranch, and to researchers who want to work with a time series of sUAS data. There are 50 flight results, derived from more than 95,585 images, totalling more than 900 GB of data. Current processed results total 38 GB of data.

Some initial work has been started creating derivative products which are more directly useful for crop analysis.

Examples of data analysis: Single Plot, Digital Surface Model, Greeness Index, Green Pixel Selection



SIGNIFICANCE AND FUTURE STEPS

- Additional optimization of flights, in particular which sensor and how often. Comparison with last season’s ground data collected by other researchers. Web interface to enable researchers to view, select, and download data.
- Provide ready to analyze data to other researchers.
- Report on effectiveness of using irrigation pipes as ground control points

By A. Margenot, D. Rippner, P.Green, K. Scow, and S. Parikh, UC Davis and University of Illinois

INTRODUCTION

Copper (Cu) salt fumigants such as copper sulfate (CuSO4) are widely used as preventative fumigants in both organic and conventional agriculture, and to treat livestock for pathogens. Cu nanoparticles (NPs) have strong potential as second-generation Cu fumigants. Previous work has shown that Cu2+ can inhibit soil enzymes responsible for mineralizing carbon (C), nitrogen (N), and phosphorus (P), with consequences for nutrient cycling and availability to both soil microorganisms and crop plants. Because Cu NPs exhibit lower Cu2+ solubility than Cu salts, we hypothesize that Cu NPs are less suppressive of soil enzyme activities than widely employed CuSO4.

Heavy metal additions and solubilization of metal oxides may impact soil enzyme activity directly through activity of metal ions (e.g., Cu2+) as well as indirectly due to changes in soil pH. Though changes (generally decreases) in soil enzyme activities during acute heavy metal exposure has been attributable to acidification, depending on the enzyme, such studies were performed with ionic metals (e.g., (CuNO3)2) (1), not with solid phases of metals (e.g., CuO).

Thus, metal NPs may have impacts on enzymes that are partially explained by but not necessarily the same as the ionic forms.

OBJECTIVES

We assessed the potential of second-generation nano-Cu fumigants to hold lessened negative impacts on soil nutrient cycling than traditional Cu salt-based Cu fumigants. To this end, we evaluated changes in soil enzyme activities following brief (1 hour) Cu exposure in the form of Cu NPs versus ionic and bulk Cu forms. We expected that Cu NPs would exhibit lower Cu2+ solubility than Cu salts, and therefore hypothesized that increased Cu particle size would be less suppressive of soil enzyme activities than ionic Cu forms due to lower Cu availability (Cu salts > 16 nm CuO > 45 nm CuO > 9 µm CuO). We additionally hypothesized that Cu availability will interact with the indirectly effect of Cu treatment on pH, such that enzyme activities would also reflect changes in assay soil pH. Finally, we hypothesized a similar response of soil enzyme activities across land use, with variation reflecting differences in soil carbon content.

APPROACH AND METHODS

Soils were sampled from five land uses at the Russell Ranch Sustainable Agriculture Facility at the University of California-Davis and the associated Putah Creek Riparian Reserve. Soils are developed on alluvium from sedimentary deposits, are classified as Rincon silty clay loam (fine, smectitic, thermic Mollic Haploxeralfs) for the agricultural plots and Yolo loam (fine-silty, mixed, superactive, nonacid, thermic Mollic Xerofluvents) for the grassland and woodland plots (2). Land uses represented diverse native vegetation and agricultural systems, with similar texture but differences in SOC (Table 1). Soils were sampled by core (20 cm diameter) for 0-10 cm depths in October 2016. Triplicate cores were combined as a composite at 3 sampling sites separated by at least 50 m, for all five (agro)ecosystems. Soils were gently crushed to pass a 2 mm sieve and air-dried prior to analysis of chemical properties and determination of enzyme activities within 4 weeks of sampling.

Table 1: Properties of surface soils (0-20 cm) across managed and unmanaged ecosystems in the Sacramento Valley. Ecosystems are on similar soil types (Mollic Haploxeralfs, Mollic Xerofluvents) developed from mixed alluvium. Sites are part of the Russell Ranch Facility of the University of California-Davis Agricultural Sustainability Institute.

Site	SOC (g kg -1)	pH (1:2 water)	Available N-NH4 (mg kg-1)	Available N-NO3 (mg kg-1)	Available P (mg kg-1)
Oak woodland	25.3 ±1.6	7.39 ± 0.03	17.6 ± 0.8	6.0 ± 0.1	15.1
Grassland	14.3 ± 0.5	7.25 ± 0.02	3.1 ± 0.3	3.7 ± 0.1	14.9
Organic	12.7 ± 0.3	7.61 ± 0.01	2.8 ± 0.2	56.3 ± 0.3	31.7
Conventional	9.8 ± 0.4	7.52 ± 0.01	2.6 ± 0.2	42.5 ± 1.3	12.3
Zero-input	8.3 ± 0.1	7.36 ± 0.03	4.8 ± 0.2	7.0 ± 0.6	13.6

Soils were exposed to Cu at 0, 10, and 1000 mg Cu kg-1 soil, in 3 forms: (1) ionic, as copper chloride ($CuCl_2$) and copper sulfate ($CuSO_4$), (2) nano, as 16 nm and 45 nm diameter CuO, and (3) bulk, as 9 µm CuO. Cu was introduced in an equal volume of nano-pure water regardless of Cu source or concentration, via pipette. Total Cu levels of 1500-3000 mg kg-1 have been observed in agricultural soils due to long-term (130-100 year) use of Cu fungicides (3-6). Additionally, $CaSO_4$ was used as a control for the potential impact of SO_4 in $CuSO_4$ treatments, and $CuCl_2$ was used as a sulfate-free control for CuO NP treatments.

Potential activities were assayed for five enzymes involved in C-, N-, P- and S-cycling (Table 2). Assays were performed using nano-pure water rather than buffers because of the potential of buffers to impact Cu^{2+} activity Assays were performed with a final substrate concentration of 20 mmol L-1 per g soil for GLU, GLM, PME, PDE, and SUL, and 5 mmol L-1 per g soil for CEL. Triplicate negative controls (no soil) were included.

Reactions were terminated with 4 mL of 0.1 mol L-1 tris(hydroxymethyl)aminomethane (THAM) buffer (pH 12.0), and 1 mL of 2.0 mol L-1 CaCl2. Assays were centrifuged to remove sediment and para- nitrophenol (pNP) in the resulting supernatant was quantified colorimetrically using absorbance at 410 nm. Mean absorbance of the negative controls was subtracted from absorbance of soil assays, and enzyme activities were corrected for incomplete recovery of released pNP (7).

Table 2: Soil C-, N-, P-, and S-cycling enzymes used to asses copper oxide nanoparticle impacts on soil nutrient cycling across diverse native and agro-ecosystems in the Sacramento Valley, California.

Enzyme	Abbreviation	Element	Substrate	EC number
β-glucosidase	GLU	C	*para* -nitrophenyl-β-D-glucopyranoside	3.2.1.21
β-glucosaminidase	GLM	C, N	*para* -nitrophenyl-N-acetyl-β- D-glucosaminide	3.2.1.52
phosphomonoesterase	PME	P	*para* -nitrophenyl phosphate	3.1.3.1
phosphodiesterase	PDE	P	*bis -para* -nitrophenyl phosphate	3.1.3.4
arylsulftase	SUL	S	*para* -nitrophenyl sulfate	3.1.6.1.

To account for potential deviations in pH during assay (1 h), pH of slurries was measured at the conclusion of the 1 h assay, but before addition of THAM and CaCl2. Soil pH was measured because inhibition of soil enzyme activities during acute heavy metal exposure has been attributable to acidification, depending on the enzyme (1). To quantify water-extractable Cu and other metal elements in solution, slurries were also analyzed for metal concentrations by ICP-MS. The effect of ecosystem type and Cu form on soil enzyme activities were tested with two-way analysis of variance For each ecosystem type, significant differences in enzyme activities among Cu forms relative to the control (no Cu) were evaluated using Dunnett’s test ($p < 0.05$). To evaluate potential effects of assay pH and available Cu on enzyme activity response to Cu treatments, regression analysis was performed between these variables. To visualize associations of soil properties with pH and metal availability with concurrently measured enzyme activities, principal component analysis (PCA) was performed.

KEY FINDINGS

As hypothesized, Cu availability was inverse to particle size (9.5 µm < 40 nm < 10 nm < ionic), and that these effects would vary by ecosystem type (Fig. 1). As hypothesized, CuCl2 and CuSO4 decreased activity of phosphatase relative to the Cu-free control, but CuO NP decreased activity depending on land use and only for 10 nm NPs. 40 nm CuO NP and CuO MPs did not change or even increased phosphatase activities. These trends were strongest in soils under organic agriculture and weakest in soils under woodland and grassland and did not occur for the agricultural soil with biochar additions. Our results indicate: While CuO NP effects on soil enzymes may not be necessarily fully mediated by Cu2+solubility and that greater inhibition occurs for copper salts, smaller sized CuO NP are more suppressive of soil enzyme activities. Immediate (1 h) response of enzyme activities responsible for nutrient mineralization to CuO NP entry to soils may be specific to land use and management.

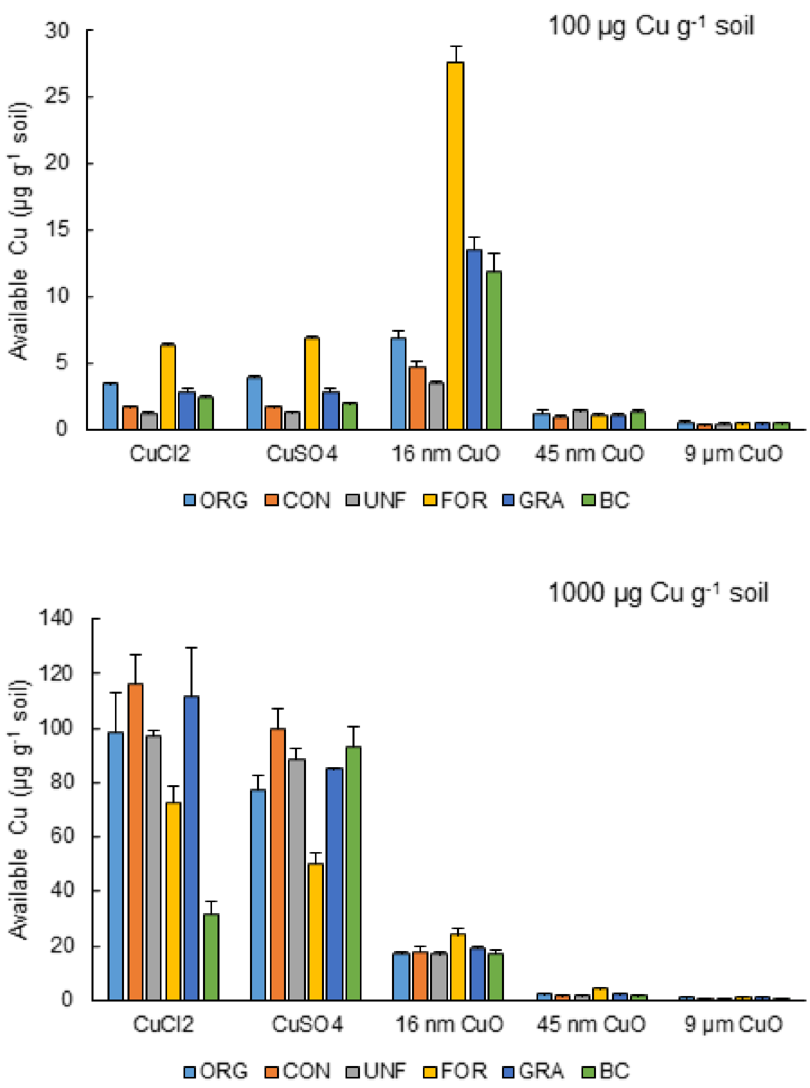


Figure 1: Availability of copper in soils measured as aqueous copper after 1 h exposure of soils in solution.

SIGNIFICANCE AND FUTURE STEPS

Previous work has shown that copper (Cu) salts, ubiquitously introduced to agroecosystems in to control of fungal and bacterial plant pathogens, may have immediate impacts on soil biological processes essential to ecosystem services such as nutrient cycling by inhibiting soil enzyme activities. Nanoparticulate Cu, increasing in use as next-generation fungicides (8), also entail suppressive of soil enzyme activities, which can be explained by greater solubility of Cu from smaller-sized CuO (e.g., 16 nm > 45 nm > 9.5 µm). Future steps are to finalize the manuscript for publication in a peer-review journal.

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By A. Margenot, D. Rippner, P. Green, K. Scow, and S. Parikh, UC Davis and University of Illinois

INTRODUCTION

Soil microorganisms are highly sensitivity to heavy metal toxicity (1). As a result, heavy metal exposure can have detrimental effects on soil processes driven by microorganisms, including nutrient cycling processes such as C, N, and P mineralization (2-5). With the advent of heavy metal nanoparticles (NPs), generally lower solubility of metal in NPs form may entail a nano-effect of heavy metals in which lower metal ion availability is observed on a total metal basis. On the other hand, localized dissolution at the NP-soil interface could entail local toxicity, which at high NP concentrations could conceivably have similar or greater detrimental effects on soil microbiology. Thus, NP represent a new form of heavy metal contamination that may uniquely impact soil nutrient cycling. Given the importance of edaphic factors such as pH and texture on Cu availably and thus soil microbial response (2), investigations of Cu impacts on soil nutrient cycling can benefit from comparing soils with varying states of nutrient cycling (e.g., management-driven) on the same soil type (texture and mineralogy). Given the affinity of heavy metals, in particular Cu, for binding organic functional groups, SOM can buffer heavy metal toxicity effects on soil microbial activity (6, 7).

Cu fungicides are ubiquitous in agricultural, and eventually lead to accumulation of applied Cu in surface soils. Soil Cu accumulation due to fungicide use has been reported in vineyards (8) and other perennial crops such as apple orchards (9) and coffee plantations (10, 11), as well as annual crops such as tomatoes. Though often foliar applied, Cu fungicides flow occurs to soil via accidental application to soil, drift, and washing of by precipitation (12) where further downward transport is minimal (13, 14) due to high affinity of Cu for SOM and clay minerals. Soil Cu enrichment has been found to impact biological drivers of nutrient cycling, including earthworms but also microorganisms as indicated by soil respiration and extracellular enzyme activities (9, 15), though it is not clear how these changes translate to nutrient availability.

OBJECTIVES

We hypothesized (1) impacts of Cu forms on microbial activity would be modulated by land use; (2) impacts on microbial indicators will be most negative for CuCl2 > nCuO > bCuO on a Cu basis; (3) such impacts are predictable by available Cu2+; and (4) changes in indicators or microbial activity (respiration, enzyme activities) will explain potential shifts in nutrient availability.

APPROACH AND METHODS

Soils were sampled from five land uses at the Russell Ranch Sustainable Agriculture Facility at the University of California-Davis and the associated Putah Creek Riparian Reserve. Soils are developed on alluvium from sedimentary deposits, are classified as Rincon silty clay loam (fine, smectitic, thermic Mollic Haploxeralfs) for the agricultural plots and Yolo loam (fine-silty, mixed, super9active, nonacid, thermic Mollic Xerofluvents) for the grassland and woodland plots (16). Land uses represented diverse native vegetation and agricultural systems, with similar texture but differences in SOC (Table 1). Soils were sampled by core (20 cm diameter) for 0-10 cm depths in October 2016. Triplicate cores were combined as a composite at 3 sampling sites separated by at least 50 m, for all five (agro)ecosystems. Soils were gently crushed to pass a 2 mm sieve and air-dried prior to mesocosms.

Table 1: Properties of surface soils (0-20 cm) across managed and unmanaged ecosystems in the Sacramento Valley. Ecosystems are on similar soil types (Mollic Haploxeralfs, Mollic Xerofluvents) developed from mixed alluvium. Sites are part of the Russell Ranch Facility of the University of California-Davis Agricultural Sustainability Institute.

	SOC ($g\ kg^{-1}$)	pH (1:2 water)	Available N-NH_4 ($mg\ kg^{-1}$)	Available N-NO_3 ($mg\ kg^{-1}$)	Available P ($mg\ kg^{-1}$)
Oak woodland	25.3 ±1.6	7.39 ± 0.03	17.6 ± 0.8	6.0 ± 0.1	15.1
Grassland	14.3 ± 0.5	7.25 ± 0.02	3.1 ± 0.3	3.7 ± 0.1	14.9
Organic ag	12.7 ± 0.3	7.61 ± 0.01	2.8 ± 0.2	56.3 ± 0.3	31.7
Conventional ag	9.8 ± 0.4	7.52 ± 0.01	2.6 ± 0.2	42.5 ± 1.3	12.3
Zero-input ag	8.3 ± 0.1	7.36 ± 0.03	4.8 ± 0.2	7.0 ± 0.6	13.6

Soil mesocosms were established using 80 g of soil in 473 mL glass Mason jars. Soils were brought to 70% of gravimetric water holding capacity (WHC) during introduction of Cu, which were added in the form of CuCl2, 16 nm and 41 nm CuO, and Bulk CuO, each at 10, 100, and 1000 mg Cu kg-1 soil. A 0 mg Cu kg-1 soil control was also included. Jars were placed in a randomized block design in an incubator at 28 °C. Soils were maintained at 70% WHC throughout the incubation by adding 18.2 MΩ·cm water via pipette. Soil respiration was determined as CO2 flux, measured as CO2 in the headspace of incubation jars at 5-6 day intervals.

Immediately at the end of the incubation (76 days), soils (70% WHC) were harvested for a suite of soil chemical, biochemical, and biological analyses. Available Cu was estimated using 3 method: as Cu2+ extractable in water, in 0.01 mol L-1 CaCl2 (1:10, 2 h) (17), and by 0.005 mol L-1 diethylenetriaminepentaacetic (DPTA) (1:2, 1 h). Soil pH and electrical conductivity (EC) were determined in 1:2 soil-water mixtures after 30 min of shaking. Available N was determined by extraction (1:4 m/v) with 2 mol L-1 KCl with shaking (120 rpm) for 60 min. Ammonium (NH4+) and nitrate (NO3-) N in the centrifuged extract were measured colorimetrically using the salicylate-hypochlorite method (18) and vanadium (III) chloride reduction method (19), respectively. Available P (Olsen P) was determined by extraction (1:20 m/v) with 0.5 mol L-1 NaHCO3 at pH 8.5 with shaking (120 rpm) for 30 min, and available P in the filtered extract was estimated as molybdate-reactive P (20).

Soil available N and P and the activities of C-, N-, P- and S-cycling soil enzymes were quantified. Potential activities were assayed for five enzymes involved in C-, N-, P- and S- cycling (Table 2).

Assays were performed using nano-pure water rather than buffers because of the potential of buffers to impact Cu2+ activity Assays were performed with a final substrate concentration of 20 mmol L-1 per g soil for GLU, GLM, PME, PDE, and SUL, and 5 mmol L-1 per g soil for CEL. Triplicate negative controls (no soil) were included. Reactions were terminated with 4 mL of 0.1 mol L-1 THAM buffer (pH 12.0), and 1 mL of 2.0 mol L-1 CaCl2. Assays were centrifuged to remove sediment and para-nitrophenol (pNP) in the resulting supernatant was quantified colorimetrically using absorbance at 410 nm. Mean absorbance of the negative controls was subtracted from absorbance of soil assays, and enzyme activities were corrected for incomplete recovery of released pNP (21).

Table 2: Soil C-, N-, P-, and S-cycling enzymes used to asses copper oxide nanoparticle impacts on soil nutrient cycling across diverse native and agro-ecosystems in the Sacramento Valley, California.

Enzyme	Abbreviation	Element	Substrate	EC number
β-glucosidase	GLU	C	para -nitrophenyl-β-D-glucopyranoside	3.2.1.21
β-glucosaminidase	GLM	C, N	para -nitrophenyl-N-acetyl-β- D-glucosaminide	3.2.1.52
phosphomonoesterase	PME	P	para -nitrophenyl phosphate	3.1.3.1
phosphodiesterase	PDE	P	bis -para -nitrophenyl phosphate	3.1.3.4
arylsulftase	SUL	S	para -nitrophenyl sulfate	3.1.6.1.

KEY FINDINGS

Nanoparticulate Cu, increasing in use as next-generation fungicides (22) appear to both positively and negatively influence N and P availability, which may be related to but not fully explained by enzymatic drivers of organic N and P mineralization from SOM. Abiotic changes (soil pH) may also explain land use- and management-specific soil nutrient and enzyme response to Cu.

SIGNIFICANCE AND FUTURE STEPS

Previous work has shown that ionic Cu forms, ubiquitously introduced to agroecosystems in to control of fungal and bacterial plant pathogens, may have immediate impacts on soil biological processes essential to ecosystem services such as nutrient cycling. This indicates that response of soil nutrient cycling to next-generation Cu fungicides following several weeks of exposure may be specific to land use and management, raising implications for differential resilience of biochemically mediated (enzymatic) nutrient cycling to Cu contamination. The next step is a statistical analyses of soil nutrient pools, available Cu, and enzyme activities.

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By D. Rippner, A. Margenot, P. Green, K. Scow, T. Young, and S. Parikh, UC Davis and University of Illinois

OBJECTIVES

We hypothesize that long-term land management processes will have distinct, unique effects on soil microbial community structure after exposure to nano and microparticulate copper oxide (16n CuO, 41n CuO, and µCuO) and copper chloride. Specifically, soil microbial community structure in soils with greater SOM will exhibit less perturbation than soils with less SOM and soil microbial communities in managed systems will be more resilient in the face of Cu exposure than will those from wild systems.

APPROACH AND METHODS

Soils (0-15 cm) were sampled in 2017 from the conventional (Con), organic (Org), unfertilized (Unf), grassland (Gra), and riparian oak (Oak) systems at Russell Ranch, air dried, sieved, and incubated at 60% water holding capacity for 70 days w/wo 1000 mg/kg 16nCuO, 41nCuO, µCuO, or CuCl2.

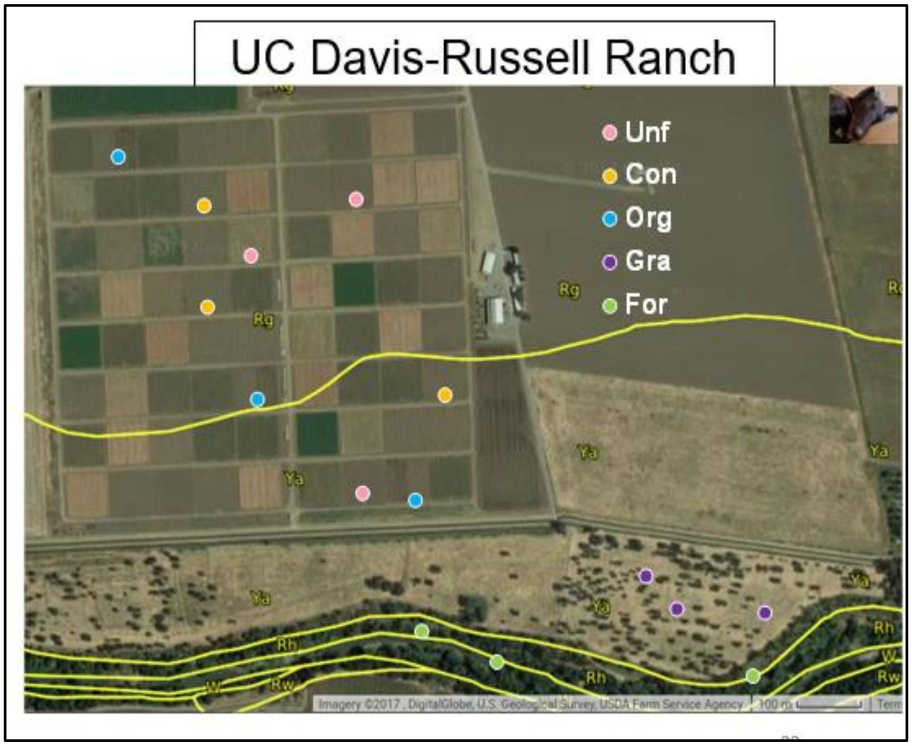

Figure 1: Russell Ranch Field Sites.

Respiration data was collected on days 1,2,3,4,5,6,7 and then every 5 days until 70 days of exposure. At the beginning and end of the experiment, available Cu was estimated by extraction with H2O.

At the end of the experiment, soils were freeze dried and sent to Midi labs for phospholipid fatty acid analysis (PLFA). Microbial biomass and community structure were determined based on the PLFA results.

KEY FINDINGS

Soil respiration was highly correlated with soil carbon; soils with more SOC had greater respiration (Fig 1). Addition of 1000 mg/kg Cu from CuCl2 significantly negatively impacted respiration in all soils, regardless of land use. Addition of 16nCuO had significant negative impacts on soil respiration in some systems (Unf, Con, Gra). Addition of 41nCuO had significant negative impacts on soil respiration in fewer systems (Con and Gra), while µCuO had no negative impact on soil respiration. Respiration inhibition appears to be associated with available Cu; treatments with the greatest available Cu, such as CuCl2 had the most negative impact on growth. Among the particulate CuO treatments, smaller particles (16nm) dissolved to a greater extent than larger particles, increasing available Cu and hindering soil respiration (Fig 2).

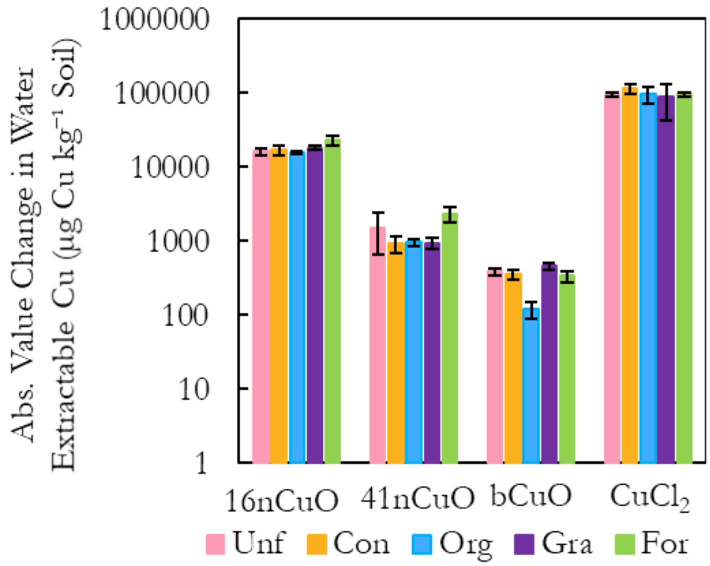

Figure 2: Absolute value of the change in water extractable Cu (ug Cu kg-1 soil) by copper treatment form. Notice the y-axis is on a log scale.

SIGNIFICANCE AND FUTURE STEPS

Copper based fungicides are used on over 1 million acres of California farm land; application amounts in vineyards and orchards range between 1-11 kg Cu ha-1 year-1, with application concentrations ranging between 500 and 30,000 mg Cu L-1 (Adaskaveg, 2007; Darriet et al., 2001; Department of Pesticide Regulation, 2017; Ferrari et al., 2000; USDA, 2001; Vicent et al., 2009). Approximately 50% is lost due to leaf runoff and drift, potentially negatively impacting soil microbial communities (Pergher and Gubiani, 1995; Pergher et al., 1997). Use of nanoparticulate Cu fungicide formulations is growing in popularity due the relatively rapid dissolution of nanoparticles compared to larger particles (Elmer and White, 2016). Our work shows that nanoparticulate CuO inhibits respiration much less than CuCl2, potentially limiting acute and chronic Cu toxicity impacts on soil microbial communities. We are currently in the process of analyzing PLFA data.

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By D. Rippner and S. Parikh, UC Davis

OBJECTIVES

We hypothesize that long term land management processes will have distinct, unique effects on total and available micronutrients and trace elements in soils at Russell Ranch. This will in turn influence the uptake and translocation of micronutrients and trace elements by plants, leading to nutritional differences in tomato fruit and corn grain grown in the different systems.

APPROACH AND METHODS

Soils (0-15 cm) were sampled in 1993 and 2018 from the conventional (Con), mixed (Mixed), and organic (Org) managed systems at Russell Ranch, air dried, sieved, then ground through a 500 um mesh. Soils were sequentially extracted using the community bureau of reference (BCR) sequential extraction developed by the European Union. This method was used to assess the bioavailability of Zn, Cu, Cd, and Ni in soils sampled from Russell Ranch. For the data presented below, the results from the 4 fractions were collated for simplicity.

Tomatoes and corn were harvested from each system in 1995 and 2017, air dried, and pulverized. Powdered tomato and corn samples were digested by EPA method 3050a. At this point only the tomato data has been analyzed; tomato Zn, Cu, Cd, and Ni data is presented below. Elemental distribution in soils, tomatoes, and corn was measured by inductively coupled plasma mass spectroscopy.

KEY FINDINGS

Over 25 years, Zn and Cu built up significantly in the Org system while no change in Zn and Cu content was measured in the Con and Mixed systems (Fig 1a, 1b). This is likely due to the high concentration of both Zn (~500 mg/kg) and Cu (~400 mg/kg) in the poultry litter compost applied at RR. However, Cd increased over the same period in soils from the Con and Mixed systems, while no change was measured in the Org system (Fig 1c). These changes are likely due to Cd impurities in phosphate fertilizers applied in the Con and Mixed systems; Cd content in the poultry litter compost applied in the Org system was low (0.15 mg/kg). No change in soil Ni was observed in any systems over time (Fig 1d).

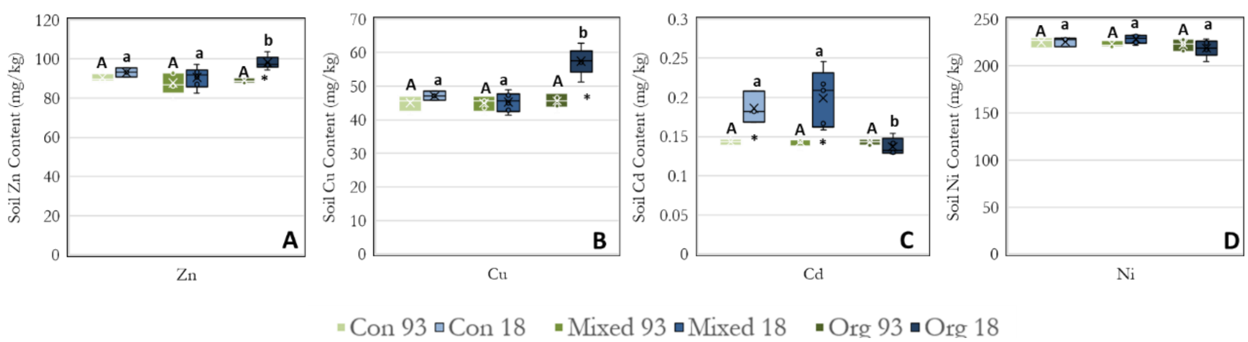

*Fig 1A-D: Effect of land management on micronutrient and trace element content of soils in the century experiment at Russell Ranch. Data (n = 3-6) are presented as mean ± standard deviation; mean values with different capital letters (93), lower case letters (18) are significantly different at P <0.05 (Tukey's HSD). Significant effects of land management on the magnitude of change in soil micronutrient content are denoted by *, P <0.05 (Tukey's HSD).*

Surprisingly, despite significant increases in soil Cu and Zn in the Org system, this increase was not reflected in tomato fruit from the Org system. Rather, tomato fruit from the Org system consistently had the lowest concentrations of Zn, Cu, Cd, and Ni in both 95 and 2017 (Fig 2a, 2b, 2c, 2d). Trace element and micronutrient content in Tomato fruit was measured to significantly decrease overtime, except for Cd in the Con system. This is likely due to changes in tomato varietal selection over time, however, it could also be attributed to increased atmospheric CO2 leading to excessive starch and sugar production at the expense of micronutrient density. This result is especially prominent for Ni; soil Ni did not change over 25 years, but tomato Ni content decreased in Tomatoes from every system (Fig 2d). Tomato Cd increased in the Con system, but was significantly reduced in the mixed system, despite similar soil Cd concentrations. Cover cropping appears to be an effective method of preventing Cd uptake and translocation by tomatoes (Fig 2c). The magnitude of change in Zn and Cu content in the tomatoes was greatest in the Mixed system compared to the Con system, potentially due to increased soil organic matter in the mixed system preferentially binding Cu and Zn over other base cations.

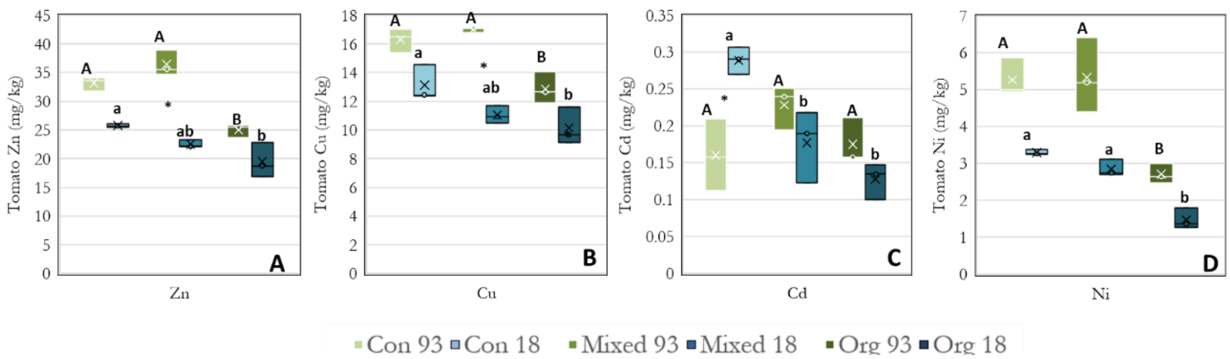

*Fig 2A-D: Effect of Conventional (Con), Mixed (Mixed), and Organic (Org) land management on micronutrient and trace element content of tomatoes from the century experiment at Russell Ranch. Data (n = 3) are presented as mean ± standard deviation; mean values with different capital letters (1993), lower case letters (2018) are significantly different at P <0.05 (Tukey's HSD). Significant effects of land management on the magnitude of change in soil micronutrient content are denoted by *, P <0.05 (Tukey's HSD).*

SIGNIFICANCE AND FUTURE STEPS

Currently, at least 1/3 of human on earth are deficient in at least one micronutrient, hindering childhood development and immune function

(Myers et al., 2014). Continued decreases in crop nutrient content due to varietal changes, increased atmospheric CO2, and management choices may exacerbate this issue, especially in communities with marginal food security (Baldantoni et al., 2018; Myers et al., 2014; Zhu et al., 2018). Our results suggest that land management can play a significant role in micronutrient availability. Practices such as compost addition may hinder crop micronutrient uptake and translocation despite increasing the supply of micronutrients in soils (Adeleye et al., 2014; Baldantoni et al., 2018). Further, practices to increase soil carbon, such as cover cropping, may reduce the availability of micronutrients through preferential binding. However, these practices also decrease the availability of Cd, the only element to increase in fruit concentration over 22 years of cropping. Increasing Cd in tomatoes grown in the Con system is likely from the use of Cd bearing fertilizers. California, the only state regulating Cd in phosphate fertilizers has set a limit of 400 mg Cd/ kg of fertilizer; such regulations may need to be revisited given evidence of continued Cd accumulation in soils receiving conventional phosphate fertilizers. Future Steps include: corn grain analysis; comparing how application of low and high phosphate composts effects crop micronutrient uptake; speciation of soil P pools by synchrotron-based x-ray absorption spectroscopy.

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By R. Rossi and S. Fendorf, Stanford University

INTRODUCTION

Soils are the largest terrestrial store of carbon (C), storing up to 3,000 Pg of C which can be transformed by microbial activity into greenhouse gases (GHGs), thus contributing to global climate warming. Recently, anaerobic microsites, small zones of oxygen depletion that form when oxygen supply is outpaced by demand, have been identified as an important control on the rate of GHG production in upland soils. While anaerobic microsites likely exert an important control on soil GHG efflux, surprisingly little is known about the size or distribution of anaerobic microsites in soils. Moreover, the effect of land management practices, which can influence both oxygen supply and demand, on upland soil anaerobic volumes is relatively unknown. As increasing soil C storage in cropland soils is a crucial strategy for mitigating global climate change, studying the distribution of anaerobic microsites in relation to agricultural soil management practices is crucial for effectively managing soil C stocks.

OBJECTIVES

Our work addresses the following questions:

- What is the anaerobic volume of upland agricultural soils?

- How do land management practices (e.g., tillage) affect oxygen distribution in these soils?
- Can we use land management to minimize soil greenhouse gas emissions and maximize soil C storage?

We hypothesize that:

- Pore water dissolved oxygen (DO) concentrations will decrease along a gradient of decreasing soil pore size domains,
- DO in pore waters from no-till and cover crop rotation plots is depleted in comparison to pore waters from tilled or fallow-rotation plots, and
- Soil CO2 emissions will decrease with increasing anaerobic pore volume.

APPROACH AND METHODS

To address these questions, we collected cores from surface soils within the NG (Native Grass), RWL (Rainfed Wheat/Legume), and RWC (Rainfed Wheat Control) plots, in addition to the riparian grassland south of the Century Experiment plots. Cores were returned to the lab, saturated with tap water, and incubated at 25°C for a total of 20 hours; CH4, CO2, and N2O efflux were measured in the final 6 hours of the incubation. Following the incubation cores were transferred to a pressure plate extractor, and pore waters were collected by sequential extraction at 100, 300, and 500 kPa under anoxic headspace. Collected pore waters were then analyzed for DO content. Finally, soils were analyzed for total C, total N, organic matter (loss on ignition, LOI), texture, and bulk density.

KEY FINDINGS

Across all management types, soil DO concentrations were lower in small (0.6 – 1 µm) pores than medium (1 – 3 µm) pores (Figure 1). Although no statistically significant differences were detected in DO concentrations within similar pore size ranges among the land management practices, preliminary data suggests that the impacts of land management manifest in smaller pore domains (Figure 1c). Comparison of soil GHG emissions and DO concentrations highlighted a negative relationship between N2O produced and DO concentrations in small pore domains (Figure 2d), in addition to a weak negative relationship with CO2 produced and DO concentrations in small pore domains (Figure 2b).

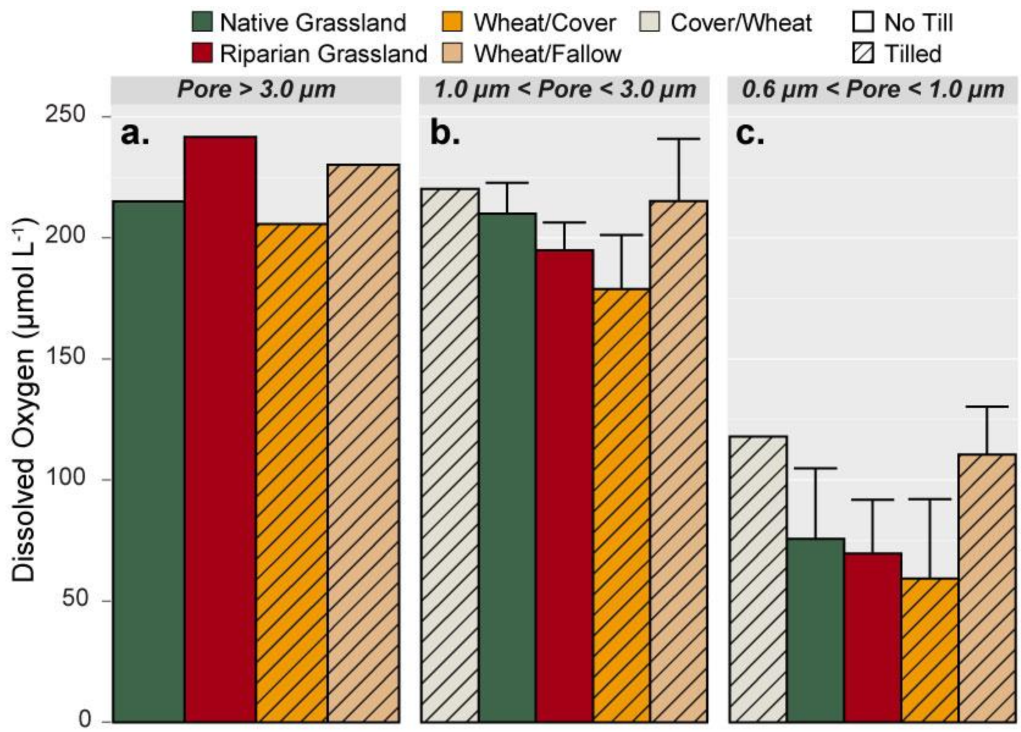

Figure 1: Measured dissolved oxygen concentrations in waters extracted from different soil pore domains. Each panel displays a separate soil pore domain. In all panels, the color of each bar represents a different land management type. Solid bars represent no till soils, whereas hatched bars indicate tilled soils.

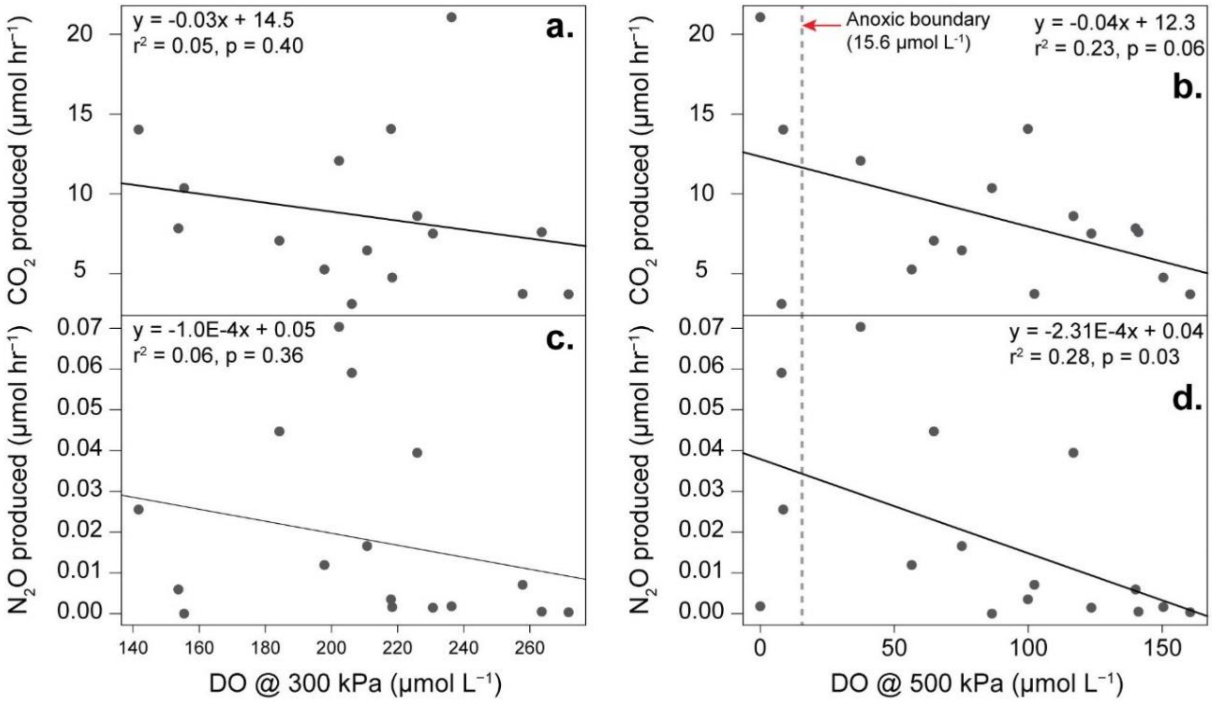

Figure 2: CO2 and N2O produced during soil incubations versus measured dissolved oxygen (DO) concentrations from pore waters in medium (300 kPa) and small (500 kPa) pore domains.

SIGNFICANCE AND FUTURE STEPS

The lower DO values measured in waters extracted from small pore domains validates the first hypothesis of our study. Due to soil pore geometry, and an increase tortuosity with smaller particle size, the diffusion length within smaller pore domains are longer than those of larger pore domains.

Assuming that oxygen demand does not change across soil pore domains, trends in DO measurements along gradients in pore domain size likely highlight changes in oxygen supply. As such, the lack of a relationship between evolved CO2 and DO in medium pores (Figure 2a), and the weak relationship observed between DO from small pores and evolved CO2 (Figure 2b) suggests that the rate of oxygen diffusion into small pores is slower than the rate of diffusion into medium or large pores.

The relatively similar DO values measured within large and medium pore domains across management types (Figure 1b & c) suggests that variations in Russell Ranch management has little effect on oxygen distribution within larger (i.e., > 1.0 µm) pore domains. While there is no statistically significant difference in DO concentrations measured in smaller pore domains, differences in oxygen concentrations between management types emerge. Because the sampled soils were held at similar moisture contents during incubations, and bulk densities and textures were generally comparable, the supply of oxygen to small pores is presumably similar across management types. Instead, variations in oxygen demand within the same pore size must account for the observed changes in DO among the soils from different land management strategies. As smaller pore domains comprise the majority (66% on average) of the total pore volume in sampled soils, it follows that the impact of land management on oxygen demand would manifest in smaller pore domains. While the current sample size limits our ability to make expansive conclusions, we observe that ~20% of the soils have no detectable oxygen within small pore domains. In the coming year, we plan to explore anaerobic volumes and greenhouse gas production resulting from differing soil properties and management. We will also examine variation in incubation times across a range of moisture contents.

The initial results of our water extraction method serve as direct evidence of heterogeneous oxygen depletion in pores of different sizes in upland soils. This and future work at Russell Ranch should provide a framework for predicting anaerobic volume of soils from existing databases and for developing management recommendations to maximize anaerobic soil volume and by extension, soil carbon storage, while minimizing soil greenhouse gas emissions.

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By J. Emerson and L. Zinke, UC Davis

OBJECTIVES

Viruses are the most abundant biological entities on Earth. However, the total viral community is mostly uncharacterized in agricultural soils, despite their potential to impact biogeochemical cycling, genetic diversity, and ecosystem health. Major questions in the viral ecology of agricultural soils remain to be answered:

- What is the role of viruses in carbon and nitrogen cycling?
- Are differences among soil viral communities related to soil health or management practices?
- Are viruses present that could directly impact plant health or crop yield?

APPROACH AND METHODS

We are addressing these questions by characterizing soil viral communities in Russell Ranch tomato fields under conventional and organic management. The upper 15 cm of soil from six conventional and organic plots have been or will be sampled during the peak growing season (July 2018), post-harvest (October 2018), and during winter cover crop (organic) or fallow (conventional) (January 2019). Soil viral characterization through DNA sequencing will be coupled to total soil microbial community characterization, soil chemical analyses, and plant health measurements. Additionally, in collaboration with Dr. Kate Scow and her student, Daniel Rath, we collected soil from nine tomato plots in August 2018, representing the 0-15, 15-30, 30- 60, and 60-100 cm soil horizons.

KEY FINDINGS

While this project is still in its early stages (PI Emerson arrived at UC Davis ~1 year ago), DNA yields from soil viral fractions suggest that viral communities are abundant in Russell Ranch soils. DNA yields varied within plots, between plots, and between the July and October sampled soils. This suggests that, like microbial communities, viral communities are heterogeneous and dynamic in soil.

SIGNIFICANCE AND FUTURE STEPS

This project will be the first in-depth, systematic characterization of soil viruses in agricultural soils. Data (currently being generated) will include 36 viral size-fraction metagenomes (viromes), 36 bulk soil metagenomes, and accompanying geochemical characterizations. Dr. Laura Zinke, a postdoctoral researcher in the Emerson lab, will analyze these data to understand viral community dynamics, viral impacts on microbial communities, and viral feedbacks to agricultural management and potentially plant health. Samples taken in collaboration with Daniel Rath and Dr. Kate Scow will be similarly investigated by Sara Geonczy, a Ph.D. student in the Emerson lab. These results will be integrated with findings from Drs. Eric Dubinsky and Eoin Brodie, who are analyzing carbon use efficiency and reconstructing bacterial and archaeal genomes, and with a suite of biogeochemical analyses from Dr. Scow’s group. Overall, our soil viral community characterizations at Russell Ranch will be a starting point to understand the importance of the diverse, abundant, and understudied viruses in agricultural systems.

Table 1. Century Experiment plots sampled by the Emerson lab in 2018. LMT: Legume/Maize/Tomato; CMT: Conventional Maize/Tomato; OMT: Organic Maize/Tomato

Plot Number	Type	Depth (cm)	Sampled
1-1	LMT	0-15	August
		15-30	August
		30-60	August
		60-100	August
1-3	CMT	0-15	July, August, October
		15-30	August
		30-60	August
		60-100	August
2-3	OMT	0-15	July, August, October
		15-30	August
		30-60	August
		60-100	August
4-5	CMT	0-15	July, August, October
		15-30	August
		30-60	August
		60-100	August
6-3	LMT	0-15	August
		15-30	August
		30-60	August
		60-100	August
6-4	OMT	0-15	July, August, October
		15-30	August
		30-60	August
		60-100	August
6-7	LMT	0-15	August
		15-30	August
		30-60	August
		60-100	August
6-8	OMT	0-15	July, August, October
		15-30	August
		30-60	August
		60-100	August
8-9	CMT	0-15	July, August, October
		15-30	August
		30-60	August
		60-100	August

By D. Wang and K. Scow, UC Davis

OBJECTIVES

Research questions:

- Can biochar amendment and agricultural management practice (compost vs. mineral fertilizer) impact soil aggregation and C storage?
- Can biochar amendment and agricultural management practice (compost vs. mineral fertilizer) impact soil water retention capacity and infiltration?

Hypotheses:

- Walnut shell biochar cannot impact soil aggregation due to its recalcitrant nature.
- Compost treatment can improve soil aggregation and carbon storage in water-stable aggregates.
- Compost treatment can improve soil water retention capacity and soil infiltration.

APPROACH AND METHODS

A long-term biochar plot was conducted at Russell Ranch since 2012 (conventional-without biochar, conventional-with biochar, organic-without biochar, and organic-with biochar). Soil samples (0-15 cm) were taken soil aggregation, soil microbial biomass and soil water retention analysis. Soil infiltration measurement was conducted in the field.

KEY FINDINGS

Compost significantly improved soil aggregation, while biochar did not significantly impact aggregation. After six years, a big difference was observed between management. The average mean weight diameter (MWD) in compost treatments were around 1980 um, while from 750-900 in mineral fertilizer treatments (Figure 1a).

The initial aggregation condition in biochar plot (March 2014) was good (~1750 um). During the following 4 years, mineral fertilizer treatments were quickly losing aggregate structure (-210 to -240 um/year), while compost treatments slowly build additional aggregate structure (30 - 55 um/year). No significant difference observed between biochar treatments (Figure 1b).

Six years of compost management significantly increased soil organic C content and C physically protected by water-stable aggregates (Figure 2). Soil microbial biomass in compost treatments was two times as high as those in mineral fertilizer treatments.

Soil field capacity, permanent wilting point, and plant available water were measured using pressure plate apparatus in Oct 2017, while no significant difference observed among treatments. The infiltration rate in compost treatments were 2.4 times as high as those in mineral fertilizer treatments, while those differences were not statistically significant.

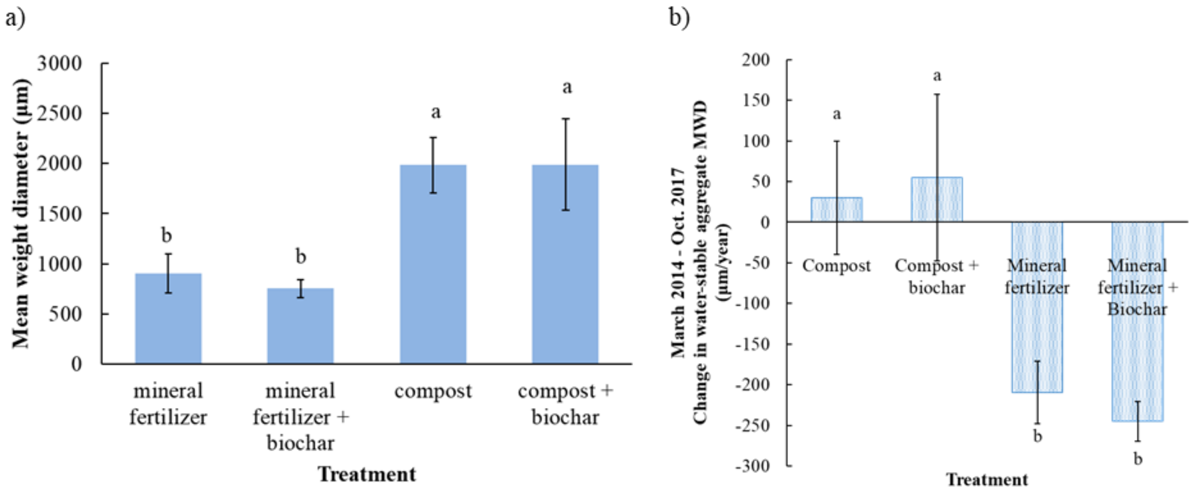


Figure 1. Mean weight diameter of soil water stable aggregates in biochar plot and soil aggregation change from March 2014 to October 2017.

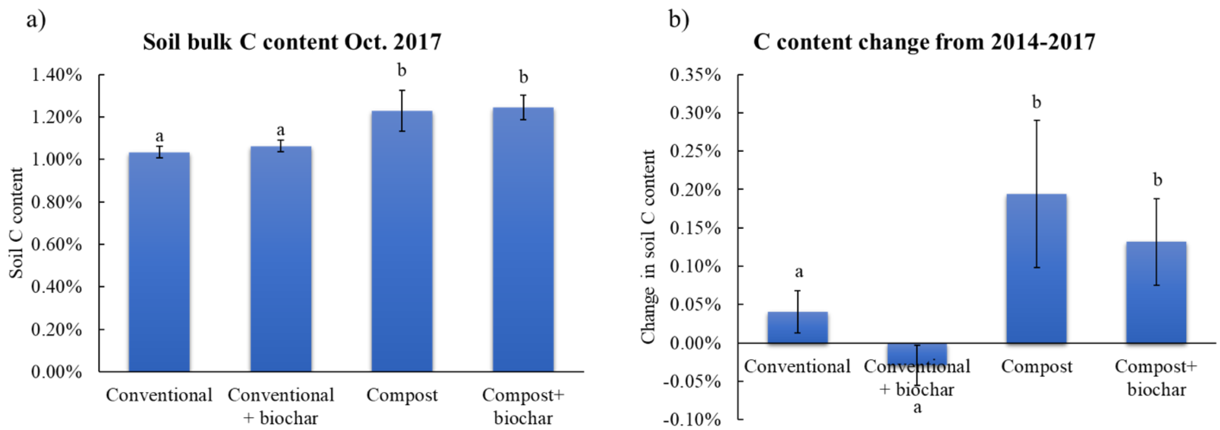


Figure 2. Soil organic C content and its change over time (March 2014 to October 2017).

SIGNIFICANCE AND FUTURE STEPS

Our results indicated compost management can benefit soil aggregation, increase soil microbial biomass and soil physically protected C. Continuous compost amendment was required to achieve such beneficial effects since no significant difference was observed within 2 years. Walnut shell biochar used in this field trial was a high-temperature biochar with large amount of recalcitrant, which was hard to be used by microbes. Thus, no significant biochar effect was observed. Soil samples were collected in March and October 2018 for soil aggregation, C distribution, and microbial community structure analysis. Soil aggregation analysis for those samples were finished. Aggregate fractions were submitted for C and N analysis. DNA extraction from those aggregate fractions was finished and will be submitted for sequencing.

By D. Wang and K. Scow, UC Davis

INTRODUCTION

Initial studies with drip irrigation indicated that yield increases came at the expense of fruit soluble solids concentration.

OBJECTIVES

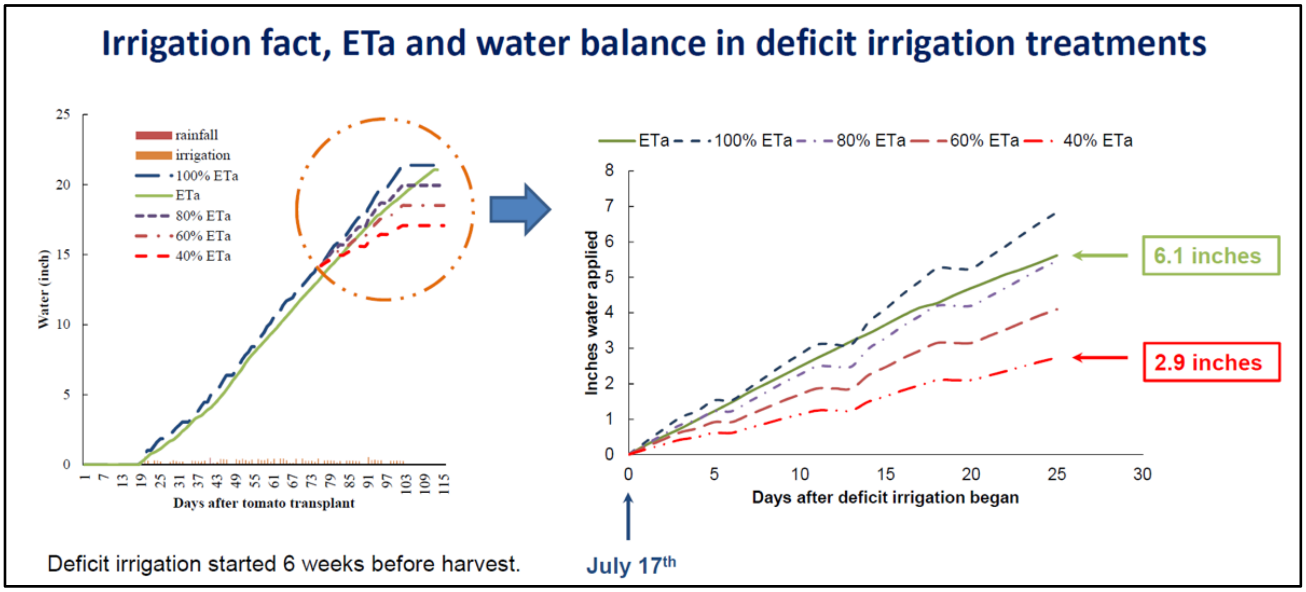
Research question: Viability and benefits of reduced irrigation applications during the time of early fruit ripening of processing tomatoes (6-weeks from harvest) grown under Sub-surface Drip Irrigation

We hypothesize that:

- late-season deficit irrigation can be managed to maintain or increase fruit soluble solids concentration without reducing brix yield (tons of fruit solids); some tradeoff between fruit yield and soluble solids concentration is likely,
- water stress induced by deficit irrigation only influences the soluble solids concentration of green fruit and
- deficit irrigation must be started early (5-6 weeks preharvest) to allow maximum control

APPROACH AND METHODS

Irrigation durations depend on ETa. Crops receive 100% ETa irrigation earlier in the season. All deficit irrigation started 6 weeks before harvest (July 17th), 4 irrigation treatments (n = 5, 100%, 80%, 60% and 40% Eta) were conducted.



KEY FINDINGS

- Both tomato yield and brix yield in 40% ETa treatment were the same as 100% ETa treatment. The only significant difference in tomato yield was that 100% ETa treatment was higher than 80% ETa treatment, while no difference observed in brix yield.
- Water stress induced by deficit irrigation (40 and 60% ETa) significantly increased brix content in red fruit. Our results also confirmed that deficit irrigation (40 and 60% ETa) can limit the amount of water in green fruit.
- We confirmed that late-season deficit irrigation can be used as a tool to increase fruit soluble solid concentration without reducing brix yield in our two-year field trial. A 50% reduction in irrigation during late-season (6-weeks pre-harvest) can be implemented to save water and energy, without jeopardizing tomato yield.

SIGNIFICANCE AND FUTURE STEPS

- We confirmed that late-season deficit irrigation can be used as a management tool to increase soluble solid concentration in processing tomato, saving water and energy and without reducing tomato yield and brix yield. Water and energy use reduction can be achieved even with an ETa based drip irrigation system.
- An early enough deficit irrigation needs to be conducted to induce a strong enough water stress at the root zone. Soil moisture content monitoring indicated that soil moisture content in the root zone may change long after deficit irrigation started, especially in fine-textured soils.
- The optimized deficit irrigation practice in processing tomato depends on soil properties (soil water holding capacity and initial soil moisture storage).

By Y. Wu, LBNL

OBJECTIVES

The field experiments conducted in the 2018 growth season at Russell Ranch were aimed to test an integrated monitoring approach to quantify soil moisture and nutrient stresses and understand their control on plant stress, growth and productivity. A specific focus was to understand the soil-plant-atmosphere hydraulic continuum, the dynamics of evapotranspiration (ET), water supply versus demand, and the plant's response to water and nutrient stresses.

APPROACH AND METHODS

The experiment was conducted in plot 5-4 using corn as the model crop. Five different treatment conditions were established, each with two rows of planting totaling ~ 750 individual plants. These five treatments include: T1 (25% water, full N); T2 (50% water, full N); T3 (full water, 50% N); T4 (full water, full N); T5 (full water, 10% N). T4 served as the control plot for both water and nitrogen stress tests, T1/T2 and T3/T5 represent the water and nutrient stress gradient, respectively.

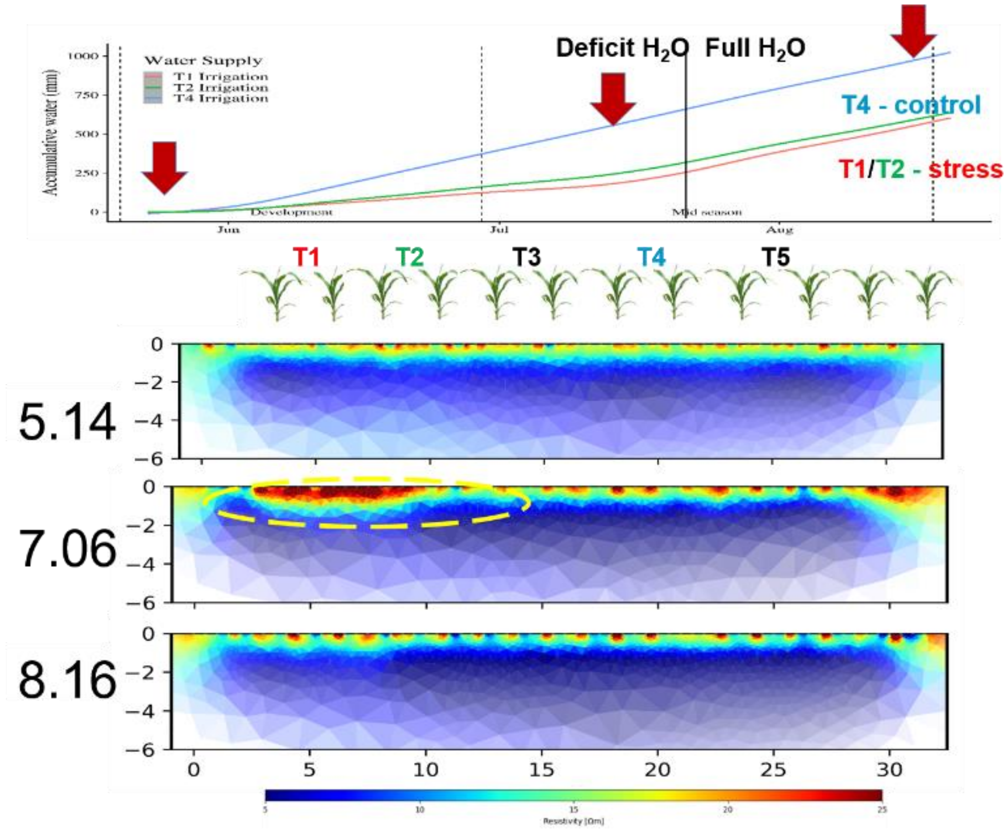


Figure 1. Top-Irrigation timeline and volume across the different treatments; Bottom- Examples of ERT resistivity profiles across the different treatments over selected time points. The yellow ellipse indicates the increase of the soil resistivity due to water stress at T1 and T2 treatments.

A suite of below and above ground monitoring approaches was tested during this experiment, which included below ground electrical resistivity tomography (ERT), soil temperature and matrix potential sensors, leaf water potential, leaf level hyperspectral and mid-range infrared imaging and environmental and weather forcings, such as precipitation, solar radiation, relative humidity, barometric pressure, wind speed, and direction among others.

Campaign mode data acquisition started in mid-May after the emergence of on average six leafs and continued until mid-September at roughly once every two weeks. At the end of the experiment, a small subset of plants from each treatment was destructively sampled for the quantification of key plant root and shoot traits including wet and try biomass, ear counts/mass, and chemical compositions. Soil samples were analyzed in the laboratory for physical parameters, such as moisture retention curve.

An ET model was developed to understand the relative contribution from evaporation and transpiration on plant water demand. Characterization of plant hyperspectral and mid-IR traits was compared between the different treatment conditions to understand the effects of treatments on plant trait development.

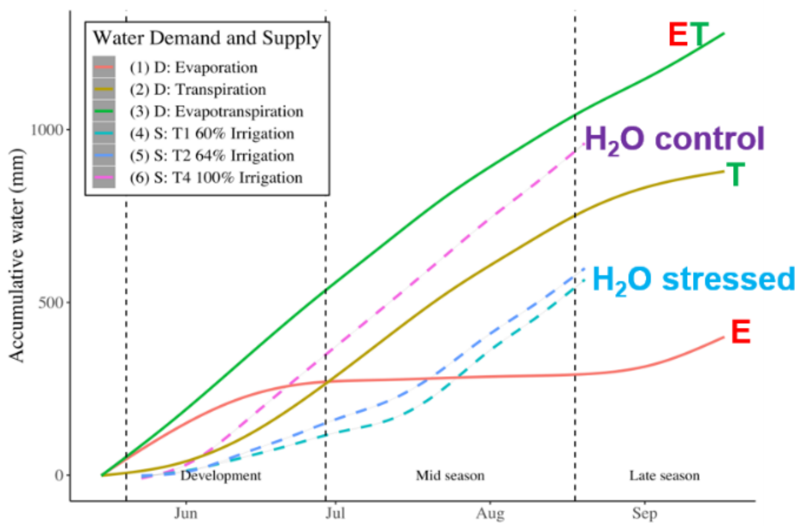


Figure 2. Water supply and ET demand across T1-T2-T4, indicating a stressed T1/T2 conditions.

KEY FINDINGS

ERT data provided a detailed time lapse dynamics of soil moisture change over time, visualizing the different water stress levels under different treatment conditions and the depth of root water uptake zone (Figure 1).

Comparison between water supply and ET demand indicated the stressed condition under controlled irrigation across T1-T2-T4 treatments (Figure 2).

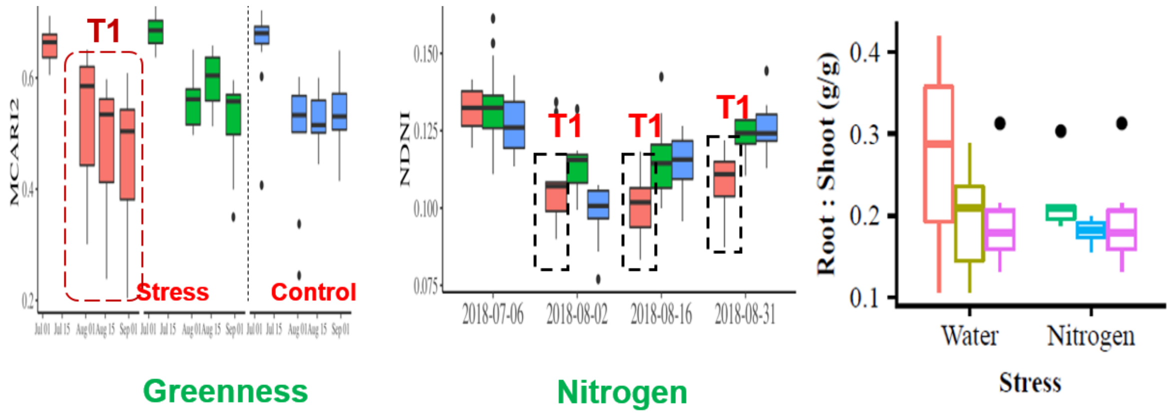


Figure 3: Plant responses to water and nitrogen stresses in terms of greenness response to water (left), leaf nitrogen content response to water (middle), and Root/shoot ratio under both water and nitrogen stresses (right).

Both water and nitrogen stress treatments resulted in obvious impacts on the development of key plant traits, including root and shoot biomass, ear mass, root: shoot ratio as well as leaf greenness, light use efficiency and nutrient content. Some examples are shown in Figure 3.

SIGNIFICANCE AND FUTURE STEPS

The results from this experiment demonstrated the capability of an integrated monitoring approach to understand the soil-plant-atmosphere continuum in terms of the cycling of water and its impact on nutrient acquisition and plant growth. Application of such an approach could provide a better understanding of plant development under different stress conditions to help improve effective water and nutrient application strategies in agriculture.

Our current results have not fully considered the differential soil moisture dynamics over time provided by the ERT data across the different treatment conditions. In addition, ongoing experiments to link ERT data with soil matrix potential to provide a 2D and dynamic view of the soil matrix potential distribution and evolution in the subsurface down to a few meters are expected to be completed in the next couple of months. With such datasets, differential ET responses of the different treatments can be better quantified to help understand the adaptation of plant development to the environmental stressors in terms of water and nitrogen.