CHANGES IN SOIL QUALITY DURING THE TRANSTITION FROM IRRIGATED TO DRYLAND CROPPING SYSTEMS

A. Núñez, R. Ball, and M. Schipanski
Colorado State University, Fort Collins, CO
Agustin.Nunez@colostate.edu

ABSTRACT

The availability of irrigation water enhances crop productivity and, in turn, increases crop residue inputs and soil quality. With increased pressure on declining groundwater resources, some formerly irrigated lands are being transitioned to dryland management. However, little is known about the shifts in soil quality after conversion from irrigated to dryland cropping systems. The objective of this work was to quantify the effect of irrigation retirement on the early changes in soil quality. In a formerly irrigated field, we installed a 3-year transition experiment with four treatments: irrigated corn, dryland corn, irrigated wheat, and dryland wheat. We quantified crop biomass production and soil properties known to indicate early changes in soil quality: chloroform-extractable microbial carbon (C), phospholipid fatty acids (PLFA) and enzyme activity. Corn production was highly affected by irrigation, with 2- to 6-fold reductions in production on dryland relative to irrigated; irrigation effect on wheat was lower but still significant, and affected grain yield more than biomass production. Treatment effects on chloroform-extractable C varied with sampling time, where irrigated corn generally had higher values than dryland corn. The PLFA analysis at the end of the experiment showed no treatment effects on fungal biomass and weak effects on bacterial biomass ($p = 0.14$), with dryland corn showing the lowest values. Total enzyme activity varied by treatment, with the soil under dryland corn having lower values than all other treatments ($p < 0.05$) and no significant differences between irrigated and dryland wheat. Wheat production, relative to corn, seems to be a viable option to minimize the negative impacts of irrigation retirement on both crop yields and soil quality.

INTRODUCTION

The Ogallala Aquifer is one of the most important aquifers in the world and has a great influence on crop production and social development in the High Plains of the United States. However, due to its intense use, Ogallala´s water reserves are declining at a rate that exceeds sustainable groundwater availability (Richey et al., 2015). To extend the life of the Aquifer and to meet water compacts with neighboring states, water pumping rates for agriculture must decrease (Whittemore et al., 2016) and an increase in irrigation retirement is expected in some regions of the Ogallala. However, little is known about the evolution of soil quality during this transition.

Soil quality can be defined as "the capacity of soil to function" (Karlen et al., 1997), which is similar in definition and proposed indicators to the more recent term soil health (e.g., Doran and Zeiss, 2000). Soil organic carbon (SOC) is accepted as one of the main indicators of soil quality, but it changes slowly and changes in response to management may not be measurable for years. Long-term increases in SOC by irrigation are usually in the range of 11% to 35% for semiarid regions like the Great Plains (Denef et al., 2008; Trost et al., 2013). In general, the effect of irrigation on SOC is much lower than the effect on biomass production, suggesting that irrigation also stimulates SOC turnover (Denef et al., 2008). A faster cycling of SOC occurs because irrigation not only increases biomass production but also soil moisture, which stimulates microbial activity (Trost et al., 2013). Because microbial activity has a great influence on SOC content and its changes are usually faster, measurement of soil microbial properties may help to understand early changes in soil quality (Cano et al., 2018).

The objective of this work was to quantify the effect of irrigation retirement on the early changes in soil quality. We focused on indicators of microbial biomass community size (chloroform-extractable C), structure (phospholipid fatty acids) and activity (enzyme activity) that have been proposed and tested in agricultural systems of the High Plains (Cano et al., 2018).

MATERIALS AND METHODS

To quantify the changes in soil quality during irrigation retirement, an experiment was started in May 2017 at the Agricultural Research, Development and Education Center (ARDEC) of Colorado State University near Fort Collins in a field that was previously managed under full irrigation. The soil is characterized as a Fort Collins loam (Aridic Haplustalfs) (USDA NRCS, 2019), with an annual precipitation of 16.05 inches and annual snowfall of 57 inches (1981-2010 normals average, https://usclimatedata.com/).

A transition experiment was installed with four treatments: (T1) irrigated corn, (T2) dryland corn, (T3) irrigated wheat, (T4) dryland wheat. Thus, the treatments represent the transition from irrigated to dryland and the still irrigated controls under each continuous crop. Prior to the start of the experiment, in March 2017, the site was tilled to homogenize the surface and to incorporate previous crop residue into the soil. During our experiment all the treatments were kept under no till, so the studied changes include both the effect of irrigation retirement and no till. The experiment was finished in November 2019 after three corn crops and two wheat crops.

Corn was planted around mid-May and wheat between late September and early October. For corn, the Producers Hybrids 5218 SSTX was planted at a seed rate of 34,000 and 17,000 seeds/acre for irrigated and dryland respectively. Avery wheat was planted at a seed rate of 90-100 and 50-60 lbs/acre for irrigated and dryland, respectively. Fertilization rates were defined based on soil nutrient concentration, and monoammonium phosphate (11-52-0) and urea (46-0-0) were broadcasted in the initial stages of crop development. Pre- and post-emergence herbicide applications were used for weed control. For the irrigated treatments irrigation was done once per week from May to October. Harvest was done in July for wheat and in November for corn. Total aboveground biomass production and grain yield per plot was estimated at physiological maturity by sampling a total area of 98 and 49 sq. ft for corn and wheat plots, respectively. Grain yield was also determined via mechanical harvesting and the results showed the same trends so only the hand sampling results are presented here.

Soil samples were taken twice a year, at Spring and Fall, to a depth of 4 inches and kept refrigerated between one and two weeks until analyses. A 10-g subsample was dried at 105°C for 48 h to estimate gravimetric water content. Chloroform-extractable carbon was determined by shaking 20-g duplicates of each sample in 100 ml of 0.5 M K_2SO_4 with or without 1 ml of chloroform, centrifuged 10 min and filtered through a 0.45 μm filter (Fierer, 2003). The extracts were analyzed for total organic C and N in a TOC-V-TN analyzer (Shimadzu Corp., Kyoto, Japan). We quantified chloroform-extractable C as the difference between the chloroform-treated and the untreated subsamples and interpreted these values as a proxy for microbial biomass carbon. In the final sampling (Fall 2019) we also quantified phospholipid fatty acid (PLFA) content and extracellular enzyme activity. A subsample of fresh soil was sieved to 2 mm, cleaned from roots, freeze-dried and sent to Ward Labs (Kearney, NE) for the PLFA extraction. We used the PLFA 18:2ω6 as a fungi biomarker and the following PLFAs as bacterial biomarkers: i14:0, i15:0, a15:0, 15:0, i16:0, 16:1ω7c, i17:0, a17:0, 17:0, 17:1 ω8c, 18:1ω7c, 18:1ω5c, 10Me17:0, and 10Me18:0 (Zelles, 1999; Frostegård et al., 1993). Six soil enzymes were assayed following the protocol of Saiya-Cork et al. (2002). Soil slurries were made by homogenizing 1 g of 8-mm sieved, fresh soil in approximately 120 mL of pH 8.1 tris buffer. Then, 200 µL of each slurry was pipetted into a 96 well plate and mixed with 50 µL of substrate. Samples were incubated at 25 °C for 4 h, and the developed fluorescence read in a microplate reader. Enzyme activities were summed based on the nutrient cycle they are mainly involved. Carbon cycling enzymes include β-D-cellubiosidase, and β-Glucosidase. Nitrogen cycling enzymes include Leucine aminopeptidase, Tyrosine aminopeptidase and B-1,4-N-acetyl-glucosaminidase. The only phosphorous cycling enzyme assayed was acid phosphatase.

We conducted analyses of variance to test the treatment effect over each measured variable considering the complete randomized block design of the experiment (n = 4). For the variables measured at several time points during the experiment we used a linear mixed model to consider the covariance structure between measurements taken from the same plot.

RESULTS AND DISCUSSION

As expected, irrigation retirement affected biomass production and soil moisture evolution, but the changes varied with each crop. Corn was strongly affected by irrigation retirement, with 2 to 6-fold decreases in biomass production and even stronger decreases in grain yield (Table 1) confirming the lack of suitability of this crop for dryland production in this area. Wheat was also affected, but irrigation effect on total biomass production was lower (~20%) and not always significantly different. The effect of irrigation on wheat grain yield was higher than in biomass production, explained by late spring irrigation that coincided with the critical reproductive period of the crop and increased its harvest index.

Table 1. Total aboveground biomass production of each crop and grain yield annually from 2017 to 2019.

	Total Biomass			Grain yield		
	2017	2018	2019	2017	2018	2019
Treatment	lbs DM / ac			lbs DM / ac		
IRRI Corn	16,889±410	17,372±691	14,244±557	10,072±222	10,587±396	7,808±304
DRY Corn	6,965±216	3,598±166	2,383±193	4,309±215	1,427±75	433±41
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
IRRI Wheat		8,836 ±907	10,452±771		2,583±280	3,579±289
DRY Wheat		7,277±777	8,677±449		1,949±221	2,717±280
p-value		0.12	0.04		0.02	0.03

Seasonal soil moisture of the dryland treatments shows the growing season of each crop, where water was used, and the moisture recovery during the fallow periods (Fig. 1). Although at the end of the first growing season (Fall 2017) irrigated and dryland corn had the same soil moisture due to rain events after physiological maturity, in Spring 2018 irrigated corn had more GWC than dryland corn. This was probably an effect of the higher soil cover in the irrigated corn that increased water infiltration and decreased evaporation compared to the dryland; in Spring

2018 soil cover was 77% and 25% in irrigated and dryland corn, respectively. Soil moisture in dryland corn decreased sharply during the growing season and tended to recover during late fall and winter, but never reached the GWC of the irrigated treatment. Irrigation had a lower effect on soil moisture in wheat due to fewer irrigation events, usually concentrated in late spring near the end of crop development. However, summer rains were not enough to completely recover soil moisture between harvest and planting of the next dryland wheat compared to irrigated.

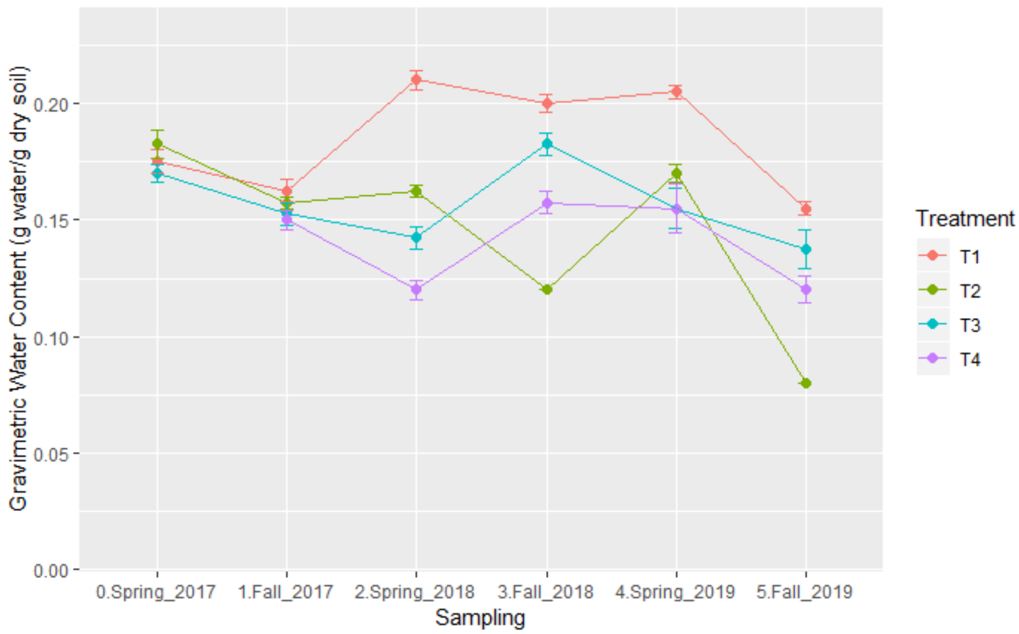

Figure 1. Soil gravimetric water content (0-10 cm) for each treatment at each sampling date. T1.Irrigated Corn; T2.Dryland Corn; T3.Irrigated Wheat; T4.Dryland Wheat

There was a Sampling by Treatment interaction in the evolution of chloroform-extractable C ($p < 0.001$, Fig. 2) indicating that the treatment differences varied with sampling time. The values tended to increase during the first year of the experiment in all the treatments, probably due to the exclusion of tillage (Balota et al., 2003), with a posterior decrease/stabilization. Irrigated corn had the highest values of chloroform-extractable C, while dryland corn usually had the lowest. The recovery in Fall 2019, where biomass production and soil moisture were the lowest for dryland corn, may be a preliminary indication of the soil microbial community adapting to dryland conditions, but more data is needed to conclude about this. This sampling moment corresponds to the analysis of PLFA for the estimation of the microbial community structure (Fig. 3). Total bacteria biomass followed the observed patterns of differences between irrigated and dryland corn with the wheat treatments in the middle and less affected by irrigation, but the treatment differences were not significant ($p = 0.14$). Fungal biomass, indicated by the PLFA biomarker 18:2ω6, was very low and not affected by treatment.

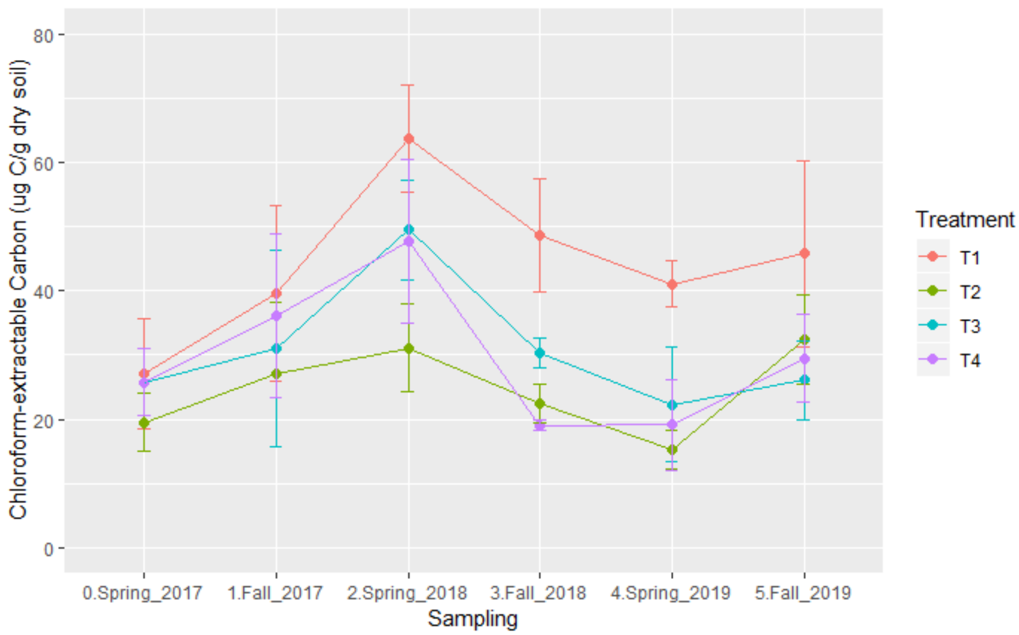

Figure 2. Chloroform-extractable carbon evolution in each sampling for each treatment. Sampling point 0.Spring_2017 corresponds to the baseline before treatment installation.

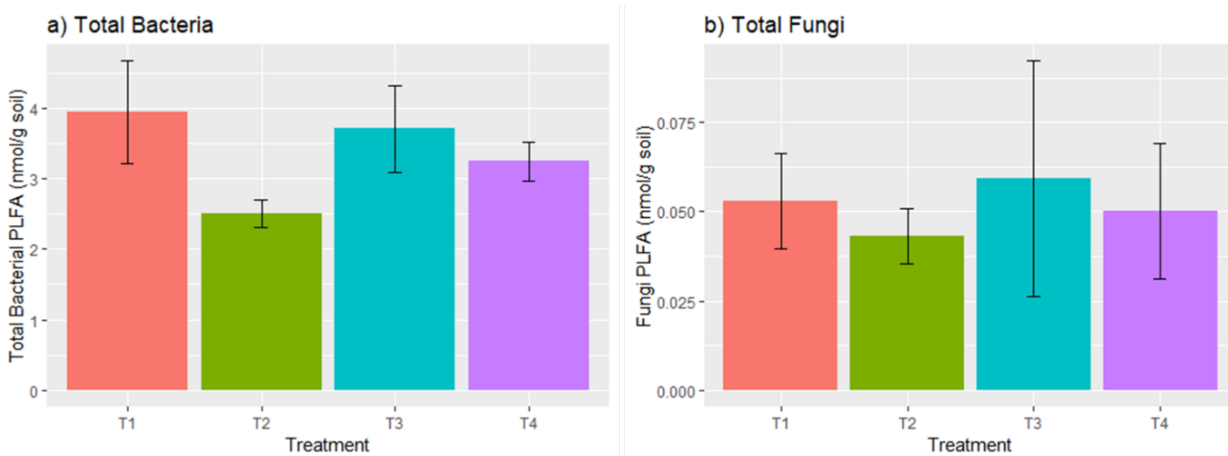

Figure 3. Phospholipid Fatty Acid results for the final sampling of Fall 2019, a) Sum of total bacterial PLFA, and b) Concentration of the fungal PLFA 18:2ω6. T1.Irrigated Corn; T2.Dryland Corn; T3.Irrigated Wheat; T4.Dryland Wheat

There was a significant treatment effect on all the enzyme groups ($p < 0.05$, Fig. 4). Coincident with the tendencies observed in the other variables, dryland corn had the lowest values in overall enzyme activity while wheat treatments were similar to irrigated corn, independent of the irrigation management. Dryland wheat had a lower enzyme activity than irrigated corn only for the phosphorus cycling enzyme. Enzyme activity is often an early indicator of changes in soil health and biogeochemical cycling (Acosta-Martínez et al., 2018), and our results indicate that soils with greater moisture content and more carbon inputs have more biogeochemical cycling activity. Moreover, dryland wheat seems to be a viable option to decrease the negative impacts of irrigation retirement on both crop yield and soil quality.

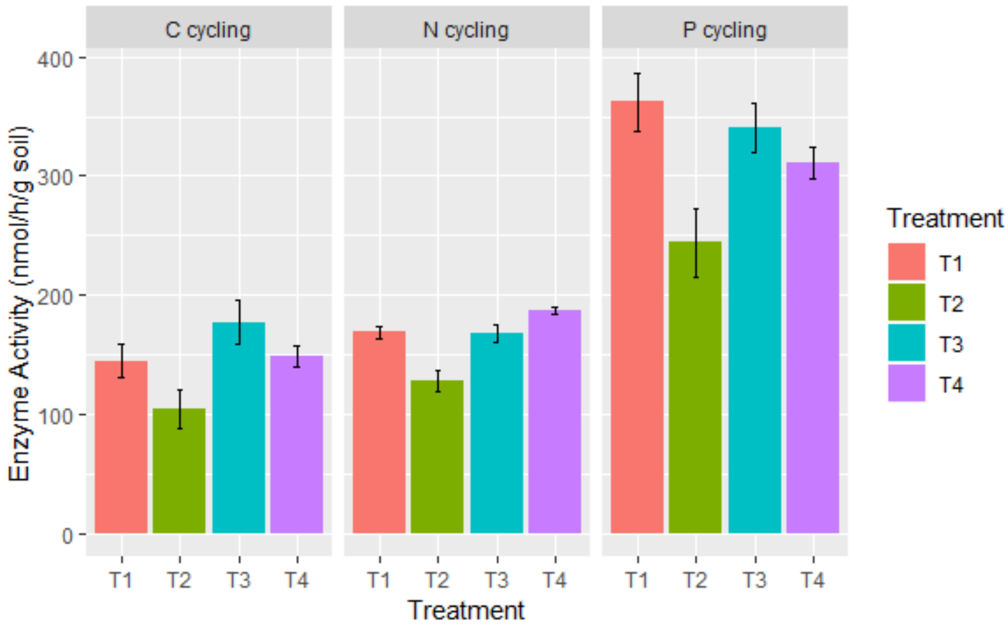

Figure 4. Extracellular enzyme activity for each treatment at the final sampling of Fall 2019. T1.Irrigated Corn; T2.Dryland Corn; T3.Irrigated Wheat; T4.Dryland Wheat

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