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Research Letter

Agricultural Management Impacts on Soil Health: Methods for Large Spatial Scales

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Core Ideas

- Organic matter stratification in soil health–managed soil resembles native soil.
- Methods are appropriate for the large spatial scale and our chosen indicators.
- Methods involving immediate sample preprocessing require field modifications.

Abstract: Agriculture in the Southern Great Plains of the United States depends on precipitation and temperature thresholds for productivity. The region's climate and weather are variable, presenting farming challenges that are predicted to increase. Building and conserving healthy, resilient soil is one way farmers manage for future uncertainty. Few studies have compared soil health–managed and conventionally managed farms at the regional scale. To better understand management effects on soil health across the Southern Great Plains, we studied farms at 12 locations. We piloted the study using three of the locations, collecting soils from 10 fields per location and analyzing them for indicators of soil health. Our objective was to test the suitability of our experimental framework and identify additional indicators and analyses of interest. Our framework was generally suitable to the purpose of this study. We also noted that soil health–managed soils had organic matter stratification similar to native soils, which we plan to explore further.

The Southern Great Plains of the United States, once dominated primarily by grasslands, is today a diverse region of productive cropland and grazingland activity (USGS, 2011). Wheat, corn, cotton, hay, sorghum, and soybean are the most common crops (USDA National Agricultural Statistics Service, 2014); together with a small number of specialty crops, these contribute more than $16 billion toward the annual agricultural value of the Southern Great Plains (Steiner et al., 2017). The region's climate is generally conducive to agricultural production and is characterized by spatial gradients of temperature and precipitation (Fig. 1). The climate presents challenges, however, especially to farms dependent on thresholds of precipitation and temperature for production (Steiner et al., 2017). Interannual variability is also pronounced; droughts are frequent, as are severe storms. Climate change is expected to increase production challenges in the Southern Great Plains via increases in annual temperature, drought frequency and intensity, and heavy rainfall events, making short-term decision-making on farms more difficult and uncertain (Steiner et al., 2015).

Adaptation to local weather and climate has led to variations in production timing, techniques, and methods across the Southern Great Plains. Traditional practices have generally incorporated tillage, crop rotations with at least one fallow period, and fertilization with nitrogen, potassium, or both. Practices such as no till or reduced till, incorporation of cover crops, and diverse rotations are less common but growing in popularity (Baumhardt and Salinas-Garcia, 2006). Dual-use cropping and grazing is common in both conventionally managed (CM) and soil health–managed (SHM) systems. In SHM systems, one or more soil health management practices (SHMPs) are used that preserve or build the organic matter stored in the soil and reduce the exposure of the soil to erosion. These practices usually focus on four "pillars" as defined by the USDA-NRCS:

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Abbreviations: CM, conventionally managed; SHM, soil health managed; SHMP, soil health management practice.

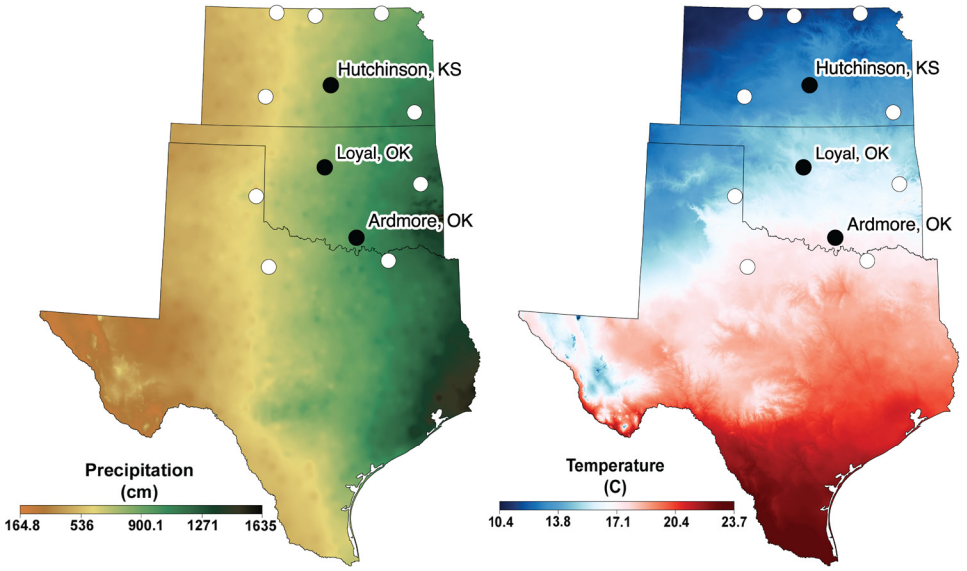

Fig. 1. Mean annual precipitation and temperature across the Southern Great Plains for the period 1981 to 2010. Mean annual precipitation (left) and temperature (right) are the 30-yr climate normals from the PRISM dataset (PRISM Climate Group, 2016). The locations of farms in the pilot study are denoted in black; the additional nine locations to be included in the full study are denoted in white.

1. Disturb the soil as little as possible.
2. Keep living roots in the soil.
3. Keep soil covered.
4. Diversify the soil biota by diversifying cash and cover crops.

As climate change leads to increased pressure on agricultural production, it will be necessary for farmers to develop new or improved SHMPs.

Studies of SHM systems within the region and elsewhere have shown improvement in the amount of soil organic matter and other soil health indicators (Havlin et al., 1990; Liu et al., 2006; Turmel et al., 2015). However, few of these studies were conducted on regional scales that incorporate spatial temperature and precipitation gradients. The climate gradients of the Southern Great Plains provide the opportunity to assess soil health on SHM farms and CM farms in different climates, as well as to elucidate the effect of precipitation and temperature on these differences. In this pilot study, we identify a framework for examining SHMPs across a regional climate gradient based on on-farm landowner information. We evaluate the suitability of an experimental design for use at a regionwide scale and determine if the methodology is sufficient to detect differences between SHM and CM farm soils. This pilot study serves as the basis for a future, more comprehensive assessment of the connections between climatic conditions and soil health in the Southern Great Plains.

Methods

Site Selection and Field Sampling

We initially identified 12 locations in a 3-by-4 grid pattern stretching from northern Kansas to northern Texas (Fig. 1). The grid was approximately 700 km north-south and approximately 600 km east-west, and each location was approximately 150 km from its nearest neighbors. For this pilot analysis, we focused on the three south-central locations: Hutchinson, KS; Loyal, OK; and Ardmore, OK. These three sites were the most central of the set of 12 locations and readily enabled follow-up data collection efforts as needed.

At each location, we identified five pairs of fields with similar soil types according to the USDA-NRCS Web Soil Survey (USDA-NRCS, 2017). Each pair consisted of a CM field and a SHM field separated by no more than a mile. For each field, we recorded the current tillage, cash and/or cover crop(s) grown, whether the field was dual use (i.e., grazed by cattle in addition to farmed for crops), and crop rotation. With the assistance of landowners, we took three sets of samples on each field: eight 2.5-cm-diameter cores for microbial biomass analysis and two 5-cm-diameter cores for all other analyses. Each core was divided into three depth sections: 0 to 5, 5 to 10, and 10 to 15 cm. We then combined cores of the same diameter by depth, resulting in six samples per set (18 samples per field). The small diameter cores were kept in coolers with ice packs during transport for subsequent analysis.

Laboratory and Statistical Analyses

We analyzed the small diameter cores for microbial biomass carbon (C) and nitrogen (N) using the chloroform fumigation extraction method (Jenkinson and Powlson, 1976). Briefly, approximately 10 g of fresh collected soil was extracted from nonfumigated soils using 25 mL of K_2SO_4, while a further 10 g of fresh collected soil was placed in glass beakers and fumigated for 24 h in $CHCl_3$ before being extracted in 25 mL of K_2SO_4. All extracted samples were filtered through No. 24 Whatman filters, and the resulting extractant was analyzed on a Shimadzu Total Organic Carbon analyzer to determine organic C and total N content. Addition of a small amount of HCL to selected samples from each location resulted in no effervescence, indicating a lack of carbonates in our soils. The samples were additionally analyzed on a Timberline analyzer for NO_3 and NH_4^+. We determined total organic N by subtracting inorganic N (NO_3–N and NH_4^+–N) from total N.

We weighed, air dried, and weighed the large core samples again to calculate the hygroscopic soil water content and soil bulk density. We then combined the samples by field and depth and sent them to the Oklahoma State University Soil, Water, and Forage Analytical Laboratory to be analyzed for texture, percentage organic matter, percentage N, percentage organic C, pH, and electrical conductivity. Finally, we

ran paired, two-tailed *t* tests with $\alpha = 0.05$ for each indicator to test for significant differences between CM and SHM systems across all sites and depths (i.e., all SHM to all CM), within sites across all depths (e.g., CM to SHM in Ardmore), and within sites and individual depths (e.g., CM to SHM in Ardmore for the 0- to 5-cm depth increment). All statistical analyses were performed using the *base* package in R (R Core Team, 2015).

Results

Electrical conductivity was significantly higher on CM fields than SHM fields across all locations ($p < 0.001$). There were no other statistically significant differences for any of our indicators between CM and SHM fields across locations, although some indicators were significantly different between the two management regimes at specific depth increments or for specific locations (Table 1). At all three locations, organic matter and the associated total N were more stratified by depth in SHM fields than in CM fields. This resulted in more organic matter and total N in the surface soils (5 cm) of SHM fields than CM fields at all locations. The reverse was true of the 5- to 10- and 10 to 15-cm depths, with greater organic matter and total N in CM than SHM fields. Overall, both organic matter and total N varied more from the top to the bottom of the sample profile in SHM fields than they did in CM fields.

Discussion

This pilot study was intended to identify a framework for examining SHMPs across a regional climate gradient based on on-farm landowner information. The results revealed few statistically significant differences between SHM and CM farms across the climatic gradient, but they nevertheless indicated that the chosen methodological framework is suitable for a study of this scale and with our stated objectives.

The presence of trends in organic matter and total N is especially interesting and worthy of further attention in the full study. The distribution of organic matter in the SHM fields is similar to that of natural systems, where organic matter is concentrated in the uppermost part of the soil profile and decreases markedly within the first 20 cm of depth (Jobbágy and Jackson, 2000). This may indicate that these soils are gradually returning to a condition more reminiscent of native

Table 1. Means and *t* test results for all comparisons between conventionally managed (CM) and soil health–managed (SHM) fields at three locations in the Southern Great Plains (Ardmore, OK; Hutchinson, KS; Loyal, OK).

Location	MAT†	MAP‡	Depth	*n*	Soil health indicator																	
					Bulk density				Electrical conductivity				pH				Organic matter				Total N			
					Mean		*t*	*P*	Mean		*t*	*P*	Mean		*t*	*P*	Mean		*t*	*P*	Mean		*t*	*P*
					CM§	SHM¶			CM	SHM			CM	SHM			CM	SHM			CM	SHM		
	°C	cm	cm	no.	– g cm^{-3} –				– S m^{-1} –								– % –				– mg kg^{-1} –			
Ardmore	18	96	5	15	1.4	1.6	−3.67	<0.01**	113.8	169.8	−1.51	0.20	5.7	6.1	−2.00	0.11	2.0	2.8	−3.54	**0.02***	0.118	0.150	−2.43	0.07
			10	15	1.1	1.2	−2.49	0.03*	98.8	108.6	−0.35	0.74	5.9	6.2	−1.40	0.23	2.0	1.5	2.80	**0.05***	0.114	0.092	1.62	0.18
			15	15	1.2	1.3	−0.51	0.61	128.8	97.0	1.59	0.19	5.9	6.2	−0.78	0.48	1.8	1.2	2.67	**0.05***	0.106	0.078	2.51	0.07
			–	45	1.2	1.3	−2.94	<0.01**	113.8	125.1	−0.62	0.55	5.8	6.2	−2.40	0.03*	1.9	1.8	0.58	0.57	0.1	0.1	0.61	0.55
Hutchinson	12	80	5	15	1.2	1.3	−0.55	0.59	440.8	364.2	1.49	0.21	6.5	6.5	−0.26	0.80	2.1	2.5	−1.85	0.14	0.126	0.146	−1.17	0.30
			10	15	1.3	1.4	−1.18	0.26	391.6	158.6	2.99	0.04	6.1	6.0	0.18	0.86	1.8	1.6	1.68	0.17	0.114	0.100	1.25	0.28
			15	15	1.5	1.4	0.44	0.67	280.4	137.2	2.28	0.09	5.7	5.8	−0.32	0.72	1.6	1.4	1.38	0.24	0.102	0.090	1.40	0.24
			–	45	1.3	1.4	−0.52	0.60	370.9	220.0	3.90	<0.01**	6.1	6.1	−0.27	0.79	1.8	1.8	−0.09	0.93	0.1	0.1	0.25	0.81
Loyal	15	90	5	15	1.8	1.7	1.15	0.27	252.0	175.2	1.83	0.14	5.7	5.1	1.79	0.09	1.6	2.0	−2.23	0.09	0.102	0.118	−1.73	0.16
			10	15	1.6	1.5	0.69	0.50	203.6	114.6	1.78	0.15	5.7	5.4	0.94	0.39	1.5	1.2	2.18	0.10	0.094	0.082	2.06	0.11
			15	15	1.7	1.7	0.05	0.96	196.0	117.8	1.93	0.13	5.9	5.5	1.47	0.39	1.2	1.1	1.43	0.23	0.084	0.074	2.24	0.09
			–	45	1.7	1.7	0.95	0.35	217.2	135.9	3.42	<0.01**	5.8	5.3	2.5	0.03*	1.5	1.4	0.38	0.71	0.1	0.1	0.40	0.69
Total				135	1.4	1.4	−0.77	0.44	234.0	160.3	3.91	<0.01**	5.9	5.9	−0.02	0.98	1.7	1.7	0.57	0.57	0.1	0.1	0.75	0.46

* Significant at $\alpha = 0.05$.

** Significant at $\alpha = 0.01$.

† Mean annual temperature.

‡ Mean annual precipitation.

§ CM practices: conventional till, no cover crops, ≤2 cash crops in rotation.

¶ Soil health management practices: no-till, monoculture or diverse species cover crops, >2 cash crops in rotation (for Hutchinson, KS, and Loyal, OK, only).

grassland soil than their CM counterparts (Franzluebbers, 2002).

Previous studies have also noted that the loss of organic C during cultivation is highly dependent on climate and soil texture. In general, loss of organic C increases with precipitation and soil coarseness (Burke et al., 1989). Incorporation of organic matter into the soil is likewise affected by precipitation and soil structure, and we would predict buildup of organic matter in fields that have transitioned from conventional to soil health management to vary between sites. We were not able to identify the presence or absence of this variation given the limited range of conditions among our three pilot sites, but we plan to address this prediction in detail in the full study.

We encountered challenges during collection and analyses of our soils, which will be addressed in the full study and which can be considered as lessons learned for similar studies. First, human error during bulk density sampling is a common source of error in these measurements. One way to reduce error is for one individual to collect all samples with specially designed sleeves to contain the soil. However, the spatial scope and number of samples involved in our study render the use of sleeves impractical. We instead chose to collect soil in 5-cm increments, emptying the probe between each sample. This may have affected the accuracy of the depth measurements. In the future, we will collect the entire core in one sample and remove 5 cm at a time by measuring the cores as they are removed from the probe.

Second, the chloroform fumigation method is not well suited to samples collected far afield. The materials required to properly preprocess and store soil samples are difficult to transport safely to and from the field, and the sensitivity of samples to heat and time presents difficulties when not returning to the laboratory overnight, which affected the integrity of our microbial biomass C and N data. For the full-scale study, we will instead determine microbial biomass, as well as basic microbial community structure, using phospholipid fatty acid analysis. This method is more lab-intensive but requires only that samples be kept frozen prior to analysis.

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