LONG-TERM CROP ROTATION DIVERSITY EFFECTS ON SOIL C AND N

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ABSTRACT

The objective of this study was to evaluate the effects of nitrogen (N) fertilizer level and crop rotation diversity on soil organic carbon (SOC) and N stocks from a 34-yr study located in eastern Nebraska. Seven crop rotations (three continuous cropping systems; two 2-yr crop rotations, and two 4-yr crop rotations) and three N levels were compared. Soil samples were taken to a depth of 60-inches. Differences in SOC stocks were largely confined to the 0 to 3-inch depth with greater SOC ($P = 0.0002$) in rotations than continuous cropping systems and greater SOC ($P = 0.0004$) in 4-yr vs. 2-yr rotations. Total soil N was greater with increased crop rotation diversity for the 0 to 12-inch soil profile. At the full sampled soil profile (0-60 inches), SOC stocks were similar between N levels and greater for the 4-yr vs. 2-yr crop rotations ($P = 0.0492$). Trends in total N stocks were similar to those of SOC stocks. Overall, crop rotation had a larger effect on SOC and N stocks than N fertilizer.

INTRODUCTION

Sustainable crop production requires management strategies aimed at enhancing the potential to sequester or increase soil organic carbon (SOC). Maintaining or increasing SOC is one method for greater resiliency for agricultural systems under extreme weather events. Agricultural management strategies to increase SOC within annual cropping systems include cover crops, residue retention, manure-application, diverse crop rotations, crops with greater root mass, and N fertilizer (Jarecki and Lal, 2003; McDaniel et al., 2014; Paustian et al., 2016; Poffenbarger et al., 2017; Tiemann et al., 2015). Diverse cropping systems that includes cover crops tend to increase SOC by increasing C input (King and Blesh, 2018; McDaniel et al., 2014). Nitrogen fertilizer has been reported to increase, decrease, or have no effect on SOC (Brown et al., 2014; Khan et al., 2007; Lu et al., 2011; Mahal et al., 2019; Poffenbarger et al., 2017; Russell et al., 2005). Significant SOC responses to management changes (i.e. crop rotation, N fertilizer management) however, may take years to detect, so the ability to quantify management effects improves with experiment duration.

Crop rotation and N fertilizer level influences grain yield and aboveground biomass impacting SOC, soil N, and other agroecosystem functions (Liebig and Varvel, 2003; Sindelar et al., 2016; Varvel, 2006). Long-term cropping studies under no-till have resulted in increased SOC and total N with increased crop rotation diversity (Alhameid et al., 2017; Maiga et al., 2019). Cropping systems that incorporate legumes under no-till have also resulted in increased SOC (Conceição et al., 2013; Hobley et al., 2018) while other results suggest incorporating legumes causes a rhizosphere priming effect on SOC, which reduces the benefit of residue retention on SOC (Chen et al., 2018).

Long-term effects from crop rotation and soil management practices on SOC and soil N stocks provides important information on sustainable cropland management under a changing climate. Quantifying SOC storage both by soil layer and cumulatively is important in detecting the influence of management on SOC changes. The objective of this study was to evaluate N fertilizer rates and crop rotation diversity on SOC and N stocks from a 34-yr study.

MATERIALS AND METHODS

The experiment was conducted at the Eastern Nebraska Research and Extension Center near Mead, NE. Soil series is a Yutan-Tomek silty clay loam-silt loam complex (fine-silty, mixed, superactive, mesic Mollic Hapludalfs and fine, smectitic, mesic Pachic Argiudolls, respectively). Mean annual temperature and precipitation is 50.9°F and 30 inches, respectively. The experiment is a randomized complete block design in a split plot arrangement with five replications. Crop rotation is the main plot, and fertilizer N rate is the split plot. The experiment comprises of seven crop rotations and three nitrogen fertilizer levels. Crop rotations include continuous crops [continuous corn (*Zea mays* L.); continuous grain sorghum (*Sorghum bicolor* (L.) Moench); continuous soybean (*Glycine max* L.)], 2-yr (corn-soybean; grain sorghum-soybean) and 4-yr crop rotations (corn–soybean–grain sorghum–oat [*Avena sativa* L.]+clover [80% *Melilotus officinalis* Lam. + 20% *Trifolium praetense* L.]; corn–oat+clover– grain sorghum–soybean). Each phase of every crop rotation is present each year for a total of 15 rotations per replication or block. Fertilizer N treatments were initiated in 1982 and included 0, 80, and 160 lbs. N acre^{-1} (0, 90, and 180 kg N ha^{-1}) for corn and grain sorghum and 0, 30, and 60 lbs. N acre^{-1} (0, 34, and 69 kg N ha^{-1}) for soybean and oat/clover. In 1983, the experiment was expanded to five replications. Split-plots are 30-ft wide (30-inch rows; n = 12) and 33-ft long. The study was annually disked twice in the spring from 1983 until 2006. In 2007, the study was converted to no-till. Crop management practices used in the study best represent those commonly used in the region and are performed with commercial-scale field equipment. Oat and rhizobium-inoculated clover is seeded in mid- March to early April at 89 and 16 lbs. acre^{-1} (100 and 18 kg ha$^{-1)}$, respectively, using a no-till grain drill with 7.5-inch row spacing. In-season crop management practices include weed control and fertilizer N application. No in-season herbicide applications occur in the oat/clover plots. Fertilizer N is manually broadcasted without incorporation.

Dry matter samples were collected for oat, corn, soybean, and grain sorghum at physiological maturity. Soybean and oat samples were weighed and dried for dry matter yield determination before being threshed using a stationary plot thresher. For corn and grain sorghum, heads or ears were removed, and the remaining plant was chopped, dried to a constant mass, and weighed. Corn ears and grain sorghum heads were dried at 140°F to a constant dry mass and threshed, and corn cobs, grain sorghum panicles, and grain were additionally weighed for total aboveground biomass determination. For all crops, 15-ft of row (3.8-m^2) was sampled. Non-grain biomass of oat, corn, soybean, and grain sorghum were analyzed for C and N. Data on non-grain biomass C and N values are from 1990 to 2016. Detailed site, management, yield, and weather information can be accessed at the USDA-ARS Agricultural Collaborative Research Outcomes System (AgCROS) website (https://agcros-usdaars.opendata.arcgis.com/).

Soil samples (n=1125) have been taken to a depth of 5-feet at sampling increments of 0 to 3, 3 to 6, and 6 to 12, 12 to 24, 24 to 36, 36 to 48, 48 to 60 inch in all five replicates in November 2016. Four cores (1.3-inch diameter) are taken from each N subplot and composited by depth. All samples are weighed for bulk density determination. All samples are air-dried, ground to pass a 2-mm screen, and analyzed for total C and N.

Statistical Analysis

The effects of crop rotation and N fertilizer rate on SOC and total N stocks were analyzed using a generalized linear mixed model approach (PROC GLIMMIX in SAS). Rotation (main plot) and N fertilizer treatments (split-plot) were fixed effects while block was analyzed as a random effect. Analysis of variance (ANOVA) were run by soil layer depth and by cumulative soil depth. Preplanned comparisons were run using the contrast statement. Statistical probability was set at 0.05.

RESULTS AND DISCUSSION

Surface SOC and N stock differences by rotation and N fertilizer level

Crop rotation impacted SOC stocks at the near surface soil depth (Table 1). Differences by rotation and N level were largely confined to the 0 to 3-inch soil level. For SOC stocks at the 0 to 3-inch soil depth, differences were found between continuous crops and rotational cropping systems (Table 1).

Table 1. Surface soil organic carbon and soil nitrogen stock for each rotation (CC = continuous corn; CSB = continuous soybean; CSG = continuous sorghum; C/SB = corn-soybean; SG/SB = sorghum-soybean; C/O/SG/SB = corn-oat+clover-sorghum-soybean); C/SB/SG/O = corn–soybean–grain sorghum–oat+clover) and N fertilizer level.

	Soil depth (inches)					
	SOC stock			Total N		
Parameters	0-3	3-6	6-12	0-3	3-6	6-12
Rotation	ton acre^{-1}					
CC	7.45	6.69	9.90	0.69	0.63	0.97
CSB	7.67	6.56	10.9	0.70	0.62	1.05
CSG	8.34	6.82	10.6	0.78	0.64	1.04
C/SB	8.03	6.65	10.9	0.74	0.62	1.05
SG/SB	8.12	6.47	9.50	0.76	0.61	0.97
C/O/SG/SB	9.01	7.14	11.8	0.84	0.67	1.12
C/SB/SG/O	8.83	6.78	11.0	0.83	0.64	1.07
N level						
Zero	7.94	6.65	10.8	0.75	0.62	1.05
Low	8.30	6.69	10.5	0.76	0.63	1.03
High	8.34	6.82	10.6	0.78	0.64	1.04
Source of variation	*P*-value					
Rotation	**0.0001**	0.3814	0.3480	**<.0001**	**0.0067**	0.3013
Continuous v rotation	**0.0002**	0.7175	0.6035	**<.0001**	0.4762	0.4171
2-yr vs. 4-yr	**0.0004**	0.0696	0.0945	**<.0001**	**0.0013**	0.0744
Among 2-yr	0.6909	0.5248	0.1713	0.2192	0.5965	0.2689
Among 4-yr	0.4524	0.2042	0.3901	0.4943	**0.0290**	0.3667
Nitrogen level	**0.0103**	0.5050	0.8362	**0.0214**	0.1193	0.8306
0 N vs N	**0.0025**	0.3500	0.5856	**0.0134**	0.0537	0.6489
Rotation x Nitrogen	0.1604	0.9818	0.9997	0.0653	0.8031	0.9981

Four-yr rotations had greater SOC stocks than 2-yr rotations. Nitrogen fertilizer level affected SOC stocks for the 0 to 3-inch soil depth with greater SOC levels under N fertilized treatments (Table 1). Crop rotation affected total N at the 0 to 3 and 3 to 6-inch soil depth (Table 1). Total soil N was lower for the continuous cropping systems compared with the rotational cropping systems at the 0 to 3-inch soil depth. Soil N was greater under the four-year rotations compared to the two-year rotations at the 0 to 3-inch and the 3 to 6-inch soil depth. Nitrogen fertilizer increased total soil N at the 0 to 3-inch soil depth (Table 1). Total soil N was greater (P = 0.0290) for the corn–oat/clover– grain sorghum–soybean 4-year rotation compared to the corn–soybean–grain sorghum–oat/clover rotation. Increased N fertilizer effects on soil organic C concentration at the 0 to 3-inch soil depth was first documented eight years after crop rotation and N fertilizer treatments were initiated (Varvel, 1994).

Cumulative SOC and N stock

The main effects of rotation and N level were similar for the 0-12, 0-24, 0-36, and 0-48 inch soil depths (data not shown). At the 24 to 36-inch soil depth, a rotation effect (P = 0.0514) occurred mainly through differences between two-year rotations (Table 2).

Table 2. Soil organic carbon stocks for each rotation (CC = continuous corn; CSB = continuous soybean; CSG = continuous sorghum; C/SB = corn-soybean; SG/SB = sorghum-soybean; C/O/SG/SB = corn-oat+clover-sorghum-soybean); C/SB/SG/O = corn–soybean–grain sorghum–oat+clover) and N fertilizer level by soil depth.

	Soil Depth (inches)					
Parameters	0-12”	12-24”	24-36”	36-48”	48-60”	0-60”
Rotation			Mg C ha^{-1}			
CC	24.0	11.3	5.76	4.24	2.85	48.1
CSB	25.2	14.3	8.47	6.11	4.01	57.9
CSG	25.7	12.4	6.16	4.46	3.17	51.9
C/SB	25.6	15.4	9.63	7.09	4.91	62.5
SG/SB	24.1	11.1	5.89	4.06	2.77	47.8
C/O/SG/SB	27.9	15.8	9.63	7.05	4.82	65.1
C/SB/SG/O	26.5	14.7	8.61	6.33	4.33	60.5
N level						
Zero	25.4	14.1	8.12	5.89	4.06	57.5
Low	25.5	13.3	7.67	5.49	3.70	55.7
High	25.8	13.3	7.45	5.44	3.70	55.7
Source of variation			*P*-value			
Rotation	0.1411	0.0976	**0.0514**	0.0610	0.0948	**0.0204**
Continuous v rotation	0.2291	0.1826	0.0823	0.1091	0.1232	0.0947
2-yr vs. 4-yr	0.0260	0.1118	0.1650	0.1429	0.1942	**0.0492**
Among 2-yr	0.3213	0.0309	**0.0177**	0.0164	0.0200	**0.0164**
Among 4-yr	0.3303	0.4833	0.4134	0.4641	0.4739	0.3355
Nitrogen level	0.8583	0.7772	0.7777	0.8060	0.7917	0.8682
0 N vs N	0.6701	0.4801	0.5056	0.5137	0.4952	0.5956
Rotation x Nitrogen	0.9994	1.0000	0.9997	0.9961	0.9982	0.9999

A rotation effect (P = 0.0204) was found for the surface to 60-inch soil depth with differences between the two-year and four-year rotations as well as among the two-year rotations. Cumulative SOC stocks ranged from a low of 47.8 tons C acre^{-1} (107.1 Mg C ha^{-1}) for sorghum-soybean to a high of 65.1 tons C acres^{-1} (146 Mg C ha^{-1}) for corn-oat+clover-sorghum-soybean (Table 2). Four-yr rotations resulted in greater SOC stocks (62.8 tons C acre^{-1}; 140.9 Mg C ha^{-1}) than 2-yr rotations (55.2 tons C acre^{-1}; 123.7 Mg C ha^{-1}). Differences between 4-yr and 2-yr rotations was largely an effect of lower SOC stocks from sorghum-soybean (47.8 tons C acre^{-1}; 107.1 Mg C ha^{-1}) compared with corn-soybean (62.5 tons C acre^{-1}; 140.2 Mg C ha^{-1}). Differences between 2-yr rotations were not the result of crop residue C mass as sorghum-soybean had similar residue C mass by N fertilizer level than corn-soybean (data not shown). This was the first time SOC stocks were statistically different by crop rotation for the cumulative soil profile at this site. Previous results from this study showed similar SOC stocks between crop rotation in the 0 to 60-inch soil profile after 14-yr, indicating the duration required to determine SOC changes from crop rotation practices (Varvel et al., 2002).

The main effect of crop rotation was significant for total soil N at the 0 to 12, 36 to 48, and 0 to 60-inch soil depths (data not shown). For the 0 to 12-inch soil depth, greater soil N was present in the crop rotational systems versus the continuous cropping systems. Four-year rotations were greater than 2-year rotations. At the 36 to 48-inch soil depth, soil N was greater for corn-soybean than sorghum soybean. Similar to SOC stocks at the 0 to 60-inch soil profile, differences in soil N were present ($P = 0.0465$) between corn-soybean and sorghum-soybean with greater total N stocks in the corn-soybean rotation (data not shown). There was no N fertilizer response on cumulative soil N stocks.

Overall, N fertilizer effects on SOC and N stocks were largely confined to surface soil depths. Long-term N fertilization levels did not impact SOC stocks for cumulative soil depths. Cumulative SOC stocks (0 to 60-inch) ranged from 47.8 tons C acre^{-1} (107.1 Mg C ha^{-1}) for sorghum-soybean to 65.1 tons C acres^{-1} (146 Mg C ha^{-1}) for corn-oat+clover-sorghum-soybean rotation. In general, 4-yr rotations resulted in greater cumulative SOC stocks for the surface to 60-inch soil depth than less complex rotations but the dominant rotation for this region (corn-soybean) had similar SOC stocks as the 4-yr rotations. Increased crop rotation diversity on SOC and N stocks was not immediate for this region, suggesting prolonged use would be required.

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