Assessment of Soil Organic Carbon, Nitrogen and C/N Ratios as Key Components for Evaluating Nitrate Reduction Strategies at a Subbasin Scale

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Introduction

- In the U.S. Midwest, many states, including Iowa, Ohio, Illinois and Minnesota, are developing strategies to reduce export of nitrate-N (NO_3-N) from agricultural nonpoint sources to the Mississippi River.
- Management of soil organic carbon (SOC) and nitrogen (N) is considered a key component to prevent N loss to groundwater and artificial drainage.
- It has been estimated that 24 to 89% of SOC has been lost from the North American prairie since settlement. Improving SOC stocks can limit nutrient loss and improve water quality, improve the economic potential of cropland, and provide resilience needed for global climate change and food security.
- Despite inherent challenges in quantifying SOC and N in agricultural landscapes, enhancing and manipulating SOC and N pools offers potential to increase crop production without sacrificing water quality.
- Our study objectives were to 1) evaluate SOC, N and C/N ratios in the top 20 cm (plow layer) of the Rapid Creek subbasin; 2) quantify watershed-scale storage of SOC and N based on landscape positions and slope class criteria; and 3) assess the groundwater quality risks associated with the shallow soils in the subbasin.

Methods

- The 780 ha subbasin is located in the northern portion of the 88 km² HUC 12 Rapid Creek watershed in Johnson County, Iowa. The subbasin is situated on the southern edge of the Iowan Surface landform region in eastern Iowa (Figure 1).

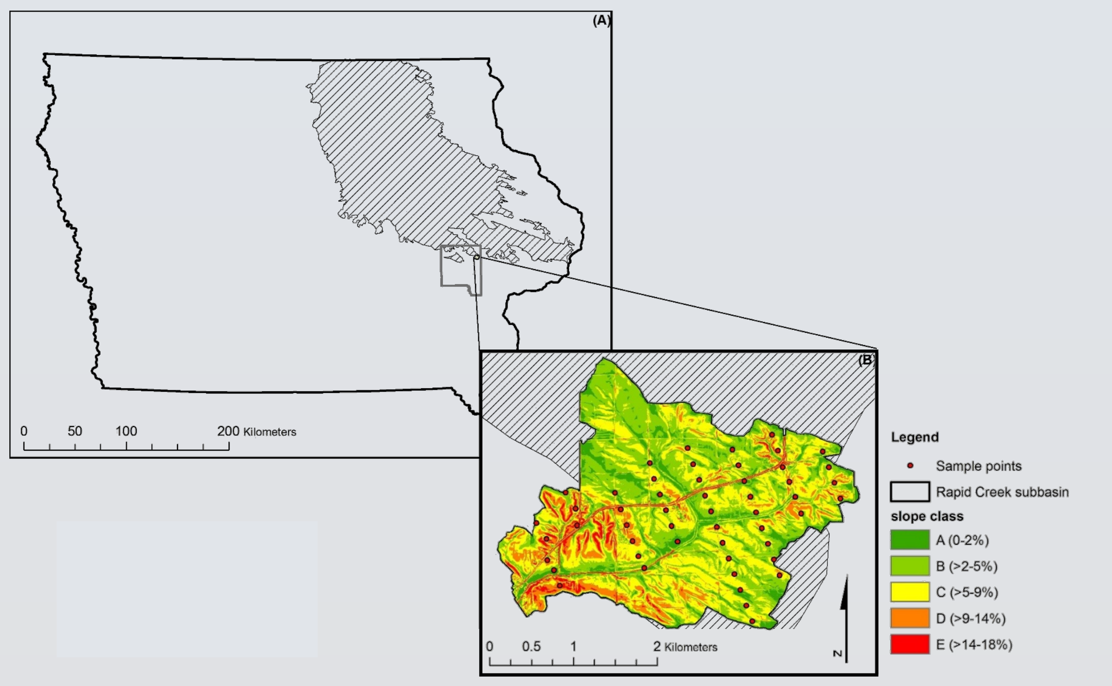


Figure 1. Location map of the Iowa Surface landform region (A) and the Rapid Creek subbasin (B).

- Soils are primarily formed in loess and alluvium.
- A 500 x 200 m sampling grid was created for the subbasin. In all, 51 sites were sampled along 8 transects. All of the sample sites were located in agricultural row crop fields where tillage consisted of either mulch or no-till (Figure 1).
- Soil samples, 20 cm deep, were collected at each location approximately 30 days after planting in 2015.
- Landscape positions were determined at the time of sampling and included headland, shoulder, backslope, and toeslope.
- Bulk density was determined at 2 depths (5-10 cm and 15-20 cm) and averaged.
- SOC and total N were determined by elemental analysis via dry combustion.
- Total mass of SOC and N was estimated based on percent by mass and mean bulk density of the plow layer for each site. These data were used to estimate total mass of each soil property for the entire subbasin assuming equal mass of each soil property for like landscape positions and slope class.

Results

	Sand	Silt	Clay	BD	SOC	N	C/N ratio
	(%)	(%)	(%)	(g cm^{-3})	(Mg ha^{-1})	(kg ha^{-1})	
n	51	51	51	51	51	51	51
Mean	2.6	55.5	40.2	2.48	8	493	18
Std. dev.	1.7	9.0	7.2	0.09	2	195	6
Median	2.0	55.7	41.3	2.48	8	496	16
Min.	1.0	4.4	4.5	2.21	3	132	1
Max.	8.6	68.6	47.8	2.69	12	1031	37

Table 1. Summary of soil texture and nutrient concentrations for 0-20 cm deep soils in the Rapid Creek subbasin study area.

- SOC and N concentrations varied across the subbasin (Figure 2).
- N concentrations ranged from 132 to 1031 kg ha^{-1} and averaged 493 ± 195 kg ha^{-1} in the 51 samples (Table 1). However, N concentrations were biased by a single sample with a concentration approximately an order of magnitude higher than the other samples (1031 kg ha^{-1}). Without this sample, N concentrations averaged 482 kg ha^{-1} and the standard deviation decreased to 182.
- SOC concentrations ranged from 3 to 12 Mg ha^{-1} and averaged 8 ± 2 Mg ha^{-1} (Table 1).
- C/N ratios averaged 18 ± 6 for the individual samples (Table 1). The C/N ratio based on the subbasin SOC and N averages was 16.
- SOC and N concentrations were normally distributed (p<0.05) whereas C/N ratios were not (p>0.05). Minor variations of SOC and N concentrations within the 95% confidence band within a normal distribution were evidently compounded when the concentrations were combined as a C/N ratio (Figure 3).

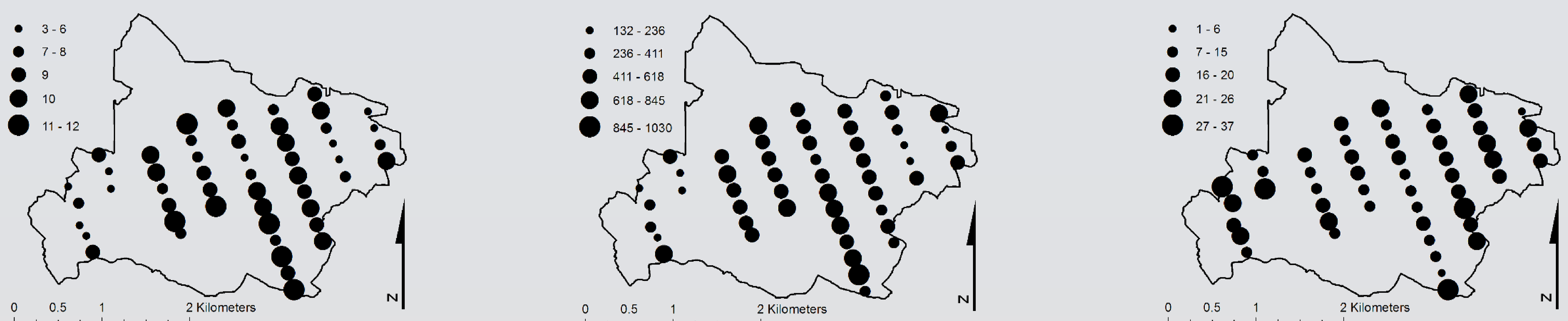
		SOC		C/N ratio		N	
		(Mg ha^{-1})				(Kg ha^{-1})	
Landscape position							
n=3	Headland	9a	+/-2	15	+/-4	626	+/-817
n=6	Shoulder	6b	+/-3	22	+/-3	296	+/-578
n=34	Backslope	8a	+/-2	17	+/-1	805	+/-243
n=8	Toeslope	7ab	+/-3	19	+/-2	426	+/-501
Slope class							
n=4	A	8	+/-1	23	+/-3	371	+/-99
n=27	B	8	+/-1	18	+/-1	516	+/-38
n=17	C	8	+/-1	16	+/-1	506	+/-48
n=3	D	7	+/-1	22	+/-4	377	+/-114

Table 2. Comparison of mean soil organic carbon (SOC) and nitrogen (N) stocks, and C/N ratios organized by landscape position and slope class. Letters report significance (p<0.05).

Slope	SOC	N		Soil series	SOC	N
A	1.49E+03	6.91E+01		Ackmore	3.28E+02	2.23E+01
B	3.01E+03	1.94E+02		Colo-Ely	8.85E+02	8.10E+01
C	1.58E+03	1.00E+02		Downs	6.42E+02	3.53E+01
D	1.30E+02	7.02E+00		Fayette	3.26E+02	1.85E+01
total	6.22E+03	3.71E+02		Tama	3.70E+03	4.00E+02
				total	5.88E+03	5.57E+02

Table 3. Mass (Mg) of soil organic carbon (SOC) and nitrogen (N) for the entire subbasin organized by slope class and soil series.

- Spatially, nutrient concentrations varied across transects and within individual fields (Figure 2).
- We found higher concentrations of SOC and N on the backslope landscape positions while the lowest concentrations were found on shoulders (Table 2).
- No significant differences were identified when SOC comparisons were made by soil slope class. No significant differences were identified when comparing C/N ratios or N among landscape positions or slope class (Table2).
- We estimated the total mass of SOC and N present in the subbasin using bulk density measurements and both slope class and soil series classifications. Both classification schemes provided similar estimates of SOC (Table 3). N stocks were higher when estimated using soil series classifications compared to slope class. Overall, the RPD between quantification methods was approximately 1 and 10 % for SOC and N, respectively.



(A) SOC Mg ha^{-1} (B) N kg ha^{-1} (C) C/N ratio

Figure 2. Spatial nutrient graphs showing distribution of (A) soil organic carbon (SOC) (B) total nitrogen (N) and (C) C/N ratio.

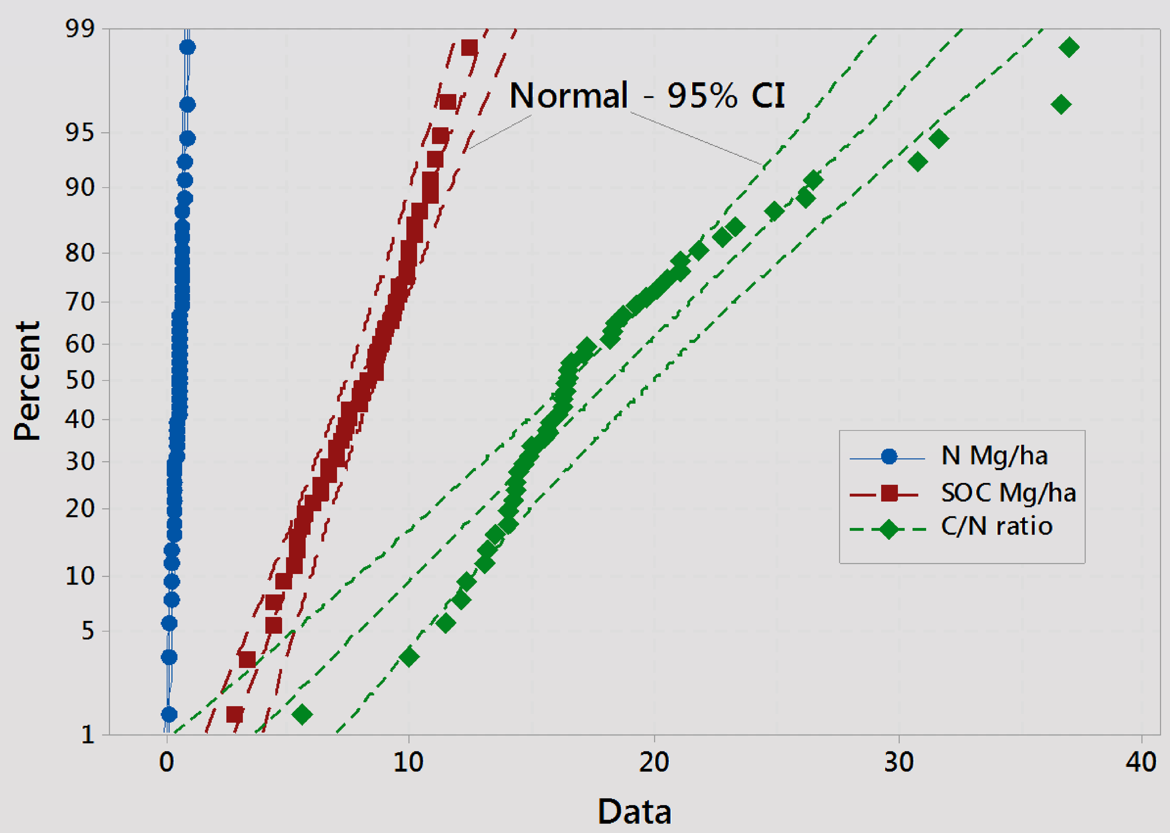


Figure 3. Probability plots for soil organic carbon (SOC), total nitrogen (N), and C/N ratio.

Discussion

- NO_3-N is being lost from the Rapid Creek agricultural row crop system. The goal of this study was to identify spatial patterns and evaluate the water quality risks associated with the surficial soils in the subbasin.
- SOC concentrations exhibited no overt spatial patterns in the watershed.
- Some fields sampled for our study have been previously enrolled in CRP. However, we did not observe any association of higher SOC in soils with CRP history.
- Sampling data indicated that only unstable shoulder positions showed some evidence for lower SOC levels. The lack of significant spatial variability is likely due to the effects of long- and short-term soil erosion processes.

- N concentrations did not show any systematic variations that would suggest potential source areas for NO_3-N loss which suggests that management history and landscape position are not major controls on N within the subbasin.
- In our study, C/N ratio, like SOC and N, was not consistently variable and could not be used to identify areas of greater N leaching threat.
- Identifying stocks of SOC and N is required to better understand the soils ability to buffer the effects of climate change and improve water quality. The similarities of SOC stocks between slope class and soil series provide evidence that both are appropriate for estimating total SOC stocks at a watershed scale.

Implications

- Study results indicate that 1) there is no "hot spot" identifying a row crop field or management practice contributing to greater NO_3-N leaching risk, and 2) a basin-wide solution is needed to reduce NO3-N loss.
- Results from our study emphasize the potentially beneficial use of cover crops or living mulch in the Rapid Creek subbasin to reduce NO_3-N export. Adding C sources would increase the basin-wide soil C/N ratios and reduce the potential for spring nitrification when NO_3-N concentrations in the stream exceed 10 mg l^{-1}. Moreover, the cover crops provide late season N to the soil microbial community and a slow feed of N to the crop. Over time, adding cover crops or other carbon sources serves to build up the SOC pool and increase C/N ratios, thereby lessening potential NO_3-N loss from the row crop agroecosystem.

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