Sediment Delivery and Nutrient Export as Indicators of Soil Sustainability in an Iowa Agricultural Watershed

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Introduction

- Eroded sediment from tilled cropland has a major adverse effect on productivity of soils and greatly affects surface water quality.
- Particulate N and P may constitute approximately 20% and 70% of total N and P in streams.
- Quantifying and tracking soil erosion and sediment N and P export from agricultural watersheds is a key component for evaluating long-term soil sustainability.
- The Revised Universal Soil Loss Equation (RUSLE) estimates gross soil erosion, but does not provide an estimation of the sediment exported from a watershed.
- Sediment delivery ratios (SDRs) are used to correct the estimate of total gross erosion for the fraction that is exported from a watershed.
- Specifically, our study objectives were to 1) evaluate and quantify watershed-scale storage of SOC, N, and P in the top 20 cm (plow layer) of the study area; 2) estimate watershed-scale sediment erosion and delivery; and 3) quantify export of SOC, N, and P to Rapid Creek and assess the long-term soil sustainability of agricultural practices in the watershed.

Methods

- The 780 ha subbasin is located in the northern portion of the 88 km^2 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).

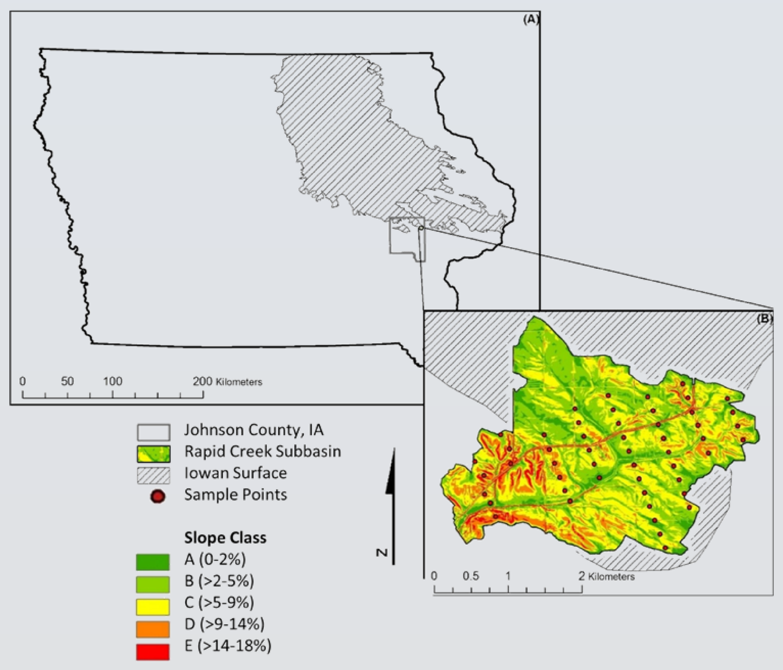


Figure 1. Location map of the Iowan Surface landform region (A) and the Rapid Creek subbasin with slope classes and sample points (B).

- 51 sites were sampled along 8 transects.
- Soil samples, 20 cm deep, were collected at each location approximately 30 days after planting in 2015.
- Bulk density was determined at 2 depths (5-10 cm and 15-20 cm).
- SOC and total N were determined by elemental analysis.
- Watershed-scale storage of SOC, N, and P was estimated based on the determined percent by mass and mean bulk density of the plow layer.
- We compiled high-frequency stream data as daily average stage (Figure 2) and converted it to daily discharge.
- Turbidity was measured at a bridge sensor and converted to TSS based on a relationship created at a nearby site.
- Sediment delivery from the subbasin to Rapid Creek was calculated by comparing the exported mass of sediment and nutrients to their watershed-scale erosion rates estimated using the RUSLE model.

Results

	Sand (%)	Silt (%)	Clay (%)	BD (g cm^{-3})	SOC (Mg ha^{-1})	N (Mg ha^{-1})
n	51	51	51	51	51	51
Mean	2.6	55.5	40.2	1.26	40	2.50
Std. dev.	1.7	9.0	7.2	0.08	11	0.99
Median	2.0	55.7	41.3	1.27	42	2.51
Min.	1.0	4.4	4.5	1.03	14	0.69
Max.	8.6	68.6	47.8	1.45	64	5.12

Table 1. Summary of soil texture and nutrient concentrations for 0-20 cm deep soils.

Slope class		SOC		N		SOC	N
		(Mg ha^{-1})		(Mg ha^{-1})		(Mg)	(Mg)
n=4	A	38	+/-2	2.35	+/-134	3.28E+03	2.03E+02
n=13	B	40	+/-1	2.54	+/-83	1.19E+04	7.44E+02
n=26	C	42	+/-1	2.58	+/-98	1.20E+04	7.35E+02
n=6	D	39	+/-1	2.56	+/-125	3.38E+03	2.24E+02
n=2	E	25	+/-2	1.33	+/-50	7.06E+02	3.70E+01
Total						3.12E+04	1.94E+03

Table 2. Comparison of mean SOC and N stocks organized by slope class and Mass (Mg) for the entire subbasin.

	Turbidity	TSS	Discharge
	NTU	(mg l^{-1})	(cf s^{-1})
n	230	230	230
Mean	43	90	3
Std. dev.	48	104	3
Median	19	39	2
Min	6	10	1
Max	298	643	35

Table 3. Summary of turbidity, TSS, and discharge values.

	SOC	N	P
	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})
Mean erosion	121	7.54	5.31
Mean export	5	0.28	0.20
Mean storage	40000	2500.00	1790.00
% of total exported	0.01	0.01	0.01

Table 4. Mean nutrient erosion and export compared to storage.

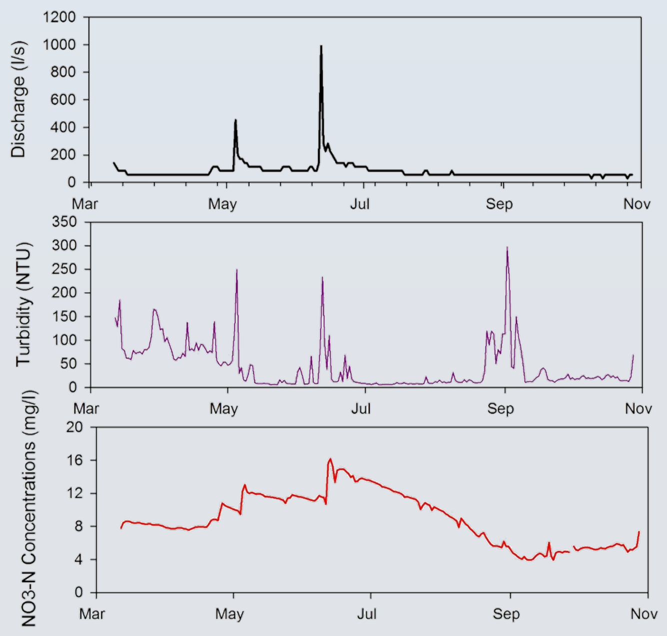


Figure 2. Continuous monitoring data collected in 2015.

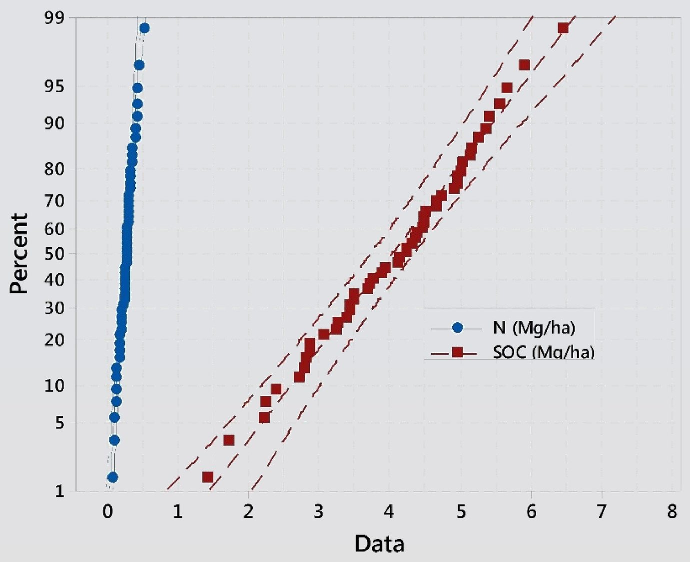


Figure 4. Probability plots (Normal -95% CI) for SOC and N.

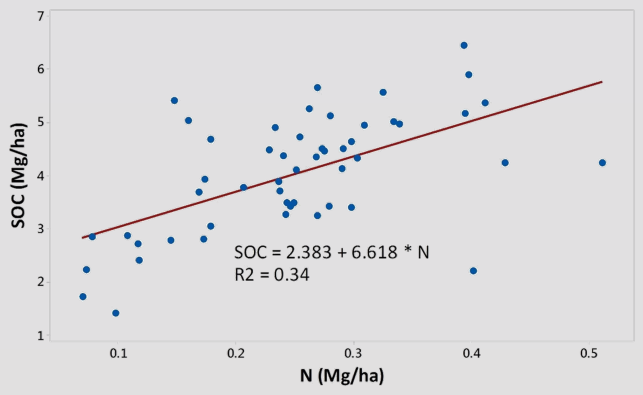


Figure 5. Relation of SOC Mg ha-1 to N Mg ha-1.

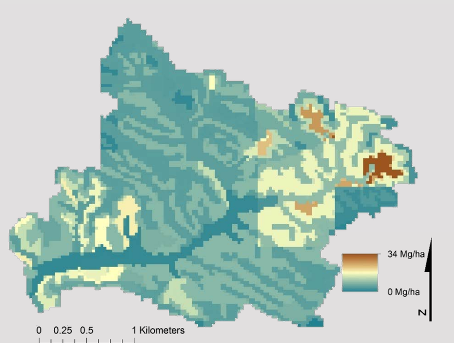
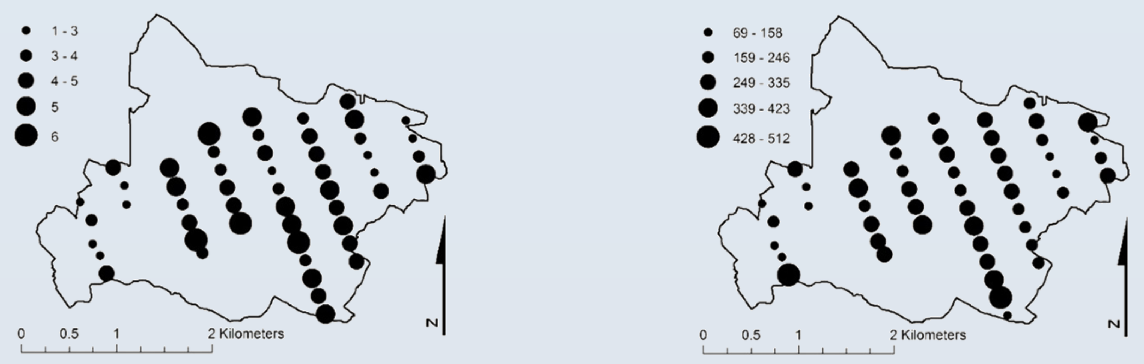


Figure 6. Erosion determined by RUSLE (30 m grid size).



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

Figure 3. Distribution of (A) SOC and (B) N.

- Soil texture was uniform across the subbasin (Table 1).
- Bulk density did not vary significantly and averaged 1.26 g cm^{-3}.
- Total SOC and N concentrations varied across the subbasin (Fig. 3).
- SOC and N concentrations were normally distributed (Fig. 4).
- SOC and N concentrations were positively correlated in subbasin soils ($P<0.0001$) (Fig. 5).
- We estimated the total mass of SOC and N to be 3.12 x 10^4 and 1.94 x 10^3 Mg, respectively (Table 2).
- P storage was estimated by using regional average concentrations (0.07% by mass) and determined to be approximately 1.79 Mg ha^{-1} or 1.39 x 10^3 Mg overall.
- Approximately 7.5 Mg ha^{-1} of soil was eroded in 2015 totaling 5227 Mg (Fig. 6).
- Daily turbidity averaged 43 NTU (Table 3).
- Approximately 193.6 Mg (279 kg ha^{-1}) of sediment was exported from the subbasin in 2015.
- The SDR for the subbasin was estimated to be 3.7%.
- Annual export of SOC was estimated to be 5 kg ha^{-1} which represented approximately 0.01% of the total storage of SOC in the subbasin.
- Particulate N and P export were determined to be 0.28 and 0.20 kg ha^{-1}, respectively (Table 4).
- Particulate N accounted for 1.4% of N in the stream.
- Particulate P accounted for 40% of P in the stream.

Discussion

- Varying reduced tillage and rotation management strategies appeared to have no effect on overall SOC concentrations in surficial soils.
- N concentrations exhibited a normal distribution and did not show any systematic field by field variations that would suggest potential source areas for NO_3-N loss.
- Approximately 31200 Mg (45 Mg ha^{-1}) of SOC are present in the plow layer of our study area.
- We estimate that approximately 1940 Mg of N (2.79 Mg ha^{-1}) are present in the plow layer of our study site.
- We estimated total P storage to be approximately 1390 Mg (1.79 Mg ha^{-1}).
- Erosion estimates based on RUSLE (7.5 Mg ha^{-1}) was less than the accepted "sustainable" rate of soil erosion set at 11.2 Mg ha^{-1}.
- We estimated that 279 kg ha^{-1} of sediment was exported from the subbasin in 2015. By comparing this value to the total soil erosion based on RUSLE, we determined the sediment delivery to Rapid Creek in 2015 be 3.7% of the total soil erosion.
- This SDR is lower compared to estimates of approximately 12% for typical Iowan Surface watersheds of the same size.
- Study results suggest that previous estimates of SDRs for the Iowan surface may be overestimating actual SDRs. This is consistent with increases in modern BMPs that work to reduce sediment and particulate nutrient export.
- Recent research suggests that ratios of sediment residence time to rainfall duration is the primary control for sediment delivery rates. This is not a significant factor in the 1998 USDA estimation, which focuses primarily on watershed size, shape, and drainage network length .
- The total yearly loss of SOC, N, and P due to erosion was estimated to be approximately 0.01% of the total plow layer storage for each.
- We estimated that only 1.4% of N export to Rapid Creek is in the form of particulate N delivered by erosion processes. This is significantly lower than previous studies which suggest that up to 20% of N export may be due to soil erosion.
- P export was lower than other study estimates (40% compared to 70%).

Implications

- In many areas, soil development has stagnated and improvements to soil health are not likely to occur under present conditions.
- In Rapid Creek, existing BMPs are reducing nutrient export to stream water but more effort is needed to establish BMPs in the study area which will reduce both non-particulate and particulate nutrient export.
- Implementation of a cover crop further reduces soil erosion thereby reducing particulate nutrient export and increases nutrient holding capacity as well as water holding capacity in the soil which reduces dissolved nutrient concentrations.
- Ultimately, agroecosystems that make better use of short- and long-term C and N pools will be more productive and environmentally sustainable.

References

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