Soil Organic Carbon in fields of switchgrass and row crops as well as woodlots and pastures across the Chariton Valley, Iowa

Final Report

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Abstract

We sought to establish soil carbon contents at the field level in the Chariton Valley with this study. Four land uses were of special interest: switchgrass fields, row cropped fields, woodlots, and pastures. The study was broken into two projects with one project focused primarily on switchgrass and the other on pastures. Field methods entailed transect sampling of 224 soil pedons from 23 fields. Our data show soil organic carbon (SOC) content to range from 5.4 to 26.8 kg m^{-2} m^{-1} and the overall mean and standard deviation being 11.8±3.9 kg m^{-2} m^{-1}. We found SOC content varies in a systematic manner across landscapes with maximum contents nearly consistently being found in toeslopes and minimum contents being found in backslopes. SOC content is also generally proportionally distributed in pedons with the top 0.2 m containing about ½ of the SOC found to a 1 m depth and the top 0.5 m containing about ¾ of the SOC found to 1 m depth. SOC content varies with land use with pastures generally having highest contents and younger switchgrass fields and row crop fields having the least.

We found SOC sequestration does occur in a manner proportional to age of perennial vegetation stand. When sequestration rate is calculated for only three to 14 year old switchgrass fields (i.e., CRP-type fields), we found an annual rate of 343 g m^{-2} m^{-1} SOC gain, which is equal to 1.5 tons per acre (to a 40 inch) depth or about 0.75 tons per acre (to a 10 inch) depth. We found SOC contents within pastures is proportional to quality of pasture management with soils from high quality pastures averaging 14.1 kg m^{-2} m^{-1} and soils from poor quality pastures averaging 11.8 kg m^{-2} m^{-1}. We also determined an overall rate of SOC sequestration in pastures to be 40 g m^{-2} m^{-1} yr^{-1}. Unfortunately, rates of SOC sequestration

specific to each level of pasture quality could not be ascertained because of the confounding effect of pasture quality and age of stands.

Introduction

Knowing how much soil organic carbon (SOC) exists in a field is a simple, pragmatic and important fact needed in the carbon sequestration arena. Yet, significant uncertainty routinely exists about that value. Difficulties arise in ascertaining field scale carbon contents because of questions about spatial variability of soils within individual fields as well as about the long-term impact of various land use practices. In turn, the uncertainty that exists for individual fields translates into uncertainty for watersheds and other larger geographic units.

This study used pedological principles as the framework to quantitatively establish soil carbon contents at the field level in the Chariton River watershed (Figure 1). Three basic relationships were examined individually and collectively: (a) soil carbon content vis-à-vis landscape properties, (b) soil carbon content as it relates to land use history, and (c) soil carbon content vis-à-vis soil morphology. More specifically this study addressed four hypotheses:

Hypothesis 1: SOC sequestration potential can be predicted using soil map unit attributes such as landscape position.

Hypothesis 2: Rates of SOC sequestration in a field or within a soil map unit or landscape position are dependent upon current and past land management.

Hypothesis 3: Maximum SOC sequestration in the Chariton Valley occurs in lands having well managed mature stands of switchgrass (*Panicum virgatum*, L.)

Hypothesis 4: Within pastures, sequestered SOC is proportional to management quality.

The Chariton River Watershed was selected for this study because of complementary research projects in biofuel production as well as soil and water quality (e.g., see Chariton Valley RC&D, 2002; Lemus, 2000; Molstad, 2001).

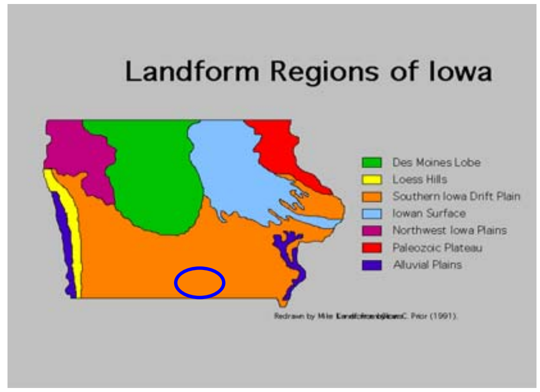

Figure 1a: Map showing major streams and general area of study (circle) in Iowa.	Figure 1 b: Map showing major land use regions.

The Chariton River watershed is a small part (3,000 km^2) of the southern Iowa drift plain, which is a land region that extends across 60,000 km^2 of southern Iowa as well as northern Missouri and eastern Nebraska and Kansas (Prior, 1991; EPA, 2000). Its landscape is characterized by rolling uplands and occasional broad alluvial plains. The dissected uplands are a product of thin Peoria loess mantling an otherwise highly weathered ancient landscape consisting of Yarmouth-Sangamon paleosols and pre-Illinioan tills. The lengthy and complex glacial and climatic history resulted in areas of prairie, forest, and savanna being present at the time of European-style settlement. These factors also resulted in a tremendous number of soil series in the watershed. A few of these include the Seymour, Edina, Clarinda, Shelby and Adair series (Iowa Ag. Home Ec. Station, 1978). Most upland pedons are Mollisols and Alfisols. Common features of the upland soil series in the watershed include being poorly drained and having "vertic" characteristics (Molstad, 2000; also see the respective NRCS soil surveys for the counties). Most alluvial soils are also Mollisols although they tend to be somewhat coarser textured and better drained than their contiguous upland counterparts. Diversified farming has been the norm in the Chariton River watershed since around 1860. Common crops during the late 20th century were corn (*Zea mays*), soybeans (*Glycine max*), a variety of cool season forages and pasture species, and woodlots. The main limitations to crop production are steep, erosive landscapes, clayey soils that alternate between being too wet and too dry, and acidic subsoils. These limitations resulted in a large proportion of the watershed being enrolled in the Conservation Reserve Program (CRP), with corresponding areas being planted to switchgrass (*Panicum virgatum*).

Materials & Methods

This report entails two field projects. In the first and larger component we examined the relationship between SOC, landscapes, and a variety of land uses. We will refer hereafter to it as the primary project. Field sampling for it began in the summer of 1999 and ended in 2000. Laboratory analyses continued well into 2001. The second component examined SOC across landscapes and soils only in pastures. We will refer hereafter to it as the pasture project. Field sampling for it began in 2000 and ended in 2001, with a few laboratory analyses still ongoing.

The experimental design for the primary project is a random complete block with empty cells. For the purpose of this study, blocks are referred to as "clusters," which are named after towns (Table 1). There are five clusters, with a complete cluster consisting of six fields: (a) "old" switchgrass, (b) "medium-aged" switchgrass, (c) "young" switchgrass, (d) row-cropped field, (e) pasture, and (f) woodlots. "Old," "medium" and "young" refer to fields where switchgrass was grown for between 14 and 26 years, five to nine years, and less than four years, respectively. The fields identified as row-cropped, pasture, and woodlots have had been so used for at least two years, with 20 or more years being more typical. All land use histories and ages of fields are based upon self-reporting by the farmers who manage the fields.

A total of 22 fields were sampled for the primary project. Nineteen fields are on uplands, and three are in alluvial settings. Each field was sampled along a transect that typically has about 10 sampling points. Upland transects begin on a summit and run down a nose to a toeslope position with sampling points evenly spaced (Figure 2). The sampling unit was the pedon, which was collected via soil coring with a truck mounted hydraulic probe. Sampling points were recorded to within 1 m using GPS and standard surveying techniques. Additionally,

Table 1: Cluster names and approximate locations of fields used to evaluate SOC sequestration across the Chariton River watershed. Data from fields with “X” were not used herein because of skewed transects.

Cluster ⇒ **Land Use ⇓**	**Iconium**	**Clio**	**Corydon**	**Norwood**	**Alluvium**
SWG-10	S. 4, T70N, R28W CV RC&D	S. 30, T68N, R22W J. Mason	S. 25, T69N, R22W, Wayne Co. C.	S. 23, T73N, R23W J.Osenbaugh	S. 27, T73N, R23W G. Chandler
SWG-6	S. 4, T70N, R18W CV RC&D	S. 2, T68N, R22W R. Blount	S. 25, T69N, R21W R. Bennett	S. 12, T71N, R21W J. Arnold	S. 27, T73N, R23W K. Fransico
SWG-3	S. 33, T70N, R18W R. Mitchell	S. 11, T67N, R20W H. Stags		S. 3, T72N, R20W J. Wright	
CS rotation		S. 14, T68N, R21W R. Alshouse	S. 5, T69N, R22W D. Petty	S. 23, T73N, R21W R. Edwards	S. 15, T73N, R23W K. Kent
Pasture		S. 24, T68N, R23W C. Neill	S. 25, T69N, R22W D. Bellon	S. 36, T73N, R21W G. Rosa, Sr.	
Woodlot			S. 25, T69N, R22W Corydon Lake	S. 30, T73N, R21W Will. Pond	

SWG –10, SWG-6 & SWG-3 = switchgrass fields of approximately 10, 6 and 3 years age, respectively. CS = corn-soybean

landscape characteristics of each sampling point were noted using the terminology of Schoeneberger et al. (1998). Core depth and diameter were 1.2 m and 0.05 m, respectively, although soil carbon content was measured by horizon and then determined for 0.2, 0.5, and 1.0 m depths. A total of 212 pedons were collected and described using a standard morphological form (excepting soil structure). As we subsequently re-examined our field sites, we eliminated three upland transects (marked with gray x’s in Table 1) from this discussion because our sampling line was skewed in an acute angle off the noseslopes. These data will be used as appropriate in subsequent manuscripts focusing on soil series.

Each horizon described was sampled, dried, ground to pass through a 2-mm sieve. Each sample was analyzed for bulk density, total organic carbon content, pH, chroma-meter color, and stable aggregate content.

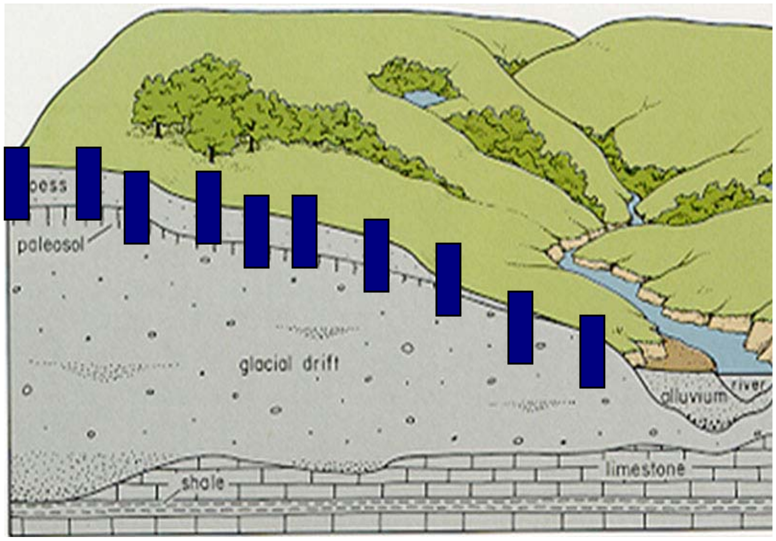

Figure 2: Cross-section showing a typical landscape and soil parent materials for the Southern Iowa Drift Plain, to which the Chariton Valley belongs. Idealized sampling sites shown with bars. (background figure from Prior, 1991).

The pasture project examined seven pastures of varying quality (Table 2). It used the same transect approach as the primary project as well as the same laboratory analyses. In addition, three of the seven pastures studied were ones sampled in the primary project. Pasture quality was established via sward inspections using two independent expert opinions. The evaluators were John Sellers and Roger Hintz. Once data analysis was well underway we learned that pasture 5 (Table 2) was formerly used as a feedlot. Thus, it was removed from this discussion. Re-evaluation of the seven pastures will occur in 2002 using a variety of approaches in order to both validate the current evaluations as well as to compare ease of use of different methodologies in pasture evaluations. A total of 75 pedons were sampled, described and analyzed with about 65 of those pedons being discussed herein.

Table 2. Pasture locations and quality (where pasture ranked 1 is best and 7 is worst).

Pasture Rank	1	2	3	4	5	6	7
Pasture location ⇒	Sec 9, T71N, R22W	Sec 8, T71N, R22W	Sec 20, T70N, R21W	Sec 36, T73, R21W	~~Sec 24, T68N, R23W~~	Sec 31, T70N, R21W	Sec 25, T69N, R22W

Results and Discussion

Carbon Content

The individual pedon carbon content (wt/vol) ranges from 5.4 to 26.8 kg m^{-2} m^{-1} (Table 3). The overall mean and standard deviation of all 224 pedons are 11.8±3.9 kg m^{-2} m^{-1}, respectively, with the upland and alluvial pedons having means and standard deviations of 11.4±3.3 kg m^{-2} m^{-1} (n = 200) and 15.5±5.7 kg m^{-2} m^{-1} (n = 24), respectively (Table 4). Factors of 10 and 4.4517 convert kg SOC m^{-2} m^{-1} soil to Mg SOC ha^{-1}-m^{-1} and tons SOC per acre-40 inches, respectively. Thus, the overall average of 11.8 kg m^{-2} m^{-1} SOC content correspond with 118 Mg SOC per hectare soil or 52.5 tons SOC per acre-40 inches. On average these 224 pedons contain 46% of their SOC is in the top 0.2 m. They contain 75% of their SOC in the top 0.5 m on average.

Table 3: SOC data for pedons collected for the primary project. All SOC data reported as grams SOC per square meter of land area to the depth specified.

Pedon No.	Grams of Soil Organic Carbon			Soil Survey		Crop at time of sampling	Duration of that crop (years)	Landscape Position
	Per 1m^2 – 1.0 m depth	Per 1m^2 – 0.5 m depth	Per 1m^2 – 0.2 m depth	Map Unit	Series Name			1 = summit 9 = toeslope >10 = alluvium
1	14204.06	11895.62	8101.502	220	Nodaway	Switchgrass	9	11
2	8897.146	6249.368	4163.186	220	Nodaway	Switchgrass	9	11
3	7976.359	5562.981	3885.379	220	Nodaway	Switchgrass	9	13
4	9414.712	7420.055	3783.918	220	Nodaway	Switchgrass	9	13
5	20960.45	10610.42	5357.136	273B	Olmitz	Switchgrass	8	17
6	19270.54	9731.857	4630.161	273B	Olmitz	Switchgrass	8	17
7	19994.82	11447.52	5936.932	273B	Olmitz	Switchgrass	8	17
8	19441.21	8636.983	3322.772	51+	Vesser	Switchgrass	8	17
9	22072.91	8483.302	3902.741	51+	Vesser	Switchgrass	8	17
10	18885.94	6349.095	3725.822	430	Ackmore	Switchgrass	8	17
11	16240.9	7430.389	4006.658	430	Ackmore	Switchgrass	8	17
12	19356.74	7411.564	2970.777	430	Ackmore	Switchgrass	8	17
13	20913.05	8526.017	3832.903	587+	Chequest	Switchgrass	8	17
14	26835.27	11194.57	4549.248	587+	Chequest	Switchgrass	8	17
15	17589.54	13316.36	9412.429	362	Haig	Switchgrass	8	1
16	13604.83	9994.057	5983.56	362	Haig	Switchgrass	8	1
17	9891.416	7883.775	4726.141	362	Haig	Switchgrass	8	3
18	10403.34	8253.336	4589.861	364B	Grundy	Switchgrass	8	5
19	10834.09	8804.856	5390.971	364B	Grundy	Switchgrass	8	5
20	10585.13	8359.093	4468.88	222C2	Clarinda	Switchgrass	8	5
21	7544.371	5213.163	2755.852	222C2	Clarinda	Switchgrass	8	5
22	7556.881	5493.912	2967.559	222C2	Clarinda	Switchgrass	8	5
23	7035.338	5755.006	2988.893	222C2	Clarinda	Switchgrass	8	7

24	10065.79	7940.007	4639.139	822D2	Lamoni	Switchgrass	8	7
25	12188.68	8655.177	5049.652	Ed	Edina	Switchgrass	26	1
26	10411.2	7194.399	4331.509	Ed	Edina	Switchgrass	26	1
27	9911.648	6424.676	4432.569	SeB	Seymour	Switchgrass	26	3
28	9406.486	7795.028	4543.523	SeB	Seymour	Switchgrass	26	5
29	9016.772	7229.597	4809.319	SfC	Seymour	Switchgrass	26	5
30	9048.385	7153.944	4277.464	SfC	Seymour	Switchgrass	26	5
31	10757.19	8587.702	5064.402	AaC2	Adair	Switchgrass	26	5
32	8904.321	6985.612	4930.347	AaC2	Adair	Switchgrass	26	5
33	9357.042	7898.381	5249.507	AaC2	Adair	Switchgrass	26	7
34	10120.12	7757.957	4951.921	SoD3	Shelby	Switchgrass	26	7
35	10856.7	8220.081	4752.838	SoD3	Shelby	Switchgrass	26	9
36	15881.92	11643.02	5795.541	LaD2	Lamoni	Switchgrass	14	7
37	11946.48	9085.054	5301.946	SeB	Seymour	Switchgrass	14	1
38	12313.23	9817.478	5779.448	SeB	Seymour	Switchgrass	14	1
39	14380.67	11288.37	8041.679	SeB	Seymour	Switchgrass	14	3
40	12152.6	9410.909	6529.902	SfC	Seymour	Switchgrass	14	3
41	12948.65	9513.252	5596.122	SfC	Seymour	Switchgrass	14	5
42	13874.78	9870.873	6841.93	ClC2	Clarinda	Switchgrass	14	5
43	13452.11	10211.64	7085.537	ClC2	Clarinda	Switchgrass	14	5
44	14702.05	11370.02	6506.694	ClC2	Clarinda	Switchgrass	14	5
45	10185.48	7822.84	4355.386	LaD2	Lamoni	Switchgrass	14	5
56	10142.37	7978.919	4929.423	131B	Pershing	Switchgrass	3	1
57	8429.527	6101.613	3744.074	131B	Pershing	Switchgrass	3	1
58	10768.9	8582.801	6043.987	131C2	Pershing	Switchgrass	3	1
59	9189.92	6609.464	4371.142	131C2	Pershing	Switchgrass	3	1
60	9382.605	6343.18	4201.423	131C2	Pershing	Switchgrass	3	3
61	8939.786	5767.607	3837.21	131B	Pershing	Switchgrass	3	3
62	8560.084	6256.681	4374.382	131B	Pershing	Switchgrass	3	5
63	7461.685	5565.866	4008.273	131C2	Pershing	Switchgrass	3	5
64	7418.537	5975.707	4079.237	131C2	Pershing	Switchgrass	3	5
65	8230.228	6625.449	4751.279	131C2	Pershing	Switchgrass	3	7
66	10011.71	7939.834	4008.816	131C2	Pershing	Switchgrass	3	9
75	11397.71	8595.439	3974.5	211	Edina	Switchgrass	4	1
76	10821.84	8006.371	4876.176	211	Edina	Switchgrass	4	1
77	8170.972	6312.89	3487.302	211	Edina	Switchgrass	4	3
78	9444.511	6675.978	3337.087	211	Edina	Switchgrass	4	3
79	8605.48	7190.335	4768.624	312B	Seymour	Switchgrass	4	5
80	8535.905	6852.531	3934.968	312B	Seymour	Switchgrass	4	5
81	7027.048	5403.01	3049.588	312B	Seymour	Switchgrass	4	5
82	6620.753	5338.85	3180.312	222C2	Clarinda	Switchgrass	4	5
83	7336.869	5617.012	3305.779	222C2	Clarinda	Switchgrass	4	5
84	6304.788	5074.756	2722.85	93D2	Adair-Shelby	Switchgrass	4	7
85	24266.2	13329.81	6309.2	CoB	Colo	Soybeans	20	7
86	9701.533	8641.127	5417.14	SoD3	Shelby	Soybeans	20	5
87	6103.675	5758.18	3751.143	SoD3	Shelby	Soybeans	20	5
88	6598.154	6142.586	4096.051	SoD3	Shelby	Soybeans	20	5
89	8306.026	5840.281	4179.05	AaC2	Adair	Soybeans	20	5
90	12617.12	10426.73	6252.029	AaC2	Adair	Soybeans	20	5

91	8958.489	6909.626	3920.746	AaC2	Adair	Soybeans	20	3
92	10846.92	8668.287	5068.298	AaC2	Adair	Soybeans	20	3
93	10119.21	8163.971	5192.298	SfC	Seymour	Soybeans	20	3
94	8860.549	7052.892	4392.093	SeB	Seymour	Soybeans	20	1
95	12227.46	8668.717	5751.845	SeB	Seymour	Switchgrass	1	1
96	11074.91	7256.951	2923.461	SeB	Seymour	Switchgrass	1	1
97	10044.26	7547.228	3314.112	SeB	Seymour	Switchgrass	1	1
98	11458.61	8788.22	5887.312	SeB	Seymour	Switchgrass	1	3
99	11881.5	9646.588	6700.953	SfC	Seymour	Switchgrass	1	3
100	11643.54	9436.089	5469.642	SfC	Seymour	Switchgrass	1	5
101	10873.94	8457.499	5547.183	SfC	Seymour	Switchgrass	1	5
102	12220.05	9194.829	6202.029	ClD2	Clarinda	Switchgrass	1	5
103	13320.83	9374.102	5553.751	ClD2	Clarinda	Switchgrass	1	5
104	15151.61	10879.28	6525.624	ClD2	Clarinda	Switchgrass	1	5
105	12415.43	9960.358	5738.55	SfC	Seymour	Switchgrass	5	1
106	9531.342	7747.297	4391.803	SfC	Seymour	Switchgrass	5	1
107	12869.93	10864.05	7421.188	SfC	Seymour	Switchgrass	5	1
108	11799.69	9192.42	5819.836	CmC3	Clarinda	Switchgrass	5	3
109	11185.34	9063.544	5514.457	CmC3	Clarinda	Switchgrass	5	3
110	9706.12	7975.471	4989.989	CmC3	Clarinda	Switchgrass	5	5
111	10326.41	8137.518	5657.002	CmC3	Clarinda	Switchgrass	5	5
112	7739.938	5995.801	3608.328	CmC3	Clarinda	Switchgrass	5	5
113	7167.603	5446.862	3655.611	OvB	Olmitz-Vesser-Colo	Switchgrass	5	5
114	5354.838	5354.838	3954.236	OvB	Olmitz-Vesser-Colo	Switchgrass	5	7
126	12126.86	9485.904	5936.532	Ed	Edina	Pasture	2	1
127	12389.12	9770.434	7222.731	SeB	Seymour	Pasture	2	3
128	12268.01	9860.087	7469.304	SeB	Seymour	Pasture	2	5
129	12045.06	9146.114	5881.506	SfC2	Seymour	Pasture	2	5
130	10248.32	8024.746	4950.734	SfC2	Seymour	Pasture	2	5
131	10873.07	8332.896	4479.842	ClC2	Clarinda	Pasture	2	5
132	9164.809	7382.558	4653.696	ClC2	Clarinda	Pasture	2	5
133	8954.407	7077.449	4312.937	ShD2	Shelby	Pasture	2	7
134	12130.29	10296.05	8044.012	ShD2	Shelby	Pasture	2	7
135	11510.7	9447.597	7877.002	OvB	Olmitz-Vesser-Colo	Pasture	2	9
136	10670.44	8110.705	4099.214	SfC	Seymour	Woodlot	70	3
137	12800.46	9306.466	4804.965	AaC3	Adair	Woodlot	70	3
138	13610.28	9901.343	3633.285	AaC4	Adair	Woodlot	70	5
139	11861.91	8901.391	5304.361	AaC4	Adair	Woodlot	70	5
140	14100.32	11137.29	5914.215	AaC4	Adair	Woodlot	70	5
141	11685.15	8631.886	5151.93	ShD2	Shelby	Woodlot	70	5
142	11565.05	9463.401	6024.87	ShD2	Shelby	Woodlot	70	5
143	6926.158	5458.565	3342.491	ShD2	Shelby	Woodlot	70	5
144	7431.862	6278.987	4203.528	ShD2	Shelby	Woodlot	70	5
145	7003.621	6601.657	4408.264	ShD2	Shelby	Woodlot	70	5
146	7673.521	6152.29	3907.091	179D2	Gara	Corn	10	15
147	9027.712	7238.124	4510.021	179D2	Gara	Corn	10	15
148	8247.643	6065.169	3264.316	179D2	Gara	Corn	10	15
149	11301.8	8751.217	5737.489	179D2	Gara	Corn	10	15

150	10740.17	8974.885	5461.176	23C	Arispe	Corn	10	15
151	10340.47	8535.377	5021.548	23C	Arispe	Corn	10	15
152	15455.19	10542.43	5209.071	23C	Arispe	Corn	10	15
153	14765.47	11072.75	8702.707	23C	Arispe	Corn	10	17
154	16024.22	12078.17	5822.349	54+	Zook	Corn	10	17
155	24236.83	13130.18	5354.879	54+	Zook	Corn	10	17
156	10046.12	8128.129	4985.219	SfC	Seymour	Switchgrass	14	3
157	10711.57	8628.322	5188.929	SfC	Seymour	Switchgrass	14	7
158	10035.37	7584.873	4794.879	SfC	Seymour	Switchgrass	14	3
159	10237.84	8176.274	4982.849	ClC2	Clarinda	Switchgrass	14	5
160	9007.366	7338.312	4478.585	ClC2	Clarinda	Switchgrass	14	5
161	8267.536	6292.836	3948.391	ClC2	Clarinda	Switchgrass	14	5
162	9427.868	7551.424	4338.802	LaD2	Lamoni	Switchgrass	14	7
163	9840.459	7901.372	4938.465	LaD2	Lamoni	Switchgrass	14	7
164	17575.01	12505.05	10046.22	LaD2	Lamoni	Switchgrass	14	9
165	22290.51	13564.26	7851.065	OvB	Olmitz-Vesser-Colo	Switchgrass	14	9
166	12068.25	9850.694	7294.496	792C2	Armstrong	Switchgrass	19	3
167	11092.43	8888.991	5039.261	792C2	Armstrong	Switchgrass	19	3
168	11216.29	8685.557	5062.382	179E2	Gara	Switchgrass	19	5
169	9018.558	6861.557	4060.846	13B	Olmitz-Vesser-Colo	Switchgrass	19	5
170	9920.906	7800.077	4384.237	179E2	Gara	Switchgrass	19	5
171	12370.71	9531.018	5129.601	179E2	Gara	Switchgrass	19	5
172	10846.4	8346.9	4602.834	179E2	Gara	Switchgrass	19	5
173	12033.56	9170.576	5347.743	13B	Olmitz-Vesser-Colo	Switchgrass	19	5
174	9417.7	7077.979	4142.868	13B	Olmitz-Vesser-Colo	Switchgrass	19	5
175	8387.561	6264.753	4043.631	13B	Olmitz-Vesser-Colo	Switchgrass	19	5
176	12571.05	9903.105	7483.705	SeB	Seymour	Corn	15	1
177	9694.244	7498.619	4791.958	SeB	Seymour	Corn	15	1
178	9156.865	7339.883	4493.438	SfC	Seymour	Corn	15	3
179	8866.483	7154.973	3873.104	SfC	Seymour	Corn	15	5
180	7623.908	6050.887	3811.967	ClC2	Clarinda	Corn	15	5
181	6518.031	5458.562	3767.687	ClC2	Clarinda	Corn	15	5
182	7313.41	5827.583	4015.614	ShD2	Shelby	Corn	15	3
183	6765.988	5751.753	3633.612	ShD2	Shelby	Corn	15	3
184	5574.028	5099.688	3498.214	ShD2	Shelby	Corn	15	5
185	10555.28	8613.374	5680.769	ShD2	Shelby	Corn	15	7
186	15952.63	11584.13	5799.677	OvB	Olmitz-Vesser-Colo	Corn	15	9
187	10286.55	8962.485	5059.453	364B	Grundy	Woodlot	50	1
188	11968.92	10201.7	6781.779	131C2	Pershing	Woodlot	50	3
189	8675.292	6923.206	4025.715	131C2	Pershing	Woodlot	50	5
190	10446.37	9232.285	6623.356	131C2	Pershing	Woodlot	50	5
191	12324.09	11548.22	8090.582	792D2	Armstrong	Woodlot	50	7
192	12624.36	11052.9	7205.421	792D2	Armstrong	Woodlot	50	3
193	17927.74	13565.69	6312.634	179E2	Gara	Woodlot	50	7
194	21806.23	15616.33	8700.908	179E2	Gara	Woodlot	50	7
195	14660.45	10742.38	7476.3	364B	Grundy	Pasture	50	1

196	11587.38	9034.391	5289.479	364B	Grundy	Pasture	50	1
197	10670.99	8482.217	5857.057	364B	Grundy	Pasture	50	1
198	13534.17	10887.23	7801.286	364B	Grundy	Pasture	50	1
199	11252.98	8982.232	5127.64	23C	Arispe	Pasture	50	1
200	11752.5	9737.832	6863.351	23C	Arispe	Pasture	50	3
201	7449.477	5864.32	3858.007	23C	Arispe	Pasture	50	3
202	7875.325	6160.324	4139.039	222C2	Clarinda	Pasture	50	5
203	8147.354	6858.359	4416.806	222C2	Clarinda	Pasture	50	5
204	17652.59	12614.14	6261.153	13B	Zook-Olmitz-Vesser	Pasture	50	7
205	13795.74	10388.29	4966.455	362	Haig	Corn	17	1
206	11158.87	8402.597	5741.985	362	Haig	Corn	17	1
207	11328.21	8410.575	4213.996	362	Haig	Corn	17	1
208	9701.887	7451.338	2781.964	362	Haig	Corn	17	3
209	10696.33	8669.612	5212.144	364B	Grundy	Corn	17	3
210	8240.603	6733.65	4367.845	364B	Grundy	Corn	17	5
211	8365.23	6372.183	4264.814	364B	Grundy	Corn	17	5
212	8782.943	6783.361	4057.851	364B	Grundy	Corn	17	5
213	9488.877	7680.193	4969.673	131C	Pershing	Corn	17	7
P1	16654.81	13880.77	8056.426	364B	Grundy	Pasture	75	1
P2	16537.85	13788.85	11453.49	23C2	Arsipe	Pasture	75	1
P3	15164.93	12576.99	8066.272	23C2	Arsipe	Pasture	75	1
P4	16517.9	13764.77	10790.7	23C2	Arsipe	Pasture	75	2
P5	14621.04	12340.9	7973.567	23C2	Arsipe	Pasture	75	3
P6	11307.01	9336.259	6351.019	822C2	Lamoni	Pasture	75	5
P7	10648.71	9129.183	6370.823	822C2	Lamoni	Pasture	75	5
P8	20978.4	16072.29	13023.88	24D2	Shelby	Pasture	75	5
P9	24622.54	15826.34	7448.17	13B	Zook-Olmitz-Vesser	Pasture	75	7
P10	15802.55	12354.07	8192.024	364B	Grundy	Pasture	100	1
P11	13126.24	10327.12	6238.173	364B	Grundy	Pasture	100	1
P12	14502.52	11609.14	7841.546	23C2	Arispe	Pasture	100	1
P13	14586.12	11623.87	6559.553	23C2	Arispe	Pasture	100	1
P14	15802.81	12171.44	8939.771	23C2	Arispe	Pasture	100	1
P15	15679.86	12390.01	7005.858	23C2	Arispe	Pasture	100	1
P16	12743.36	10150.64	5478.878	222C2	Clarinda	Pasture	100	1
P17	12778.05	10243.47	6773.531	822C2	Lamoni	Pasture	100	1
P18	11934.83	9468.827	6527.069	822C2	Lamoni	Pasture	100	3
P19	10868.91	8679.507	6077.259	822C2	Lamoni	Pasture	100	5
P20	15814.87	11231.46	8619.511	822C2	Lamoni	Pasture	100	7
P21	12370.89	10367.7	6190.741	SfC	Seymour	Pasture	35	1
P22	13627.07	11063.15	6719.967	SfC	Seymour	Pasture	35	1
P23	11174.27	9058.652	5792.177	AaC2	Adair	Pasture	35	5
P24	7980.938	6572.41	4240.162	AaC2	Adair	Pasture	35	5
P25	9827.85	7766.446	4530.715	AaC2	Adair	Pasture	35	5
P26	13544.96	10115.47	5127.867	SoD3	Shelby	Pasture	35	5
P27	17074.53	13197.87	8350.218	SoD3	Shelby	Pasture	35	5
P28	17213.24	11564.73	5383.077	SoD3	Shelby	Pasture	35	7
P29	15474.76	12409.38	8335.43	OvB	Olmitz-Vesser-Colo	Pasture	35	9
P30	20685.55	10865.75	6921.723	OvB	Olmitz-	Pasture	35	9

					Vesser-Colo			
P31	15890.43	12670.89	7866.286	SfC	Seymour	Pasture	51	1
P32	15367.62	12445.54	7344.361	SfC	Seymour	Pasture	51	3
P33	13081.21	10719.34	6732.824	ClC2	Clarinda	Pasture	51	4
P34	11860.41	8983.423	5604.845	AaC2	Adair	Pasture	51	5
P35	9445.509	7577.71	5006.985	AaC2	Adair	Pasture	51	5
P36	9287.607	7506.434	4825.038	AaC2	Adair	Pasture	51	5
P37	10494.81	8564.725	5269.446	AaC2	Adair	Pasture	51	5
P38	9175.257	8106.258	4817.741	ShE2	Shelby	Pasture	51	5
P39	10849.27	7563.722	4697.798	ShE2	Shelby	Pasture	51	7
P40	18314.61	13113.47	8237.068	OvB	Olmitz-Vesser-Colo	Pasture	51	7
Mean	11811.53	8815.979	5397.218					
Stdev.	3872.052	2272.485	1646.032					
Ratio		0.75	0.46					
n	224	224	224					

Comparison of the average 118 Mg SOC per hectare soil (*i.e., about 50 tons SOC per acre-40 inches*) with published values indicates this is reasonable amounts for the Chariton Valley, especially given that about ½ of this SOC is present in the top 20 cm. Sobecki et al. (2001) show the Chariton Valley region having 30 to 60 Mg ha-1 SOC although they do not make it clear the depth to which these values apply. Assuming it is to 20 cm, then their values and our values are quite comparable. Flach et al (1997) cite reports that SOC under temperate row crop fields contain about 35 to 70 Mg per hectare to a depth of 20 cm. Post (2002), using data from 3,000 pedons worldwide predicts soils in an area such as the Chariton Valley will contain about 100 to 120 Mg SOC per hectare to a 1-m depth. Post (2002) also cites FAO-UNESCO data that show on a global basis Chernozems, Gleysols, Luvisols, Greyzems, and Planosols collectively range from 65 to 197 Mg SOC per hectare to a 1-m depth with Chernozems and Gleysols having mean SOC contents of 125 and 131 Mg per hectare to 1-m depth, respectively. And while it is not intuitive, these are the FAO-UNESCO soil orders common in the Chariton Valley. Finally, Post (2002) reports that 112 Mg per hectare by 1-m as the mean SOC in crop biomes.

Table 4: Average SOC contents to 1-meter depth in pedons partitioned by landscape position and land use, Chariton Valley, Iowa.

Upland Position⇒	Summit	n	Shoulder	n	Backslope	n	Footslope	n	Toeslope	n	Total Carbon	n
Land Use⇓	*--- all SOC data reported as mean±standard deviation kg SOC per m^2 soil area to a depth of 1.0 m ---*											
SWG-old	12.6±2.3	4	11.4±1.6	7	10.7±1.9	21	9.9±0.5	6	16.9±5.8	3	11.4±2.7	41
SWG-med	13.2±2.9	5	11.0±1.0	3	9.1±1.5	9	7.5±2.4	3	-	-	10.2±2.8	20
SWG-yg	10.5±1.2	9	9.9±1.5	6	9.6±2.7	13	7.3±1.4	2	10.0	1	9.8±2.1	31
Pasture	14.1±1.9	21	12.4±2.6	7	11.2±3.1	21	15.7±5.0	8	15.9±4.6	3	13.1±3.4	60
Row Crop	11.2±1.8	6	9.2±1.5	8	8.1±1.9	12	14.6±8.0	3	16.0	1	10.0±3.6	30
Woodlot	10.3	1	12.0±1.0	4	10.3±2.7	10	17.4±4.8	3	-	-	11.9±3.7	18
All fields	12.6±2.3	46	10.9±2.0	35	10.1±2.6	86	13.0±5.4	25	15.5±4.6	8	11.4±3.3	200
Alluvial Pedons												
SWG-old	17.5±5.5	14										
Row Crop	12.8±5.0	10										
All fields	15.5±5.7	24										

**SWG = switchgrass, "old" = stands ranging from 8 to 26 years in age; "med" = stands ranging in age from 5 to 6 years in age, "yg" = stands ranging in age from 1 to 3 years.*

Table 5: Results of t-test analyses comparing SOC contents to 1-meter depth between landscape positions, Chariton Valley, Iowa.

Land Use⇒	SWG-old	Row Crop	Pasture**	All Land Uses
Landscape Position ⇓	*Two Tail T-test -- P(T<=t).*			
Summit vs. Shoulder	0.34	0.04	0.23	0.02
Summit vs. Backslope	0.10	0.00	0.03	0.00
Summit vs. Footslope	0.02	0.32	0.76	0.93
Summit vs. Toeslope	0.22	0.06	0.65	0.01
Shoulder vs. Backslope	0.41	0.19	0.76	0.12
Shoulder vs. Footslope	0.06	0.08	0.47	0.27
Shoulder vs. Toeslope	0.04	0.00	0.78	0.00
Backslope vs. Footslope	0.35	0.01	0.17	0.02
Backslope vs. Toeslope	0.00	0.00	0.48	0.00
Footslope vs. Toeslope	0.02	0.91	0.81	0.19

***only includes Rosa and Bellons pastures. The other four pastures need to be added.*

Table 6: Results of t-test analyses comparing SOC contents to 1-meter depth between land uses, Chariton Valley, Iowa.

Landscape Position ⇒	Summit	Shoulder	Backslope	Footslope	Toeslope	Total
Land Use ⇓	*One Tail T-test -- P(T<=t)*					
SWG-old vs. SWG-medium	0.37	0.34	0.02	0.02	-	0.06
SWG-old vs. SWG-young	0.02	0.05	0.09	0.00	0.20	0.00
SWG-old vs. Pasture	0.40	0.27	0.23	0.06	0.25	0.48
SWG-old vs. Row Crop	0.16	0.01	0.00	0.08	0.45	0.03
SWG old vs. Woodlot	0.22	0.35	0.33	0.00	-	0.27
SWG-medium vs. SWG-young	0.01	0.15	0.31	0.46	-	0.28
SWG-medium vs. Pasture	0.26	0.40	0.13	0.07	-	0.08
SWG-medium vs. Row Crop	0.10	0.05	0.11	0.11	-	0.41
SWG-medium vs. Woodlot	0.21	0.11	0.12	0.02	-	0.06
SWG-young vs. Pasture	0.01	0.32	0.34	0.10	-	0.01
SWG-young vs. Row Crop	0.16	0.20	0.07	0.16	-	0.40
SWG-young vs. Woodlot	0.45	0.02	0.26	0.03	-	0.01
Pasture vs. Row Crop	0.15	0.15	0.02	0.37	-	0.07
Pasture vs. Woodlot	0.14	0.17	0.42	0.15	-	0.28
Row Crop vs. Woodlot	0.32	0.00	0.02	0.33	-	0.04
Alluvial--SWG vs. Row	-	-	-	-	-	0.02

***only includes Rosa and Bellons pastures. The other four pastures need to be added.*

Table 7: Average SOC contents to 0.5-meter depth in pedons partitioned by landscape position and land use, Chariton Valley, Iowa.

Upland Position⇒	Summit	n	Shoulder	n	Backslope	n	Footslope	n	Toeslope	n	Total Carbon	n
Land Use ⇓	--- all SOC data reported as mean±standard deviation kg SOC per m^2 soil area to a depth of 0.5 m ---											
SWG-old	9.1±1.9	4	8.9±1.6	7	8.3±1.4	21	7.9±0.4	6	11.4±2.8	3	8.6±1.7	41
SWG-med	10.4±2.0	5	8.7±0.7	3	7.1±1.5	9	6.4±1.4	3	-	-	8.0±2.1	20
SWG-yg	7.7±0.9	9	7.3±1.6	6	7.3±1.9	13	5.8±1.1	2	7.9	1	7.4±1.5	31
Pasture	11.3±1.6	21	10.0±2.2	7	8.9±2.2	21	11.2±2.9	3	10.9±1.5	3	10.3±2.3	60
Row Crop	8.6±1.3	6	7.3±1.1	8	6.7±1.5	12	9.8±2.9	3	11.6	1	7.7±1.9	30
Woodlot	9.0	1	9.0±1.0	4	8.3±1.8	10	13.6±2.0	3	-	-	9.5±2.5	18
All fields	9.9±2.0	46	8.5±1.8	35	7.9±1.9	86	9.7±3.1	25	11.3±3.0	8	8.8±2.3	200
Alluvial Pedons												
SWG-old	8.6±2.2	14										
Row Crop	9.3±2.4	10										
All fields	8.9±2.2	24										

**SWG = switchgrass, "old" = stands ranging from 8 to 26 years in age; "med" = stands ranging in age from 5 to 6 years in age, "yg" = stands ranging in age from 1 to 3 years.*

Table 8: Results of t-test analyses comparing SOC contents to 0.5-meter depth between landscape positions, Chariton Valley, Iowa.

Land Use⇒	Swg-old	Row Crop	Pasture**	All land uses
Landscape Position ⇓	*Two Tail T-test -- P(T<=t).*			
Summit vs. Shoulder	0.79	0.08	0.31	0.09
Summit vs. Backslope	0.28	0.02	0.03	0.01
Summit vs. Footslope	0.15	0.39	0.75	0.96
Summit vs. Toeslope	0.25	0.09	0.89	0.04
Shoulder vs. Backslope	0.36	0.32	0.66	0.12
Shoulder vs. Footslope	0.20	0.06	0.50	0.26
Shoulder vs. Toeslope	0.10	0.01	0.74	0.00
Backslope vs. Footslope	0.56	0.02	0.14	0.01
Backslope vs. Toeslope	0.00	0.01	0.32	0.00
Footslope vs. Toeslope	0.01	0.67	0.88	0.23

***only includes Rosa and Bellons pastures. Four additional pastures need to be included.*

Table 9: Results of t-test analyses comparing SOC contents to 0.5-meter depth between land uses, Chariton Valley, Iowa.

Landscape Position ⇒	Summit	Shoulder	Backslope	Footslope	Toeslope	Total
Land Use ⇓	*One Tail T-test -- P(T<=t) one tail*					
SWG-old vs. SWG-medium	0.19	0.44	0.02	0.01	-	0.12
SWG-old vs. SWG-young	0.04	0.05	0.06	0.00	0.20	0.00
SWG-old vs. Pasture	0.31	0.38	0.31	0.05	0.30	0.28
SWG-old vs. Row Crop	0.30	0.03	0.00	0.07	0.48	0.02
SWG old vs. Woodlot	0.47	0.21	0.49	0.00	-	0.06
SWG-medium vs. SWG-young	0.00	0.09	0.36	0.35	-	0.09
SWG-medium vs. Pasture	0.21	0.43	0.11	0.06	-	0.21
SWG-medium vs. Row Crop	0.06	0.05	0.29	0.07	-	0.30
SWG-medium vs. Woodlot	0.28	0.15	0.07	0.00	-	0.03
SWG-young vs. Pasture	0.00	0.19	0.23	0.07	-	0.00
SWG-young vs. Row Crop	0.07	0.45	0.18	0.09	-	0.20
SWG-young vs. Woodlot	0.11	0.02	0.13	0.01	-	0.00
Pasture vs. Row Crop	0.08	0.15	0.04	0.48	-	0.02
Pasture vs. Woodlot	0.29	0.20	0.36	0.07	-	0.20
Row Crop vs. Woodlot	0.41	0.00	0.02	0.08	-	0.00
Alluvial--SWG vs. Row	-	-	-	-	-	0.25

***only includes Rosa and Bellons pastures. Four additional pastures need to be included.*

Table 10: Average SOC contents to 0.2-meter depth in pedons partitioned by landscape position and land use, Chariton Valley, Iowa.

Upland Position⇒	Summit	n	Shoulder	n	Backslope	n	Footslope	n	Toeslope	n	Total Carbon	n
Land Use ⇓	--- all SOC data reported as mean±standard deviation kg SOC per m^2 soil area to a depth of 0.2 m ---											
SWG-old	5.1±0.6	4	5.8±1.4	7	5.1±0.9	21	4.8±0.4	6	7.5±2.7	3	5.3±1.3	41
SWG-med	6.6±1.9	5	5.4±0.6	3	4.2±1.0	9	3.9±0.8	3	-	-	4.9±1.6	20
SWG-yg	4.4±1.1	9	4.6±1.4	6	4.6±1.2	13	3.7±1.4	2	4.0	1	4.5±1.1	31
Pasture	7.3±1.7	21	6.6±1.3	7	5.8±2.0	21	6.6±1.7	8	7.7±0.7	3	6.6±1.8	60
Row Crop	5.3±1.2	6	4.3±0.9	8	4.3±0.8	12	5.6±0.6	3	5.8	1	4.7±1.0	30
Woodlot	5.1	1	5.4±1.2	4	4.9±1.1	10	7.7±1.2	3	-	-	5.4±1.5	18
All fields	6.2±1.8	46	5.4±1.4	35	4.9±1.4	86	5.7±1.7	25	6.9±2.0	8	5.5±1.7	200
Alluvial Pedons												
SWG-old	4.4±1.3	14										
Row Crop	5.3±1.4	10										
All fields	4.8±1.4	24										

**SWG = switchgrass, "old" = stands ranging from 8 to 26 years in age; "med" = stands ranging in age from 5 to 6 years in age, "yg" = stands ranging in age from 1 to 3 years.*

Table 11: Results of t-test analyses comparing SOC contents to 0.2-meter depth between landscape positions, Chariton Valley, Iowa.

Land Use⇒	SWG-old	Row Crop	Pasture**	All land uses
Landscape Position ⇓				
Summit vs. Shoulder	0.40	0.10	0.77	0.44
Summit vs. Backslope	0.91	0.05	0.13	0.01
Summit vs. Footslope	0.40	0.63	0.93	0.88
Summit vs. Toeslope	0.13	0.70	0.32	0.06
Shoulder vs. Backslope	0.14	0.98	0.16	0.10
Shoulder vs. Footslope	0.14	0.04	0.89	0.62
Shoulder vs. Toeslope	0.19	0.14	0.47	0.02
Backslope vs. Footslope	0.57	0.02	0.30	0.04
Backslope vs. Toeslope	0.00	0.09	0.07	0.00
Footslope vs. Toeslope	0.03	0.58	0.52	0.10

***only includes Rosa and Bellons pastures. It does not include the four other pastures.*

Table 12: Results of t-test analyses comparing SOC contents to 0.2-meter depth between land uses, Chariton Valley, Iowa.

Landscape Position ⇒	Summit	Shoulder	Backslope	Footslope	Toeslope	Total
Land Use ⇓	*One Tail T-test -- P(T<=t) one tail*					
SWG-old vs. SWG-medium	0.09	0.32	0.02	0.02	-	0.14
SWG-old vs. SWG-young	0.13	0.07	0.11	0.05	0.18	0.00
SWG-old vs. Pasture	0.05	0.42	0.43	0.05	0.46	0.06
SWG-old vs. Row Crop	0.42	0.01	0.01	0.03	0.31	0.01
SWG old vs. Woodlot	0.09	0.48	0.30	0.00	-	0.30
SWG-medium vs. SWG-young	0.01	0.20	0.22	0.45	-	0.12
SWG-medium vs. Pasture	0.36	0.30	0.06	0.06	-	0.02
SWG-medium vs. Row Crop	0.10	0.04	0.45	0.02	-	0.23
SWG-medium vs. Woodlot	0.25	0.35	0.11	0.01	-	0.12
SWG-young vs. Pasture	0.00	0.12	0.17	0.11	-	0.00
SWG-young vs. Row Crop	0.09	0.32	0.20	0.06	-	0.25
SWG-young vs. Woodlot	0.30	0.13	0.09	0.02	-	0.00
Pasture vs. Row Crop	0.09	0.03	0.04	0.33	-	0.00
Pasture vs. Woodlot	0.19	0.42	0.31	0.16	-	0.23
Row Crop vs. Woodlot	0.44	0.03	0.08	0.03	-	0.01
Alluvial--SWG vs. Row	-	-	-	-	-	0.07

***only includes Rosa and Bellons pastures. It does not include the four other pastures.*

Discussion of Hypotheses 1 through 3

<u>*Hypothesis 1:*</u> SOC sequestration potential can be predicted using soil map unit attributes such as landscape position.

<u>*Hypothesis 2:*</u> Rates of SOC sequestration in a field or within a soil map unit or landscape position are dependent upon current and past land management.

<u>*Hypothesis 3:*</u> Maximum SOC sequestration in the Chariton Valley occurs in lands having well managed mature stands of switchgrass (*Panicum virgatum*, L.)

Prior to conducting any fieldwork in this study, we hypothesized that SOC content would vary systematically across the landscape in the following manner: toeslopes > summits > footslopes > backslopes > shoulders. The basis of our hypothesis was the research from Walker (1966), Ruhe (1969), Burras and Scholtes (1987), Konen (1999) and Daniels and Hammer (1992). We were aware these publications might likely be misleading or mistaken because they tended to focus on the Des Moines Lobe and we recognized the considerably different nature of the Quaternary stratigraphy found on the Southern Iowa Drift Plain relative to the Des Moines

Lobe. However, we also recognized that in general SOC contents do vary systematically across landscapes and we sought to quantify this phenomenon in terms of the Chariton Valley.

There are important differences in SOC content across the landscape (Tables 4, 5, 7, 8, 10, and 11). In addition, the data in Tables 3 through 12 also illustrates there is considerable SOC content variability within and between landscape positions. The general trend of SOC content across <u>all land uses</u> and depths of measurement (i.e., 1-m, 0.5-m, or 0.2-m) is

toeslopes ≥ summits = footslopes ≥ shoulders ≥ backslopes.

The same landscape trend is also statistically demonstrable in row cropped landscapes. It was not statistically significant in old switchgrass fields or pastures. In the case of the pastures, the lack of a clear landscape trend is because only pedons from two pastures were considered. We anticipate the overall general trend of maximum and minimum SOC content in toeslopes and backslopes, respectively, being confirmed once we include the other pastures we have sampled as part of the pasture project.

In the case of the old switchgrass fields, two unexpected findings emerged from these comparisons of SOC content by landscape position. First, when SOC contents for 1-m depths are compared the footslope pedons are found to have as low of SOC as the backslope pedons. Second, SOC contents for 0.5-m and 0.2-m depths show very little systematic variability across the landscape. This is thought reflect an leveling effect in terms of SOC content over time as switchgrass root mass is humified into SOC. The low SOC content found in the footslope positions, at least relative to comparably sited pedons for all land uses and row crops, is thought to reflect the lack of SOC accumulated within hillslope sediment from sheet erosion. In other words – and at the risk of over interpreting a couple of tables of numbers – SOC sequestration in old switchgrass fields appears to occur successfully across the landscape at fairly shallow depths while also controlling sheet erosion.

Returning to the primary trend wherein SOC content is distributed across the landscape as

toeslopes ≥ summits = footslopes ≥ shoulders ≥ backslopes,

a couple of additional points should be made. First, this trend is consistent with the findings of Molstad (2000), who noted the low SOC of shoulders and backslopes probably reflects their highly erosional nature. Second, this trend is only slightly different than the one we hypothesized at the outset of this study, i.e. we predicted that shoulders, not backslopes would have the lowest SOC content.. In general we interpret the low SOC content of shoulders and backslopes to reflect their less effective precipitation since more water runs off. Finally, these landscape positions also often have paleosol or till derived soils, which are generally much less productive than the loess derived soils found on summits and colluvial derived soils found on footslopes and toeslopes. We are continuing to explore these ideas as we prepare this data into refereed publications.

The following discussion is an evaluation of our pre-study hypotheses (Hypotheses 2 and 3) that SOC content partitioned by land use would vary in the following manner: maximum SOC in old switchgrass fields, followed by pastures and woodlots, which in turn would be followed by medium-aged switchgrass fields, then young switchgrass fields and pastures, and finally be minimum in row cropped fields.

Our initial hypotheses were reasonable albeit imperfect based upon the data given in Tables 4, 6, 7, 9, 10, and 12. We were partially wrong in predicting maximum SOC content in pedons from old switchgrass fields. Pedons from old switchgrass fields, pastures, and woodlots have statistically identical SOC contents – at least when compared to 1-m depths while in the case of 0.2-m depths, pastures have the greatest SOC content. (NOTE – Inclusion of the pasture project data into this study will show pastures contain more SOC than any other land use. This analysis will be developed for manuscript submission. Lee Burras, January 25, 2002) Our initial hypothesis was also wrong in predicting that SOC content would differ between soils under intermediate and young switchgrass stands. They have statistically identical SOC contents along with ones from row cropped fields.

These are very interesting findings. They indicate that SOC sequestration occurs under switchgrass production in one – or some combination - of the three following manners. First, possibly SOC sequestration under switchgrass occurs at such a slow linear rate that for the first several years that it is impossible to detect any gain with the methods we employed. Second, possibly SOC sequestration rates under switchgrass stands are curvilinear with the rate becoming much faster after about five years (i.e., the age of most intermediate aged stands we studied). Third, it is possible that normal spatial variability masks SOC gains for long time periods.

In order to help evaluate SOC sequestration rates, we plotted SOC contents against age of stand against for the 160 upland pedons (Figure 3). This subset of pedons does not include the pasture project pedons (labeled with a "P-number" in Table 3). Then, we applied simple linear regression as a curve fitting measure and in order to determine the best-fit slope, which is fact a measure of SOC sequestration rates. From this, we determine the soils of the Chariton Valley have been sequestering an annual average of 23 g SOC per m^2 per 1-m depth or 10 g SOC per m^2 per 1-m depth (Figure 3). These values are remarkably low (i.e., 0.1 tons $acre^{-1}$ yr^{-1} or 0.23 Mg ha^{-1} yr^{-1}) at least according to Watson et al (2000), who report 0.3 Mg ha^{-1} yr^{-1} is the mean rate and 0.05 to 1.3 Mg ha^{-1} yr^{-1} is the range in rates for SOC sequestration in North America when tillage is changed from conventional to conservation. Unfortunately, no more direct comparison of our data was found. It is thought our values are so low (albeit not completely inconsistent with Watson et al's (2000) report) because we made two questionable assumptions. First, in this approach we assume that 70 years ago the SOC content was equal to the regression constants of 10,206 g SOC per m^2 per 1-m depth and 4891 g SOC per m^2 per 1-m depth. It is unlikely this assumption is reasonable (see Flach et al., 1997) although we have not yet determined a better baseline for all data. Second, with this approach we also assume that all three types of perennial vegetation examined (trees, pasture, switchgrass) have equal rates of SOC sequestration and that sequestration rates are linear. It is also possible that we have an excessively old age for the woodlots.

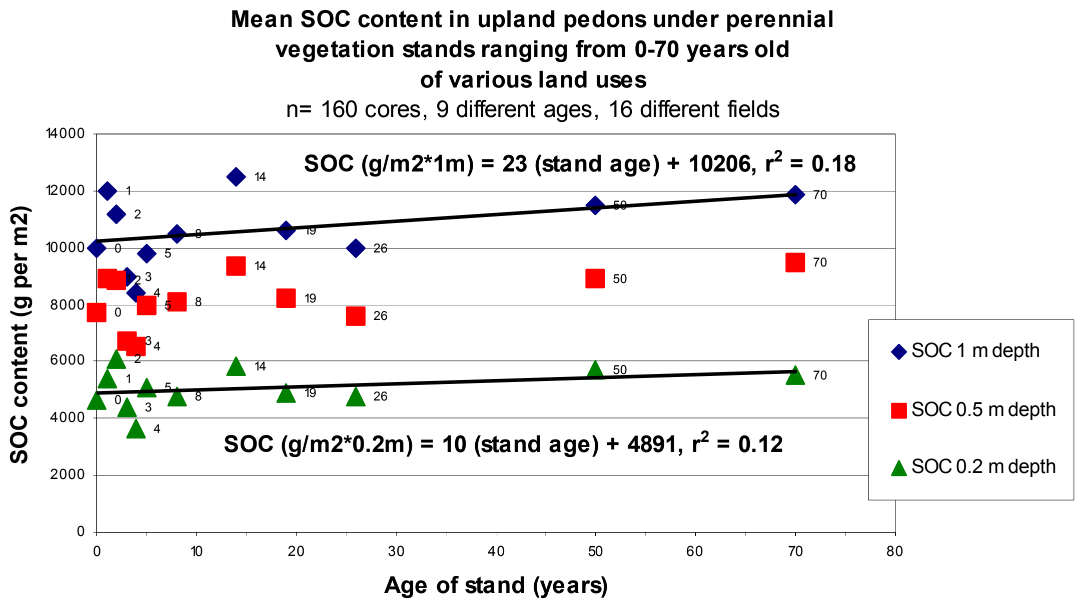

Figure 3: Mean field SOC contents in pedons from four land uses (row crop, switchgrass, pasture, and woodlots) in the Chariton Valley, Iowa. Diamonds, squares, and triangles are SOC contents to 1-m, 0.5-m, and 0.2-m depths, respectively. Row crop fields were assigned zero years of perennial vegetation. All stand ages are given as small numbers adjacent to data points. Switchgrass stands ranged from 3 to 26 years, pastures (only two) were 2 or 50 years old, respectively, and woodlots were 70 years.

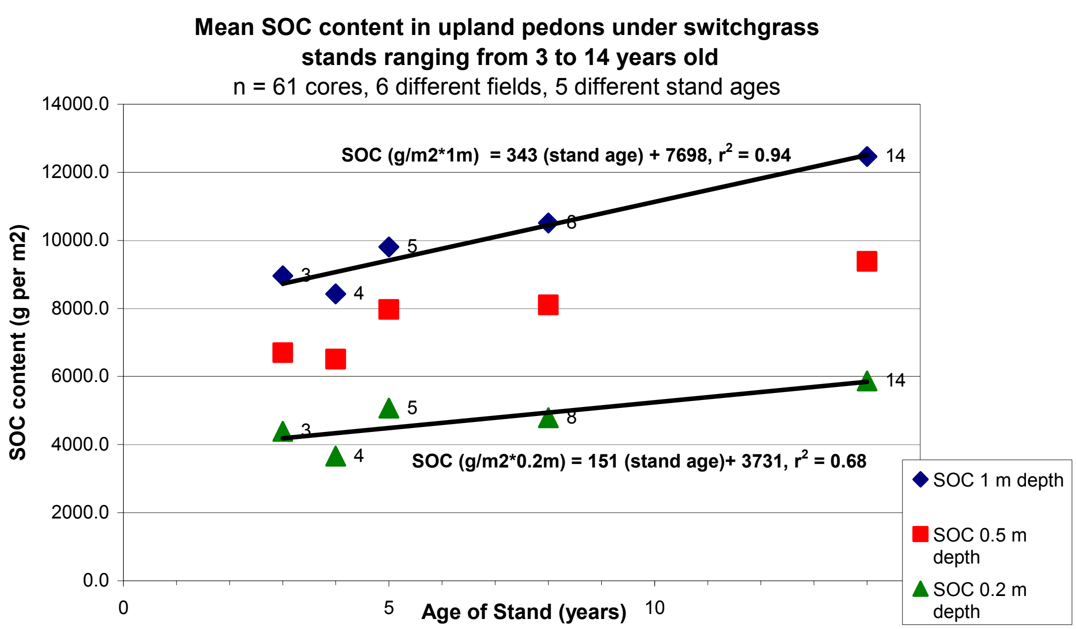

Figure 4: Mean field SOC contents in pedons from selected switchgrass fields, Chariton Valley, Iowa.

In order to better test rates of SOC sequestration – specifically under switchgrass having typical stand ages for the Chariton Valley, we refined our simple linear regression approach to only include switchgrass stands that are between 3 and 15 years old (Figure 4). These ages were selected because most stands in the Chariton Valley were planted as part of the original conservation reserve program of the late1980's through 1990's. Using the regression equation slopes shown in Figure 4 shows rates of SOC sequestration under switchgrass to be 343 g m^{-2} m^{-1} depth yr^{-1}. This is equal to 1.5 tons $acre^{-1}$ 40 in^{-1} yr^{-1} or 3.4 Mg ha^{-1} yr^{-1}. The rate of SOC within the top 20 cm of these switchgrass stands was 151 g m^{-2} m^{-1} depth yr^{-1}, which is equal to 0.67 tons $acre^{-1}$ 40 in^{-1} yr^{-1} or 1.5 Mg ha^{-1} yr^{-1}. These rates of SOC gain are consistent with Watson et al, 2000 although it is recognized their results apply to conversion from conventional to conservation tillage.

Our data indicate that pastures may be sequestering more SOC in the upper 0.2-m of a pedon than switchgrass or trees (Table 10). This is surprising because forest-derived soils generally have proportionally more SOC at shallow depth than do grass-derived soils. It is also surprising because perennial grasses are the predominant vegetation in both pastures and switchgrass fields; thus, it is unclear why they would show differences in SOC depth trends. It is speculated it might reflect the impact of grazing (typically excessive grazing) on root growth in pastures and the lack of grazing in switchgrass stands. Alternatively or in addition, the predominance of cool season forage species may promote shallow SOC gains in pastures.

Pasture Project

This project component examined <u>*Hypothesis 4:*</u> *Within pastures, sequestered SOC is proportional to management quality*. It entailed using the two pastures from the primary project as well as five – really four - additional pastures. As mentioned in Materials and Methods, we eliminated one pasture ("no. 5" in Table 2 and subsequent discussions) from much of the discussion because of its prior use as a feedlot.

The rationale behind this study is the recognition that pastures have great potential as sinks for soil organic carbon because of their continuous cover, perennial vegetation, biomass production, and enhanced nutrient cycling. Historically the primary goal of pasture management has been to maximize animal production; although successful pasture management also enhances environmental quality relative to other agronomic land uses through increased water retention, decreased water runoff, and decreased erosion (Barnes and Baylor, 1995). Increased soil carbon sequestration appears to be yet another environmental benefit of pasture management although this benefit was only peripherally studied and documented (e.g., Clement and Williams, 1964; McLaughlin and Burras, 2000) until very recently (see Follett et al, 2001). Thus, our assumptions for potential SOC gains in pastures is based upon studies like (a) Clement and Williams (1964), who found a 15% increase in soil carbon after four years of pasture in England, (b) Franzluebbers et al. (2000), who found calculated maximum soil organic C was 37% greater under grazed tall fescue than under hayed hybrid bermudagrass and (c) Patton (1999), who found 40% more organic carbon content in fields managed for about 20 years with long term rotations (including hay and manure) when compared to traditionally row cropped fields in southern Minnesota.

Pasture Results

SOC content of pasture pedons range from 7.4 to 24.6 kg m^{-2} m^{-1} with the overall mean and standard deviation being 13.2±3.4 kg m^{-2} m^{-1} (n = 60, see Table 3). This is equal to Chariton Valley upland pastures soils having 132 Mg ha^{-1} m^{-1} or 58.8 tons $acre^{-1}$ 40-in depth. Within these 60 pedons, 67% and 52% of the SOC is found in the top 0.5 and 0.2 m, respectively. As mentioned in the previous section, these values suggest relatively more of the SOC is present at shallow depths in pastures relative to the average of all land uses in the Chariton Valley.

When the pastures are grouped according to pasture quality, the mean SOC contents are 14.1, 12.7, and 9.9 kg m^{-2} m^{-1} (Table 13), which is the same as saying the upland soils in high quality pastures contain about 60-65 tons $acre^{-1}$ 40-in depth and upland soils in poor quality pastures contain about 40-45 tons $acre^{-1}$ 40-in depth. Confounding any interpretation about SOC sequestration occurring within pastures is the differences in ages of these pastures. That is, the two high quality pastures are estimated by their managers as being 75 and 100 years old. The medium quality pastures are estimated as 35 and 51 years of age while the poor quality pastures are two and 50 years of age. Thus, while it is possible to calculate a mean rate of SOC sequestration (Figure 5), it is not readily possible to ascertain rate differences that might be occurring between pastures of various quality.

Table 13: Brief summary of SOC in six pastures from the Chariton Valley, Iowa.

Pasture Numbers*	1 and 2	3 and 4	6 and 7
	---------Pasture Quality-----------		
Depth ⇓	High	Medium	Low
0-20 cm	7.6 kg m^{-2}	6.0 kg m^{-2}	6.0 kg m^{-2}
0-50 cm	11.4 kg m^{-2}	9.6 kg m^{-2}	9.9 kg m^{-2}
0-100 cm	14.1 kg m^{-2}	12.7 kg m^{-2}	11.8 kg m^{-2}

**Pasture 5 not include because it was formerly a feedlot.*

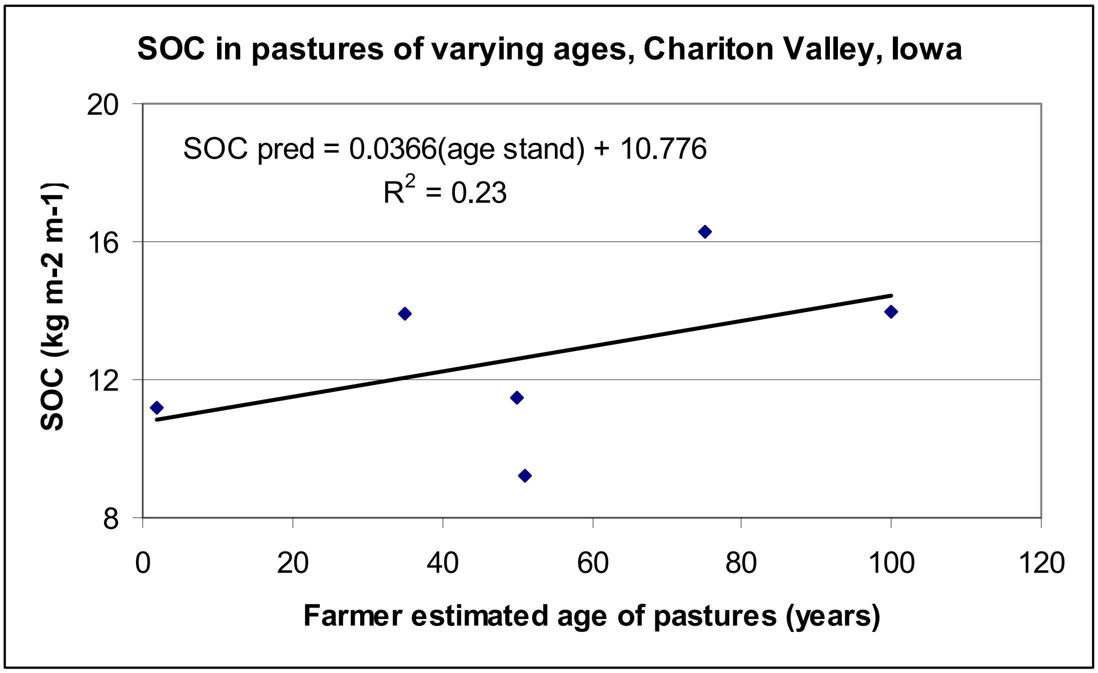

Figure 5: Mean SOC content of six pastures of various ages in the Chariton Valley, Iowa.

Using the slope of the best fit linear equations shown in Figure 5, it appears that pastures gain about 0.04 kg SOC annually to a depth of 1 m. Or they annually gain about 0.18 tons $acre^{-1}$ 40 inches depth or 0.4 Mg ha^{-1} m^{-1}. This rate of gain is consistent with the 0.2 to 0.7 Mg ha^{-1} reported by Watson et al. for grazing lands globally (2000).

Irrespective of pasture quality, 67% and 53% of all soil organic carbon is found in the 0 to 50 cm and 0 to 20 cm depths, respectively. This suggests soil organic carbon contents evolve proportionally throughout the entire solum with changes in pasture quality. Thus, as with the primary project, it appears shallow sampling may be a possible proxy to obtain total SOC within a pedon.

Overall, soil tilth is related to pasture quality. This is shown in part by low bulk density (Figure 6) and high percent stable aggregate content in the high quality pasture (data not reported).

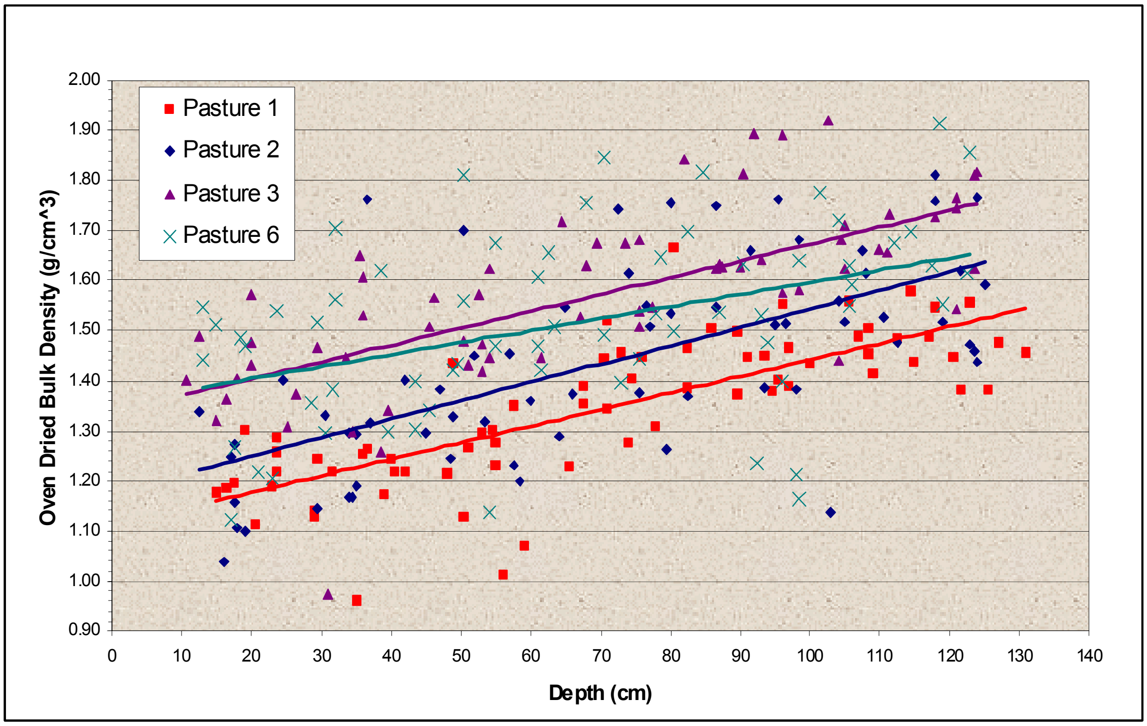

Figure 6: Bulk density with pedon depth for four pastures in the Chariton Valley, Iowa. Pastures 1 and 2 have high quality management while Pastures 3 and 6 have lower quality management.

Additional corollary results being developed using all data

Relationships between landscape positions and SOC contents and SOC sequestration rates. Analyses are ongoing and will be included in refereed publications. These publications will be made available once they are completed.

Relationships between pedon color and carbon content

Preliminary data shows a strong quantitative relationship exists between soil carbon content (wt/wt) and horizon color within a pedon. Use of value and chroma from either a chroma meter or from Munsell color books can predict %OC quite successfully (e.g., r^2 ~0.7). The relationship is best when value and chroma are measured with the chroma meter. A preliminary linear regression equation using chroma meter data is:

$$\%OC = 4.204 - 0.536(value) - 0.332(chroma),\ r^2 = 0.67^{**},\ n = 225$$

Comparable results were obtained by Konen (1999).

Pedon ClassificationPreliminary suborder classifications of 212 pedons show 77 Aqualfs, 47 Udalfs, 51 Aquolls, and 37 Udolls. The "aquic" nature of the fields was expected. (Molstad, 2000) The large number of Alfisols was not. These Alfisols are thought to be largely due to eroded Mollic epipedons. Further work is needed to assess the number of native Alfisols versus eroded Mollisols. In addition, classification shows that only about 1/3 of the pedons collected belong to the series of the soil survey map unit in which they were collected. In many cases, though, pedon are being found to belong to a like series, which is not uncommon within soil survey.

Relationships between pedon properties and landscape properties, SOC content and SOC sequestration rates.

These ideas will be developed within refereed manuscripts. These manuscripts will be made available once they are completed.

Summary and Conclusion

We found SOC content varies from about 5 to 27 kg m^{-2} m^{-1} in the Chariton Valley with an overall mean value of 11.8 kg m^{-2} m^{-1}. This is equal to an average of about 50 to 55 tons per acre (40 inch depth). We found SOC content varies in a systematic manner across landscapes with maximum contents nearly consistently being found in toeslopes and minimum contents being found in backslopes. SOC content is also generally proportionally distributed in pedons with the top 0.2 m containing about ½ of the SOC found to a 1 m depth and the top 0.5 m containing about ¾ of the SOC found to 1 m depth. SOC content varies with land use with pastures generally having highest contents and younger switchgrass fields and row crop fields having the least.

We found SOC sequestration does occur in a manner proportional to age of perennial vegetation stand. When all types and ages of perennial vegetation stands are included, we ascertained an annual rate of 23 g m^{-2} m^{-1} SOC gain for the Chariton Valley. When sequestration is calculated for three to 14 year old switchgrass fields, we found an annual rate of 343 g m^{-2} m^{-1} SOC gain, which is equal to 1.5 tons per acre (to a 40 inch) depth or about 0.75 tons per acre (to a 10 inch) depth.

We found SOC contents within pastures is proportional to quality of pasture management with soils from high quality pastures averaging 14.1 kg m^{-2} m^{-1} and soils from poor quality pastures averaging 11.8 kg m^{-2} m^{-1}. We also determined an overall rate of SOC sequestration in pastures to be 40 g m^{-2} m^{-1} yr^{-1}. Unfortunately, rates of SOC sequestration specific to each level of pasture quality could not be ascertained because of the confounding effect of pasture quality and age of stands.

In conclusion, we think SOC sequestration potential is interpretable using soil attributes such as landscape position and that rates of SOC sequestration are dependent on land management history. We do not think switchgrass results in the maximum SOC contents in the Chariton Valley although rates of SOC sequestration are impressive (e.g., 1.5 tons acre per year) in switchgrass stands about 5 to 15 years old. We speculate SOC content is proportional to level of pasture management although we will need to complete more sophisticated analyses to make a more definitive conclusion.

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