2004 FINAL REPORT
Soil Carbon and Quality in Seymour and Clarinda Soil Map Units, Chariton Valley, Iowa

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Abstract

Soil organic carbon (SOC) content and soil quality are increasingly important factors in many policy decisions yet both remain elusive to spatially quantify. This study sought to quantify each by comparing three soil map units (SMU) from each of two soil series, Clarinda and Seymour. These SMU's represented different erosion classes. SMU's under a variety of land uses were sampled, including row crop, switchgrass, pastures, and woods. The study area was the Chariton Valley of south central Iowa. Field methodologies including using centroid pedons, grid pedons, and grab samples. Laboratory analyses consisted of standard morphological descriptions followed by horizon-by-horizon analyses for bulk density, SOC content, stable aggregate content (SAC), and cation exchange capacity (CEC). Results include average SOC contents of about 5 kg m^{-2}*20 cm, 10 kg m^{-2}*50 cm and 12 kg m^{-2}*100 cm for all six SMU's sampled, regardless of whether centroid or grid pedons were used. Depending on the method of sampling and statistical analyses, row cropped SMU's generally have lower SOC content than the other land uses. Some data supports SOC content increasing proportional to stand age of perennial vegetation. No clear differences were observed between SOC content for either Clarinda or Seymour series with regards to uneroded and eroded SMU's. Stable aggregate content, CEC and A horizon thicknesses do segregate by land use. Erosion classes of SMU's do not appear to be important controls or predictors with regards to SAC, CEC and A horizon thickness. The relative rate of recovery for SOC contents is unclear for both the Clarinda and Seymour SMU's. The recovery rate for soil quality is correlated with stand age of perennial vegetation. Recovery rates do not appear to be different between Clarinda and Seymour SMU's. SAC increases by about 2 to 3 percent annually. The A horizon thickness increases by about 0.4 cm annually. Soil CEC is thought to be annually increasing by about 0.02 $cmole_c\ kg^{-1}$. Finally, applying geostatistics and GIS to the data does result in clear, useable maps although we caution users to realize these maps are no better than the data used to make them. This means - given the overlap in properties across SMU's and, to some degree, land uses – maps like the ones we present are probably best at the field or even regional scale and less accurate at the SMU scale.

Introduction

Soil organic carbon (SOC) is directly and indirectly related to a myriad of parameters including soil series, landforms, climate, erosion rates, cropping systems, farming practices land use, etc. Likewise, soil quality is directly and indirectly affected by these same parameters albeit not necessarily in identical ways. Individual parameters can largely be divided into two categories: natural (e.g., soil series, landforms) and human-controlled (e.g., farming practices, land uses). Thus, understanding and predicting SOC content and soil quality requires somehow accounting for two quite distinct sets of variables.

The “natural” world of soils is generally referred to as pedology. Pedological theory holds that all soil properties inclusive of soil quality and soil organic carbon are functions of the five state factors controlling pedogenesis. These state factors are parent material, climate, biota, relief, and time (Jenny, 1941). In terms of this project, that theory predicts Seymour and Clarinda soils have inherently different SOC content and soil quality because they formed from different parent materials of different ages (i.e., 30,000 year old Peoria loess and 300,000 year old Yarmouth-Sangamon paleosol, respectively). Finally, pedological theory predicts these differences will be identifiable even after significant human impacts have occurred.

Human-controlled factors such as farming practices and land uses are important because, as suggested in paragraph one, these are known to cause change in SOC content and soil quality (Lal et al, 2004; Stevenson and Cole, 1999; Fenton et al, 1999; Lal, et al, 1998; Paul et al, 1997; Lal et al, 1994; Liebig et al, 2005). Type and duration of vegetative cover are generally the best predictors of SOC content and soil quality with the best gains in SOC content and soil quality generally being proportional to duration, vigor and extent of perennial vegetation growth. Thus, the USDA Conservation Reserve Program (CRP) is widely hailed as a promoter of SOC sequestration and soil quality because its central requirement is farmers plant and maintain permanent vegetation (Sullivan et al, 2004; Lewandrowski, 2004). These benefits were unintended – although not necessarily unexpected or unwanted - consequences of the program. Likewise, USDOE programs associated with biofuel production are generally thought to have ancillary soil benefits – again because of their general emphasis on continuous plant growth and biomass production.

The preceding discussion may seem to imply SOC and soil quality are well-understood properties. One might be inclined to especially think this way given the five books, two reports and two refereed articles briefly mentioned in paragraph three minimally represent the myriad of literature generated on these topics over the past decade. The reality – though – is the opposite. A multitude of practical problems exist within the scientific arena studying SOC and soil quality. The main challenge germane to this report is discerning the interplay between soil variability (pedological-controlled) and land use (human-controlled). Previous research that focused on the human approach suggest the general lesson is soils can be treated as being more or less homogenous at the field scale. Extensive classical pedology has shown SOC and other soil properties vary in a systematic manner across a field (or any area) with the variability being controlled by the five state factors (e.g., see Jenny, 1941; Ruhe, 1969; Burras and Scholtes, 1987; Mausbach and Wilding, 1991: Konen et al, 2003). Thus, considerable research remains necessary to successful understand and predict quantity and spatiality of SOC and soil quality.

The Chariton River Watershed is an ideal location for study of this issue. The six counties included in Iowa’s portion of the watershed have several major land uses and a multitude of soil series that differ significantly with respect to their pedogenesis. About 90% of the watershed area is considered farmable land (Miller, 2003) with about 40% of the six counties are typically devoted to row cropped fields. Other uses for the area's farmable land are Conservation Reserve Programs (CRP), pasture, woodlots, and row cropped fields. Pastures and woodlots comprise about one-half of the total Chariton Valley. The diversity of these land uses reflects the broad range in soils present in the watershed.

This study was initiated in order to (a) provide more information pertaining to SOC and soil quality in relationship to non-row cropped land uses, and to (b) provide spatially referenced, detailed knowledge pertaining to SOC and soil quality across both productive and unproductive soil map units (SMU).

Objective and Approach

The three objectives of this project are:

(1) Quantify soil carbon content and distribution in uneroded, eroded, and "recovering" Seymour and Clarinda soil map units (SMU) from the Chariton Valley,

(2) Quantify CEC, stable aggregate content, and A horizon thickness of uneroded, eroded, and "recovering" Seymour and Clarinda map units from the Chariton Valley, and

(3) Estimate the relative rate of recovery for SOC contents and soil quality for recovering soils with special regard for recovery dynamics in switchgrass fields.

Seymour and Clarinda soils were selected because their inherent crop productivity ratings (specifically, corn suitability ratings (CSR)) differ significantly yet they are common soils in the Chariton Valley. Their CSR's differ because of their pedogenesis, especially parent material. The average CSR for all SMU's of Seymour and Clarinda are about 50 and 20, respectively, with uneroded Seymour on B slopes having a CSR of 60 and severely eroded Clarinda on D slopes having a CSR of 5. In other words, the best and worst SMU's of these two soils have CSR values that differ by an order of magnitude. Seymour and Clarinda similarities include both being present on summits and shoulders, both have imperfectly drained sola and both have high contents of expanding clays in their B-horizons. Thus they are quite comparable soils except in terms of pedogenesis and its apparent impact on crop productivity.

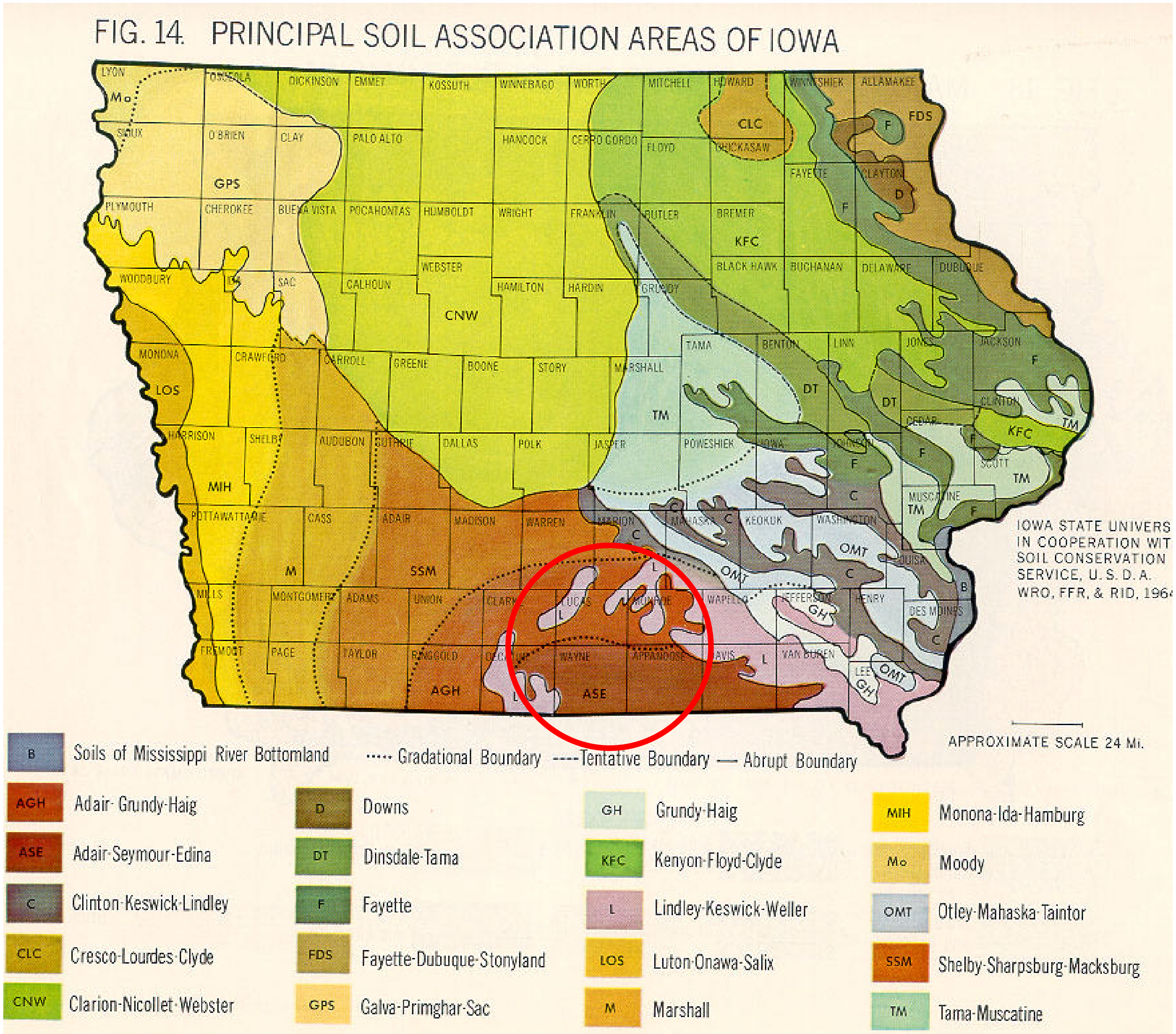

Figure 1. Location of the Chariton Valley in Iowa (approximate watershed circled).

Figure 2. Example of a common landscape in the Chariton Valley, Iowa.

Experimental Design & Methods

A total of 108 soil map units (SMU) were planned to be sampled with subsets of these SMU's representing five-land use "treatments" (conventionally managed row crop fields, switchgrass fields, woodlots, and pastures). In order to secondarily evaluate if a geostatistical or pedological approach provides more useful information, three sampling schemes were in use:

a. one soil core (5 cm dia. to a depth of 1.2 m) from the centroid of the proposed 108 SMUs (Table 1);

b. about 10 soil cores (5 cm dia. by 1.2 m depth) collected in a grid across the ClC2 SMU for each land use and across the young switchgrass fields for each map unit (Table 2).

c. About 25 soil cores (5 cm dia by 20 cm depth) collected at random across the SMU used in (b).

Figures 3 is an example map, showing the location of one centroid pedon. Placement of centroid pedons was according to a standard GIS centering algorithm, which as Figure 3 qualitatively suggests sometimes – or even often – differed from where an individual might qualitatively place it. Written another way, geometrically-calculated centroids in SMUs that are long a narrow sometimes appear to be in odd locations. This suggests these SMU's may have no intuitive geographical "center."

Field methods included site evaluation (e.g., estimation of field quality, slope, and aspect) and collection of soil cores. All cores were described to identify profile morphology characteristics for the SMUs and land use. Sampling scheme (b) was used to determine pedon variability within SMUs and land uses while sampling scheme (c) provides data on SOC and quality in just the "management layer." All three sampling schemes are also used to evaluate spatiality of soil properties for one representative field (Field 123) following the multiple variable indicator kriging approach discussed in Smith et al. (1994).

Following profile descriptions using NRCS nomenclature (Schoeneberger et al., 2002), the following soil properties were measured on all or a predetermined subset of samples collected on a horizon-by-horizon basis: bulk density, pH, cation exchange capacity (CEC), SOC content, coarse fragment content, particle size, chromameter color, and stable aggregate content. Land use history was established through a questionnaire to farmers, NRCS and FSA records, and evaluation of various aged aerial photographs.

Table 1a. Location of 82 of the 91 centroid pedons (locations given using UTM coordinates, all locations reside in UTM NAD 83, Zone 15).

CENTROID PEDONS				
Field Identifier	Land Use	SMU	Easting (m)	Northing (m)
040	swg10	ClC2	473834.000000	4496281.000000
040	swg10	SfC	473729.000000	4496325.000000
095	swg10	SfC	463380.000000	4500277.000000
103	swg5	SfC2	478722.656242	4522665.217080
104	swg5	ClC	478895.000000	4522872.000000
105	swg5	ClC2	486570.604400	4517097.963030
105	swg5	CmC3	486592.104313	4517441.136390
105	swg5	SfC	486617.557459	4517413.538110
105	swg5	SfC2	486698.404808	4517258.198830
116	swg10	ClC	478585.534240	4519894.645110
116	swg10	CmC3	478440.183076	4519738.771350
116	swg10	SeB	478646.483808	4519793.051600
116	swg10	SfC2	478578.657739	4519787.759770
117	swg10	ClC	477799.563676	4520845.874840
117	swg10	ClC2	477979.660492	4520830.211600
117	swg10	SeB	477823.086530	4520920.233340
117	swg10	SfC2	477814.603092	4520866.193690
118	swg10	ClC2	477755.946877	4519603.414610

Table 1a. - continued.

Table 1a. (continued) Location of 82 of the 91 centroid pedons (locations given using UTM coordinates, all locations reside in UTM NAD 83, Zone 15).

Field Identifier	Land Use	SMU	Easting (m)	Northing (m)
118	swg10	SeB	477707.923266	4519705.470080
118	swg10	SfC2	477737.896264	4519662.082290
120	swg5	ClC	478818.105421	4519483.420100
120	swg5	SfC	478841.846012	4519412.859470
121	swg5	ClC	478740.089812	4520233.507940
121	swg5	SeB	478854.281117	4520283.657220
121	swg5	SfC2	478795.101983	4520263.224460
122	swg10	ClC2	478650.945934	4520350.437220
122	swg10	CmC3	478665.193728	4520483.112390
122	swg10	SfC2	478677.936797	4520393.470910
123	swg5	ClC2	478836.636246	4520491.812770
123	swg5	CmC3	478736.749239	4520633.470130
123	swg5	SeB	478762.956775	4520394.454300
123	swg5	SfC2	478750.884371	4520511.424760
124	swg5	ClC	478504.000000	4519303.000000
124	swg5	CmC3	478437.000000	4519472.000000
124	swg5	SeB	478458.000000	4519389.000000
185	swg5	ClC	470685.000000	4507982.000000
185	swg5	CmC3	470712.000000	4507909.000000
208	swg10	SeB	471240.531250	4511307.000000
208	swg10	SfC	471221.937500	4511373.000000
245	swg5	SfC	479103.637693	4522117.220790
p01	pasture	ClC2	480709.910938	4521199.659660
p01	pasture	SeB	480827.597548	4521172.612380
p01	pasture	SfC	480781.316579	4521220.611080
p02	pasture	ClC	481955.093750	4526807.000000
p02	pasture	ClC2	482086.250000	4526878.500000
p02	pasture	SfC	482100.093750	4526947.500000
p03	pasture	ClC	480566.468750	4526178.500000
p03	pasture	ClC2	480556.656250	4525527.500000
p04	pasture	ClC2	477535.375000	4514503.000000
p04	pasture	SeB	477415.500000	4514613.000000
p04	pasture	SfC	477465.562500	4514557.500000
p04	pasture	SfC2	477581.000000	4514622.000000
p05	pasture	SeB	479061.664543	4514316.954480
p05	pasture	SfC	479072.976503	4514288.800900
p06	pasture	CmC3	477981.437500	4514789.000000
p06	pasture	SeB	478001.781250	4514704.500000
p06	pasture	SfC2	477969.562500	4514744.000000
p07	pasture	SfC2	477331.812500	4513016.000000
p08	pasture	SfC2	477130.968750	4513083.500000
r02	row crop	SeB	479131.000000	4519947.500000
r02	row crop	SfC	479226.187500	4519790.500000

Table 1a. - continued.

Table 1a. (continued) Location of 82 of the 91 centroid pedons (locations given using UTM coordinates, all locations reside in UTM NAD 83, Zone 15).

r02	row crop	SfC2	479047.937500	4520097.500000
r03	row crop	ClC	475482.031250	4520734.500000
r03	row crop	ClC2	475312.375000	4520561.000000
r03	row crop	SeB	475409.562500	4520687.500000
r03	row crop	SfC2	475441.750000	4520696.000000
r04	row crop	ClC2	475598.718750	4520160.000000
r04	row crop	SeB	475508.468750	4520085.000000
r04	row crop	SfC	475631.093750	4520033.500000
r04	row crop	SfC2	475539.781250	4520205.500000
r05	row crop	CmC3	475974.156250	4520757.000000
r06	row crop	CmC3	476970.968750	4514022.000000
r07	row crop	CmC3	480951.812500	4524566.000000
r07	row crop	SfC	480580.797132	4524636.124300
r08	row crop	CmC3	472899.406250	4524097.500000
t01	trees	ClC2	472873.062500	4524772.000000
t02	trees	ClC2	471617.937500	4511767.000000
t02	trees	SfC	471476.267193	4511270.885300
t03	trees	ClC	480901.678974	4524404.612320
t03	trees	CmC3	480739.751247	4524591.989020
t03	trees	SfC	480922.035837	4524624.373750
t04	trees	SfC	475632.038995	4500225.729640

Table 1b. Location of grid pedons (locations given using UTM coordinates, all locations reside in UTM NAD 83, Zone 15).

GRID PEDONS

Field Identifier	Land Use	SMU	Easting (m)	Northing (m)
005	swg5	ClC	463028.599660	4518431.577600
005	swg5	ClC	462998.599660	4518401.577600
005	swg5	ClC	462978.599660	4518391.577600
005	swg5	ClC	463008.599660	4518301.577600
005	swg5	ClC	462928.599660	4518271.577600
005	swg5	ClC	462938.599660	4518251.577600
005	swg5	ClC	462948.599660	4518151.577600
005	swg5	ClC	462968.599660	4518061.577600
005	swg5	ClC	462918.599660	4518041.577600
005	swg5	ClC	462948.599660	4518041.577600
117	swg10	ClC2	477991.888879	4520880.299270
117	swg10	ClC2	477981.648841	4520871.104340
117	swg10	ClC2	477981.787632	4520847.316490
117	swg10	ClC2	477972.414582	4520837.168570
117	swg10	ClC2	477971.905428	4520819.252680
117	swg10	ClC2	478002.113220	4520809.820680

Table 1b. - continued.

Table 1b. (continued) Location of grid pedons (locations given using UTM coordinates, all locations reside in UTM NAD 83, Zone 15).

117	swg10	ClC2	477962.205293	4520799.245820
117	swg10	ClC2	477981.799219	4520800.017780
121	swg5	ClC	478750.087284	4520253.506610
121	swg5	ClC	478760.087243	4520253.506590
121	swg5	ClC	478720.087321	4520243.506730
121	swg5	ClC	478750.087197	4520243.506670
121	swg5	ClC	478780.086987	4520233.506670
121	swg5	ClC	478690.087357	4520233.506850
121	swg5	ClC	478790.086859	4520223.506710
121	swg5	ClC	478730.087106	4520223.506830
121	swg5	ClC	478770.086942	4520223.506750
121	swg5	ClC	478690.087183	4520213.506970
123	swg5	ClC2	478866.640000	4520621.814170
123	swg5	ClC2	478856.639868	4520601.814310
123	swg5	ClC2	478846.639823	4520591.814390
123	swg5	ClC2	478856.639781	4520591.814370
123	swg5	ClC2	478806.639901	4520581.814520
123	swg5	ClC2	478826.639645	4520561.814600
123	swg5	ClC2	478836.639604	4520561.814590
123	swg5	ClC2	478846.269564	4520561.844570
123	swg5	ClC2	478836.638736	4520461.815190
123	swg5	ClC2	478857.278044	4520391.885570
123	swg5	CmC3	478676.751235	4520673.474220
123	swg5	CmC3	478646.751272	4520663.474340
123	swg5	CmC3	478746.750597	4520633.474330
123	swg5	CmC3	478756.750382	4520613.474430
123	swg5	CmC3	478766.750341	4520613.474410
123	swg5	CmC3	478776.750213	4520603.474450
123	swg5	CmC3	478796.750130	4520603.474410
123	swg5	CmC3	478796.749956	4520583.474530
123	swg5	CmC3	478746.749990	4520563.474750
123	swg5	CmC3	478736.749944	4520553.474830
123	swg5	SeB	478742.389407	4520494.345180
123	swg5	SeB	478732.809106	4520455.085430
123	swg5	SeB	478742.858977	4520445.035470
123	swg5	SeB	478783.078549	4520414.865570
123	swg5	SeB	478742.958538	4520394.455780
123	swg5	SeB	478752.958409	4520384.455820
123	swg5	SeB	478772.958327	4520384.455780
123	swg5	SeB	478772.958153	4520364.455900
123	swg5	SeB	478782.957939	4520344.456000
123	swg5	SeB	478772.957806	4520324.456140
123	swg5	SfC2	478691.160896	4520641.314390
123	swg5	SfC2	478671.050892	4520631.264490

Table 1b. - continued.

Table 1b. (continued) Location of grid pedons (locations given using UTM coordinates, all locations reside in UTM NAD 83, Zone 15).

123	swg5	SfC2	478711.790723	4520631.264410
123	swg5	SfC2	478731.850465	4520611.154490
123	swg5	SfC2	478671.050634	4520601.574670
123	swg5	SfC2	478681.110592	4520601.574650
123	swg5	SfC2	478711.270380	4520591.524650
123	swg5	SfC2	478781.159829	4520561.364700
123	swg5	SfC2	478790.738750	4520441.675400
123	swg5	SfC2	478800.788535	4520421.575500
245	swg5	SfC	479113.639449	4522317.219790
245	swg5	SfC	479123.639477	4522317.220000
245	swg5	SfC	479103.638298	4522187.220360
245	swg5	SfC	479113.638066	4522157.220760
245	swg5	SfC	479133.638036	4522147.221260
245	swg5	SfC	479053.637121	4522067.220010
245	swg5	SfC	479093.637233	4522067.220880
245	swg5	SfC	479063.637063	4522057.220290
245	swg5	SfC	479103.637002	4522037.221280
245	swg5	SfC	479103.636915	4522027.221340
p01	pasture	ClC2	480749.912250	4521339.659670
p01	pasture	ClC2	480739.911879	4521299.659700
p01	pasture	ClC2	480729.911680	4521279.659610
p01	pasture	ClC2	480779.911735	4521269.660750
p01	pasture	ClC2	480799.911791	4521269.661180
p01	pasture	ClC2	480769.911621	4521259.660590
p01	pasture	ClC2	480779.911478	4521239.660930
p01	pasture	ClC2	480729.911166	4521219.659970
p01	pasture	ClC2	480659.910368	4521149.658880
p01	pasture	ClC2	480629.910112	4521129.658360
r01	row crop	ClC2	474579.562500	4521795.000000
r01	row crop	ClC2	474549.562500	4521735.000000
r01	row crop	ClC2	474569.562500	4521785.000000
r01	row crop	ClC2	474499.562500	4521695.000000
r01	row crop	ClC2	474519.562500	4521695.000000
r01	row crop	ClC2	474549.562500	4521775.000000
r01	row crop	ClC2	474559.562500	4521775.000000
r01	row crop	ClC2	474549.562500	4521765.000000
r01	row crop	ClC2	474539.562500	4521755.000000
r01	row crop	ClC2	474529.562500	4521745.000000
t01	trees	ClC2	472883.000000	4524802.000000
t01	trees	ClC2	472893.000000	4524802.000000
t01	trees	ClC2	472903.000000	4524802.000000
t01	trees	ClC2	472863.000000	4524782.000000
t01	trees	ClC2	472883.000000	4524782.000000
t01	trees	ClC2	472863.000000	4524762.000000

Table 1b. - continued.

Table 1b. (continued) Location of grid pedons (locations given using UTM coordinates, all locations reside in UTM NAD 83, Zone 15).

t01	trees	ClC2	472853.000000	4524752.000000
t01	trees	ClC2	472863.000000	4524752.000000
t01	trees	ClC2	472853.000000	4524742.000000
t01	trees	ClC2	472843.000000	4524722.000000
t01	trees	ClC2	472853.000000	4524722.000000

Table 1c. Location of grab epipedon (locations given using UTM coordinates, all locations reside in UTM NAD 83, Zone 15).

GRAB - EPIPEDONS (20 CM)

Field Identifier	Land Use	SMU	Easting (m)	Northing (m)
005	swg5	ClC	462988.599660	4518351.577600
005	swg5	ClC	462988.599660	4518341.577600
005	swg5	ClC	462928.599660	4518291.577600
005	swg5	ClC	462978.599660	4518281.577600
005	swg5	ClC	463018.599660	4518271.577600
005	swg5	ClC	462918.599660	4518171.577600
005	swg5	ClC	462958.599660	4518171.577600
005	swg5	ClC	462938.599660	4518161.577600
005	swg5	ClC	462928.599660	4518121.577600
005	swg5	ClC	462958.599660	4518111.577600
005	swg5	ClC	462968.599660	4518081.577600
005	swg5	ClC	462988.599660	4518081.577600
005	swg5	ClC	462998.599660	4518071.577600
005	swg5	ClC	462968.599660	4518051.577600
005	swg5	ClC	462888.599660	4517981.577600
117	swg10	ClC2	477987.965988	4520890.968210
117	swg10	ClC2	477982.020745	4520860.350410
117	swg10	ClC2	477989.554803	4520870.547330
117	swg10	ClC2	477991.133711	4520860.778390
117	swg10	ClC2	477990.893623	4520850.645450
117	swg10	ClC2	477981.953570	4520840.287530
117	swg10	ClC2	477990.377537	4520840.540510
117	swg10	ClC2	477972.975346	4520810.384730
117	swg10	ClC2	477991.609271	4520810.690700
117	swg10	ClC2	477971.596255	4520799.311800
117	swg10	ClC2	477992.125170	4520799.306760
117	swg10	ClC2	477982.274122	4520789.153850
117	swg10	ClC2	478001.866050	4520790.286800
121	swg5	ClC	478770.087202	4520253.506570
121	swg5	ClC	478780.087161	4520253.506550
121	swg5	ClC	478700.087403	4520243.506770

Table 1c. - continued.

Table 1c. (continued) Location of grab epipedon (locations given using UTM coordinates, all locations reside in UTM NAD 83, Zone 15).

121	swg5	ClC	478710.087362	4520243.506750
121	swg5	ClC	478760.087156	4520243.506650
121	swg5	ClC	478770.087115	4520243.506630
121	swg5	ClC	478700.087316	4520233.506830
121	swg5	ClC	478710.087275	4520233.506810
121	swg5	ClC	478720.087234	4520233.506790
121	swg5	ClC	478730.087193	4520233.506770
121	swg5	ClC	478770.087028	4520233.506690
121	swg5	ClC	478700.087229	4520223.506890
121	swg5	ClC	478740.087065	4520223.506810
121	swg5	ClC	478760.086983	4520223.506770
121	swg5	ClC	478700.087142	4520213.506950
123	swg5	ClC2	478856.640128	4520631.814130
123	swg5	ClC2	478816.640120	4520611.814320
123	swg5	ClC2	478836.639864	4520591.814400
123	swg5	ClC2	478816.639686	4520561.814620
123	swg5	ClC2	478826.639554	4520551.314670
123	swg5	ClC2	478816.639079	4520491.815050
123	swg5	ClC2	478796.959074	4520481.895140
123	swg5	ClC2	478807.018945	4520471.835180
123	swg5	ClC2	478807.018771	4520451.735310
123	swg5	ClC2	478827.118688	4520451.735270
123	swg5	ClC2	478826.168343	4520411.515510
123	swg5	ClC2	478847.228173	4520401.945530
123	swg5	ClC2	478857.278131	4520401.945510
123	swg5	ClC2	478857.277957	4520381.835630
123	swg5	ClC2	478856.327874	4520371.865690
123	swg5	CmC3	478696.751239	4520683.474120
123	swg5	CmC3	478716.751069	4520673.474140
123	swg5	CmC3	478746.750945	4520673.474090
123	swg5	CmC3	478746.750684	4520643.474270
123	swg5	CmC3	478766.750515	4520633.474290
123	swg5	CmC3	478756.750469	4520623.474370
123	swg5	CmC3	478746.750337	4520603.474510
123	swg5	CmC3	478766.750254	4520603.474470
123	swg5	CmC3	478736.750205	4520583.474650
123	swg5	CmC3	478766.750081	4520583.474590
123	swg5	CmC3	478736.750118	4520573.474710
123	swg5	CmC3	478736.750031	4520563.474770
123	swg5	CmC3	478776.749866	4520563.474690
123	swg5	CmC3	478746.689905	4520553.704810
123	swg5	CmC3	478756.639864	4520553.704790
123	swg5	SeB	478742.859493	4520504.395110
123	swg5	SeB	478723.239486	4520494.345210

Table 1c. - continued.

Table 1c. (continued) Location of grab epipedon (locations given using UTM coordinates, all locations reside in UTM NAD 83, Zone 15).

123	swg5	SeB	478742.239233	4520474.235300
123	swg5	SeB	478743.339058	4520454.605410
123	swg5	SeB	478743.338884	4520434.495530
123	swg5	SeB	478753.398842	4520434.495510
123	swg5	SeB	478783.078454	4520403.855640
123	swg5	SeB	478732.958579	4520394.455800
123	swg5	SeB	478752.958496	4520394.455760
123	swg5	SeB	478742.958364	4520374.455900
123	swg5	SeB	478762.958281	4520374.455860
123	swg5	SeB	478722.958359	4520364.456000
123	swg5	SeB	478792.958071	4520364.455860
123	swg5	SeB	478782.958025	4520354.455940
123	swg5	SeB	478762.958021	4520344.456040
123	swg5	SfC2	478720.790769	4520640.834330
123	swg5	SfC2	478641.371010	4520630.784550
123	swg5	SfC2	478730.900295	4520591.044610
123	swg5	SfC2	478791.219871	4520570.934620
123	swg5	SfC2	478721.319902	4520541.254930
123	swg5	SfC2	478750.879781	4520541.424870
123	swg5	SfC2	478730.899775	4520531.204980
123	swg5	SfC2	478721.319731	4520521.625050
123	swg5	SfC2	478760.879479	4520511.425040
123	swg5	SfC2	478781.159135	4520481.415180
123	swg5	SfC2	478771.588825	4520441.205440
123	swg5	SfC2	478781.158786	4520441.205420
123	swg5	SfC2	478801.268703	4520441.205380
123	swg5	SfC2	478821.378101	4520381.355700
123	swg5	SfC2	478890.317472	4520341.625800
245	swg5	SfC	479013.638133	4522197.218360
245	swg5	SfC	479113.638326	4522187.220580
245	swg5	SfC	479123.638354	4522187.220800
245	swg5	SfC	479113.637980	4522147.220820
245	swg5	SfC	479043.637525	4522117.219490
245	swg5	SfC	479113.637634	4522107.221070
245	swg5	SfC	479123.637490	4522087.221410
245	swg5	SfC	479073.637091	4522057.220510
245	swg5	SfC	479093.637146	4522057.220940
245	swg5	SfC	479053.636948	4522047.220140
245	swg5	SfC	479063.636890	4522037.220410
245	swg5	SfC	479063.636803	4522027.220470
245	swg5	SfC	479083.636773	4522017.220970
245	swg5	SfC	479093.636801	4522017.221180
245	swg5	SfC	479113.636770	4522007.221680
p01	pasture	ClC2	480759.912278	4521339.659890

Table 1c. - continued.

Table 1c. (continued) Location of grab epipedon (locations given using UTM coordinates, all locations reside in UTM NAD 83, Zone 15).

p01	pasture	ClC2	480749.911907	4521299.659920
p01	pasture	ClC2	480769.911878	4521289.660410
p01	pasture	ClC2	480779.911821	4521279.660690
p01	pasture	ClC2	480789.911849	4521279.660910
p01	pasture	ClC2	480789.911763	4521269.660970
p01	pasture	ClC2	480759.911593	4521259.660380
p01	pasture	ClC2	480789.911506	4521239.661150
p01	pasture	ClC2	480739.911280	4521229.660130
p01	pasture	ClC2	480759.911336	4521229.660560
p01	pasture	ClC2	480769.911364	4521229.660780
p01	pasture	ClC2	480729.911080	4521209.660030
p01	pasture	ClC2	480719.910966	4521199.659880
p01	pasture	ClC2	480729.910994	4521199.660090
p01	pasture	ClC2	480719.910880	4521189.659940
r01	row crop	ClC2	474549.562500	4521745.000000
r01	row crop	ClC2	474529.562500	4521735.000000
r01	row crop	ClC2	474529.562500	4521725.000000
r01	row crop	ClC2	474539.562500	4521725.000000
r01	row crop	ClC2	474549.562500	4521725.000000
r01	row crop	ClC2	474559.562500	4521725.000000
r01	row crop	ClC2	474519.562500	4521715.000000
r01	row crop	ClC2	474529.562500	4521715.000000
r01	row crop	ClC2	474539.562500	4521715.000000
r01	row crop	ClC2	474519.562500	4521705.000000
r01	row crop	ClC2	474509.562500	4521695.000000
r01	row crop	ClC2	474529.562500	4521695.000000
r01	row crop	ClC2	474539.562500	4521695.000000
r01	row crop	ClC2	474539.562500	4521765.000000
r01	row crop	ClC2	474539.562500	4521745.000000
t01	trees	ClC2	472913.000000	4524812.000000
t01	trees	ClC2	472913.000000	4524802.000000
t01	trees	ClC2	472863.000000	4524792.000000
t01	trees	ClC2	472873.000000	4524792.000000
t01	trees	ClC2	472883.000000	4524792.000000
t01	trees	ClC2	472893.000000	4524792.000000
t01	trees	ClC2	472903.000000	4524792.000000
t01	trees	ClC2	472863.000000	4524772.000000
t01	trees	ClC2	472883.000000	4524772.000000
t01	trees	ClC2	472863.000000	4524742.000000
t01	trees	ClC2	472843.000000	4524732.000000
t01	trees	ClC2	472853.000000	4524732.000000
t01	trees	ClC2	472863.000000	4524732.000000
t01	trees	ClC2	472843.000000	4524712.000000

Table 2. Farmers, field locations, and other pertinent information about the soil map units (SMU's) used for grid pedon and grab sample analyses.

Soil Map Unit	Conventionally Managed Row Cropped Fields (15 yrs old)	Switchgrass fields Approximately 10 yrs old	Switchgrass fields Approximately 5 yrs old	Woodlots (15 yrs old)	Pastures (15 yrs old)
Grid Sampling Sites					
SeB			John Sellers Field #123 (est.1998) Sect 27, T70N R21W Sampled 06/19-06/20/02		
SfC			Joann Cemensky Field #245 (est.1998) Sec.23, T70N, R21W Sampled 06/26/02		
SfC2			John Sellers Field #123 (est.1998) Sect 27, T70N, R21W Sampled 06/19-06/20/02		
ClC			Wallace Harvey Field #005 (est. 2001) W1/2 Sect. 31 T70N, R22W Sampled 05/19/03		
ClC2	Mark Batchelder Field #r01(est.1979) Sect. 20, T70N, R21W Sampled 04/23/03	John Sellers Field #117 (est.1987) NW1/4 Sect.27, T70N, R21W Sampled 06/26/02	John Sellers Filed #123 (est.1998) Sect. 27, T70N, R21W Sampled 06/20/02	Mark Batchelder Field #t01 (est.) Sect. 7, T70N, R21W Sampled 10/30/03	Jim Fetters Field #p01(est.1986) SW , Sect.24, T70N, R21W Sampled 09/17/02
CmC3			John Sellers Field #123 (est.1998) Sect. 27, T70N, R21W Sampled 06/19-06/20/02		

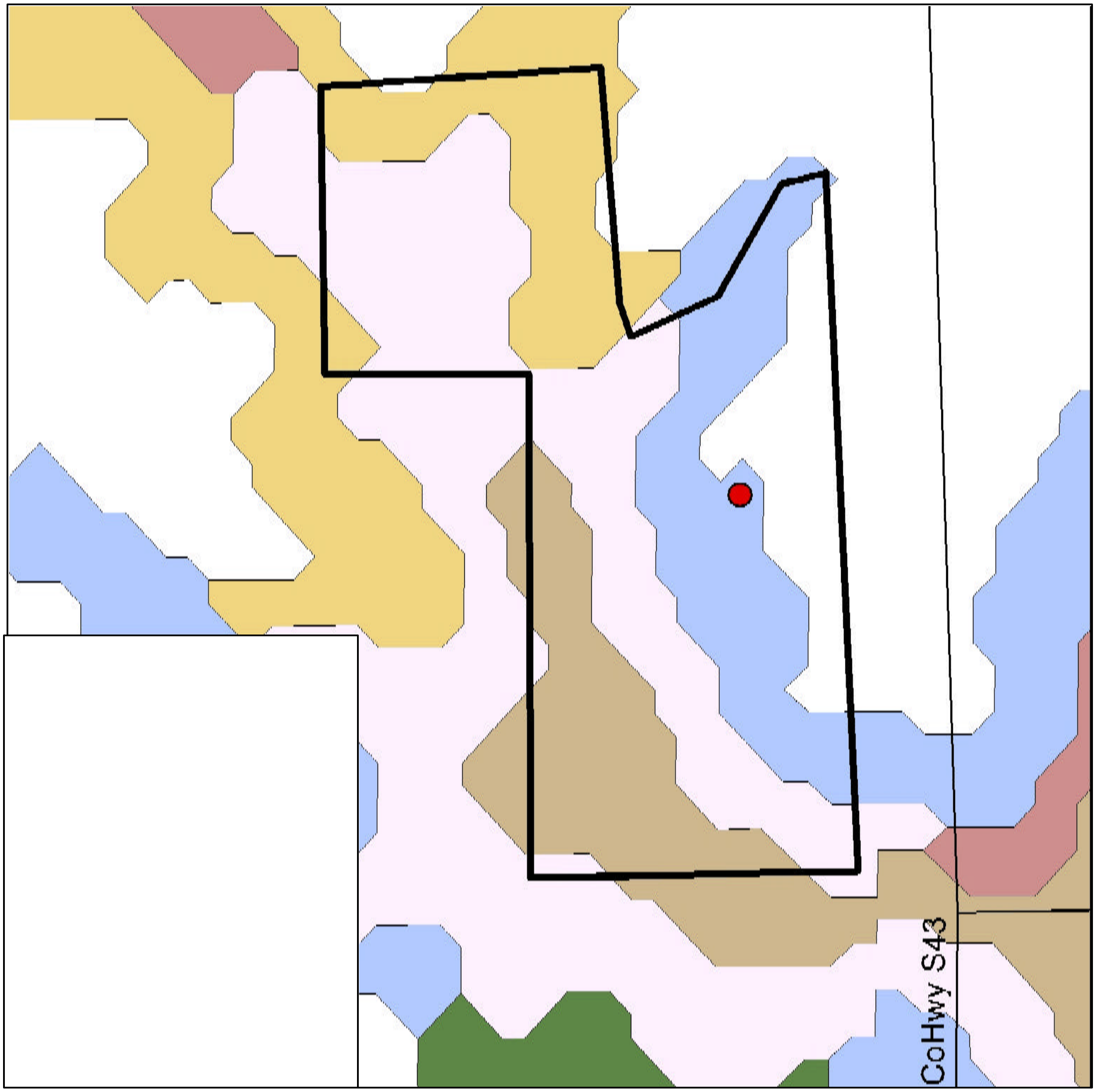

Figure 3. Example map showing a centroid pedon location. This shows Field #123 (Switchgrass 5 years old) S ½, NE ¼, Section 27, T70N, R21W showing ClC2 centroid. The field owner is John Sellers.

Results & Discussion

General Properties

This study collected, described and analyzed 200 pedons with 91 being centroid pedons and the other 109 being grid pedons. The centroid pedons come from 91 SMU's, which were distributed among 33 fields (Table 1a). The grid pedons were, obviously perhaps, collected from grids superimposed on eight fields (Table 1b). The eight fields and grid points were selected at random. Epipedon "grab" (n = 162) samples were collected at random points on grids from the same eight fields as the grid pedons (Table 1c).

Morphological descriptions of these pedons (descriptions not given) reveal a number of interesting features pertinent to this study although these observations are perhaps obscure to anyone but a soil scientist due to the complexity of the jargon and abbreviations used. In an attempt to amalgamate this data and present it in a generally communicative form, we used Soil Taxonomy (USDA, 1999) to classify 41 of the 200 described pedons. These 41 pedons were selected at random (Table 3). Classification is to the great group level and based entirely upon the morphological descriptions. Table 4 summarizes the classification into major components.

Table 3. Actual taxonomic classification of 41 pedons selected at random from Clarinda and Seymour soil map units in the Chariton Valley, Iowa.

n	SMU	Pedon number	Actual taxonomic classification (solely morphology-based)
Pedons from Clarinda soil map units. Official pedon classification = Vertic Argiaquoll			
1	ClC	11r013	Cumulic Endoaquoll
2	ClC	111243	Vertic Epiaqualf
3	ClC	2100530161	Aquertic Hapludalf
4	ClC	2100530741	Typic Hapludalf
5	ClC2	12p013	Vertic Argiaquoll
6	ClC2	12r033	Typic Argiaquoll
7	ClC2	12r013	Typic Argiaquoll
8	ClC2	22p013	Vertic Epiaqualf
9	ClC2	22p013036	Cumulic Endoaquoll
10	ClC2	22p013042	Cumulic Endoaquoll
11	ClC2	22p013101	Vertic Endoaqualf
12	ClC2	22r013	Typic Endoaqualf
13	ClC2	22r013004	Abruptic Argiaquoll
14	ClC2	2211730011	Typic Argiaquoll
15	ClC2	2211730101	Typic Argiaquoll
16	ClC2	221173002	Aquertic Hapludalf
17	ClC2	2212330091	Typic Hapludalf
18	CmC3	2312330161	Aquertic Hapludalf
19	CmC3	131243-c1	Aquertic Argiudoll
20	CmC3	13t033-c1	Typic Argiaquoll
21	CmC3	13r073	Mollic Epiaqualf

Table 3. – continued.

Table 3. (continued) Actual taxonomic classification of 41 pedons selected at random from Clarinda and Seymour soil map units in the Chariton Valley, Iowa.

n	SMU	Pedon number	Actual taxonomic classification (solely morphology-based)
Pedons from Seymour soil map units. Official pedon classification = Aquertic Argiudoll			
22	SeB	14p053	Aquertic Hapludalf
23	SeB	14p043	Aquertic Hapludalf
24	SeB	14p013	Vertic Argiaquoll
25	SeB	14r043	Cumulic Endoaquoll
26	SeB	2412330531	Typic Argiaquoll
27	SfC	15r073	Typic Argiaquoll
28	SfC	15p023	Aquertic Argiudoll
29	SfC	15p053	Vertic Epiaqualf
30	SfC	151183-c1	Typic Argiaquoll
31	SfC	150403-c1	Vertic Epiaqualf
32	SfC	2524530471	Aquertic Argiudoll
33	SfC	2524531021	Aquertic Argiudoll
34	SfC	15t033-c1	Typic Argiaquoll
35	SfC	151053-c1	Vertic Epiaqualf
36	SfC	15t043-c1	Typic Argiudoll
37	SfC2	2612330491	Vertic Epiaqualf
38	SfC2	2612330501	Typic Argiaquoll
39	SfC2	2612330631	Typic Argiaquoll
40	SfC2	2612330711	Aquertic Hapludalf
41	SfC2	2612331291	Vertic Argiaquoll

Table 4. Comparison of ideal and actual taxonomic classification of 41 pedons selected at random from Clarinda and Seymour soil map units in the Chariton Valley, Iowa. Column one indicates how pedons were partitioned.

Part A. Official USDA-NRCS series classification					
Series or SMU	n	Order	Suborder	Great Group	Subgroup
Clarinda	21	Mollisol	Aquoll	Argiaquoll	Vertic Argiaquoll
Seymour	20	Mollisol	Udoll	Argiudoll	Aquertic Argiudoll
Part B. Number of pedons matching official series classification.					
Series or SMU	n	Order	Suborder	Great Group	Subgroup
All Clarinda pedons	21	11	10	7	1
ClC pedons	4	1	1	0	0
ClC2 pedons	13	8	8	6	1
CmC3 pedons	4	2	1	1	0

Table 4. – continued.

Table 4. (continued) Comparison of ideal and actual taxonomic classification of 41 pedons selected at random from Clarinda and Seymour soil map units in the Chariton Valley, Iowa. Column one indicates how pedons were partitioned.

Series or SMU	n	Order	Suborder	Great Group	Subgroup	
All Seymour pedons	20	13	4	4	3	
SeB pedons	5	3	0	0	0	
SfC pedons	10	7	4	4	3	
SfC2 pedons	5	3	0	0	0	
Part C. Number of pedons having udic and aquic soil moisture regimes (SMR). Ideal Clarinda pedons would have aquic SMR. Ideal Seymour pedons would have udic SMR.						
	n	udic	aquic			
All Clarinda pedons	21	6	15			
All Seymour pedons	20	7	13			
Part D. Number of pedons having ochric, mollic or cumulic epipedons based on ≤ 3/3 moist chroma and moist value and having argillic or cambic B horizons. Ideal Clarinda and Seymour pedons would have mollic epipedons and argillic B horizons.						
	n	ochric	mollic	cumulic	argillic	cambic
All Clarinda pedons	21	10	8	3	18	3
ClC pedons	4	3	0	1	3	1
ClC2 pedons	13	5	6	2	11	2
CmC3 pedons	4	2	2	0	4	0
All Seymour pedons	20	7	12	1	17	3
SeB pedons	5	2	2	1	4	1
SfC pedons	10	3	7	0	8	2
SfC2 pedons	5	2	3	0	5	0

Tables 3 and 4 summarize the considerable morphological variability present in Clarinda and Seymour SMU's in the Chariton Valley. Only 24 out of the 41 (60%) pedons are Mollisols, with Mollisol being the soil order to which these two series belong (Table 4, part B). The other 40% are Alfisols. The conversion of Mollisols to Alfisols probably reflects excessive erosion of the A-horizon, which is due to long-term and largely discontinued farming practices. In other words, the commonality of Alfisols is not surprising given the well-documented erodibility of the soils of the Chariton Valley and the history of the area's farming. What is surprising is the lack of correlation between SMU erosion class and prevalence of Alfisols. Uneroded SMU's (i.e. ClC and SeB) are as likely to contain Alfisol pedons as severely eroded SMU's (i.e., CmC3 and SfC2). It is possible this finding reflects erosion that occurred subsequent to the USDA-NRCS soil surveys used to identify the SMU's sampled.

About one-third of the Clarinda pedons have udic soil moisture regimes (SMR) instead of the expected aquic SMR (Table 4, part C). Likewise about one-third of the Seymour pedons have aquic SMR instead of the expected udic SMR (Table 4, part C). Pragmatically this suggests many Clarinda SMU's are a little better drained than expected and that many Seymour SMU's are a little more poorly drained than expected. In turn, this means these soils are probably a little more alike than we thought they would be from our perusal of the literature. This finding likely reflects classical pedology's use representative pedons for comparisons as opposed to differentiating soils based upon some sort of spatially continuous model.

The preceding observations contain two important findings vis-à-vis this project's objectives. First, differences across SMU erosion classes within a series are not as substantive as expected. Thus, it will be more difficult to estimate rates of recovery under switchgrass, which is the heart of objective (3). The second important finding is Clarinda and Seymour SMU's have more in common morphologically than expected. In conjunction, these two findings suggest SMU's may not be a key controlling factor with regards to SOC and soil quality. This possibility will be furthered explored in the synthesis section.

Centroid Pedons

The use of representative pedons for characterization of SMU's is common in pedology with "representative" often being theoretically more-or-less synonymous with "centroid." The advantages of a centroid approach are manifold and that is why this study used it. These advantages include it being simple because it is one identifiable point – the geographical center of an SMU. Second, centroids have an intuitive appeal, again, because each is the geographical center of a SMU. Third, by being the center it is often assumed to be the single point that best represents the SMU. And if it really represents the SMU then statistical analyses are unnecessary, thus, saving the time and costs associated with measuring whole population characteristics (which are needed before classical statistics can be applied). Fourth, the representative approach is valid statistically, provided an expert – such as an experienced soil surveyor - is the one identifying the point and he/she uses the formal Braun-Blanquet relevé methodology (e.g., see Barbour et al, 1982). The key weakness of the representative/centroid approach is population characteristics are not known.

Table 5 summarizes five important properties of just the uppermost horizon of the combined Clarinda and Seymour centroid pedons. (The term "epipedon" will sometimes be used instead of "uppermost horizon" or "horizon 1" although epipedon is a scientifically explicit term while the others are not). Table 5 indicates most A horizons are between 15 and 25 cm thick (i.e., the typical thickness of historical plowing), have excellent bulk densities for plant growth, and contain very roughly 23 tons of SOC per acre and 2 tons of soil organic nitrogen (SON) per acre. They also possess ideal carbon to nitrogen ratios (C:N) for plant growth.

Table 5. Summary of selected properties of "horizon 1" for the centroid pedons, Chariton Valley, Iowa.

	Thickness	Bulk Density	SOC	SON	C:N
	(cm)	(g cm^{-3})	(%)	(%)	
Mean	20.3	1.26	2.29	0.19	12.85
St. Dev.	5.76	0.13	0.59	0.06	1.89
% St. Dev.	28.4	10.0	25.9	34.2	14.7
Min. Value	9	0.91	1.44	0.09	7.50
Max. Value	37	1.78	4.22	0.45	20.01
Skewness	0.61	0.37	1.20	1.57	0.37
Kurtosis	0.37	2.29	1.32	3.23	1.99

The skewness and kurtosis values in Table 5 indicate A horizon thickness has a normal distribution with a distinct peak around the mean value and obvious tails. With respect to bulk density, the skewness value of 0.37 indicates a normal distribution while the kurtosis value of 2.29 indicates that distribution is slightly flat (i.e., not much range in the values). The "flatness" in a bulk density histogram having normal distribution is reasonable given the overall homogeneous set of soil properties and land use histories.

Table 6 summaries centroid pedon properties using specific depth increments, which is different than Table 5, which solely looked at the topmost A horizon. The depth approach is used extensively in this report because specific depth increments are popular within the carbon sequestration arena. The advantages and limitations of depth increment use will not be discussed herein. Table 6 shows bulk density increases with depth and SOC decreases with depth. Both results are expected and consistent with McLaughlin (2003) and Burras and McLaughlin (2002). Table 6 suggests the rough SOC content to 0.2 m (8 inches), 0.5 m (20 inches) and 1.0 m (40 inches) are 24, 42, and 55 tons per acre, respectively. These values are consistent with those reported by Burras and McLaughlin (2002).

Table 6. Summary of bulk density (oven dried) and SOC (weight/volume) for three depths in the centroid pedons, Chariton Valley, Iowa.

	Bulk Density	SOC	Bulk Density	SOC	Bulk Density	SOC
	(g cm^{-3})	(kg m^{-2})	(g cm^{-3})	(kg m^{-2})	(g cm^{-3})	(kg m^{-2})
	0.0 to 0.2 m depth		0.0 to 0.5 m depth		0.0 to 1.0 m depth	
Mean	1.27	5.4	1.32	9.5	1.41	12.4
St. Dev.	0.12	1.2	0.09	2.3	0.10	3.3
% St. Dev.	9.3	22.4	7.0	24.1	6.8	26.6
Min. Value	0.91	3.1	1.02	5.1	1.12	7.5
Max. Value	1.69	9.6	1.53	15.8	1.70	23.9
Skewness	0.11	0.97	-0.09	0.41	0.18	0.66
Kurtosis	1.52	1.26	0.61	-0.14	1.57	0.45

On average 45% and 77% of the SOC content of centroid pedons is found in the top 20 cm and 50 cm, respectively (Table 7). This is consistent with the findings of Burras and McLaughlin (2002) and McLaughlin (2003). The data exhibit a nonskewed normal distribution lacking in kurtosis (Table 7), which is ideal for making predictions such as, ultimately, the Chariton Valley RC&D, ORNL and USDOE seek.

Table 7. Proportion of SOC content (wt/volume values) in the upper profile of centroid pedons from a variety of land uses in the Chariton Valley, Iowa. Reference SOC contents are 1.0 m.

		Proportion of SOC in upper 20 cm	Proportion of SOC in upper 50 cm
Mean		0.45	0.77
St. Dev.		0.08	0.06
% St. Dev.		17.7	7.2
Min. Value		0.26	0.60
Max. Value		0.66	0.90
Skewness		-0.20	-0.74
Kurtosis		-0.28	0.97

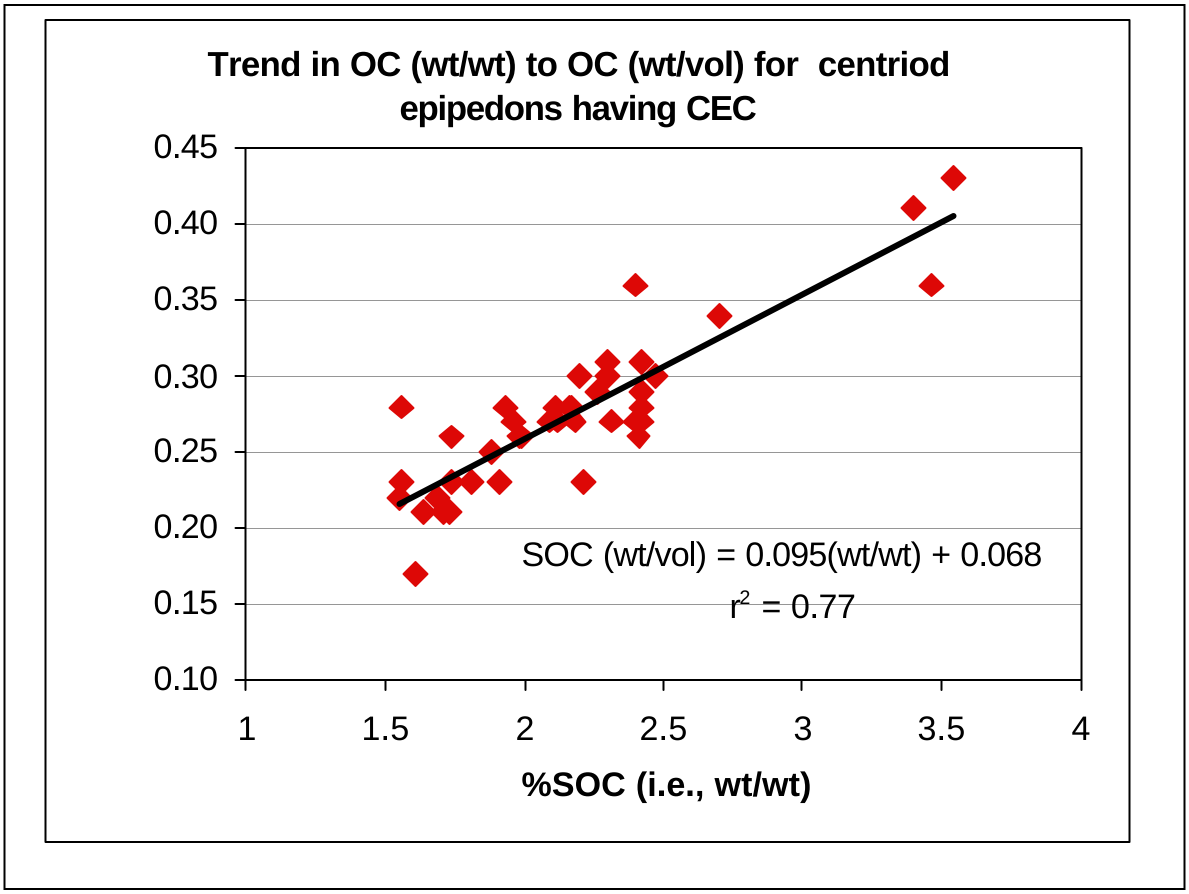

Figure 4. Relationship between SOC content in 41 centroid pedons determined on a weight-weight basis versus weight-volume basis. These pedons were also analyzed for CEC.

It is important to note the SOC content of interest in the policy arena of carbon sequestration is the weight of SOC per unit area of land (or, really, per unit area of land to some depth) the laboratory analyses of SOC content must occur on a weight-weight basis (i.e., SOC is determined as a percent of the total soil weight). In order to mathematically convert between these two forms of SOC one must know soil bulk density although Figure 4 suggests a strong regression relationship exists between these two SOC numbers. Thus, at least for centroid pedons in the Chariton Valley simply measuring SOC as a weight percentage might be adequate for SOC policy decisions.

Table 8. Summary of selected properties of “horizon 1” for centroid pedons partitioned by soil map unit and land use, Chariton Valley, Iowa. Values are given as means±standard deviation when n ≥ 3, as mean when n = 2 and as value when n = 1.

SMU by land use ⇓	n	Thickness	Bulk Density	SOC	SON	C:N
		(cm)	(g cm^{-3})	(%)	(%)	
ClC – Row Crop	4	23.0±10.4	1.28±0.10	2.38±0.83	0.20±0.08	12.4±0.8
ClC – Woodlots	0					
ClC – SWG 5	4	20.3±2.8	1.35±0.09	1.98±0.40	0.15±0.03	13.6±1.1
ClC – SWG 10	2	23.5	1.28	2.07	0.14	14.8
ClC – Pasture	2	15.8	1.31	2.77	0.26	10.7
ClC2 – Row Crop	3	26.8±9.2	1.22±0.04	2.08±0.21	0.15±0.02	13.4±0.4
ClC2 – Woodlots	2	26.5	1.32	2.12	0.15	13.7
ClC2 – SWG 5	4	16.8±5.2	1.22±0.13	2.22±0.25	0.18±0.03	12.7±1.0
ClC2 – SWG 10	4	21.6±6.0	1.29±0.05	2.14±0.22	0.15±0.01	14.0±1.3
ClC2 – Pasture	4	18.9±4.5	1.31±0.06	2.62±0.73	0.21±0.06	12.6±0.7
CmC3 – Row Crop	3	21.0±9.5	1.27±0.22	1.70±0.25	0.14±0.03	12.6±0.7
CmC3 – Woodlots	1	25.0	1.18	4.08	0.45	9.2
CmC3 – SWG 5	4	22.5±7.2	1.25±0.04	2.31±0.48	0.19±0.05	12.7±1.2
CmC3 – SWG 10	2	19.0	1.39	1.75	0.13	13.9
CmC3 – Pasture	1	17.5	1.32	2.07	0.18	11.6
SeB – Row Crop	4	25.3±4.7	1.31±0.08	1.97±0.15	0.13±0.03	16.2±3.0
SeB – Woodlots	1	21	1.13	3.74	0.24	15.6
SeB – SWG 5	4	19.1±3.2	1.39±3.22	2.27±0.79	0.21±0.08	10.8±1.2
SeB – SWG 10	4	19.3±3.8	1.20±0.12	2.22±0.14	0.19±0.01	11.8±1.5
SeB – Pasture	4	21.0±4.8	1.25±0.10	2.30±0.37	0.20±0.04	11.8±1.9
SfC - Row Crop	4	17.5±9.7	1.34±0.12	1.90±0.31	0.15±0.04	13.1±1.5
SfC - Woodlots	3	23.2±9.0	1.00±0.08	3.46±0.66	0.27±0.06	13.0±0.8
SfC – SWG 5	4	17.1±3.8	1.25±0.18	2.48±0.81	0.23±0.10	11.0±1.7
SfC – SWG 10	4	17.4±4.8	1.15±0.04	2.66±0.22	0.17±0.01	15.5±0.6
SfC - Pasture	7	20.2±3.4	1.27±0.11	2.40±0.50	0.20±0.06	12.5±1.5
SfC2 - Row Crop	4	19.9±3.9	1.24±0.12	1.88±0.30	0.15±0.02	13.4±0.7
SfC2 - Woodlots	0					
SfC2 – SWG 5	4	17.6±4.2	1.21±0.07	2.18±0.33	0.21±0.03	10.3±3.9
SfC2 – SWG 10	3	18.8±3.8	1.29±0.02	1.84±0.13	na	na
SfC2 - Pasture	1	14.5	1.40	2.94	0.26	11.5
na = not available						

Table 9. Summary of SOC (weight/volume) for three depths for centroid pedons partitioned by soil map unit and land use, Chariton Valley, Iowa. Values are given as means±standard deviation when n ≥ 3, as the mean when n = 2 and as the value when n = 1.

SMU by land use ⇓	n	SOC	SOC	SOC	Proportion of SOC in upper	
		(kg m^{-2})	(kg m^{-2})	(kg m^{-2})		
		0.0 to 0.2 m	0.0 to 0.5 m	0.0 to 1.0 m	20 cm	50 cm
ClC - Row Crop	4	5.6±1.6	11.5±2.6	15.0±2.6	0.37	0.76
ClC - Woodlots	0					
ClC – SWG 5	4	5.9±0.6	10.0±1.1	13.5±2.1	0.39	0.75
ClC – SWG 10	2	4.8	9.8	13.3	0.40	0.76
ClC - Pasture	2	6.4	10.2	11.6	0.55	0.87
ClC2 - Row Crop	3	5.0±0.5	10.1±2.1	13.3±3.3	0.39	0.76
ClC2 - Woodlots	2	6.9	11.6	14.4	0.48	0.81
ClC2 – SWG 5	4	4.7±0.6	7.9±1.9	10.1±2.5	0.48	0.78
ClC2 – SWG 10	4	5.3±0.8	9.9±2.8	12.8±4.4	0.44	0.79
ClC2 - Pasture	4	6.4±1.5	10.9±2.7	14.7±6.4	0.48	0.78
CmC3 - Row Crop	3	3.9±0.5	7.0±1.5	9.6±3.0	0.43	0.75
CmC3 - Woodlots	1	9.6	15.7	19.1	0.50	0.82
CmC3 – SWG 5	4	5.5±0.8	9.4±1.9	12.6±3.2	0.44	0.76
CmC3 – SWG 10	2	4.6	7.4	9.1	0.51	0.81
CmC3 - Pasture	1	5.1	9.3	15.3	0.34	0.61
SeB - Row Crop	4	5.2±0.6	10.1±1.2	13.8±2.6	0.39	0.74
SeB - Woodlots	1	8.4	12.7	16.2	0.52	0.79
SeB – SWG 5	4	5.8±1.7	9.3±3.2	11.8±4.2	0.51	0.80
SeB – SWG 10	4	5.0±0.6	8.4±1.5	10.8±2.5	0.48	0.78
SeB - Pasture	4	5.5±0.8	9.6±1.2	12.3±1.5	0.45	0.78
SfC - Row Crop	4	4.5±1.00	7.9±2.4	10.7±2.9	0.42	0.74
SfC - Woodlots	3	6.8±1.4	13.3±2.2	17.5±2.6	0.38	0.76
SfC – SWG 5	4	5.8±1.1	9.97±2.2	12.0±2.5	0.48	0.80
SfC – SWG 10	4	5.8±0.7	9.9±1.3	12.9±1.7	0.45	0.77
SfC - Pasture	7	5.8±1.2	9.5±1.8	11.9±2.1	0.49	0.80
SfC2 - Row Crop	4	4.5±1.1	7.9±2.4	10.8±4.2	0.44	0.75
SfC2 - Woodlots	0					
SfC2 – SWG 5	4	5.0±0.8	8.3±1.7	10.8±2.6	0.47	0.78
SfC2 – SWG 10	3	4.5±0.71	7.4±1.6	9.3±1.6	0.48	0.79
SfC2 - Pasture	1	6.7	10.4	12.4	0.55	0.84

Table 10. Summary of selected properties of "horizon 1" for Clarinda centroid pedons partitioned by land use, Chariton Valley, Iowa. Values are given as means±standard deviation.

SMU by land use ⇓	n	Thickness	Bulk Density	SOC	SON	C:N
		(cm)	(g cm^{-3})	(%)	(%)	
Row Crop	10	23.6±9.0	1.26±0.12	2.09±0.58	0.17±0.05	12.8±0.7
Woodlots	3	26.0±4.6	1.27±0.12	2.77±1.32	0.25±0.17	12.2±2.6
SWG 5	12	19.8±5.5	1.27±0.10	2.17±0.38	0.17±0.04	13.0±1.1
SWG 10	8	21.4±6.3	1.31±0.12	2.03±0.30	0.14±0.02	14.2±1.0
Pasture	7	17.8±3.6	1.31±0.09	2.59±0.68	0.22±0.07	11.9±1.1
All Clarinda centroid pedons	40	21.2±6.6	1.28±0.11	2.24±0.60	0.18±0.07	12.9±1.3

Table 11. Summary of SOC (weight/volume) for three depths for Clarinda centroid pedons partitioned land use, Chariton Valley, Iowa. Values are given as means±standard deviation.

SMU by land use ⇓	n	SOC	SOC	SOC	Proportion of SOC in upper	
		(kg m^{-2})	(kg m^{-2})	(kg m^{-2})		
		0.0 to 0.2 m	0.0 to 0.5 m	0.0 to 1.0 m	20 cm	50 cm
Row Crop	10	4.9±1.2	9.7±2.7	12.9±3.5	0.39	0.76
Woodlots	3	7.8±1.6	13.0±2.3	15.9±2.7	0.49	0.81
SWG 5	12	5.1±0.7	9.1±1.8	12.1±2.8	0.44	0.76
SWG 10	8	5.0±0.7	9.3±2.5	12.0±4.1	0.44	0.79
Pasture	7	6.2±1.3	10.5±2.2	13.9±4.9	0.48	0.78
All Clarinda centroid pedons	40	5.4±1.3	9.8±1.3	12.9±3.7	0.44	0.77

Table 12. Summary of selected properties of “horizon 1” for Seymour centroid pedons partitioned by land use, Chariton Valley, Iowa. Values are given as means±standard deviation.

SMU by land use ⇓	n	Thickness	Bulk Density	SOC	SON	C:N
		(cm)	(g cm^{-3})	(%)	(%)	
Row Crop	12	20.9±6.9	1.30±0.11	1.92±0.24	0.14±0.03	14.3±2.4
Woodlots	4	22.6±7.4	1.03±0.09	3.53±0.56	0.26±0.05	13.7±1.4
SWG 5	12	18.0±3.5	1.29±0.19	2.31±0.63	0.22±0.08	10.8±1.8
SWG 10	11	18.5±3.8	1.21±0.09	2.28±0.37	0.18±0.01	13.7±2.2
Pasture	12	20.0±4.0	1.27±0.10	2.41±0.45	0.20±0.05	12.2±1.5
All Seymour centroid pedons	51	19.6±5.0	1.25±0.14	2.33±0.59	0.19±0.06	12.7±2.3

Table 13. Summary of SOC (weight/volume) for three depths for Seymour centroid pedons partitioned land use, Chariton Valley, Iowa. Values are given as means±standard deviation.

SMU by land use ⇓	n	SOC	SOC	SOC	Proportion of SOC in upper	
		(kg m^{-2})	(kg m^{-2})	(kg m^{-2})		
		0.0 to 0.2 m	0.0 to 0.5 m	0.0 to 1.0 m	20 cm	50 cm
Row Crop	12	4.7±0.9	8.6±2.1	11.7±3.3	0.42	0.74
Woodlots	4	7.2±1.4	13.1±1.8	17.2±2.2	0.42	0.76
SWG 5	12	5.5±1.2	9.1±2.3	11.5±3.0	0.48	0.79
SWG 10	11	5.1±0.8	8.6±1.7	11.1±2.4	0.47	0.78
Pasture	12	5.8±1.0	9.6±1.5	12.1±1.8	0.48	0.80
All Seymour centroid pedons	51	5.4±1.2	9.3±2.2	12.1±3.0	0.46	0.78

Tables 8 through 13 reflect more detailed numerical analyses of the 91 centroid pedons uppermost horizons’ SOC content, SON content, bulk density and thickness than that given in Tables 4 through 7, which likewise summarized centroid pedons. In addition, numerous Student’s t-tests were completed to compare across and between the Clarinda and Seymour SMU’s as well as land uses. In essence t-test results indicate few statistically significant differences exist between SOC, SON, and bulk density within and across land uses and series when using centroid pedons. Student’s t-tests were used because of their simplicity, statistical robustness and the observational nature of this study.

To restate this, there are few differences between Clarinda and Seymour SMU's using centroid pedons – again provided we consider just Student's t-test results for the uppermost horizon for SOC, SON, and bulk density. This is not surprising because (a) the properties used are not ones used to differentiate these series, and (b) there is a mixed jumble of land uses within the combined pedons. Ergo, total pedon comparisons have little land use meaning. Perhaps if mollic thicknesses and such were compared something would be different. A few of the Student's t-test results for <u>centroid pedons</u> that do show differences are:

(1) Significant differences in C:N ratios in pasture versus other land uses of each respective series. In addition it appears as switchgrass stands age, the C:N ratios become different in Clarinda and Seymour SMU's.

(2) The 20 cm of Clarinda centroids used for pastures and woods have more SOC (wt/vol) than when used for row cropping or switchgrass (pastures same as woods). These differences in SOC (wt/vol) are not apparent at 50 or 100 cm.

(3) Seymour SMU's used for row cropping have less SOC (wt/vol) in their top 20 cm than when pastures, woods or switchgrass.

The preceding suggests a whole field approach to sampling might be better than partitioning by SMU's and sampling SMU centroid pedons – at least for SOC-type data. Or, as already demonstrated by Burras and McLaughlin (2002), transect sampling of pedons by landscape position works well when seeking to efficiently quantify SOC contents across land uses.

The stable aggregate content (SAC) and cation exchange capacity (CEC) of centroid pedons was also measured as per objective 2. This data is summarized in the figures below although only a random subset of the centroid pedons were used to generate some of the figures. Those figures are labeled as such.

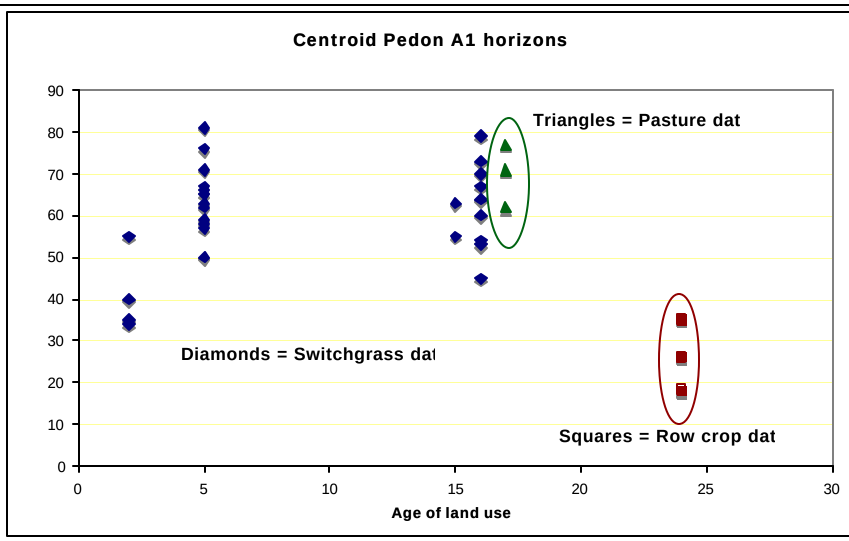

Figure 5. Stable aggregate content plotted against age of particular land uses in 41 centroid pedons also analyzed for CEC.

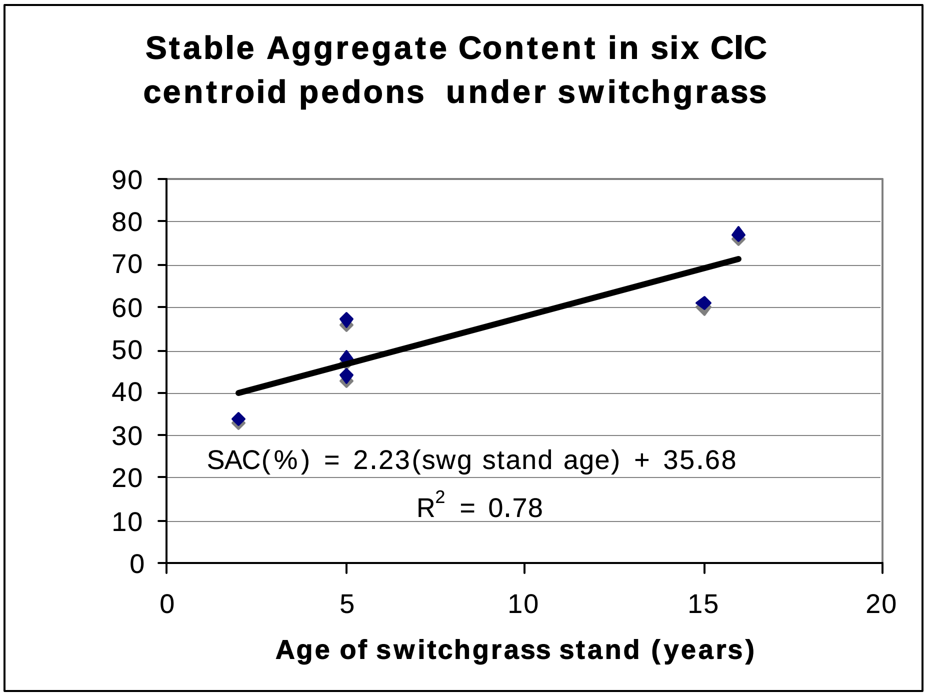

Figure 6. Stable aggregate content in the six ClC centroid pedons that were analyzed for CEC.

SAC increases over time in soils having perennial vegetation, including switchgrass and pasture. This was previously demonstrated by Burras and McLaughlin (2002) and McLaughlin (2003). It applies to centroid pedons, as demonstrated by Figures 5 and 6. And since SAC is an excellent indicator of overall soil quality in the Chariton Valley (Barker, 2004), sampling centroid pedons is an adequate means to evaluate soil quality changes with land use. Too little data was available – or too great of SMU variability occurred – to effectively use centroid pedons to evaluate recovery rates in soil quality across SMU erosion classes.

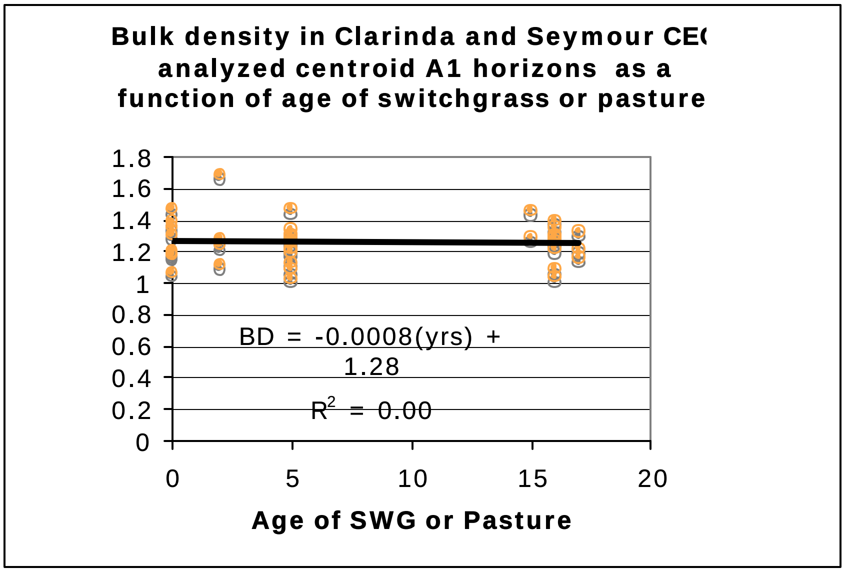

Figure 7. Bulk density change with time under perennial vegetation, centroid pedons Chariton Valley, Iowa.

Bulk densities of centroid pedon A1 horizons do not appear to be affected by age of perennial vegetation stand (Figure 7). This finding was unexpected although given the generally low bulk density of all land uses not surprising.

Perhaps the best measure of the chemical buffering capacity of soil and perhaps its total reactivity is CEC. This is why CEC was included as part of objective 2. Given the great cost of CEC, only a few analyses were completed (about 80). This data is from centroid pedon samples. This report only considers 41 CEC results because they represent 41 different centroid A horizons. The other 40 CEC measurements were for subsoil samples. They are not included simply for the sake of clarity.

The average soil CEC of all 41 centroid pedons analyzed was 29.5 $cmole_c/kg$. This CEC indicates these soils have high reactivity and high chemical buffering capacity. In other words, these are chemically robust soils and should have few limitations in uses - again from just a chemical perspective. Little total variation occurred between series, SMU's, land uses or age of land use (total standard deviation = 3.0 $cmol_c/kg$) although that is not to suggest that the variability does not have meaning. In fact it is our prediction CEC differences will be highly significant when the other 40 samples are included and a more sophisticated numerical analyses is completed.

One important finding with regards to CEC documented by this study is the success at which CEC can be partitioned between SOC content and clay content using linear regression (Table 14). A second attempt wherein CEC was regressed against SOC content, clay content, and age of perennial vegetation stand resulted in no improvement of fit. In fact, age of stand was not found to be a significant factor in CEC values. The regression equation that can be gleaned from Table 14 is:

Equation 1. Pred. CEC (A1 horizons) = 5.98(%SOC) + 0.604(%clay), r^2 = 0.99, n = 41

As Table 14 shows, this equation is both highly significant (sign. <0.0001) and statistically tight. That is, the coefficient of determination (r^2) suggests that CEC can be predicted with 99% success when clay content and SOC contents are known. This finding was expected given the importance of clay and SOC to CEC is well known and understood. Furthermore, the coefficients for SOC and clay content seem reasonable. That is the 0.604 coefficient for the clay content indicates that on average the pure clay fraction of these pedons has a CEC of 60.4 $cmole_c$/kg (which equals 0.60 meq CEC per one gram of soil clay) while on average the pure organic carbon fraction of these pedons has a CEC of 598 $cmole_c$/kg (which equals 6.0 meq CEC per one gram of SOC). A clay CEC equal to 60.4 $cmole_c$/kg is consistent with the known predominately smectiitic (with less vermiculitic and illitic) clay mineralogy of the soils in the Chariton Valley. The average SOC CEC of 598 $cmole_c$/kg also seems reasonable based on known values although we will come back to this value.

Table 14. Regression results wherein A1 horizon CEC was regressed against clay content and SOC content, Chariton Valley centroid pedons.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.997
R Square	0.993
Adjusted R S	0.967
Standard Erro	2.504
Observations	41

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	35680.47	17840	2844	<0.0001
Residual	39	244.6254	6.272		
Total	41	35925.1			

	Coeff.	*Stnd. Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
%SOC	5.908	0.632109	9.346	<0.001	4.6292468	7.186370952	4.6292468	7.18637095
%CLAY	0.604	0.050724	11.9	<0.001	0.5012616	0.706459356	0.5012616	0.70645936

The attempt to include age of perennial vegetation stand as another controlling factor in regression analysis was based on the premise that as stands age they not only increase in SOC content but also the SOC becomes more reactive as it is humified. As mentioned, attempting to include stand age failed. Somehow by adding stand age the regression was confounded.

A second important aspect of analyzing for CEC and then regressing it against clay content and SOC content is by doing so it is possible to statistically derive the CEC of just the SOC fraction. In a rough sense that is what the 598 $cmole_c$/kg is. With rounding this indicates there are 6.0 meq CEC per one gram of SOC – but that is a general value. It is expected and likely CEC of the SOC varies with soil series, type of land use and age of field.

With one more assumption it is possible to ascertain whether the reactivity of SOC varies according to series and land use. This has meaning with regards to which land use or SMU is best because organic matter properties strongly influence soil quality and potential uses (Lal et al, 1998; Lal et al, 2004). Mathematically, the CEC contribution from SOC (CECsoc) across land uses and SMU's can be sorted out by knowing the total CEC (CECtot) and assuming the clay CEC (CECclay) is a constant 0.60 meq/gram. This is a reasonable assumption given the generally homogenous nature of the clays in this region as well as their generally slow weathering rates. The practical equation for getting CEC-soc on a sample by sample basis is

Equation 2. CECsoc = CECtot – 0.60meq/gram*(%clay)

Next, dividing the total CECsoc of a sample by its SOC content allows for comparison of CECsoc across land uses that have differing SOC content. These results are given in Figures 8 and 9. Little statistical discussion is warranted because there were too few of observations (degrees of freedom) to assess significance. After writing that caveat, it is interesting to note it the mean CECsoc is lowest for row crops in both ClC and ClC2 pedons (Figure 8). This would suggest that as SOC is intensively used its reactivity decreases. Or to write that in the positive, additions of SOC from perennial cover results in improved SOC reactivity. The paucity of evidence – and total lack of statistics - to support that discussion, though, becomes clear by including Figure 9 in this discussion. Row cropped SMU's have both the highest and lowest mean CECsoc values.

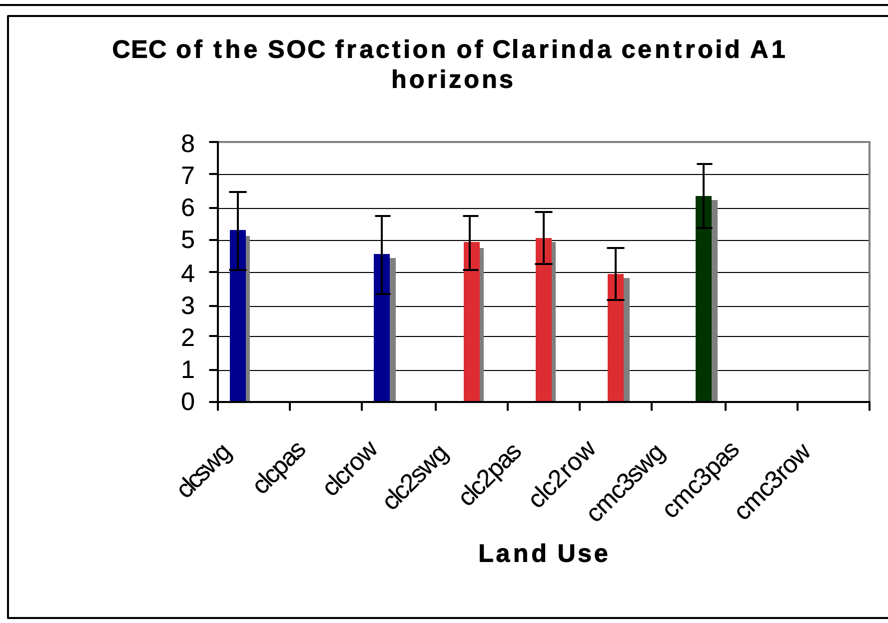

Figure 8. CEC of the SOC fraction of selected Clarinda centroid pedons, Chariton Valley, Iowa.

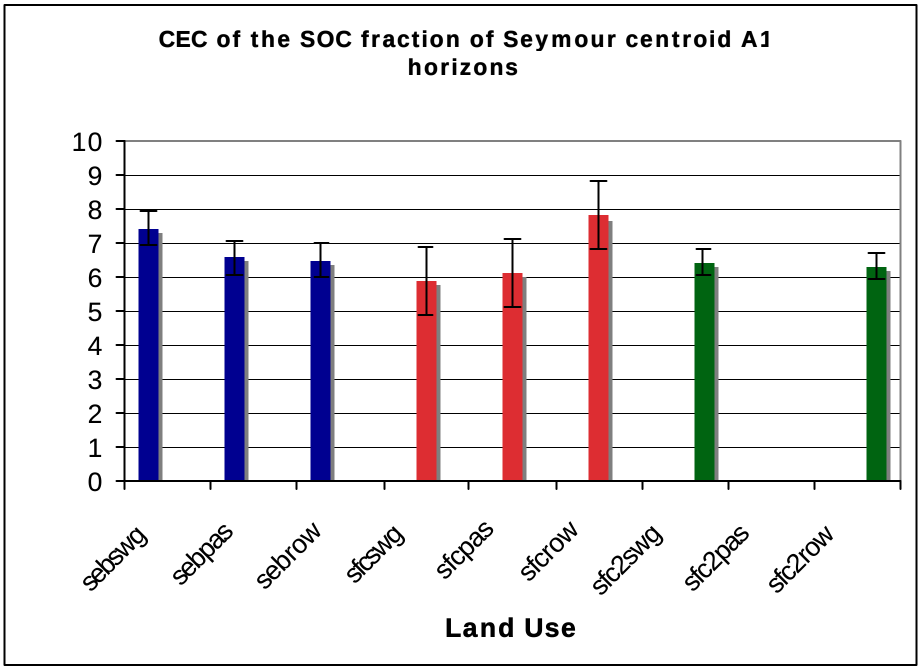

Figure 9. CEC of the SOC fraction of selected Seymour centroid pedons, Chariton Valley, Iowa.

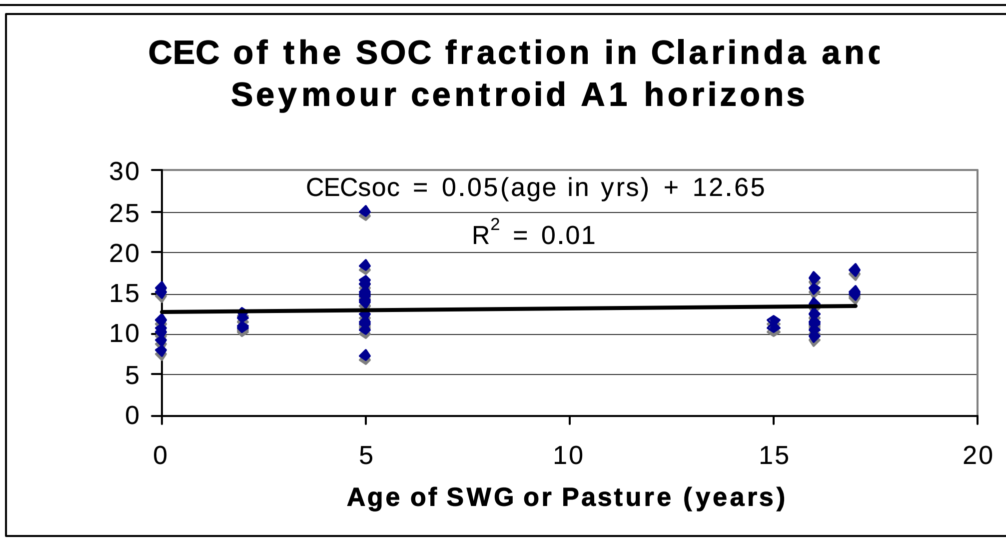

Figure 10. Relationship between CECsoc and age of perennial vegetation, Chariton Valley, Iowa.

Figure 10 shows the relationship between CECsoc and age of perennial vegetation stand for the 41 centroid pedons. This data weakly suggests there may be a 0.05 cmolc/kg increase in CECsoc annually. Judicious addition data is needed to rigorously test that hypothesis.

Soil pH is an additional limitation when considering CEC variability. Soil pH significantly affects CECsoc with higher soil pH causing CECsoc to increase as carboxyl groups become more H+-enriched. Perplexingly, though, the CECtot and CECsoc of these 41 A1 horizons showed only a very weak (or –plainly - no) relationship with soil pH (Figures 11 & 12).

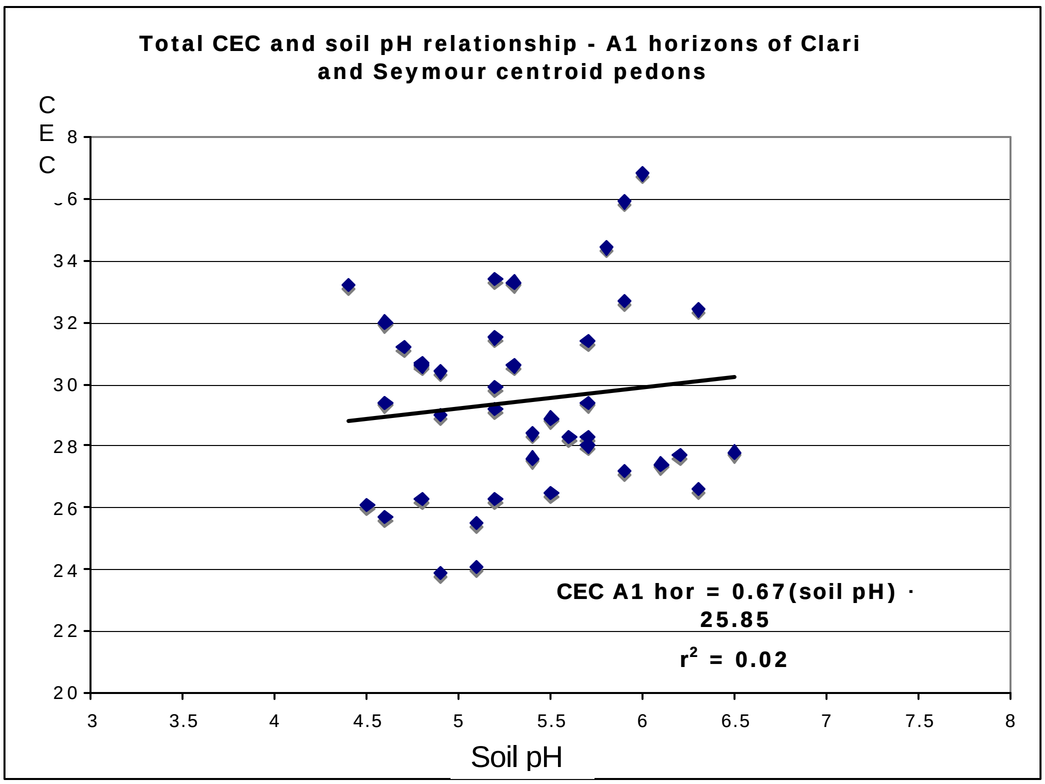

Figure 11. Relationship between CEC and soil pH for 41 centroid pedons, Chariton Valley, Iowa.

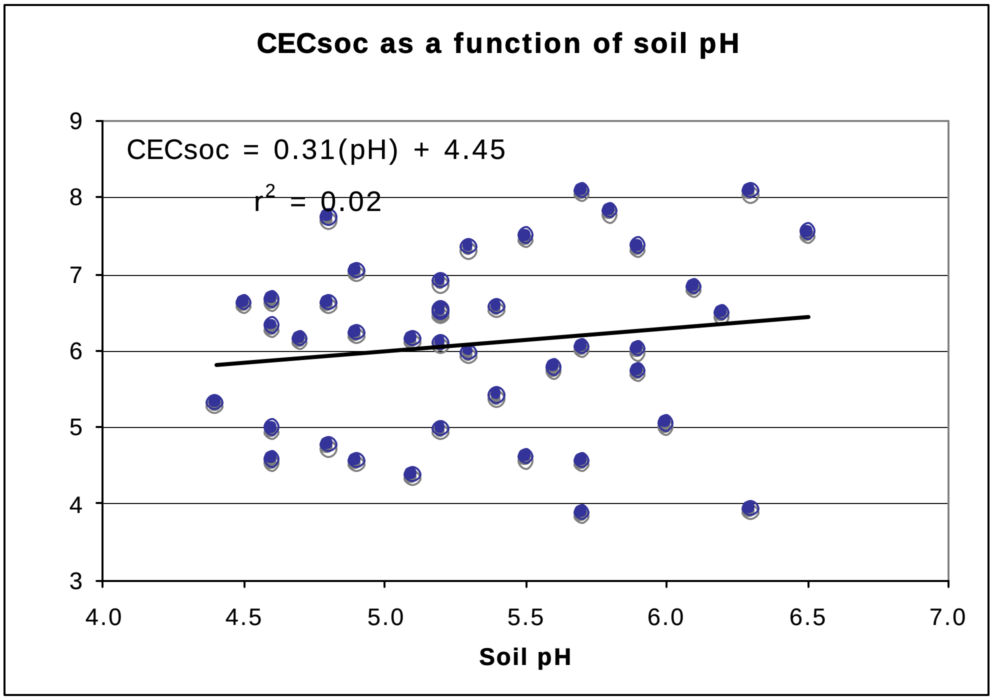

Figure 12. Relationship between CECsoc and soil pH for 41 centroid pedons, Chariton Valley, Iowa.

To summarize the centroid pedon approach is less than ideal although it does permit identification and documentation of some valuable trends (see Figure 13). The key drawback, though, is centroid pedons – at least using the approach we did – failed to successfully differentiate SOC content, SOC distribution, and CEC across SMU's of the Seymour and Clarinda series. The key success with centroid pedons is successful differentiation of SAC and A horizon thickness, which are important indicators of soil quality. However, that success is mostly in terms of age of perennial vegetation (again, see Figure 13) and not so much in terms of SMU. This leads us to think that sampling pedons randomly across a field with a given land use would provide as good or even more meaningful data as sampling centroid pedons.

The limitation mentioned in the previous paragraph has three components. First, centroid pedons are generally not centered in a SMU at least vis-à-vis being furthest away from other SMU's (as already discussed). Second, SMU's have not been static since they were identified during soil surveying although our initial assumptions treated them as if they had been. To wit, an uneroded Clarinda SMU might have experienced severe erosion subsequent to it being mapped 10 or 20 or more years ago. Third, Clarinda and Seymour SMU's are often adjacent soils in the continuum across the landscape. In conjunction these factors create the possibility – or even likelihood – that within any given field a centroid Clarinda pedon and a centroid Seymour pedon could be geographically very close to one another (i.e., basically, just the same soil) while in the next field they could be quite dissimilar from the first field and from each other.

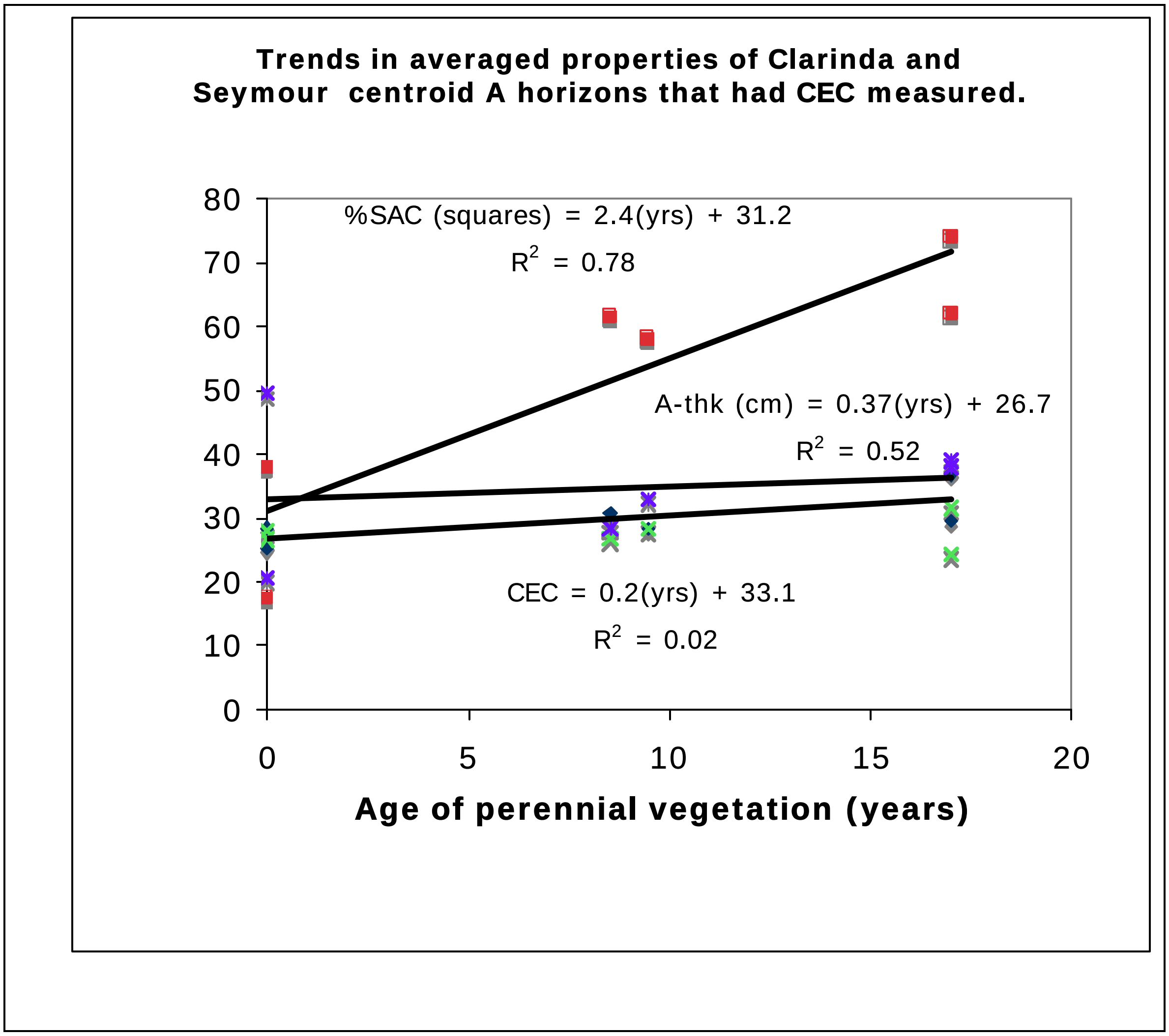

Figure 13. Summary trends with regards A horizons in 41 centroid pedons, Chariton Valley, Iowa

Grid Sampling

The use of grid sampling in order to characterize SMU's is common as would be expected given the diverse population of properties that are known to exist across a SMU. General advantages of the grid approach are (a) the resulting data allow for documenting the range of characteristics within and between SMU's, and (b) statistical analyses become possible. The drawbacks with grid sampling include time and expense (which tend to limit the number of SMU's that can be characterized) as well as the tendency to overuse classical statistics in analyses (Webster and Oliver, 2001, Webster, 2000, Webster, 2001). Classical statistical analyses are often problematic given the non-normal spatiality of properties and the lack of treatments in experiments (i.e., SMU studies are inherently observational studies).

Table 15 summarizes bulk density and SOC content according to land uses for pedons sampled along grids in the ClC2 SMU. Tables 16 through 19 show that in general significant differences occur when row cropped ClC2 pedons are compared to ClC2 pedons from every other land use as well as, interestingly, old switchgrass stands and pasture.

Table 15. Summary of bulk density soil organic carbon (SOC) contents and bulk density for pedons collected on a grid across ClC2 map units representing five land uses, Chariton Valley, Iowa. "SWG" refers to switchgrass. Tabulated values are means±standard deviations.

Land Use	n	Bulk Density	SOC	Bulk Density	SOC	Bulk Density	SOC
		(g cm^{-3})	(kg m^{-2})	(g cm^{-3})	(kg m^{-2})	(g cm^{-3})	(kg m^{-2})
		0.0 to 0.2 m depth		0.0 to 0.5 m depth		0.0 to 1.0 m depth	
Row Crop	10	1.17±0.17	4.1±1.1	1.28±0.12	7.9±2.3	1.37±0.09	10.2±3.0
Woodlots	10	1.18±0.09	6.3±1.6	1.19±0.12	11.0±3.7	1.35±0.09	15.8±6.6
SWG 5	10	1.27±0.11	5.1±1.5	1.34±0.09	8.1±2.7	1.47±0.07	10.2±3.3
SWG 10	10	1.26±0.05	4.9±0.4	1.33±0.04	8.1±0.7	1.46±0.05	10.1±0.8
Pasture	10	1.14±0.30	5.9±0.8	1.18±0.36	9.9±2.5	1.27±0.41	13.0±4.9
Mean		1.20	5.3	1.26	9.0	1.38	11.9

Table 16. Student's t-test (two-tailed, assumed unequal variance) results for SOC content (kg m^{-2}) for ClC2 grid samples (20 cm depth) from a variety of land uses.

		Row Crop	Woodlots	SWG 5	SWG 10	Pasture
Row Crop			0.002	0.13	0.064	0.001
Woodlots				0.09	0.020	0.465
SWG 5					0.721	0.161
SWG 10						0.004
Pasture						

Table 17. Student's t-test (two-tailed, assumed unequal variance) results for SOC content (kg m^{-2}) for ClC2 grid samples (50 cm depth) from a variety of land uses.

		Row Crop	Woodlots	SWG 5	SWG 10	Pasture
Row Crop			0.036	0.816	0.756	0.080
Woodlots				0.061	0.034	0.420
SWG 5					0.979	0.154
SWG 10						0.057
Pasture						

Table 18. Student's t-test (two-tailed, assumed unequal variance) results for SOC content (kg m^{-2}) for ClC2 grid samples (100 cm depth) from a variety of land uses.

		Row Crop	Woodlots	SWG 5	SWG 10	Pasture
Row Crop			0.030	0.986	0.929	0.148
Woodlots				0.031	0.023	0.293
SWG 5					0.953	0.153
SWG 10						0.099
Pasture						

Table 19. Proportion of SOC content (using wt/volume values) in the upper profile for ClC2 grid pedons from a variety of land uses in the Chariton Valley, Iowa. Reference SOC contents are 1.0 m. "SWG" refers to switchgrass. Tabulated values are means±standard deviations.

Land Use	n		Proportion of SOC in upper 20 cm	Proportion of SOC in upper 50 cm
Row Crop	10		0.41±0.06	0.77±0.05
Woodlots	10		0.44±0.12	0.73±0.12
SWG 5	10		0.50±0.05	0.79±0.03
SWG 10	10		0.48±0.04	0.80±0.02
Pasture	10		0.49±0.11	0.79±0.09
Mean			0.46	0.78

There are no meaningful differences in SOC contents with depth in the ClC2 SMU regardless of land use – at least when sampled using a grid approach (Table 19). These results suggest if one were to sample the upper 20 cm of this soil under any of these land uses, the SOC content in that sample will account for about 46% of the total SOC content of the upper 1.0 m. Likewise analyzing soil to 50 cm depth will account for 78% of the total SOC present in the upper 1.0 m.

Tables 20 through 23 show the ClC SMU has the lowest 0 to 20 cm SOC content of all six SMU's. At greater depths, by and large, all six SMU's have equivalent SOC contents although a case could be made that SfC contains more than some other SMU's (Tables 22 and 23). The inconsistent levels of t-test significance weaken this supposition.

Table 20. Summary of bulk density soil organic carbon (SOC) contents and bulk density for pedons collected on a grid across six soil map units growing switchgrass for five years. Tabulated values are means±standard deviations.

Soil Map Unit	n	Bulk Density	SOC	Bulk Density	SOC	Bulk Density	SOC
		(g cm^{-3})	(kg m^{-2})	(g cm^{-3})	(kg m^{-2})	(g cm^{-3})	(kg m^{-2})
		0.0 to 0.2 m depth		0.0 to 0.5 m depth		0.0 to 1.0 m depth	
ClC	10	1.34±0.16	3.7±1.5	1.46±0.15	6.2±2.8	1.57±0.14	8.3±3.2
ClC2	10	1.27±0.11	5.1±1.5	1.34±0.09	8.1±2.7	1.47±0.07	10.2±3.3
CmC3	10	1.29±0.08	4.9±0.9	1.38±0.05	7.4±1.3	1.49±0.07	9.3±1.7
SeB	10	1.36±0.08	5.1±0.6	1.35±0.07	8.5±1.4	1.43±0.05	10.8±1.9
SfC	10	1.20±0.11	5.4±0.9	1.28±0.08	9.6±1.3	1.40±0.07	12.0±1.6
SfC2	10	1.25±0.08	5.3±0.7	1.31±0.07	8.8±1.3	1.44±0.06	11.1±1.5
Mean		1.29	4.9	1.35	8.1	1.47	10.3

Table 21. Student's t-test (two-tailed, assumed unequal variance) results for SOC content (kg m^{-2}) for grid samples (20 cm depth) from a variety of soil map units under switchgrass in the Chariton Valley, Iowa.

Soil Map Unit		ClC	ClC2	CmC3	SeB	SfC	SfC2
ClC			0.062	0.050	0.023	0.011	0.010
ClC2				0.744	0.971	0.635	0.659
CmC3					0.617	0.262	0.229
SeB						0.403	0.358
SfC							0.921
SfC2							

Table 22. Student's t-test (two-tailed, assumed unequal variance) results for SOC content (kg m^{-2}) for grid samples (50 cm depth) from a variety of soil map units under switchgrass in the Chariton Valley, Iowa.

Soil Map Unit		ClC	ClC2	CmC3	SeB	SfC	SfC2
ClC			0.134	0.222	0.037	0.004	0.019
ClC2				0.483	0.723	0.135	0.492
CmC3					0.101	0.002	0.030
SeB						0.070	0.596
SfC							0.165
SfC2							

Table 23. Student's t-test (two-tailed, assumed unequal variance) results for SOC content (kg m^{-2}) for grid samples (100 cm depth) from a six soil map units under switchgrass in the Chariton Valley, Iowa.

Soil Map Unit		ClC	ClC2	CmC3	SeB	SfC	SfC2
ClC			0.200	0.385	0.046	0.005	0.025
ClC2				0.452	0.609	0.139	0.453
CmC3					0.074	0.001	0.022
SeB						0.148	0.746
SfC							0.186
SfC2							

Table 24. Proportion of SOC content (using wt/volume values) in the upper profile for grid pedons from soil map units under switchgrass in the Chariton Valley, Iowa. Reference SOC contents are 1.0 m. Tabulated values are means±standard deviations.

Soil Map Unit	n		Proportion of SOC in upper 20 cm	Proportion of SOC in upper 50 cm
ClC	10		0.46±0.07	0.74±0.08
ClC2	10		0.50±0.05	0.79±0.03
CmC3	10		0.53±0.04	0.80±0.03
SeB	10		0.47±0.04	0.78±0.02
SfC	10		0.45±0.05	0.80±0.03
SfC2	10		0.48±0.04	0.79±0.04
Mean			0.48	0.78

There are no meaningful differences in SOC contents with depth across these six SMU's – at least when sampled using a grid approach (Table 24). This result, when coupled with that for ClC2 across land uses (Table 19) as well as previous findings by Burras and

McLaughlin (2002) and McLaughlin (2003) indicate depth distributions of SOC contents are basically constant regardless of soil and land use in uplands of the Chariton Valley. These results suggest if one were to sample the upper 20 cm of any upland soil in the watershed the SOC content in that sample will account for about 46 to 48% of the total SOC content of the upper 1.0 m. Likewise analyzing soil to 50 cm depth will account for about 78% of the total SOC present in the upper 1.0 m.

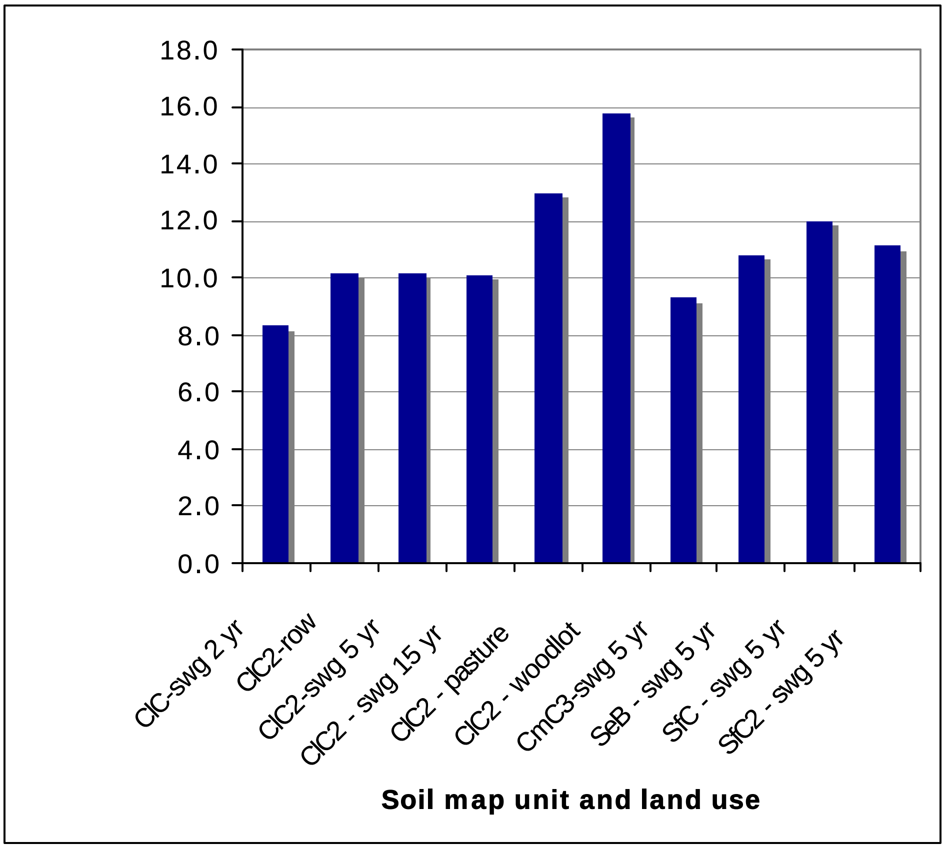

Figure 14. Mean SOC content from grid pedons partitioned according to SMU and land use, Chariton Valley, Iowa.

It is tempting to conclude from Figure 14 that woodlot ClC2 SMU's have more SOC to a one meter depth than any other SMU under any land use. Unfortunately- and has been stressed – this study did not generate enough data to definitively make that conclusion.

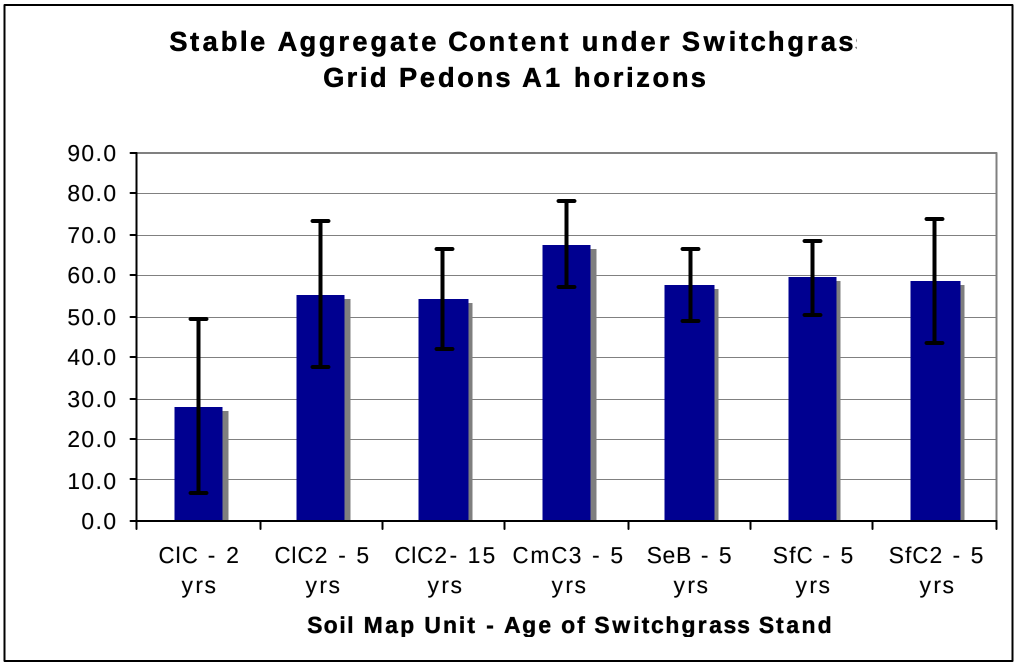

Figure 15. SAC variability across SMU's and age of switchgrass stands, Chariton Valley, Iowa. Data given as means±standard deviation.

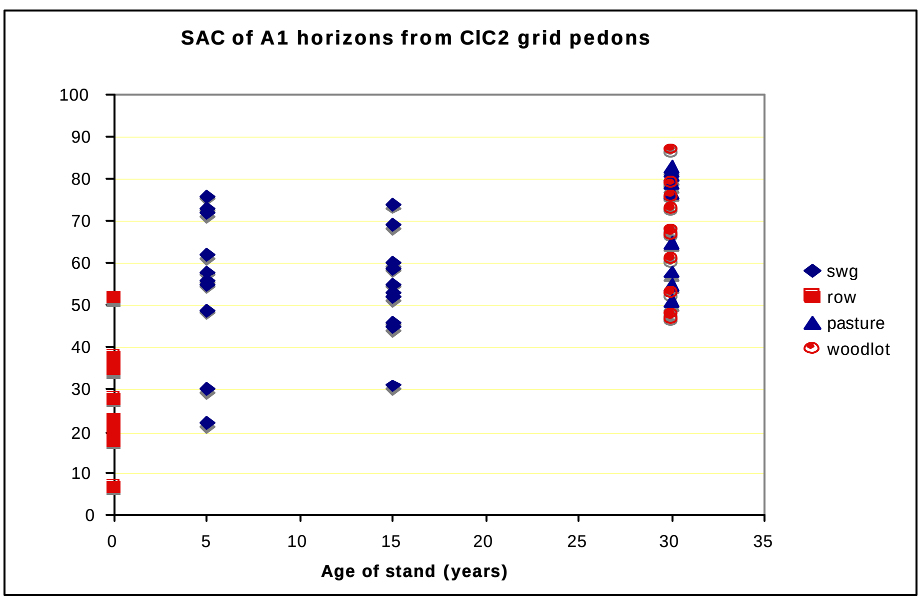

Figure 16. SAC variability across SMU's and age of switchgrass stands, Chariton Valley, Iowa.

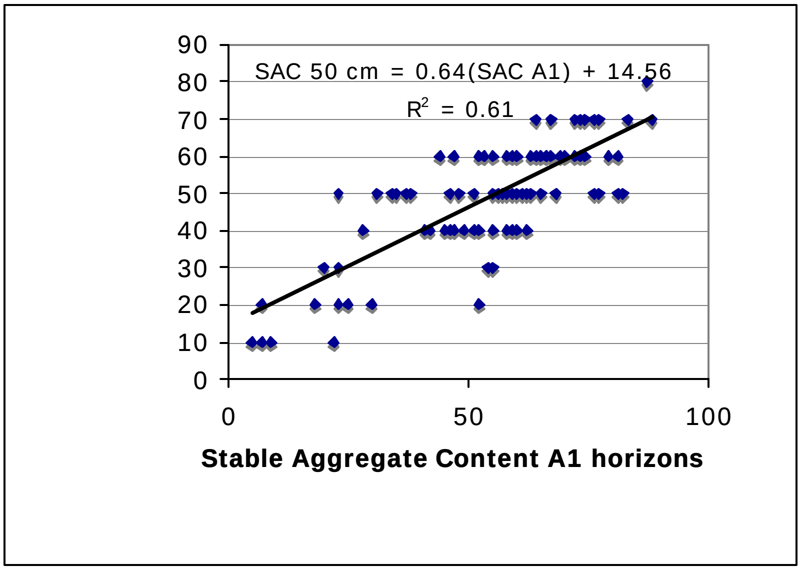

Figure 17. SAC content of A1 horizon compared to upper 50 cm of the solum for grid pedons across all land uses and SMU's, Chariton Valley, Iowa.

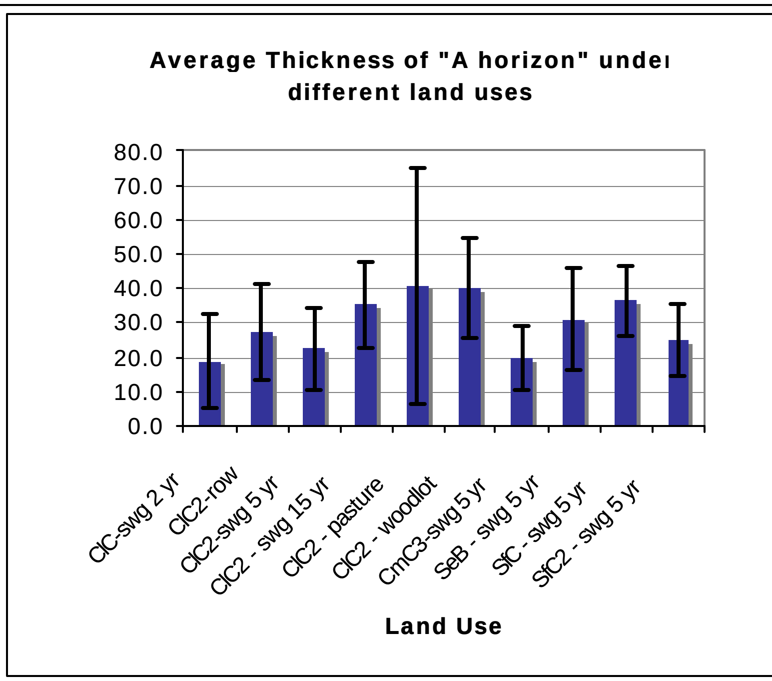

Figure 18. Epipedon thickness across SMU's and age of switchgrass stands, Chariton Valley, Iowa. Data given as means±standard deviation.

Soil quality is positively affected by age of stands of perennial vegetation across Clarinda and Seymour series (Figures 15 through 18). This observation is valuable and suggests that recovery rates for eroded – or more likely, any type of degraded – SMU's is measurable in years or decades at most. This recovery is not just in terms of surficial properties but extends to at least 50 cm depth (Figures 17 and 18). Furthermore, integrating Figures 17 and 18 with Figure 13 suggests that SAC increases at 2.4% per year and epipedon thickness deepens at 0.37 cm per year when any of these SMU's is managed as perennial vegetation.

Grab Sampling

The use of shallow soil samples (a.k.a., "grab samples") collected on a grid is a commonly used technique. It is fairly cheap, quick and typically highly useful because for most purposes the key zone of soil is the upper few centimeters. The key drawback they provide little information about properties and processes occurring deeper in the soil. That drawback is minimized if adequate deep sampling occurs or had occurred such that grab sample data can be correlated with deeper data. As Tables 19 and 24 and Figures 17 and 18 illustrate, this can be done with respect to SOC content and SAC for Seymour and Clarinda soils in the Chariton Valley. Thus, the remaining question is – do grab samples predict the same SOC and SAC contents as the centroid and grid pedons did?

Table 25. Summary of bulk density soil organic carbon (SOC) and nitrogen (SON) contents from a five land uses for ClC2 "grab" samples, Chariton Valley, Iowa. "Grab" samples were collected on a grid across the soil map unit to a depth of 20 cm. "SWG" refers to switchgrass. Tabulated values are means±standard deviations

Land Use	n	Bulk Density	SOC	SOC	SON	C:N
		(g cm^{-3})	(%)	(kg m^{-2})	(%)	
Row Crop	25	1.29±0.12	1.69±0.40	4.35±1.15	0.14±0.04	12.5±1.1
Woodlots	5	1.31±0.16	2.21±1.81	5.45±4.40	0.15±0.11	15.2±5.3
SWG 5	25	1.29±0.10	2.29±0.41	5.90±1.05	0.20±0.03	11.2±0.9
SWG 10	25	1.45±0.25	2.48±0.26	7.18±1.38	0.20±0.02	12.4±0.9
Pasture	25	1.33±0.17	2.57±0.61	6.74±1.24	0.21±0.05	12.5±0.8

Table 26. Student's t-test (two-tailed, assumed unequal variance) results for SOC content (kg m^{-2}) for ClC2 "grab" samples (20 cm depth) from a variety of land uses.

		Row Crop	Woodlots	SWG 5	SWG 10	Pasture
Row Crop			0.609	0.000	0.000	0.000
Woodlots				0.831	0.430	0.550
SWG 5					0.001	0.013
SWG 10						0.236
Pasture						

SOC content of the upper 20 cm of the ClC2 SMU is between about 4 and 7 kg m^{-2} (Table 25), which is about the same as the results from grid pedon sampling (Table 15). Taken in tandem, the Tables 25 and 26 indicate the top 20 cm of soils in row cropped ClC2 have significantly less SOC content – at least on a weight per volume basis - than soils under switchgrass or pasture. ClC2 grab samples from young switchgrass stands have significantly less SOC content than older switchgrass stands and pastures. In the ClC2 map units, SOC content is identical for older switchgrass stands and pastures. Student's t-test did not work to evaluate ClC2 SOC differences between woodlots and other land uses in part or whole because we collected too few woodlot samples.

The bulk density of ClC2 grab samples under old switchgrass stands is significantly greater than samples from row crop, young switchgrass stands and pastures (t-test results range from 0.05 to 0.005). It is unclear why bulk density values are greater in this old switchgrass stand relative to the other land uses. Other bulk density analyses from this and other studies generally found shallow bulk densities diminish as switchgrass stands mature. It is possible the antecedent moisture contents were high the day the grab samples were collected although it seems unlikely given that numerous grab samples from multiple sites were collected that day. These high bulk densities are not the cause of differences in SOC contents discussed in the previous paragraph, though, because SOC on a percentage basis (i.e., wt/wt) show the same trends as on a weight per volume basis.

Table 27. Summary of bulk density soil organic carbon (SOC) and nitrogen (SON) contents from six SMU's "grab" samples, Chariton Valley, Iowa. "Grab" samples were collected on a grid across the soil map unit to a depth of 20 cm. Each SMU had been raising switchgrass for five years except the ClC field, which was only two years old.

Soil map unit	n	Bulk Density	SOC	SOC	SON	C:N
		(g cm^{-3})	(%)	(kg m^{-2})	(%)	
ClC	35	1.28±0.13	2.01±0.66	5.03±1.35	0.15±0.07	13.0±2.1
ClC2	25	1.29±0.10	2.29±0.41	5.90±1.05	0.20±0.03	11.2±0.9
CmC3	25	1.28±0.10	2.20±0.54	5.60±1.24	0.20±0.04	11.2±1.9
SeB	25	1.23±0.10	2.29±0.38	5.62±0.90	0.20±0.03	11.6±2.4
SfC	25	1.19±0.14	2.74±0.44	6.51±1.14	0.25±0.04	11.3±2.9
SfC2	25	1.22±0.11	2.39±0.29	5.85±0.92	0.22±0.03	11.1±2.0

Table 28. Student's t-test (two-tailed, assumed unequal variance) results for SOC content (kg m^{-2}) for six SMU's "grab" samples (20 cm depth). Five of the SMU's were planted to switchgrass five years before sampling. The remaining one, ClC, was planted two years prior to sampling.

		ClC	ClC2	CmC3	SeB	SfC	SfC2
ClC			0.007	0.095	0.045	0.000	0.007
ClC2				0.365	0.327	0.056	0.860
CmC3					0.942	0.010	0.428
SeB						0.004	0.389
SfC							0.030
SfC2							

Tables 27 and 28 effectively show SMU's do not discretely break out from one another – at least when sampled using a grab sample approach. This is not surprising for several reasons. First, these results are consistent with those already presented for centroid pedons and grid pedons. Second, it is known there are dissimilar and similar inclusions of other soil types found in any given SMU. Third, it is known these SMU's are from soils commonly not only contiguous but also possessing properties that are distributed across the landscape in a continuous fashion. In sum, we think soil variability is likely best explained using a simple controller such as landscape position. That approach is likely to be more powerful and appropriate in identifying SOC trends and partitioning fields.

<u>Geospatial analysis – Field 123.</u>

Field 123 is a five year old switchgrass field belonging to John Sellers. It was selected for detailed spatial analysis and map making for the following reasons. First, it is a typical sized field (5.4 hectares = 13.4 acres). Second it contains four of the six map units being studied. Third, it was sampled extensively – i.e., four centroid pedons and about 40 grid pedons, and 40 grab samples. Fourth, it is a switchgrass field, which is of special interest to this project in general. Fifth, Mr. Sellers had intimate knowledge of the project as well as excellent records of this site and a wonderful working relationship with the authors. Sixth, Field 123 is located near the literal center of the Lake Rathbun watershed. Analyses use data available for the top 20 cm only. This data includes grid and centroid pedon data as well as grab sample data. Post-report analyses will examine the whole pedon data. The method of analysis was using the most current version of ARCGIS in the summer 2004.

Table 29. Selected data generated by using ARCGIS on Field 123.

SMU		Area (actual)		Areas "used" in maps (see below)		Area Diff.	Bulk Density		SOC		SOC	
		ha	ac	ha	ac	%	g cm^{-3}		% for top 0.2 m		Kg m^{2}-0.2 m^{-1}	
							*raw average/area weighted averages**					
ClC2		1.35	3.33	1.11	2.75	17.7	1.30	1.30	2.30	2.26	5.28	5.23
CmC3		0.97	2.40	0.89	1.97	8.2	1.30	1.30	2.16	2.12	4.83	4.77
SeB		1.09	2.69	0.86	2.19	30.1	1.23	1.22	2.30	2.30	4.60	4.58
SfC2		2.03	5.02	1.82	4.50	10.3	1.23	1.24	2.42	2.36	4.56	4.57
Total		5.44	13.4	5.33	13.2	2.0	1.26	1.26	2.28	2.29	4.76	4.81

**Raw average is the simple arithmetic mean of the data with each datum representing a map pixel generated by ARCGIS. Area weighted average is the sum of each pixel datum multiplied by its area with the summed value divided by the total area.*

As Table 29 indicates, areas used in the maps to be discussed are smaller than the actual areas in the fields because ARCGIS, kriging, co-kriging and other interpolation programs evaluate trends from data point to data point. This means SMU boundaries are always outside the areas being analyzed by ARCGIS. To state this, hopefully, more plainly, quantitative tools such as ARCGIS do not recognize visual map boundaries. They simply interpolate between two data points. Since those data points reside within a SMU, as one visually sees it, then ARCGIS are actually evaluating a subarea of the whole SMU. The percentage difference from one map unit to another – or for that matter the whole field – is controlled by three factors: the number of data points with in a map unit, their locations within the map unit and the geometry of the map unit. Table 29 indicates long narrow SMU's are especially prone to area errors whereas a whole field that is more or less square or rectangular like Field 123 has minimal area error.

Figures 19 through 22 are example copies of the settings used to generate the semivariograms that were then were used to generate the maps to be discussed (i.e., Figures 23 through 30). They are simply included to illustrate the type of software and some of the parameters used.

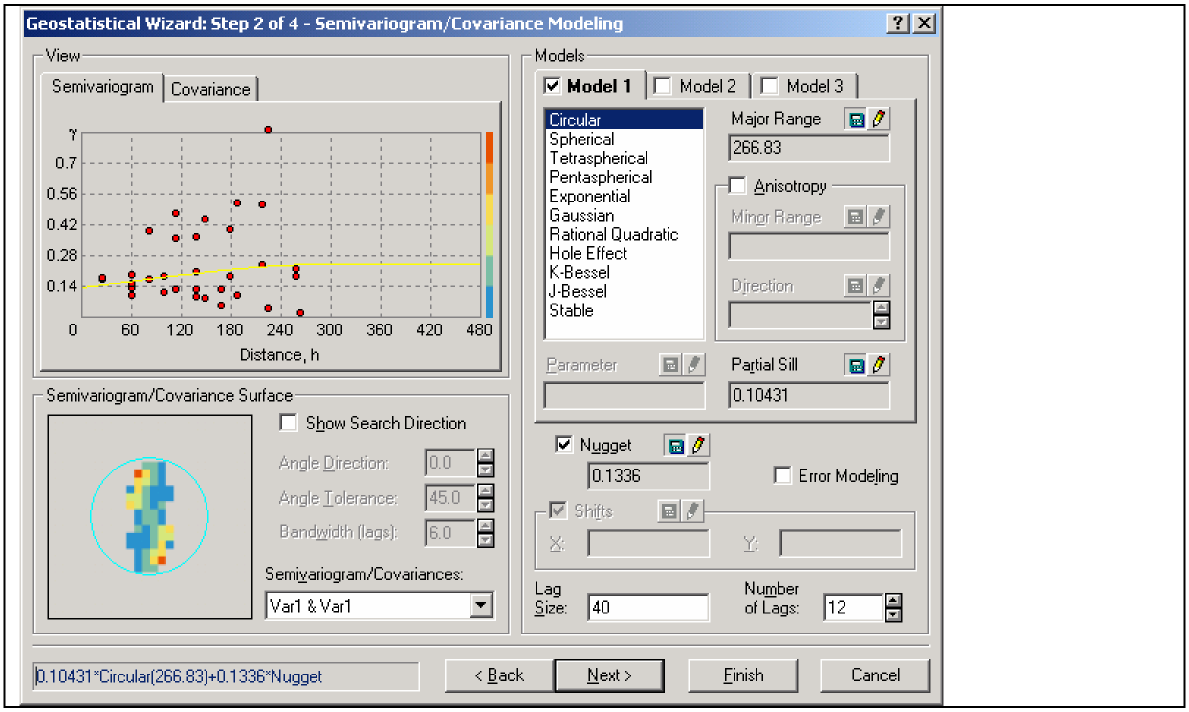

Figure 19. Example of showing ARCGIS model used for analysis of semivariogram.

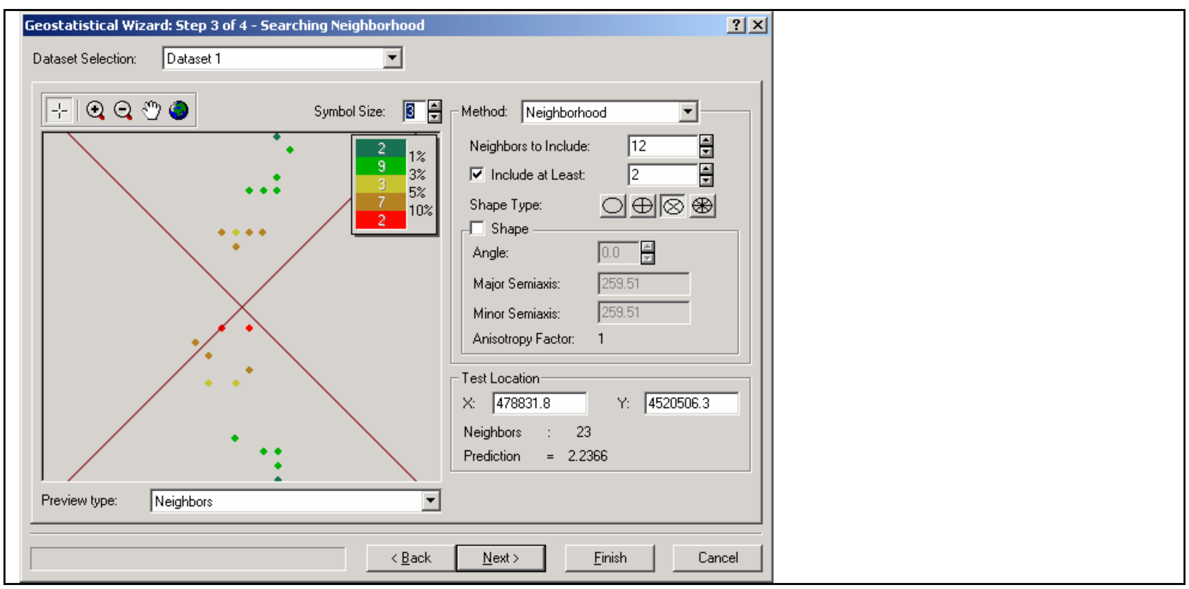

Figure 20. Additional example setting for ARCGIS.

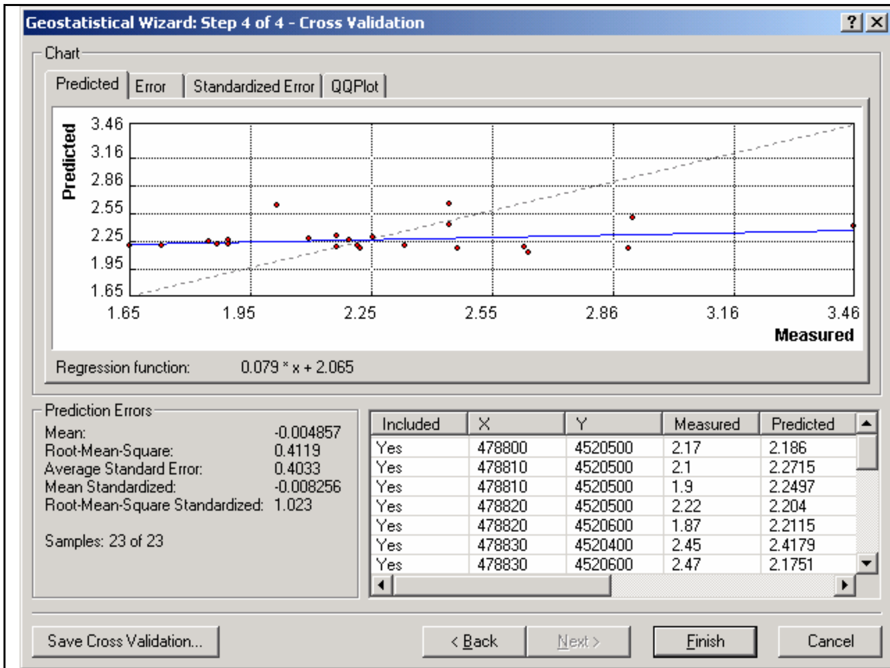

Figure 21. Example of cross validation settings used in ARCGIS.

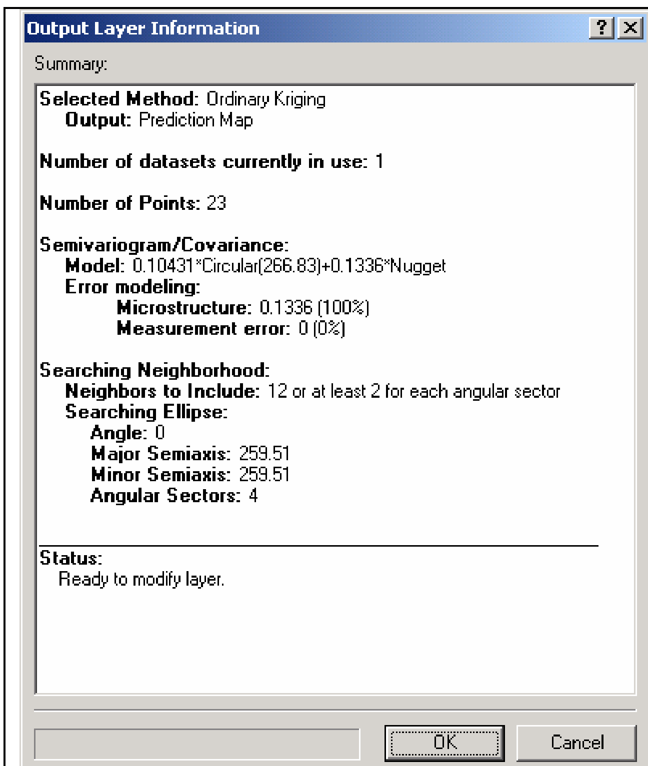

Figure 22. Example settings of output layer information in ARCGIS.

Figures 23 through 30 illustrate the power of ARCGIS in creating maps to show the distribution of any soil property measured, either at the SMU level or at the field level. The maps demonstrate the value of using an integrated GIS and geospatial approach although it is important to remember these maps use the same data as already discussed. Thus, they are limited by the same challenges already discussed with centroid pedons, grid pedons, and grab samples. Given that, it is likely these maps are most accurate when all data is pooled. We further think these maps support the idea of sampling across fields of known land use rather than by SMU's. Our findings are consistent with those of Bruland and Richardson (2005), who used similar approaches to ours to study created, restored and natural wetlands. They found patterns of soil variability to be complex. They concluded these patterns differ by soil property, by type of site, as well as by the hydrogeomorphic setting. Our findings are also consistent with Wills (2005), who applied similar methodologies as ours to a row cropped site and a native prairie in northern Iowa.

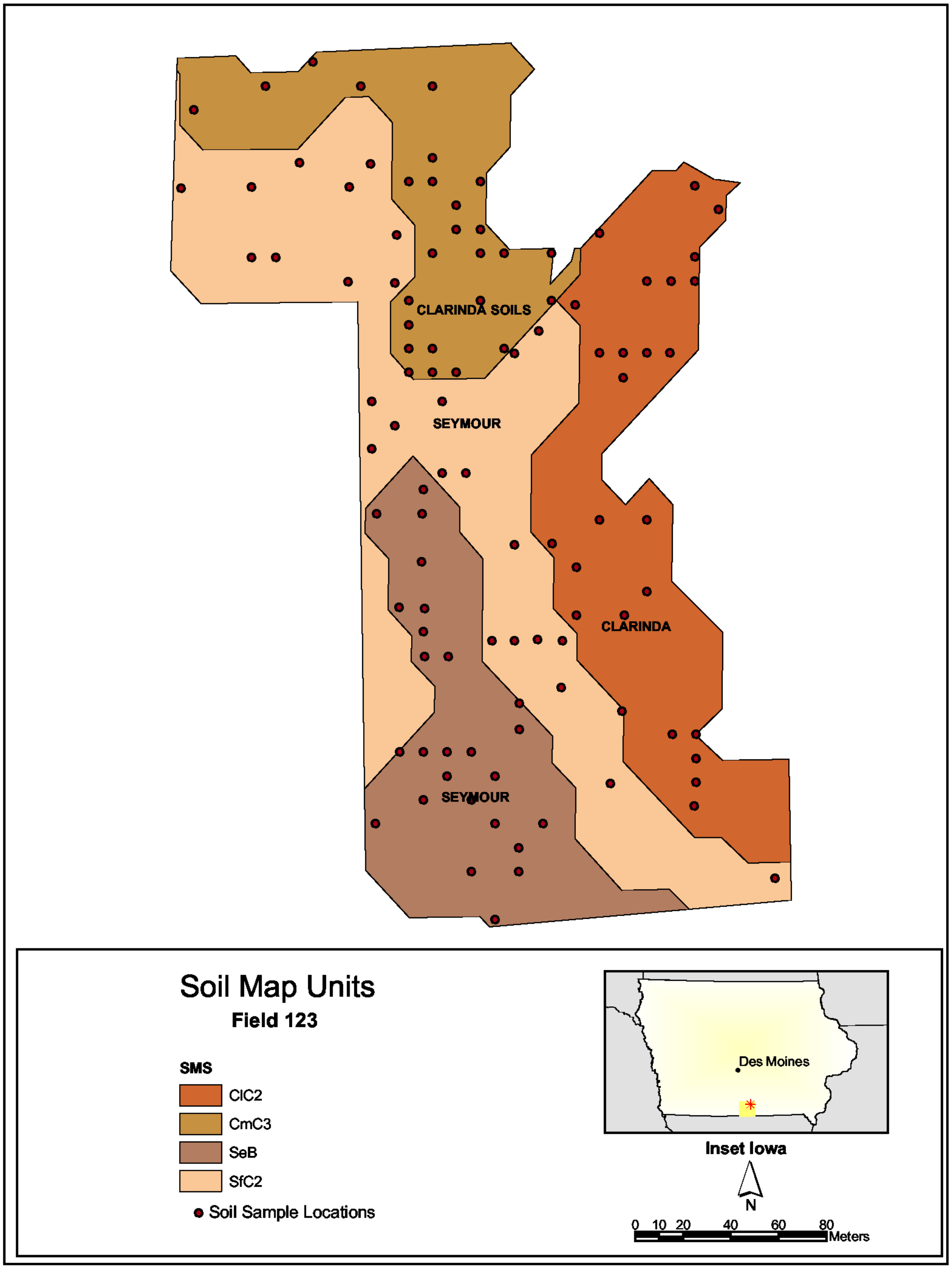

Figure 23. Map of Field 123 showing SMU's and location of sampling points, Chariton Valley, Iowa.

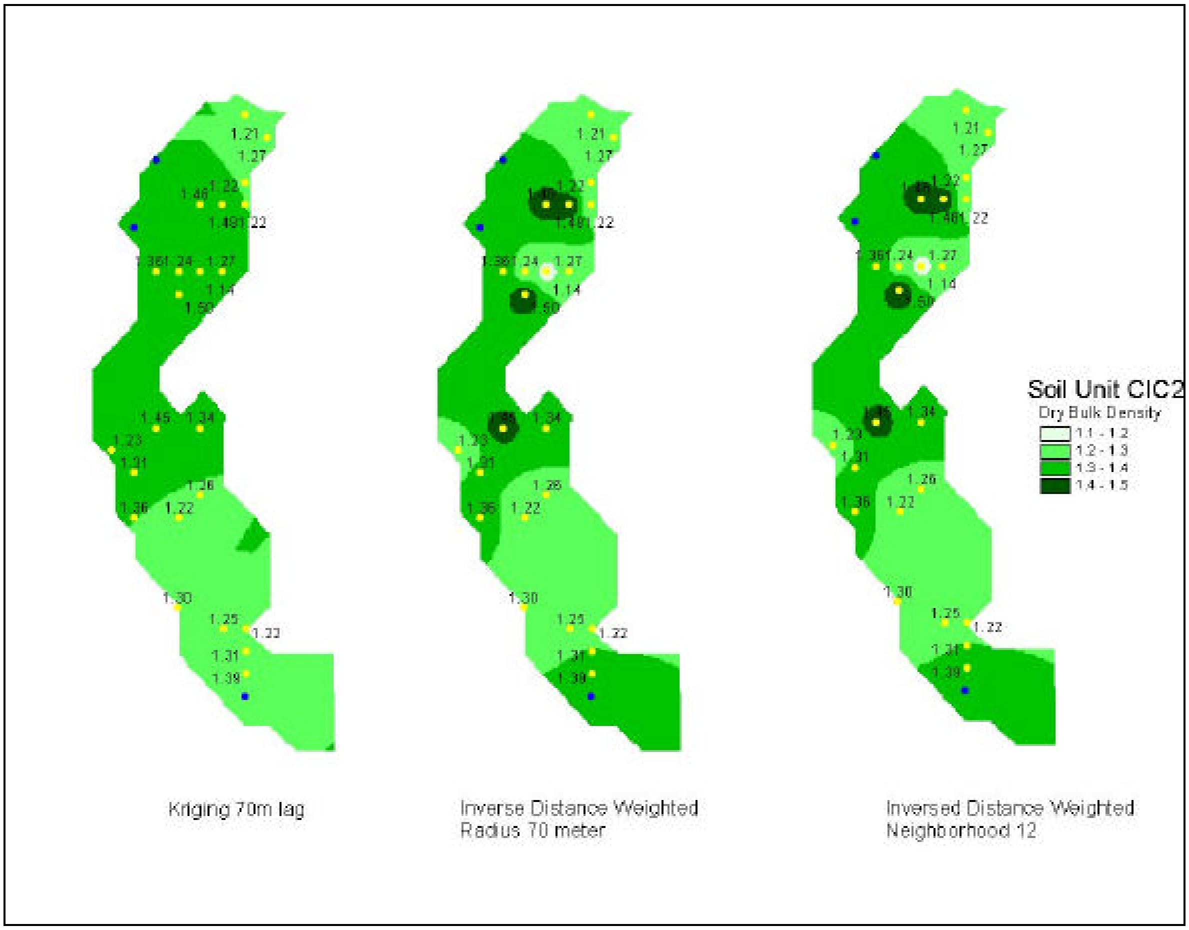

Figure 24. Spatiality of soil bulk density in ClC2 SMU, Field 123, using kriging and two inverse distance weighting methods in ARCGIS, Chariton Valley, Iowa.

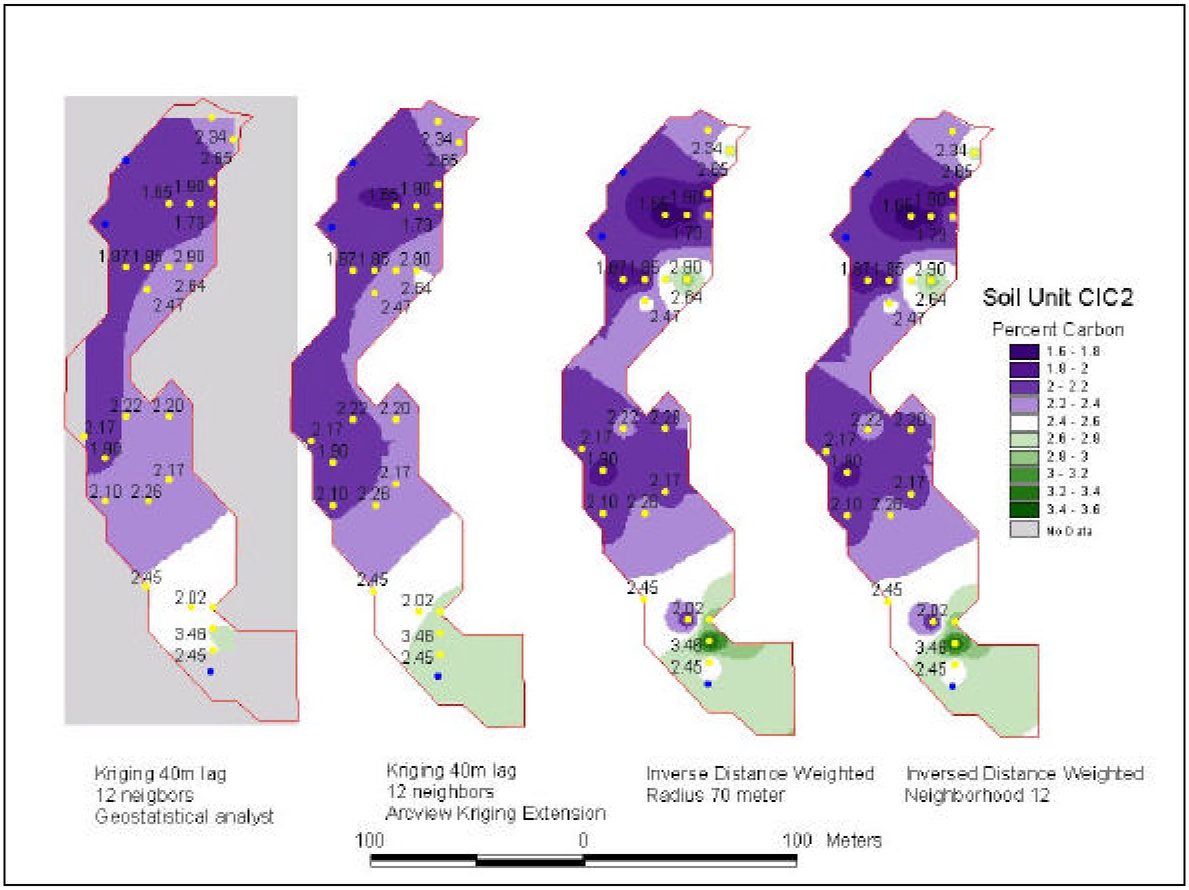

Figure 25. Spatiality of SOC content (wt/wt) in ClC2 SMU, Field 123, using two kriging and two inverse distance weighting methods in ARCGIS, Chariton Valley, Iowa.

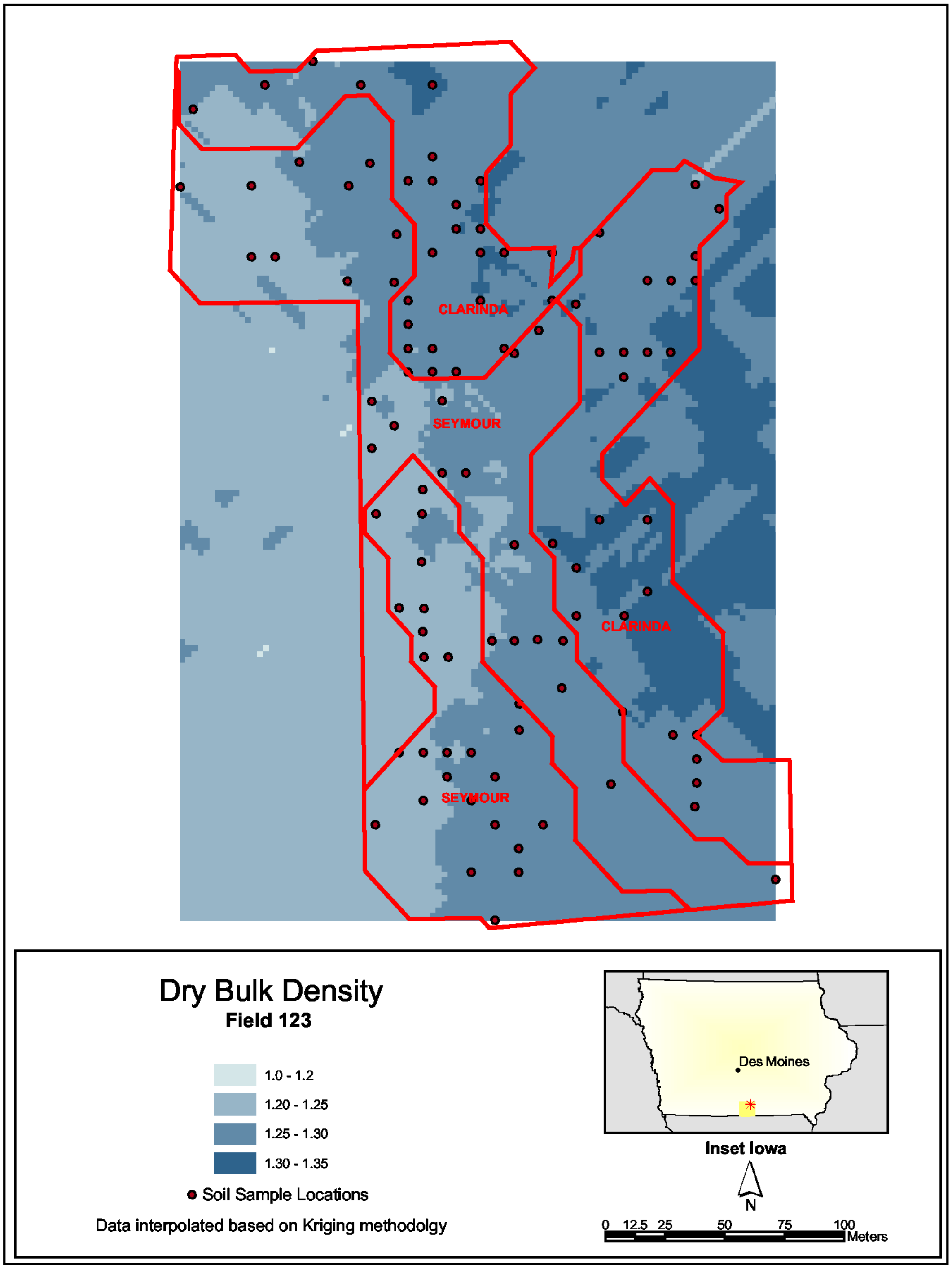

Figure 26. Kriged distribution of bulk density across Field 123, Chariton Valley, Iowa.

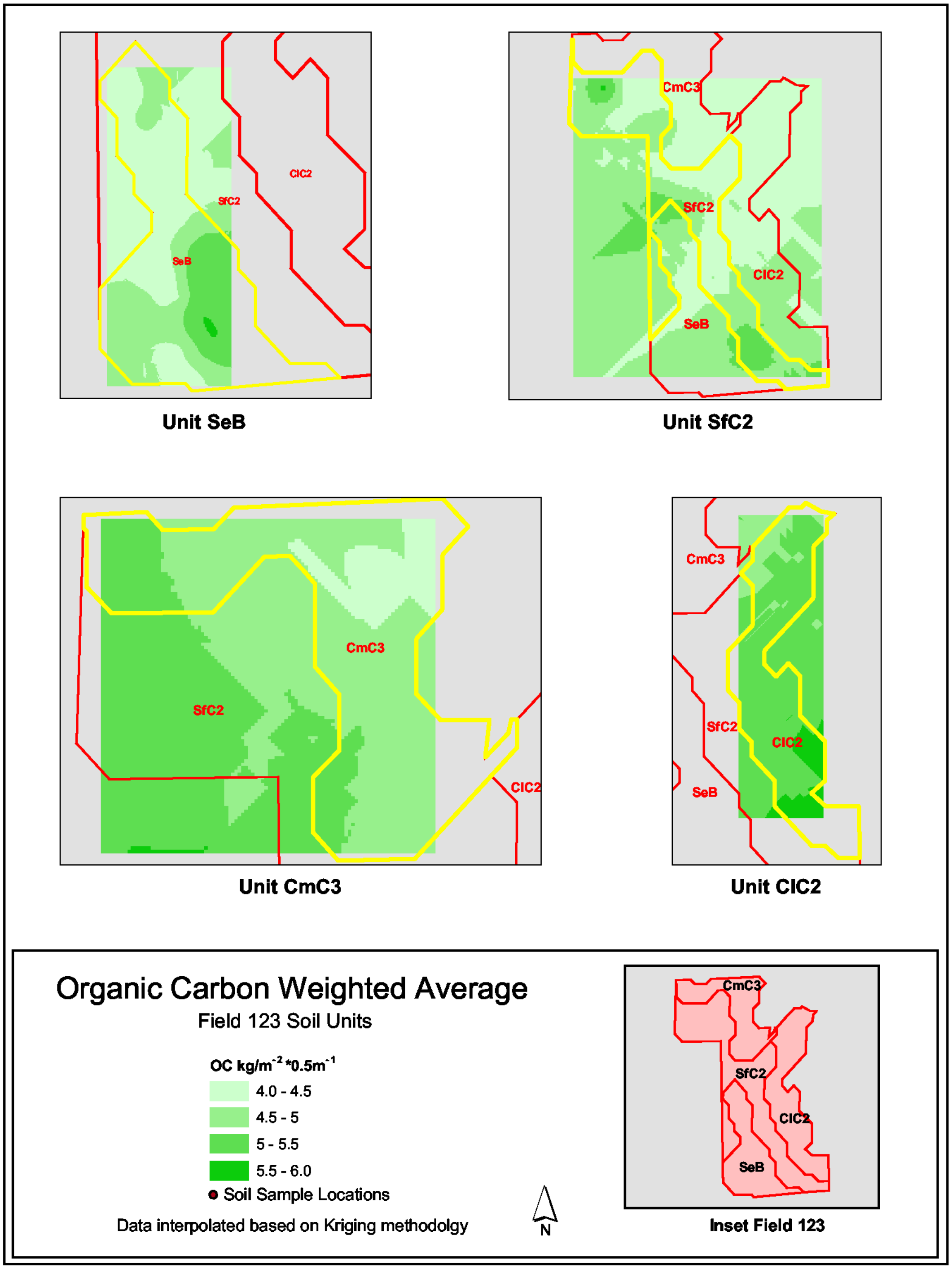

Figure 27. Kriged distribution of SOC (wt/volume) by SMU in Field 123, Chariton Valley, Iowa.

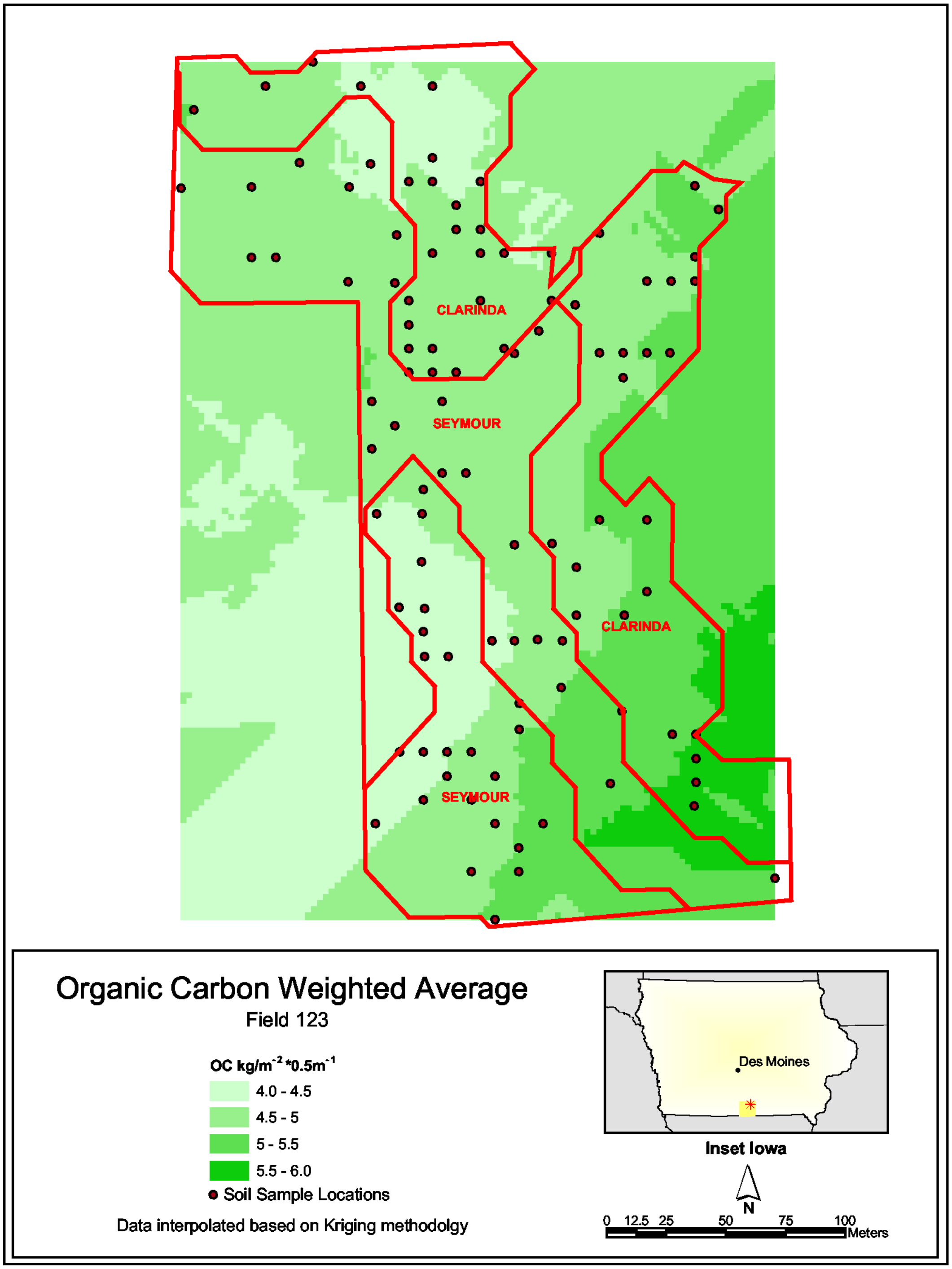

Figure 28. Kriged distribution of SOC (wt/volume) across the whole of Field 123, Chariton Valley, Iowa.

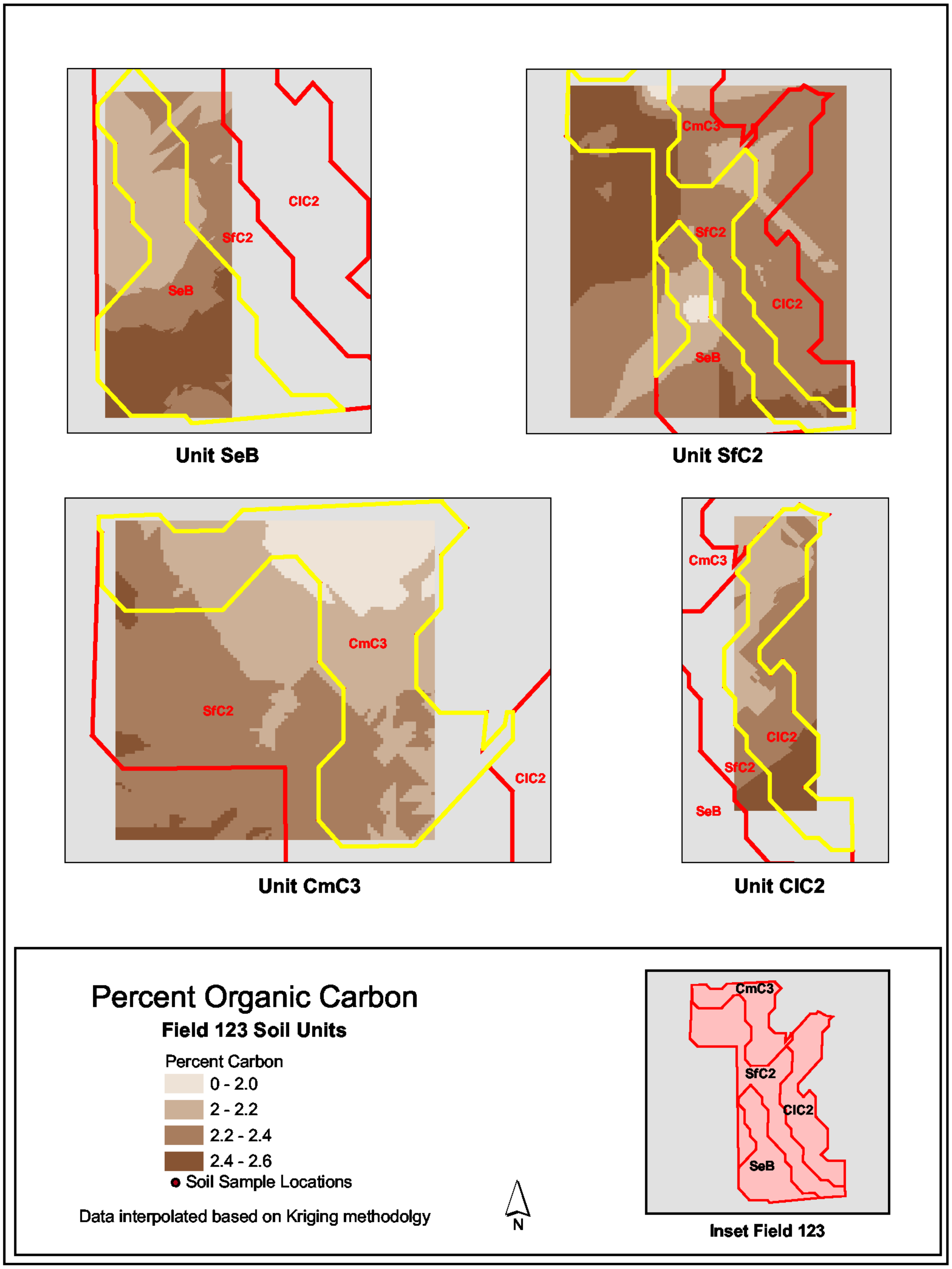

Figure 29. Kriged distribution of SOC (wt/wt) by SMU in Field 123, Chariton Valley, Iowa.

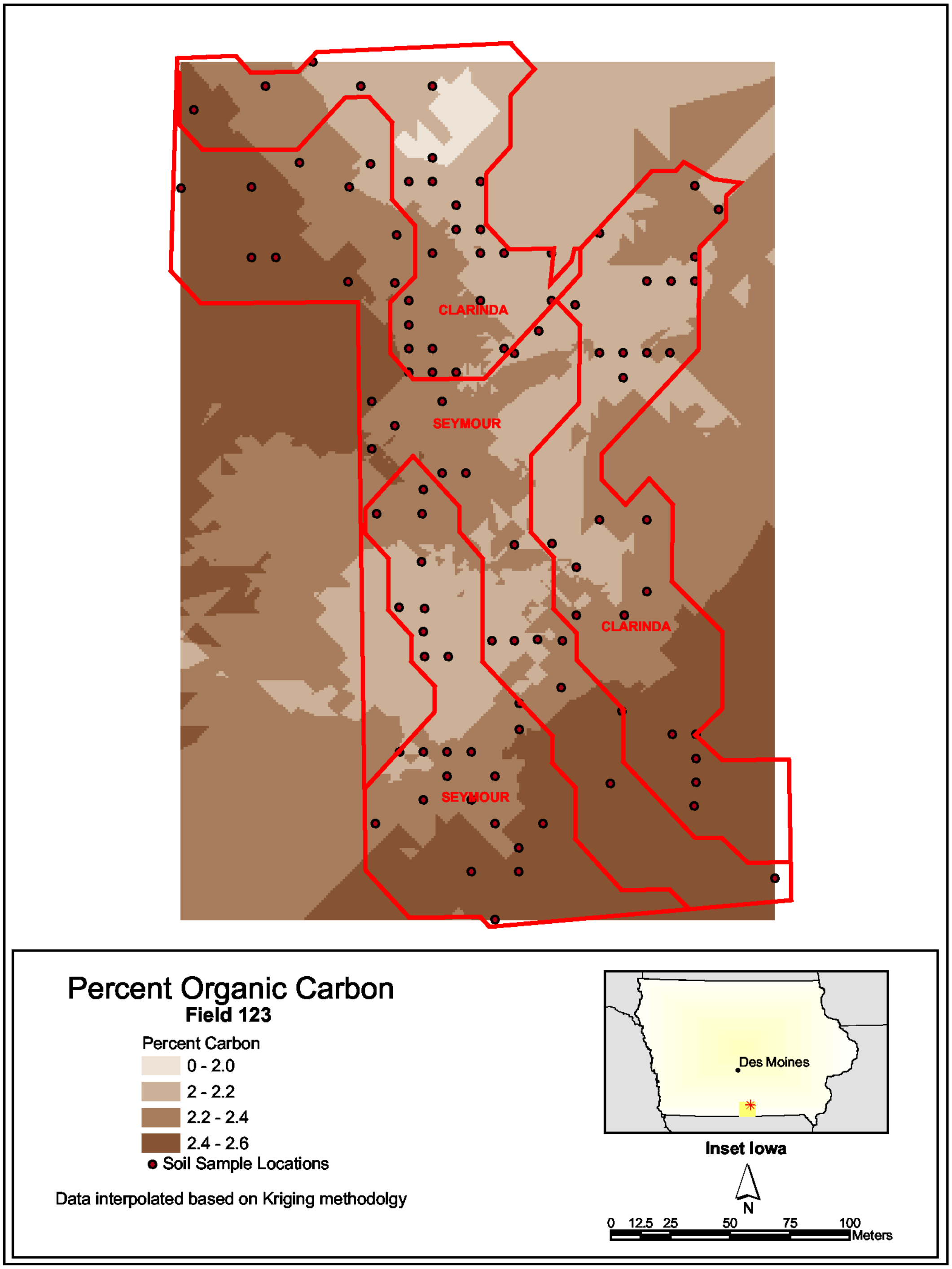

Figure 30. Kriged distribution of SOC (wt/wt) for the entire Field 123, Chariton Valley, Iowa.

Summary of Results & Discussion

1. Perennial vegetation (switchgrass, pastures or woodlots) appear to have higher contents of SOC and definitely have higher SAC than do row crop fields. This is evident regardless of sampling approach although statistical robustness is dependent upon number of samples. This interpretation is consistent the results of Burras and McLaughlin (2002) as well as other reports from outside of the Chariton Valley.

2. Notwithstanding comment one, both SMU-based grid sampling and centroid sampling result in considerable data overlap. This is just another way of saying this study provides fewer statistically significant results than originally expected. We assess this to be due to three limitations. First, the Clarinda and Seymour SMU's in the Chariton Valley are very similar vis-à-vis texture (clayey), drainage class, slope and landscape position as well as every other of Jenny's (1941) soil forming factors. Hence, they are basically identical with regards to their natural SOC content, their erosivity and their general sensitivity to human impacts. Although this interpretation is somewhat surprising to us – and obviously inconsistent with our initial hypothesis that Clarinda and Seymour would be different - once we began field sampling we found that in fact they are very comparable soils morphologically. Perhaps most strikingly we found the upper solum of every soil core to be comprised of clayey loess or clayey loess-derived colluvium. The second limitation we found was Clarinda and Seymour SMU's are quite impure and extend across numerous landscape positions. A given SMU might even include a shoulder, a backslope, a toeslope and even a summit and/or drainageway. This meant that some pedons collected in any SMU might have an ochric epipedon (unusually thin A horizon) while others might have cumulic mollic epipedons (unusually thick A horizon). This is not to suggest that a systematic spatiality does not exist in soil properties. It just does not show up well with SMU-based sampling. It does show up if a landscape transect approach is used (Burras and McLaughlin, 2002).

   Selecting sampling locations within each SMU was the third limitation. This was especially problematic for centroid pedons. The concept of centroid pedons is that the SMU is sampled in its middle location. The reality is that a mathematical algorithm places the "middle point" at a location dependent on the SMU geometry. Our SMU's have geometries that wrap around a hillslope - cutting across convex noses and concave drainageways, resulting in the middle point sometimes being in a drainageway, sometimes on a shoulder, sometimes on a footslope and sometimes on a summit. In other words, whereas a centroid pedon intuitively should be equal to a relevé (the most representative spot of an ecological unit), the mathematics driving its geostatistical location results in anything but intuitive locations. On the positive side, selecting random pedon locations within a grid meant all of the variability of the SMU was sampled. But given the SMU's overlapped in landscape positions and their significant amount of dissimilar inclusions (i.e., much of each SMU consists of other soils), few statistically significant difference were found between SMU's.

3. A significant advantage of showing properties with a map is spatial trends are visually apparent. This is valuable, although, these maps should not be seen as both precise and accurate. They are accurate to the point that they give about the same weighted average SOC contents, bulk density, SAC or any other property as any other method. This has to be. The maps use the same data as the other approaches. Conversely the maps are not uniquely precise because their precision is limited by the questions remaining about scale variability. As odd as this might sound, this is analogous to

rainfall maps. There are three common ways to prepare rainfall maps. Each uses the same data. The three methods are raw average method, Thiessen method, and area weighted average method. They routinely give quite different results, with magnitude of differences being dependent on the number of rain gauges and their locations as well as watershed geometry (Ward and Trimble, 2004). Interestingly - given the importance of these maps to everything from crop production to flood risks, the Thiessen method continues to be routinely used yet it is the method that has the most build in subjectivity.

4. Based on our review of this data as well as the other projects we have completed, we think whole fields and/or landscape-based transects rather than SMU's are much better geographical units to use in determining contents of SOC, SAC and other strongly human influenced soil properties. This interpretation is consistent with results from similar types of geospatial studies but at locations away from the Chariton Valley (e.g., Bruland and Richardson, 2005; Wills, 2005). We think using whole fields and/or transects is especially useful in the Chariton Valley because of the extensive history of soil degradation in the area as well as the generally low degree of SMU purity. The poor SMU purity reflects the complex geologic and ecologic history of the area as well as the lack of extensive fundamental pedological research in the area. For example, it is not at all clear that "eroded" Clarinda and Seymour SMU's were in fact originally Mollisols that have subsequently been eroded. Further review of the data herein as well as that provided in Burras and McLaughlin (2002) and Molstad (2000) will allow us to better evaluate this speculation.

5. Applying spatial quantitative tools such as kriging and then creating ARCGIS maps results in what appears to be much "cleaner" results than using traditional statistics. We think this appearance is likely deceiving. These quantitative tools were applied to a single field, which means it is impossible to compare it to some sort of control or even another field. More importantly – this approach is not transparent. The software, ARCGIS, and the accepted approach for its use permit considerable latitude in application in order to optimize results (Wills, 2005). Hence, two analysts examining the same data could come up with quite different results. This suggests the method is science but with a strong "expert system" (a.k.a. "art") component. That is identical to traditional soil surveying. As this report shows, the soil surveys of this region of Iowa have considerable impurity within each SMU. Finally, even if neither of the other concerns were valid (and they are), the visual aspect of this approach provides a psychological boost. That is, a reader thinks "if I can see this it must be true." when, in fact, all cartographers recognize every map is limited. A more blunt way to state this is the soil surveys of the area have significant SMU limitations although they are used very, very successfully and appropriately for many purposes. Those same limitations likely apply to ARCGIS maps and data.

6. Comparing the results within this report and previous work for the Southern Iowa Drift Plain, we conclude field history and landscape position are the two key variables controlling distribution of SOC content, SAC and other important soil properties at least for upland sites. If we are correct, this suggests accurate maps could be constructed by integrating minimal soil sampling (perhaps on the scale of second order soil surveys) with on-site GPS-generated elevation and good land use records. The limitation to this approach will be gullying and other more catastrophic environmental challenges that arise from the difficult in establishing perennial vegetation.

7. Clear trends occur with respect to SOC content with depth across all SMU's and land uses. Likewise, clear trends were found with duration of perennial vegetation.

Conclusion

Average SOC content is about 5 kg m^{-2}*20 cm, 10 kg m^{-2}*50 cm and 12 kg m^{-2}*100 cm for all six SMU's sampled, regardless of whether centroid or grid pedons are used to determine it. Depending on the method of sampling and statistical analyses, row cropped SMU's generally have lower SOC content than the other land uses. Likewise, some data supports SOC content increases proportional to stand age for perennial vegetation. No clear differences in SOC content was found between uneroded and eroded SMU's. Actually, ClC did appear to have less SOC content than it's eroded counterparts as well as all Seymour SMU's. This might indicate there is a fundamental difference between Seymour and Clarinda, as originally hypothesized, except the other Clarinda SMU's do not have clearly unique SOC contents when compared to Seymour SMU's. Stable aggregate content, CEC and A horizon thicknesses do segregate by land use. Each property increases (improves) proportional to stand age in perennially vegetated sites. Erosion class of SMU's do not appear to be important controls or predictors with regards to SAC, CEC and A horizon thickness. The relative rate of recovery for SOC contents is unclear for both the Clarinda and Seymour SMU's. The recovery rate for soil quality is clearly correlated with stand age of perennial vegetation. Recovery rates do not appear to be different between Clarinda and Seymour SMU's. SAC increases by about 2 to 3 percent annually. The A horizon thickness increases by about 0.4 cm annually. Even CEC could be annually increasing by about 0.02 cmolec kg^{-1}. Finally, coupling geostatistics and GIS with the sampling does result in clear, useable maps although we caution map users to realize any map is only as good as the data used to make it. Given the overlap in properties across the SMU's sampled – and to some degree land uses – the maps we present are probably best at the field scale and less accurate at the SMU scale.

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