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FEATURE

Exploring agricultural soil health through constraints of place: How pedology adds context to understanding soil health evaluation

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Defining and measuring agricultural soil health is a relatively new practice for farmers compared with measuring agricultural soil fertility. It was only recently that the Soil Health Institute North American Project to Evaluate Soil Health Measurements (NAPESHM) published a press release and paper announcing its recommended measurements for assessing soil health (Bagnall et al. 2023). The team evaluated over 30 soil health measurements and concluded that the minimal best suite of tests includes these three metrics: soil organic carbon (SOC), the directly measurable C component of organic compounds in soil organic matter, 24-hour C mineralization potential following rewetting of air-dried soil using the Solvita method to measure soil respiration, and soil aggregate stability, which describes how strongly soil particles group together, affecting water infiltration, nutrient run off, erosion, aeration, and root growth.

Most labs generating soil health measurements from systems such as the Comprehensive Assessment of Soil Health (CASH), the Soil Management Assessment Framework (SMAF), and the Haney test, will include one or more of the above NAPSHEM indicators in addition to a suite of other measures that are often less familiar to farmers. The practical value of these scientifically precise, chemically based, yet unfamiliar measures may not always be clear to farmers engaging in this space for the first time, especially when compared to the fertility metrics from which they already know how to extract agronomic value. Additionally, soil health measurements increase soil test costs, which can add friction to the value proposition for farmers. Eliminating added cost and using a metric farmers are familiar with may help to remove initial barriers to their willingness to explore the value of soil health measurements on their farm.

Starting with SOC, which is familiar to farmers as a component of soil organic matter, can help to build a natural progression of interest in soil health measurement. SOC can be used as a reasonable proxy measurement of soil health since a change in the level of SOC can indicate changes in soil biological and chemical functions related to not only agricultural productivity but ecosystem health as well (Nunes et al. 2021). The USDA Agricultural Research Service (ARS) National Lab for Agriculture and the Environment uses SOC as one of the key soil health metrics in its Soil Health Assessment Protocol and Evaluation, or "SHAPE," to score soil health.

The SHAPE SOC score differs from other soil health metrics that rely solely on chemical or biological measurements in that it considers several key environmental factors that affect plant growth and decomposition to develop a relative performance metric. The SHAPE SOC score principally considers the local long-term precipitation and temperature history along with the soil texture and suborder that affect a location's ability to store organic C. The SHAPE calculates how these aspects of the natural environment impact a soil's expected health potential and generates a performance score relative to that calculated potential. This enhances the SHAPE SOC score's beneficial value in two basic ways. First, it can provide a useful soil health performance score from a farmer's soil organic matter fertility test data at no additional cost. Second, the SHAPE SOC score may reveal that a seemingly good organic matter percentage value is disguising much of the soil's actual health and productivity potential. Conservation and other management practices could help farmers to realize more of this potential.

Although the SHAPE SOC score is contextually a more environmentally nuanced measure of soil health than organic matter or SOC values alone, even the SHAPE SOC removes soil from the rest of its natural habitat. Soil, like other biological organisms, will present only a limited profile of its full behavior when studied in the lab. Removing soil from the mechanical forces of weather on the local topography will limit a measurement's ability to generate relative comparisons between the productive capacities of different landscapes. Consequently, the implications of a precise, scientific metric like SOC can differ widely between environments with different topographical and mechanical terraforming histories. Implementing management practices to reduce erosion and enhance the landscape's ability to retain organic matter can help to mitigate these differences, but they cannot fully erase the topographical challenges affecting agricultural soil health. The Iowa Soybean Association (ISA)'s Soil Health Interpretation Portal (SHIP) summarizes SHAPE SOC scores by physiographic subregion of the state, which can provide additional context for farmers to easily, with no extra cost, evaluate the relative health of their soil.

PHYSIOGRAPHIC SUBREGIONS AND PERCENTAGE BACKSLOPE

In 2023, ISA launched an online Soil Health Interpretation Portal (SHIP). A key feature of the SHIP is its focus on Iowa's pedology or soil formation and evolution in the context of the natural environment. The geologic history of the land deeply affects soil characteristics and how soil health should be understood or compared (Anderson et al. 2018). Soil health is measured in the topsoil, generally within the top 6 in (~15 cm), just below the undecomposed and partially decomposed litter accumulated on the surface. Because of its inherent characteristics to support plant growth with fewer inputs than other soils, the A horizon, or surface mineral layer, of Iowa topsoil is some of the most economically valuable agricultural soil in the world.

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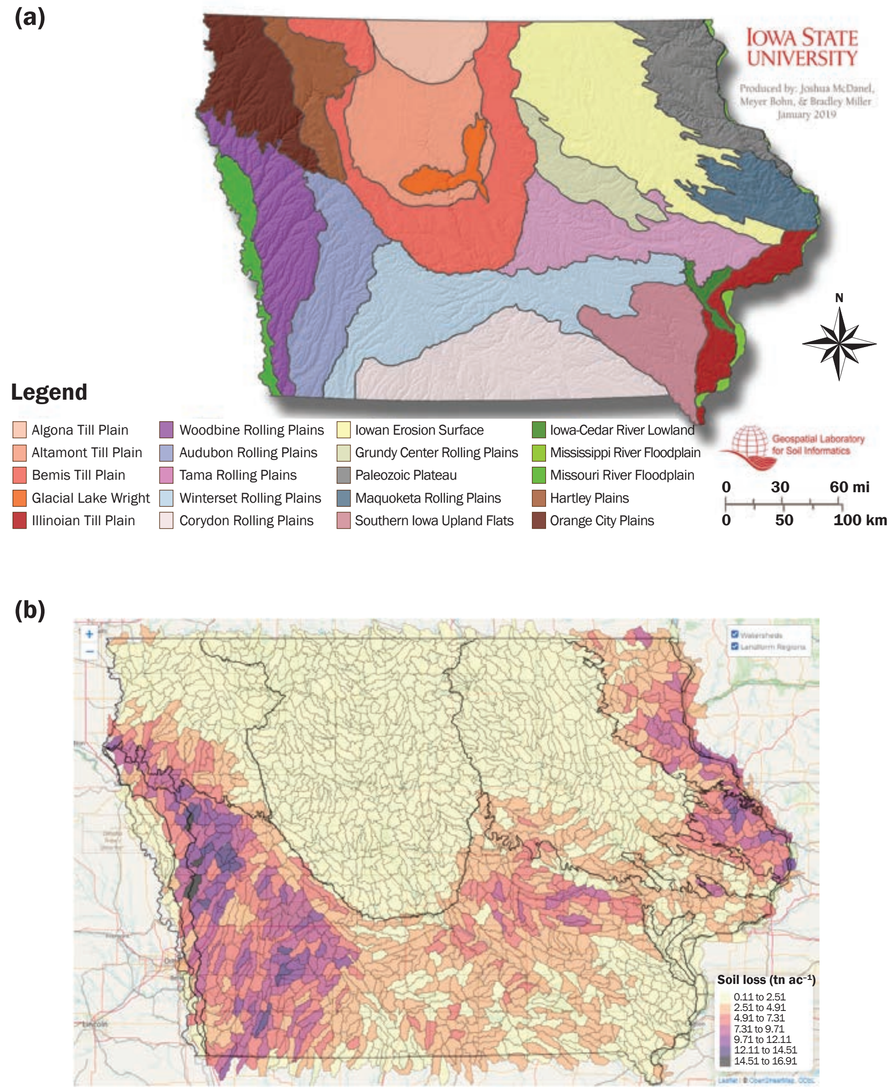
These soils took approximately 12,000 years to form (Cho 2012), yet in the last 100 plus years, conventional farming practices have changed the topsoil structure making it more susceptible to erosion, especially when left exposed to wind and water, resulting in billions of tons of topsoil lost from farm fields (Thaler et al. 2022).

The SHIP's summarization of SHAPE SOC scores divides Iowa's 10 landform regions into 20 physiographic subregions to provide additional soil history and environmental context for farmers to consider when using the SHAPE SOC score to evaluate their soil health and management practices. This context may provide a more representative expectation of comparative soil health scores and soil health improvement capacity considering landscape constraints and farm practice history. The terrain of each subregion is described in a document published by the Geospatial Laboratory for Soil Informatics at Iowa State University and is accessible in their blog and through the SHIP under "Extras." In examining differences between subregions, researchers at ISA focused on the percentage of backslope, calculated using the digital hillslope position classification tool (Miller and Schaetzl 2015). Backslopes are steep, transportational slopes that lie between upslope areas dominated by erosion and lower slopes that accumulate sediment (Furley 1971). These are areas where debris and water move most rapidly (Gile 1958; Young 1969; Huggett 1976; Schlichting and Schweikle 1980), affecting the susceptibility of the topsoil to erosion. Slope length also determines how much material moves through and along the backslope (Hall 1983). Conventional farming practices have added to the effects of wind and water on a location's ability to retain its topsoil, leaving subregions with a high percentage of backslope at a higher risk of loss. With decades required to build a fraction of an inch of new topsoil, one of the most effective ways to improve soil health is simply to retain it.

The SHIP is located online at https://shportal.iasoybeans.com/. The tabs across the top of the application allow users to select Maps, Quick Look, Extras, FAQs, Instructions, and Accounts. The Quick Look feature of the SHIP houses two benchmark databases where soil test lab results can be filtered by management practice and summarized by physiographic subregion. The map of physiographic subregions was created at the Iowa State University Geospatial Laboratory for Soil Informatics by Joshua McDanel, Meyer Bohn, and Dr. Bradley Miller in January of 2019 (Miller et al. 2019). The project used previously created glacial boundary maps, gSSURGO soil maps, and elevation derived from lidar in Geographic Information System (GIS) to identify regional boundaries between distinctive topographical features with structurally different soil qualities. The map subdivides Iowa's 10 landform regions into 20 pedologically similar subregions. The map of the subregions is shown in figure 1a. There are notable similarities between some of the subregion boundaries in figure 1a and Iowa's annual soil erosion patterns visualized in figure 1b on the map of the 15-year annual average soil loss in tons per acre between 2007 and 2021 as surveyed by Iowa State University through their Daily Soil

Figure 1
(a) Iowa State University Geospatial Laboratory for Soil Informatics, Physiographic Sub-Regions of Iowa. (b) Iowa State University Daily Erosion Project annual average erosion pattern by HUC12 watersheds.



Erosion Project (Gelder et al. 2017). For example, the boundaries of the Woodbine Rolling Plains (deep purple near the western edge of Iowa) and the Audubon Rolling Plains (medium slate blue just east of the Woodbine Rolling Plains) in figure 1a track closely with erosion patterns in the Western Southern Iowa Drift Plain in figure 1b. This is also true for the Grundy Center Rolling Plains (light gray) on the southwestern edge of the Iowan Erosion Surface (light yellow) in eastern Iowa beside the Paleozoic Plateau (dark gray) and East Central Iowa Drift Plain, identified as the Maquoketa Rolling Plains subregion (dark slate blue) in figure 1a, which are actual Landform Regions.

THE SHIP DATABASES

The SHIP summarizes each of the metrics stored in its two background benchmark databases by Iowa's physiographic subregions. The soil fertility test database contains data from 917 test sites. The fertility data set is substantially larger than the soil health test database in part because those tests have been around much longer, and because it includes soil fertility test data from 864 sites that participated in a statewide nutrient benchmarking survey conducted by ISA in 2011. Farmers were asked to sample both a good area and a poor area of a field. The additional 53 fertility test sites are cover crop "trial" sites. There are a total of 59 trial sites in the soil health test database from fields that participated in soil health experiments or "trials" conducted by ISA, or by Iowa Corn Growers through their Soil Health Partnership initiative since 2014. This data group will be referred to as "trial" data. All but 6 of the soil health database sites were also tested for soil fertility, and those data are in the fertility database. There are no soil health test data for the 2011 survey sites.

The SHIP is equipped to calculate SHAPE SOC scores from soil organic matter test data that are georeferenced with latitude and longitude. The SHIP applies the van Bemmelen conversion factor of 1.72, which places SOC at about 58% of organic matter, or it uses actual SOC values from either fertility or soil health test results where available to run the SHAPE SOC computation. Although there is some question regarding the scientific basis of the van Bemmelen conversion factor, it has been widely accepted for 150 years (Pribyl 2010). The SHIP uses it as a uniform way to generate relative SHAPE SOC values that are suitable for comparison within each data set. Individual labs may use slightly different methodologies to deter-

Table 1

Mean 2011 SHAPE SOC scores by physiographic subregion sorted in ascending order with percentage of the subregion in backslope. The highest level of SHAPE SOC score average improvement with conservation practice implementation appears in areas with high backslope and high early loess depth. Early loess depth does not appear to be a factor in low backslope areas that show lower response in SHAPE SOC score to conservation practices.

Subregion	2011 SHAPE SOC	Backslope (%)	Trial SHAPE SOC	SHAPE improvement	Early loess depth (m)
Paleozoic Plateau	18.47	79	26.17	7.70	3.7
Woodbine Rolling Plains (SIDP)	24.44	72	41.17	16.73	19.8
Illinoian Till Plain (SIDP)	27.08	45	44.88	17.80	9.1
Audubon Rolling Plains (SIDP)	28.54	62	31.76	3.22	13.7
Southern Iowa Upland Flats (SIDP)	31.45	50	50.92	19.47	3.0
Tama Rolling Plains (SIDP)	31.84	51	40.62	8.78	4.6
Winterset Rolling Plains (SIDP)	32.82	62	44.25	11.43	6.1
Orange City Plains	34.58	30	64.46	29.88	3.0
Grundy Center Rolling Plains	35.06	23	51.56	16.50	6.1
Iowa-Cedar River Lowland	35.70	12	46.55	10.85	6.1
Algona Till Plain (DSM Lobe)	37.54	14	55.50	17.96	0.6
Iowan Erosion Surface	41.06	17	44.27	3.21	7.6
Bemis Till Plain (DSM Lobe)	42.91	20	51.22	8.31	0.6
Glacial Lake Wright (DSM Lobe)	47.46	10	54.69	7.23	0.6
Altamont Till Plain (DSM Lobe)	48.48	11	57.37	8.89	0.6
Means	34.50	37	47.03	12.53	19
Medians	34.58	30	46.55	10.85	10
	Below 35%	≥45%	Below 35%	Below 8% improved	Early loess <1.5 m
Legend	35% to 49%	30% to 45%	35% to 49%	8% to 15% improved	Early loess <6.1 m
	Above 50%	Below 30%	Above 50%	>15% improved	Early loess ≥6.1 m

mine test values, so some additional noise can be expected in results, but not enough to negate general observations.

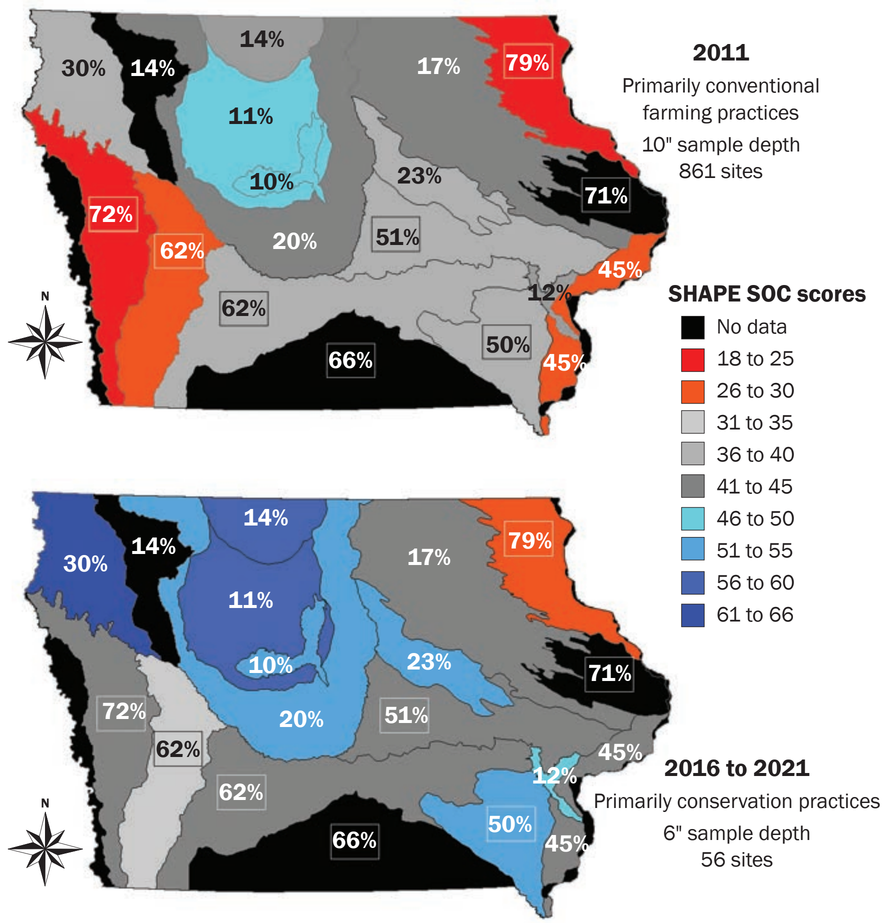
BENCHMARK INDICATIONS

One exploration of the soil fertility data set made by ISA comparing SHAPE SOC scores was to see if there appeared to be any difference in subregion mean scores that might be attributable to management practices. In 2011 only 33% of fields surveyed were using no-till or conservation tillage practices, and cover crop usage information was not even collected. Cover crops were being discussed in Iowa but rarely practiced. In contrast, the trial sites in the databases almost uniformly practice no-till and had cover crops implemented in test strips covering 50% of the site area for between one and eight years while participating in the different research studies. The cover crop management practice differences between the 2011 survey data and the soil health trial data make them easy to filter into separate data sets in the SHIP. To obtain just the 2011 data, cover crops and no cover crops were deselected under Management Practice Choices in the SHIP. To eliminate 2011 survey data from the data set, cover crop status unknown was deselected in the SHIP.

Sample depth can affect SOC values. All samples in the databases were above 11.8 in (30 cm) and in the tillage zone of influence. All samples included the first 4 in (10 cm), which contain the highest SOC concentration, but that portion of the sample will naturally be a smaller fraction of the deeper 9.8 in (25 cm) samples that were taken in 2011 than the 6 to 7.8 in (15 to 20 cm) samples taken specifically for soil health testing in the trial samples. This difference accounts for some difference in score results between the two sample groups (Franzluebbers 2020). With this understanding, we documented preliminary exploration of the mean SHAPE SOC scores by subregion in the benchmark databases as shown in table 1.

The first result we observe in table 1 is that soil SHAPE SOC scores of fields participating in research trials implementing conservation practices are higher than the 2011 fields using primarily conventional practices. Trial sites in 7 of the 15 subregions where conservation practices were implemented have SHAPE scores above 50%, whereas none of the 2011 sites using largely conventional management have scores above 50%. If less than half of SHAPE SOC score improvements are due to management practice differences rather than sample depth or random factors, it reflects a possible effect from conservation practice implementation in only about a decade.

Figure 2
The percentage of each physiographic subregion characterized as backslope by the digital hillslope position tool is indicated on each of the maps. Values in boxes are 50% or greater. Without mitigating factors such as significant historical loess, subregions with larger percentage of backslope tend to have lower average SHAPE SOC scores.



The second observed result of interest ISA studied is that the percentage of a subregion that is in backslope appears to influence SHAPE SOC scores in both management practice groups. Recall, backslope is the topographical area where water picks up downhill speed, making it subject to greater erosion potential. Correlation is not causation; however, negative correlation between SHAPE SOC scores and backslope percentage in both sample groups is high. In the 2011 data, it is –0.88 and in the trial data it is –0.74. The change in degree of negative correlation between sample groups may be an indicator that conservation practices may have a measurable impact on SOC retention. Table 1 supports the idea that although SHAPE scores reflect essential environmental factors related to SOC formation and sequestration, they do not account for topographical environmental factors contributing to erosion that may relate to the retention of topsoil and SOC.

Figure 2 includes two maps, one for 2011 survey SHAPE scores and the other for trial SHAPE scores. Both maps use colors to indicate the mean SHAPE SOC scores by subregion with the percentage backslope displayed in each subregion. Subregions in black indicate that there are no comparable data between the two groups. Backslope percentages of over 50% are outlined with a box. The top map shows 2011 scores and the lower map shows the trial scores. Subregions with a high percentage of backslope are primarily in the Paleozoic Plateau and subregions of the Southern Iowa Drift Plain and Lower backslope areas are in the Des Moines Lobe, Iowan Erosion Surface, and Northwest Iowa Plains. Subregions showing some of the greatest possible response to conservation management practices tended to have higher backslope percentages along with higher early loess depth measurements. Mapping these scores highlights the degree to which pedology and topography and 100 years of conventional agriculture are environmental factors that should not be completely left out of the soil health potential computation. Farmers intuitively understand the role topography plays in their operations. By ignoring this element in the comparative soil health equation, we may leave farmers skeptical of the value of a metric that considers apples and pineapples to simply both be "fruit."

SUMMARY

Maintenance of the soil's productive capacity is a key end goal of soil health measurement. Keeping track of differences in measurements over time, between management practices, and between locations has the potential to inspire beneficial change. Different soil health measurement systems look at this end goal from various biological and chemical perspectives. Only the USDA ARS National Lab for Agriculture and the Environment considers the impact of several key environmental factors on measures of soil health potential with the SHAPE score measurement system. Even so, the SHAPE score methodology does not factor in the impact of topographical features in the calculation of agricultural soil health potential. Our analysis indicates that in areas with considerable backslope the mechanical effects of weather and farming are evident in SHAPE SOC scores.

Implementing conservation practices like no-till, vertical or strip till, and adding cover crops help to reduce erosion of topsoil and improve its aggregate stability, and may also create conditions that are more conducive to the generation of organic matter and SOC (Francaviglia et al. 2023). The most immediate value of conservation practices being implemented across our landscape, however, may simply be the retention of our amazing topsoil resource.

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