What is soil health, how do we measure it, and why the emphasis on soil biology?

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Summary

- The current interest in soil health is largely due to increased awareness of the importance of soil biology.
- While there are a variety of biological soil health indices, there is currently no consensus among scientists.
- The current soil health tests are relatively expensive and show inconsistent results amongst management practices.
- Further research into calibrating and validating all soil health indicators is needed, especially for biological indicators.

Introduction and background

The recent appeal of soil health is largely due to the interest in soil biology, since only something living can be healthy (or unhealthy). Even though the biology in soil has been relatively ignored in traditional soil tests used for fertilizer recommendations, it is critical for aspects of soil fertility like cycling nutrients and generating more soil organic matter. In one acre of soil, all of the living soil organic matter (or biomass) would weigh the same as about 1-2 African elephants (Table 1).

Table 1. Size (micrometers or µm), numbers, biomass, and elephant equivalents in one acre of soil (Adapted from *Principles and Applications of Soil Microbiology 2nd Ed.*, Sylvia).

Soil Flora or Fauna	Size (µm)	Numbers (per g of soil)	Biomass (lbs. / ac)	Elephant Equivalents* (per acre)
Viruses	0.02 × 0.3	$10^{10} – 10^{11}$	???	
Bacteria	0.5 × 1.5	$10^{8} – 10^{9}$	300 – 3,000	0.27
Actinomycetes	0.5 – 2.0	$10^{7} – 10^{8}$	300 – 3,000	0.27
Fungi	8.0	$10^{5} – 10^{6}$	300 – 4,500	0.45
Algae	5 × 13	$10^{3} – 10^{6}$	10 – 1,500	0.13
Protozoa	15 × 50	$10^{3} – 10^{5}$	5 – 200	0.02
Nematodes	1,000	10 – 100	1 – 100	0.01
Earthworms	100,000		10 – 900	0.09
Total			**926 – 13,800**	**1.23**

* Based on a 10,000 lb. elephant, but African elephants range from 6,000-10,000 lbs.

It has been argued that the term 'soil health' is just a reinvention of the wheel – and in this case it may be that the wheel was reinvented twice. Soil health was preceded by the term 'soil quality', and before it 'soil tilth'. The popularity of soil health, and its relationship to the phrases 'soil quality' and 'soil tilth' can be seen by looking at Google's enormous database of the content of books going back to the 1800's (Google, 2017). The use of soil health and tilth in books peaked around the 1950's (Figure 1), likely due to the devastating impact of the Dust Bowl in the late 1930's and considering a 10-year or so lag in publishing time. Use of 'soil quality' in books increases rapidly in the 1970's and 1980's. Then by the 1990's and 2000's the rate of publication of soil health increases at an even greater rate to near present and continues to increase day (Figure 1).

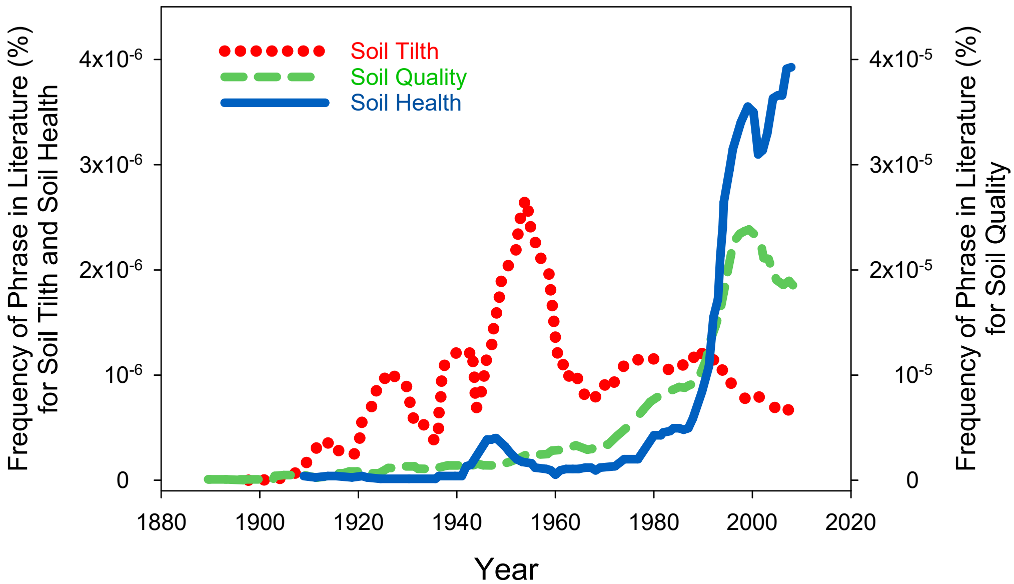

Figure 1. Frequency, or occurrence, of the phrases 'soil tilth', 'soil quality', and 'soil health' from all books Google has scanned and made available on their Ngram Viewer. The axes are in scientific notation of percent of all books that include these phrases (10^{-6} = 0.000001%). Soil tilth and health are expressed on the left axis, while quality is on the right axes because it is about an order of magnitude great than the other two.

Currently, the Natural Resources Conservation Service defines soil health as, "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans" (NRCS, 2017). This definition reinforces the idea of the increased emphasis on soil biology since only living, like soil biota, can be healthy. There is a massive effort to come up with biological soil health indicators since soil biology are often considered more sensitive to management practices than physical and chemical indicators. The Soil Health Institute, a nonprofit organization lead in part by soil scientists, has recommended several soil health indicators in their 'Tier 1' category that is defined as "specific measurements are regionally defined, have known thresholds, and help define management strategies to improve soil function" (Table 1, SHI 2017). However, only two biological indicators are included on this list – potentially mineralizable carbon and nitrogen. Although, it is interesting to note that crop yield is included, which could be considered a biological indicator if the yield was a from a check plot with no fertilizer addition.

Table 2. Physical, Chemical, and Biological indicators endorsed by the Soil Health Institute as 'Tier 1' indicators.

Physical	Chemical	Biological
Water-stable aggregation	Organic carbon	Carbon mineralization
Texture	pH	Nitrogen mineralization
Penetration resistance	Cation exchange capacity	Crop yield
Erosion rating	Electrical conductivity	
Bulk density	Base saturation	
Available water holding capacity	Plant available nutrients (e.g. N, P, K)	
Infiltration rate	Micronutrients	

A search for a better soil health test, and what indicators should be included, is now underway. An ideal soil health test should be a) broadly applicable across soil types and time, b) sensitive to management practices, and c) comprehensive in including physical, chemical and biological indicators of soil health. Moreover, recent passage of soil health initiatives in California and Maryland Soil make it imperative to have these tests grounded in robust data. A good soil health test should be convenient for a farmer to take a sample or measurement, but many of the physical measurements typically need to be done in the field and some with the use of special equipment. The current soil health tests, and indicators included therein, vary from laboratory to laboratory and there is currently no consensus on what are the key biological measures should be included in a comprehensive soil health test. Not to mention these tests can be rather expensive, ranging from $25.00 up to $150.00 per sample. Finding a broadly applicable, relatively inexpensive, convenient, yet scientifically robust soil health test that relates to yield is the challenge but is needed in order to make management recommendations.

Preliminary findings and discussion on soil health

A recent study by Roper and others (2017) examined soil health scores from two well-known soil health tests: a) the Haney Soil Health Test (HSHT), and b) Cornell's Comprehensive Assessment of Soil Health (CASH). They compared values from both of these tests on three long-term experiments, ranging from 15 to 30 years of a variety of different management practices. Roper and colleagues (2017) showed that soil health scores varied very little from these three long-term experiments, despite the history of drastically different management practices. The HSHT showed a significantly higher score of 16 (out of 50) for a no-till soil compared to a chisel and moldboard plow scores of 8 and 5 respectively, but only in the piedmont ultisol soils (Roper and others, 2017). The CASH test found the overall score for organic, no-till management (score of 55 out of 100) was significantly higher than no-till chemical (score: 44) and conventional till organic (score: 44); however, again this was only on the mountain soils but not piedmont or coastal ultisols. Overall it appears that two popular soil health tests show inconsistent results among soil types and management, even within the same soil order (ultisols).

From the Roper and colleagues (2017) study it is also important to note that there were inconsistencies between the two soil health tests, but that the soil biological indicators (like respiration, soil protein and active carbon) were where the cause of the significant differences among management practices in the overall test scores. There were little differences among treatments with the physical and chemical soil health indicators (Roper and others, 2017). These results emphasize the importance of soil biology as part of a soil health measurement, and further suggests biological measurements are more sensitive to management practices like tillage (Doran, 1980), fertilizer type (Ladd and others, 1994), and crop rotations (McDaniel and others, 2014). However, what might be most problematic with some of these soil health tests is that they do not relate to crop productivity (Figure 2). More research on what are the proper soil health indicators and refinement of scoring is needed if we are to come up with a broadly applicable (or consistent) soil health test that relates to productivity.

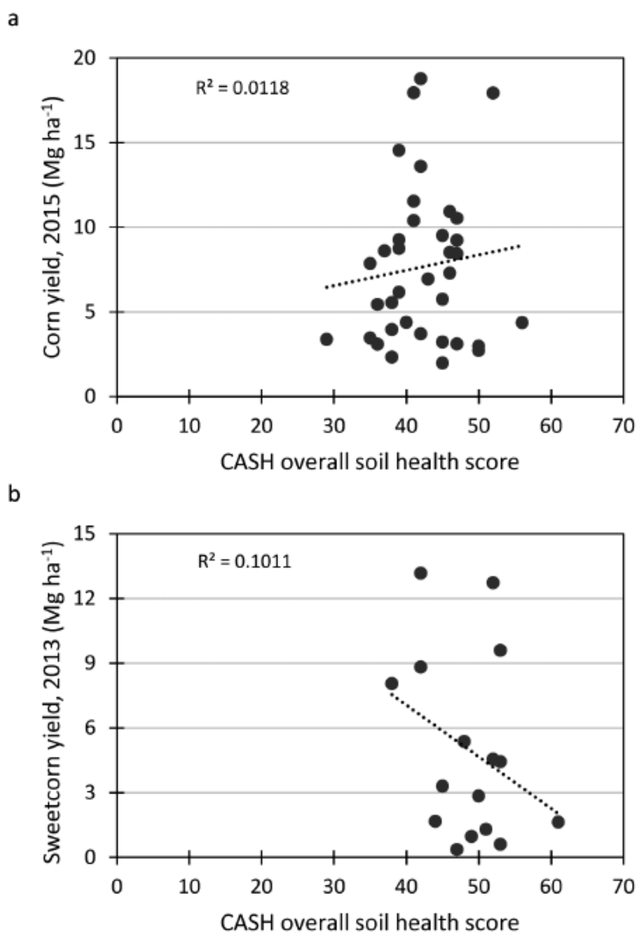

Figure 2. From Roper and others (2017). Their figure shows the relationship between the Cornell Comprehensive Assessment of Soil Health (CASH) and yield of corn in 2015 (a), and sweetcorn in 2013 (b). Regressions were not significant, or in other words, there was no relationship between productivity and soil health scores.

Figure 3. Soil your undies demonstration done by Neil Sass at Soil Survey Office in Waverly, IA. The percent mass of cotton left at the end of 6 weeks in (top and clockwise) perennial pasture, no-till soy with rye cover, no-till soybean, conventional corn, and alfalfa. Original cotton underwear shown in upper left.

Since decomposition of crop residues is a key process regulated by soil biology, it seems imperative to include decomposition be part of any soil health test. Furthermore, decomposition of an 'artificial' residue has the potential to be a comprehensive soil health indicator. This is because the rate of decomposition is not only controlled by the presence and activity soil biota, but also regulated by physical and chemical characteristics of a soil. Several researchers and extension specialists have begun to use decomposition of household materials as an easy indicator of soil health, but currently mostly as a demonstration and extension tool such as with the "Soil Your Undies" demonstration (Figure 3). The use of tea decomposition seems promising and has less issues (Keuskamp and others, 2013; McDaniel unpublished data). The use of these 'do-it-yourself' soil health indicators allow a producer to collect their own data, participating in citizen science, which has recognized benefits for conservation practices (Cooper and others, 2007). A scientifically-robust, broadly applicable decomposition index has yet to be found. But when it is, it will likely be less expensive than current methods of measuring biological indicators of soil health.

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Financial stress in Iowa farms: 2014-2016

Summary

Iowa farm financial conditions have deteriorated since 2012, but average indicators of liquidity and solvency remain close to their long-term levels. However, average financial measures mask the variability across farms. This article tracks the evolution of financial stress in Iowa farms using a panel of financial statements for 273 farms collected by the Iowa Farm Business Association (IFBA). The share of financially stressed farms (vulnerable liquidity or solvency ratings) increased from 38 percent in December 2014 to 47 percent in December 2016. On average, farms lost $180 per acre of working capital over that period, but farms with vulnerable liquidity ratings lost almost twice that amount. Iowa State University Extension and Outreach makes available a number of resources free of charge to help farmers with their farm financial planning.

Average accrued net farm income in Iowa declined by 89 percent from its peak of $243,072 in 2012 to $27,927 in 2015, before recovering slightly to $45,597 in 2016 (Figure 1). As a consequence of this erosion in farm profitability (Plastina 2017), a deterioration of the overall financial health of the farm sector ensued. Relative measures of solvency[1] (such as the debt-to-asset ratio) and liquidity[2] (such as the current ratio) have deteriorated rapidly since 2012, and are now close to their 2006 levels (Figure 2). However, average net worth per acre[3] has remained stable at around $2,750 since 2011 (Figure 1).

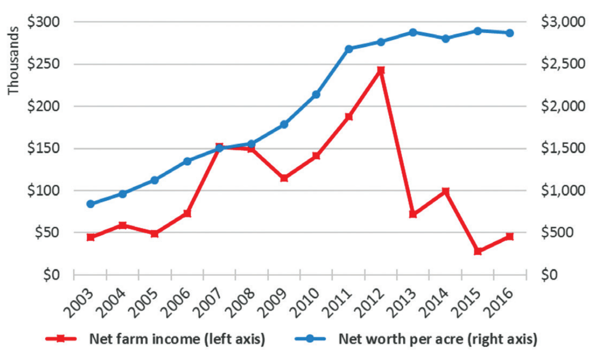

Figure 1. Average net farm income and net worth per acre in Iowa

[1] Solvency refers to the degree to which all debts are secured and the relative mix of equity and debt capital used by the farm. The total debt-to-asset ratio is a relative measure of solvency, and is calculated as the ratio of total farm liabilities to total farm assets.

[2] Liquidity refers to the degree to which debt obligations coming due over the following year can be paid from cash or assets that soon will be turned into cash. The current ratio is a relative indicator to gauge farms' liquidity, and is calculated as the ratio of current farm assets to current farm liabilities.

[3] Net worth is measured on a cost basis. See the Data section for more details.

Although state averages show to some extent the recent deterioration of farm financial conditions, they also seem to indicate that the liquidity and solvency situations as of December 2016 are similar to their pre-2010 levels, when far fewer editorials about financially stressed farms made news.

This article provides an assessment of the degree of financial stress across Iowa farms and its recent evolution using a panel of farm financial statements from the IFBA, and lists the resources that ISU Extension and Outreach makes available free of charge to farmers to facilitate their financial planning and coping with the associated stress.

To ensure the comparability of financial indicators across farms of different sizes, the assessment is conducted using the debt-to-asset ratio (DTA) as an indicator of solvency, and the current ratio as an indicator of financial liquidity. At each point in time, each farm is assigned a solvency rating and a liquidity rating. Then, farms are grouped into different categories according to their ratings. The evolution of the farm financial situation is assessed by comparing the composition and characteristics of the different groups of farms through time.

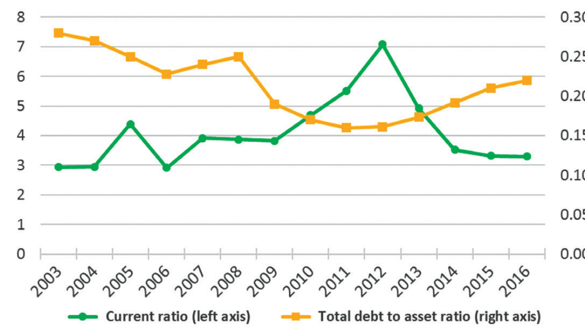

Figure 2. Average current ratio and total debt-to-asset ratio in Iowa

Data

The 273 farms analyzed in this study were selected from the IFBA database based on the availability of complete and detailed financial statements for 2014, 2015, and 2016.

The IFBA is an independent farm business management association, managed and controlled by its members. Because the IFBA data come from actual accounting records, they are generally more accurate and consistent than data obtained from cross-sectional surveys (Hoppe et. al). However, because the data are not obtained using survey sampling methods, they may not be fully representative of the Iowa farm population.