Developing Standard Protocols for Soil Quality Monitoring and Assessment

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Abstract

Africa’s agricultural viability and food security depend heavily on its soil quality. However, while approaches to measuring air and water quality are widely established, soil quality assessment protocols are largely non-existent. This paper describes the process we have used in selecting and developing a set of inexpensive, agronomically meaningful, low-infrastructure-requiring indicators of soil quality (SQ), which make up the Cornell Soil Health Test (CSHT). The CSHT is now available to the public in New York State (NYS), United States, similarly to the widely available soil nutrient tests. Case studies show the CSHT’s success at measuring constraints in agronomically essential soil processes, and differences between management practices in NYS. It thus helps farmers specifically target management practices to alleviate quantified constraints. Such indicators have the potential to be developed into standardized soil quality tests for use by African agricultural non-governmental and government organizations and larger commercial farmers to better understand agricultural problems related to soil constraints and develop management solutions. Their low cost and infrastructure requirements make them excellent tools for numerous low-budget extension and NGO-based experiments established in collaboration with local small farmers, as well as to quantify the status and trends of soil degradation at regional and national scales.

Keywords: Soil Health, Soil Quality, Soil Quality Assessment, Soil Quality Indicators, Soil Quality Monitoring

1. Introduction

1.1. Soil Quality Degradation and the Need for Standards

Declining soil quality (SQ) is emerging as an environmental and economic issue of increasing global concern as degraded soils are becoming more prevalent due to intensive use and poor management, often the result of over-population (Eswaran et al., 2005). Pressing problems such as erosion, compaction, acidification, organic matter losses, nutrient losses and desertification reduce agricultural production capacity. SQ decline severely impacts the environment and agricultural viability, and thus ecosystems and the population’s health, food security, and livelihoods.

Tests to monitor air and water quality have been standardized and widely adopted internationally (Riley, 2001). However, although an estimated 65% of the land area world wide is degraded (FAO, 2005), no standardized SQ tests exist currently, especially for use in the tropics (Winder, 2003). The World Soils Agenda developed by the International Union of Soil Scientists lists as the first two agenda items 1) assessment of status and trends of soil degradation at the global scale and 2) definition of impact indicators and tools for monitoring and evaluation

(Hurni et al., 2006). There is clearly a need for international standards to measure SQ. These could be useful for agricultural research and extension agencies, non-governmental organizations, governments and farmers to better understand, implement and monitor sustainable soil management practices.

1.2. Soil Quality, Its Assessment and Indicators

Soil quality includes an inherent and a dynamic component (Carter, 2002). The former is an expression of the soil forming factors, documented by soil surveys as expressed by land capability classification. Dynamic SQ, however, refers to the condition of soil that is changeable in a short period of time largely due to human impact and management (Carter, 2002). The SQ concept encompasses the chemical, physical and biological soil characteristics needed to support healthy plant growth, maintain environmental quality, and promote human and other animal health (Doran et al., 1994). With farmer and lay audiences, the term “soil health” is often preferred when referring to this dynamic SQ concept as it suggests a holistic approach to soil management (Idowu et al., 2007).

New regulations have catalyzed a proliferation of various indicators and "environmental report cards" for assessing vulnerability and improvement towards sustainability (Riley, 2001). Indicator suitability can be judged by several criteria, such as relevance, accessibility to users, and measurability (Nambiar et al., 2001). Criteria and thresholds for relevant indicators must then be set by which to assess performance level relative to a standard (Manhoudt et al., 2005).

SQ cannot be measured directly, but soil properties that are sensitive to changes in management can be used as indicators (Larson and Pierce, 1991). Methods for measuring individual indicators and minimum data sets (Dexter, 2004) and for calculating indices from groups of indicators (Andrews et al., 2004) are being developed for SQ monitoring over time and for evaluating the integrated sustainability of agricultural management practices. However, such tests must be inexpensive and dependent on minimal infrastructure if they are to be widely adopted beyond the research domain and especially in the developing regions such as Africa.

Limited experience exists with the use of such methods, other than for standard agricultural soil tests. Such tests have provided farmers and consultants around the world with relevant information for nutrient and lime management. In a more holistic SQ paradigm, integrative assessment of the three SQ domains (physical, biological and chemical) would be accomplished by SQ indicators that represent soil processes relevant to soil functions and provide information that is useful for practical soil management. Our approach identifies soil constraints and aids in the selection of management solutions (Idowu et al., 2007). The interpretation of CSHT results requires professional judgment that takes into account the land use objectives and resource availability to devise locally appropriate strategies.

The objective of this paper is to 1) discuss the methods of the selection of key SQ indicators, as implemented through the new CSHT, 2) highlight the utility of the test through the results from example cases based in New York State, United States, and 3) discuss the potential for applications of internationally applicable SQ standards using the CSHT as the starting framework.

2. Methods - Cornell Soil Health Test Development

2.1 Approach

The CSHT was developed through a triage process for potential SQ indicators and streamlining of methodologies. The new SQ test was envisioned to provide critical quantitative information that would allow for better management and protection of agricultural soil resources.

Specifically, the test was developed for the following reasons: 1) Improved soil inventory assessment by adding evaluation of dynamic SQ to the inherent SQ reported in soil surveys, 2) Quantifying soil degradation or aggradation from management, 3) Targeting management practices to address measured soil constraints, 4) Education through addressing site-specific SQ and soil management issues, and 5) Land valuation to facilitate monetary rewards for good land management.

Thirty-nine potential SQ indicators were evaluated (Table 1). The suitability of the soil properties as such was evaluated through samples from (i) long-term, replicated research experiments related to tillage, rotation, harvest type and cover cropping studies, and (ii) commercial farms (including grain, dairy, vegetable and fruit operations on a number of soil types) that provided real-world perspective under the range of soil management conditions in New York State.

2.2 Sampling and Analysis

For all management units, two undisturbed soil core samples were collected from the 5 to 66-mm depth using stainless steel rings (61 mm height, 72 mm ID, 1.5 mm wall thickness). Disturbed samples were collected from the 5 to 150 mm depth using trowels. All samples were stored at $2^{o}C$ until analysis.

Physical tests were mostly based on standard methodology, as discussed by Moebius (2007), except for wet aggregate stability which involved the application of simulated rainfall of known energy (Ogden et al., 1997) to aggregates on sieves. Biological tests also mostly involved established methods: Decomposition rate was based on loss of filter paper volume over 3-weeks of incubation on soil. The active carbon test involved a $KMnO_4$ oxidation procedure based on work by Weil et al. (2003). The root health assessment involved a bioassay method where sampled soil is planted with snap bean seeds and root damage is rated based on root morphological features (Abawi and Widmer, 2000).

Analysis of the chemical indicators was based on the standard soil fertility test offered by the Cornell Nutrient Analysis Laboratory. Available nutrients are extracted with Morgan's solution, a sodium acetate/acetic acid solution, buffered at pH 4.8. The extraction slurry is filtered and analyzed for K, Ca, Mg, Fe, Al, Mn, and Zn on an inductively-coupled plasma spectrometer (ICP) and plant-available PO_4-P is measured using an automated rapid flow analyzer. Using a standard pH meter, pH is determined from a 1:1 soil:water mix.

2.3 Indicator Selection

The general criteria used for physical and biological indicator selection into the test included: 1) Sensitivity to management, i.e., frequency of significant treatment effects in the controlled experiments and directional consistency of these effects, 2) precision of measurement method, i.e, coefficients of variability, 3) relevance to important functional soil processes such as aeration, water infiltration/transmission, water retention, root proliferation, nitrogen mineralization, development of root diseases, etc., 4) ease and cost of sampling and analysis (Moebius et al., 2007).

Many soil physical properties were rejected as suitable indicators due to the requirement for undisturbed samples, or due to high variability. For example, although it is widely regarded as an important physical indicator, bulk density was not included, because of the impractical need for undisturbed core samples (Moebius et al., 2007) and generally strong correlations with other physical indicators in the test. The use of ring samplers for bulk density proved to be a serious obstacle with field practitioners and technicians. Therefore, the reliability of the results was questionable due to frequent improper sampling, especially with soils containing coarse fragments. Many soil biological indicators were rejected due to the high cost of analysis, often associated with labor intensity. The seven soil chemical indicators adopted in the integrated SQ test are part of well-established standard soil nutrient analysis tests that are widely used at reasonable cost in NYS.

2.4 Selected Test Indicators

Table 2 shows the physical, biological and chemical indicators that have been selected for the soil health test (Idowu et al., 2007). These are indicators of critical soil processes (e.g., aeration, infiltration, water and nutrient retention, root proliferation, N mineralization, toxicity prevention, pest suppression, etc.), which in turn relate to soil functions such as plant production, landscape water partitioning and filtration, and habitat support. The standard soil health test thereby evaluates the soil's ability to accommodate ecosystem functioning within landscapes.

The indicators are measured based on a composited disturbed sample, which we recommend to be obtained from two locations nested within five sites on a management unit (Gugino et al., 2007). The test includes penetrometer measurements as the only in-field assessment. Soil texture is an integrative property and provides the basis for result interpretation through scoring functions. Root health assessment is an integrative biological measurement related to overall pressure from soil-borne disease organisms (Abawi and Widmer, 2000). The minor elements of the chemical analysis were grouped to prevent a bias of the soil health assessment in favor of chemical quality. Based on an economic analysis (Moebius et al., 2007), the standard test can be offered for less than US $50 in NYS. In countries with lower wages, and with careful selection of a subset of indicators, these costs could be further reduced.

Most indicators were shown to have significant within-season variability (Moebius et al., 2007), and soil management practices can be a confounding influence for soil physical and biological indicators. Thus, samples should be collected at an appropriate and consistent time to be established regionally. In NYS, early spring sampling prior to tillage is best, due to favorable soil water conditions (near field capacity), and relatively uniform biological conditions following over-wintering.

2.5 Data Interpretation and Scoring Curves

Effective use of soil health test results requires the development of an interpretive framework for the measured data. The general approach of Andrews et al. (2004) was applied for this purpose. Different scoring functions for the three main textural classes, sand, silt and clay were developed for all soil indicators to rate test results. Scoring functions were defined in the simple linear-plateau framework, as no justification existed for curvilinear functions. Three types of scoring functions were considered, “more is better,” “less is better,” and “optimum” (Fig. 1). The critical high and low cutoff values were developed based on the frequency distribution of data throughout NYS. Test results with values less than the 25th percentile were given scores of 1, and greater than the 75th percentile were given scores of 10. This approach was evaluated relative to literature reports and in some cases minor modifications were made. Scoring curves for other indicators are reported in Gugino et al. (2007).

2.6 Soil Health Test Report

A standard soil health test report was designed for practitioner audiences, and facilitates both integrative assessment and targeted identification of soil constraints. This is accomplished through the combined use of quantitative data and color coding (Fig. 2). The physical, biological and chemical indicators are grouped by blue, green, and yellow colors, respectively. For each indicator, the measured value is reported as well as the associated score from its scoring function. The latter is interpreted with colors in that scores of less than 3 receive a red code, scores greater than 8 a green code, and those in between are coded yellow. This provides for an intuitive overview of the test report. If results are coded red, the associated soil constraints are additionally listed (Fig. 3). Finally, the percentile rating is shown for each indicator, based on the sample's ranking in the database of soil indicator measurements (Fig. 2). An overall soil health score is provided at the bottom of the report, which is standardized to a scale from 1 to 100. It is noted that the interpretation of the test results are generalized for agricultural systems and may require alternative interpretation in other cases. Hence, we recommend that the reports are interpreted by professional consultants and include consideration of site-specific information.

Soil management recommendations were developed to address specific soil management constraints in NYS agricultural systems (Gugino et al., 2007), which may be partly applicable to other climates and soil types. A training manual was developed to explain the basic approaches to soil health assessment, the reporting and interpretation of the results, and the suggested management approaches. It can be accessed and downloaded from the Cornell Soil Health web site at http://soilhealth.cals.cornell.edu.

3. Results and Discussion

3.1 Case Study 1: Two Vegetable Production Scenarios

Fig. 2 shows the test reports for two very different scenarios of vegetable production. Fig. 2a reports data for a farm near Geneva, NY on a glacial till-derived Honeoye-Lima silt loam. This farm has been used for production of processing vegetables (cabbage, beets, sweet corn, snap beans, etc.) using intensive, conventional (moldboard plow) tillage. Fig. 2b reports data for the organic vegetable garden that is part of an organic dairy near Keesville, NY on a Nellis/Amenia gravelly sandy loam. The garden is being managed without tillage, and with large manure applications. Both test reports show generally favorable results for chemical indicators, with high rating scores (7.5 or above). Only P in the vegetable garden is suboptimally high, likely a result from high manure applications, which could lead to environmental P loading.

For the conventionally managed vegetable operation, the remaining indicators have low scores and therefore show evidence of low physical and biological SQ. Very unfavorable results for aggregate stability, available water capacity, and organic matter content (1, 2, and 1, respectively) are evidence of soil degradation from long-term intensive tillage, and limited use of soil-building crops. Low to intermediate scores for active carbon, PNM, and root health (3, 2, and 5, respectively) indicate that the soil is biologically degraded and unbalanced. Scores of 3 to 4 for soil hardness indicate a mild soil compaction problem. The overall score of 49.5 signifies considerable opportunity for targeted improvement.

Biological and physical SQ of the vegetable garden, by contrast, are high, likely due to careful, concentrated management using ample organic matter additions, crop rotations and no tillage. All indicators except aggregate stability show ratings of 9 or above. Low aggregation is common in sandy soils. Nevertheless, stability is greater in the vegetable garden than in the conventionally managed operation on a silt loam. Furthermore high aggregation in a sandy soil is not as essential as with finer textured soils, as aeration, infiltration, shallow rooting, and crusting are not generally limiting. The overall score of 87.5 signifies that only minor changes in current management may be advisable.

3.2 Case Study 2: Comparison of Tillage Management

Fig. 3 shows the test reports for two tillage management styles, a) plow tillage and b) zone tillage, practiced side by side on a research farm near Aurora, NY on a glacial till-derived Honeoye Lima silt loam. Zone tillage is a conservation tillage system that limits soil disturbance to the area of the planting row, and leaves the areas between the crop rows undisturbed. Both plow and zone tillage treatments have been under maize-soybean rotation since 1992. Both test reports show generally favorable results for chemical indicators, with mostly high rating scores (7.0 or above). Both root health ratings are also high (8 and 9 for plow till and zone till respectively), likely because the bean root assay is mostly sensitive to vegetable diseases which are uncommon in maize-soybean rotations. Surface hardness is better under plow till (10) than no till (7), likely due to loosening after traffic under plow till.

However, the remaining indicators, have lower scores under plow tillage, showing evidence of degraded physical and biological SQ for the conventionally plowed fields. Especially low scores for aggregate stability (2), available water capacity (2) and organic matter (2), and intermediate scores for subsurface hardness (5), active carbon (3) and potentially mineralizable nitrogen (4) are evidence of soil degradation from long-term intensive tillage, and lacking use of soil-building crops or organic matter additions. The overall score of 58.8 for plow till as compared to 81.7 for no till signifies that no till is better able to maintain physical and biological SQ, and considerable opportunity for improvement exists in this plow till system.

These reports exemplify the need for broader assessment of SQ. Based on traditional soil testing methodology, i.e., the chemical indicators, all soils appeared to be of good quality. This is commonly the case, as most NYS farmers are diligent about submitting soil samples for nutrient analysis and subsequently correcting the deficiencies. Chemical constraints are readily remedied by application of inorganic chemicals, which generally provides instant results. In contrast, the lack of routine tests for soil physical and biological indicators has resulted in inadequate attention to these facets of the soil, especially in larger scale, conventional operations. Moreover, enhancing the physical and biological quality of soils generally requires a longer-term commitment to soil management through practices such as conservation tillage, improved rotations, cover cropping, and organic amendments, as discussed in Gugino et al. (2007). The soil health test therefore identifies a broader set of constraints and provides farmers with information that allows for holistic soil management.

3.3 Applications in Africa

There is great potential to adapt the CSHT for international use by carrying out case studies to determine its utility. One such study took place at the Kakamega and Nandi Forest Margins in Western Kenya during July and August of 2007. This study will 1) evaluate the CSHT's ability to measure long-term trends in soil degradation status and specific constraints, as well as aggradation due to short term organic matter additions, 2) evaluate soil reflectance using visible/near-infrared and mid-infrared reflectance spectroscopy (VNIRRS) as a method for rapid and very inexpensive SQ assessment, and 3) evaluate the CSHT's relationship with maize yield, using a chronosequence of farms converted from primary forest between 0 and 100+ years ago.

Further development of SQ indicators has significance to farmers, communities, and applied researchers, and may be adaptable to other tropical conditions worldwide. Standardized SQ tests and management recommendations could be provided on a for fee basis to larger commercial farmers, to help them manage for specific constraints. For example compaction and erosion problems are common in the sugar cane industry in Kenya, and better management could help cut down on the costs of tillage and fertilizer application ($525/ha, Odipo, 2007), while preventing the non-point source nutrient pollution of Lake Victoria (Ochala, 2007).

Standardized SQ tests could also be subsidized or provided at no cost by locally active agricultural non-profits, international research organizations, governments and universities that have access to micro-loans and development grants, and a stake in improving environmental quality and food security. The availability of such tests, and development programs formed around their use, can motivate and empower innovative farmers and communities to experiment with soil management strategies. Subsistence farmers who are experimenting with raised beds, organic methods, water harvesting strategies and other methods, are expressing interest in learning about their soils' constraints and alternative management strategies (Mwoshi, 2007). Self-designed innovations are more likely to take advantage of locally-available resources and practices, and to be widely adopted via information sharing and demonstrations within farmer-to-farmer networks.

The simplicity of the proposed SQ tests, in conjunction with their low cost and infrastructure requirements, makes them excellent tools for numerous low-budget extension and NGO-based experiments established in collaboration with local farmers, and based on the environmental and economic needs of, and resources available to communities. Additionally, the new SQ test may have global implications by establishing a standard for widespread assessment of soil degradation and calling attention to the need to internationally coordinate soil protection measures. Inexpensive analysis will allow for widespread assessment, monitoring and evaluation of SQ across farms, regions and countries. Standard monitoring raises awareness, and can lead to environmental policy regulations based on measurable criteria, as has been the case with the establishment of water and air quality standards.

5. Conclusions

Soil quality management requires an integrated approach that recognizes the physical, biological and chemical processes in soils. The development of an inexpensive integrated SQ test was seen as a priority to allow widespread soil monitoring and better management decisions. The CSHT developed for NYS is a significant step forward from the conventional soil tests, which focus exclusively on chemical indicators. The use of a holistic test that provides information about the three aspects of soils, physical, biological, and chemical, is a more meaningful approach to monitoring SQ and provides farmers, consultants and agencies with a tool to identify soil constraints and target management practices or remediation strategies. This tool has great potential as a basic framework from which to establish international SQ standards that similarly address soil quality issues.

6. Acknowledgements

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Table 1. Thirty-nine soil health indicators evaluated for the Cornell Soil Health Test.

Physical Indicators	Biological Indicators	Chemical Indicators
Bulk density	Root health assessment	pH
Macro-porosity	Organic matter content	Phosphorus
Meso-porosity	Beneficial nematode population	Potassium
Micro-porosity	Parasitic nematode population	Magnesium
Available water capacity	Potential mineralizable nitrogen	Calcium
Residual porosity	Decomposition rate	Iron
Penetration resistance at 10 kPa	Particulate organic matter	Aluminum
Saturated hydraulic conductivity	Active carbon test	Manganese
Dry aggregate size (<0.25 mm)	Weed seed bank	Zinc
Dry aggregate size (0.25 - 2 mm)	Microbial respiration rate	Copper
Dry aggregate size (2 - 8 mm)	Glomalin content	
Wet aggregate stability (0.25 -2 mm)		
Wet aggregate stability (2 - 8 mm)		
Surface hardness (penetrometer)		
Subsurface hardness (penetrometer)		
Field infiltrability		

Table 2. Soil quality indicators included in the standard Cornell Soil Health Test, and associated processes.

Soil Indicator	Soil Process
Physical	
Soil Texture	all
Aggregate Stability	aeration, infiltration, shallow rooting, crusting
Available Water Capacity	water retention
Surface hardness	rooting at the plow layer

Subsurface hardness	rooting at depth, internal drainage
Biological	
Organic Matter Content	energy/C storage, water and nutrient retention
Active Carbon Content	organic material to support biological functions
Potentially Mineralizable Nitrogen	ability to supply N
Root Rot Rating	soil-borne pest pressure
Chemical-standard	
pH	toxicity, nutrient availability
Extractable P	P availability, environmental loss potential
Extractable K	K availability
Minor Element Contents	micronutrient availability, elemental imbalances, toxicity

Figure captions

Figure 1. Models of scoring curves used for the interpretation of measured values of soil quality indicators.

Figure 2. a) Conventionally managed vegetable farm, b) No till vegetable garden on organically managed dairy farm

Figure 3. Tillage management comparison of soil quality reports of (a) PT and (b) NT on the same farm in a Honeoye Lima silt loam

Figure 1.

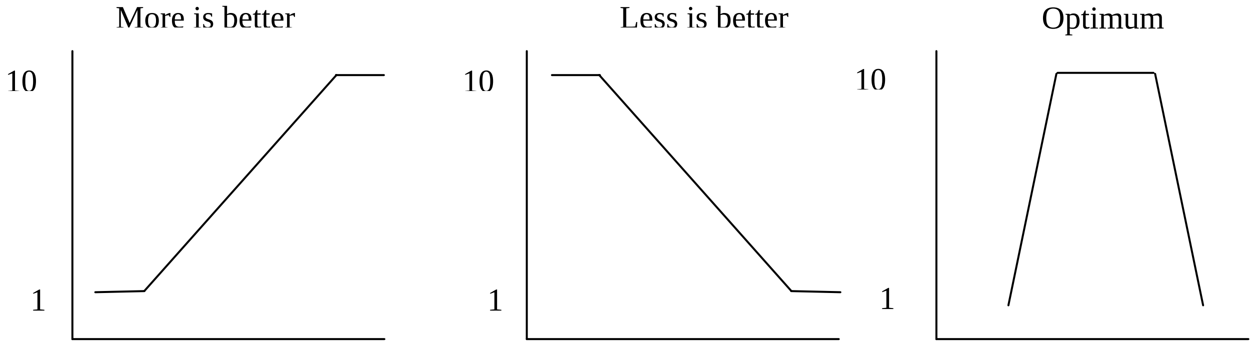
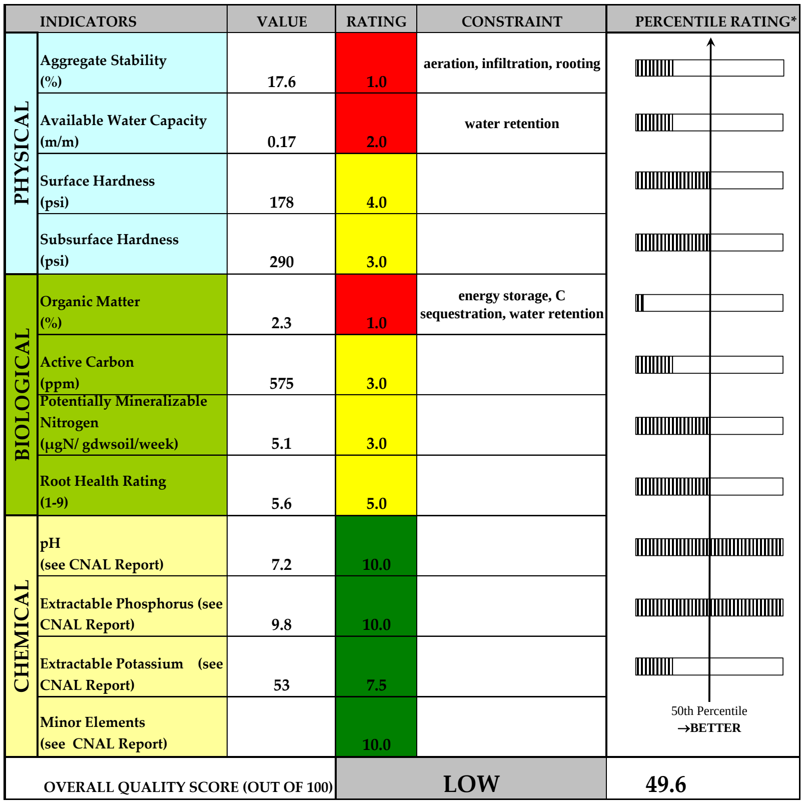


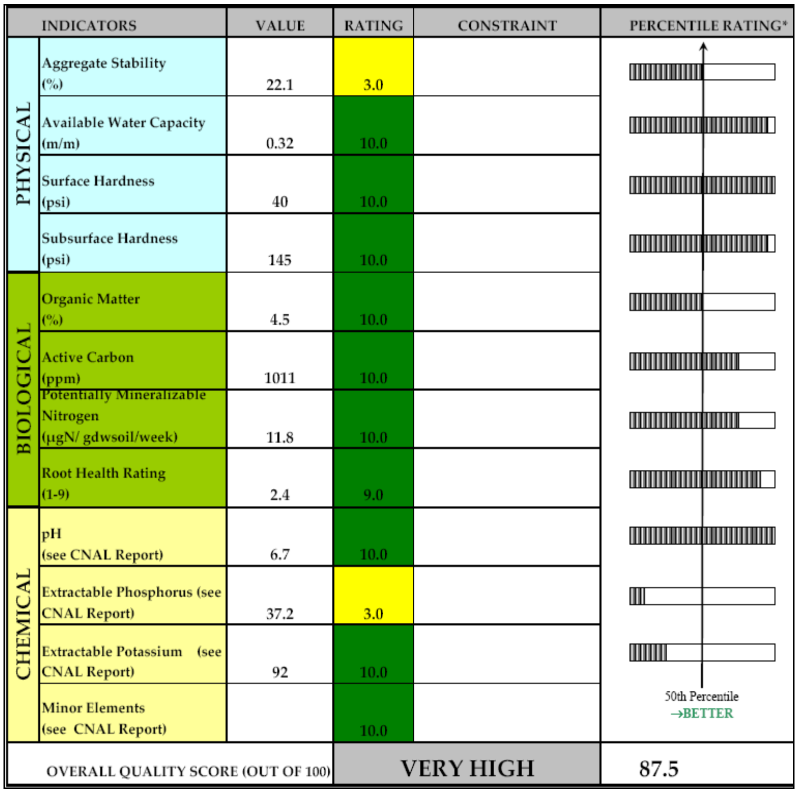
Figure 2.

a)



	INDICATORS	VALUE	RATING	CONSTRAINT	PERCENTILE RATING*
PHYSICAL	Aggregate Stability (%)	17.6	1.0	aeration, infiltration, rooting	
	Available Water Capacity (m/m)	0.17	2.0	water retention	
	Surface Hardness (psi)	178	4.0		
	Subsurface Hardness (psi)	290	3.0		
BIOLOGICAL	Organic Matter (%)	2.3	1.0	energy storage, C sequestration, water retention	
	Active Carbon (ppm)	575	3.0		
	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	5.1	3.0		
	Root Health Rating (1-9)	5.6	5.0		
CHEMICAL	pH (see CNAL Report)	7.2	10.0		
	Extractable Phosphorus (see CNAL Report)	9.8	10.0		
	Extractable Potassium (see CNAL Report)	53	7.5		
	Minor Elements (see CNAL Report)		10.0		50th Percentile →BETTER
	OVERALL QUALITY SCORE (OUT OF 100)		LOW		49.6

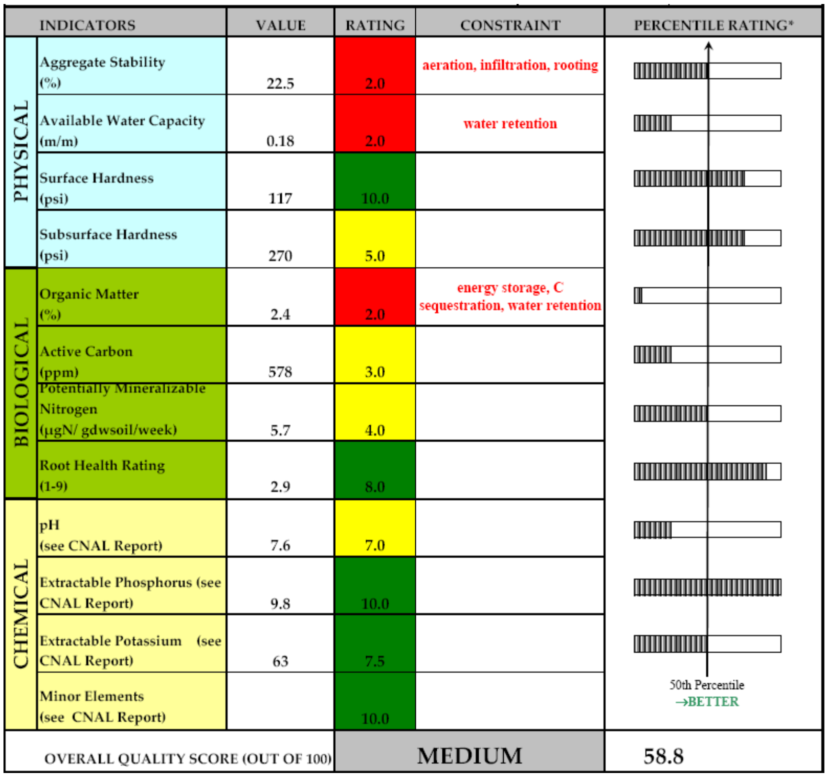
b)



	INDICATORS	VALUE	RATING	CONSTRAINT	PERCENTILE RATING*
PHYSICAL	Aggregate Stability (%)	22.1	3.0		
	Available Water Capacity (m/m)	0.32	10.0		
	Surface Hardness (psi)	40	10.0		
	Subsurface Hardness (psi)	145	10.0		
BIOLOGICAL	Organic Matter (%)	4.5	10.0		
	Active Carbon (ppm)	1011	10.0		
	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	11.8	10.0		
	Root Health Rating (1-9)	2.4	9.0		
CHEMICAL	pH (see CNAL Report)	6.7	10.0		
	Extractable Phosphorus (see CNAL Report)	37.2	3.0		
	Extractable Potassium (see CNAL Report)	92	10.0		
	Minor Elements (see CNAL Report)		10.0		50th Percentile →BETTER
	OVERALL QUALITY SCORE (OUT OF 100)		VERY HIGH		87.5

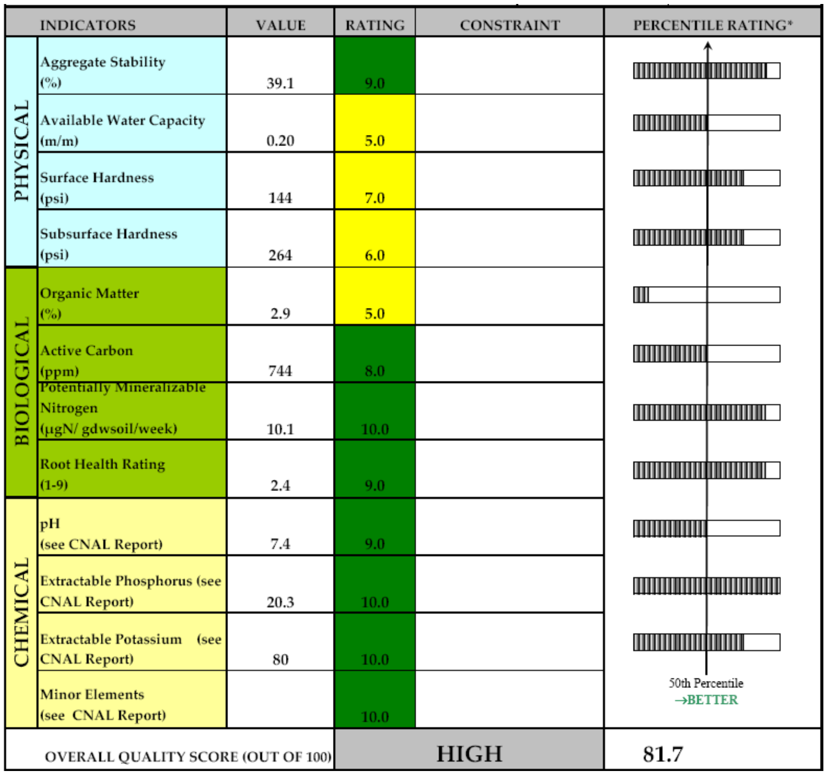
Figure 3.

a)



	INDICATORS	VALUE	RATING	CONSTRAINT	PERCENTILE RATING*
PHYSICAL	Aggregate Stability (%)	22.5	2.0	aeration, infiltration, rooting	
	Available Water Capacity (m/m)	0.18	2.0	water retention	
	Surface Hardness (psi)	117	10.0		
	Subsurface Hardness (psi)	270	5.0		
BIOLOGICAL	Organic Matter (%)	2.4	2.0	energy storage, C sequestration, water retention	
	Active Carbon (ppm)	578	3.0		
	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	5.7	4.0		
	Root Health Rating (1-9)	2.9	8.0		
CHEMICAL	pH (see CNAL Report)	7.6	7.0		
	Extractable Phosphorus (see CNAL Report)	9.8	10.0		
	Extractable Potassium (see CNAL Report)	63	7.5		
	Minor Elements (see CNAL Report)		10.0		50th Percentile →BETTER
	OVERALL QUALITY SCORE (OUT OF 100)		MEDIUM		58.8

b)



	INDICATORS	VALUE	RATING	CONSTRAINT	PERCENTILE RATING*
PHYSICAL	Aggregate Stability (%)	39.1	9.0		
	Available Water Capacity (m/m)	0.20	5.0		
	Surface Hardness (psi)	144	7.0		
	Subsurface Hardness (psi)	264	6.0		
BIOLOGICAL	Organic Matter (%)	2.9	5.0		
	Active Carbon (ppm)	744	8.0		
	Potentially Mineralizable Nitrogen (µgN/ gdwsoil/week)	10.1	10.0		
	Root Health Rating (1-9)	2.4	9.0		
CHEMICAL	pH (see CNAL Report)	7.4	9.0		
	Extractable Phosphorus (see CNAL Report)	20.3	10.0		
	Extractable Potassium (see CNAL Report)	80	10.0		
	Minor Elements (see CNAL Report)		10.0		50th Percentile →BETTER
	OVERALL QUALITY SCORE (OUT OF 100)		HIGH		81.7