The Soil Quality Indices Literature

Compiler's Report
SQI Literature Project 2003
December 12, 2003

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INTRODUCTION

A literature review for the Alberta Environmentally Sustainable Agriculture (AESA) Soil Quality Monitoring Program was initiated within the Conservation and Development Branch of Alberta Agriculture, Food and Rural Development (AAFRD), with the intent to synthesize current literature on soil quality indices. This review has included coverage of publications dealing with the various approaches used in developing soil quality indices. It will assess the literature, by March 2004, for indices appropriate to western Canadian conditions and with respect to the needs of the AESA Soil Quality Program.

A professional librarian, Connie Hall, provided the project component of searching for and compiling all relevant literature, from September to December 2003. This work included the creation and administration of electronic databases to include all of the search results, to rate them according to project parameters for relevance, to provide brief comments in the form of annotations concerning content of the most highly-related publications found, and to record these in the databases for use by the reviewer and AESA staff. Deliverables of the literature review, by Eric Bremer, will incorporate this information to produce a final report, with a target completion date of March 31, 2004.

The Soil Quality Literature project of 2003 was required in order to compile science-based literature for review. Most specifically, this project identifies soil quality indices and indicators that may be used in Alberta according to the needs of the AESA program, and will contribute to soil quality reporting and monitoring within the province.

INDICES

The *American Heritage® Dictionary of the English Language*, Fourth Edition Copyright © 2000 by Houghton Mifflin Company defines an **index** as:

> Something that serves to guide, point out, or otherwise facilitate reference; …
> Something that reveals or indicates; a sign; …
> An indicator or pointer; or, in mathematics, as …
> A number derived from a formula, used to characterize a set of data.

Econometrics, geometrics, and geostatistics are fields that use indices (plural of 'index') to indicate measures of condition—the state of factors at a point in time or space—and for trends analyses—the changes in factors through time. We are familiar with some of these indices, such as the Consumer Price Index or the Index of Social Progress in socio-economics; or with Canada's recently-developed Water Quality Index, for example.

The Pembina Institute (2003) recently examined sustainability in terms of indicators which it terms "Genuine Progress Indicators":

> (GPI) is a measurement system for use by nations, states and communities to determine their progress towards a sustainable future. The GPI provides a

> comprehensive account of sustainable development - including economic, social and environmental factors - as compared to a more narrow and traditional measure of development, such as Gross Domestic Product (GDP), which considers only economic growth.

The World Bank (2003; Dumanski, Gameda & Pieri, 1998), the Organisation for Economic Development (OECD 1998; 1999; 2001), the Food and Agricultural Organisation of the United Nations (UN-FAO 2003), and the European Union (Jesinghaus, 1998; 1999) all have dealt with the development of sustainability indicators, such as "Environmental Sustainability Indicators," for example. In order to examine and monitor land-use and human activity effects on arable land in Europe and throughout the world, index development has progressed throughout the 1990s and into the 21st Century. Cooperative research has occurred in order to assess land quality and soil health for sustainable agricultural production, as well as for pollution and soil degradation or mitigation amid growing pressures on land and soil resources from the earth's ever-increasing human population.

SOIL QUALITY INDICES

In considering soil quality, attempts have been made to examine the factors that indicate ‘good’ soil health or soil quality, to reach consensus on the definition, upon the key soil attributes that translate into variables (pedotransfer functions) to be examined, on their data value ranges, their value limits, threshold values, comparability; and to aggregate or integrate the variables/values in such a way as to then develop meaningful indices that characterize the quality/health of varying soils in various world regions, across nations, or in local areas, and at the farm level. In order to analyze the body of scientific results available concerning these efforts, a literature survey was undertaken by the AESA Soil Quality Program. Literature was examined that deals with soil quality index discussion, definition, description, development, assessment and evaluation, testing and measurement, refinement, laboratory and field application, with farmer input and expert analyses, as well as related soil quality, soil monitoring, land-use assessment, and environmental indicators, and assessment or monitoring programs.

The goal of this literature project was to characterize the existing body of currently-published and 'grey' literature, by identifying the most relevant papers that specifically deal with soil quality indexing in concept or in practice, with an emphasis upon agricultural soils, their productivity, and sustainability. No geographic limits or language restrictions were imposed. ‘Current’ literature was considered as that published within the last 10 to 15 years, with some older publications being considered if they met project criteria for inclusion.

At the same time that searches for relevant literature were being conducted, databases were designed to compile the bibliographic information discovered, using ProCite™ bibliographic software (ISI-ResearchSoft. ©1995-1999. *ProCite for Windows, Version 5.0*. Web site at URL: http://www.procite.com). Search results that matched project parameters were entered into the databases, based upon suitability criteria developed for this project.

Relevance criteria were developed in consultation with the staff expertise within the Soil Quality Monitoring Program unit, Conservation and Development Branch, AAFRD, in order to include or to exclude references from the vast amount of world literature about soil quality.

CRITERIA

Project parameters were delineated and factors for determining the relevance of articles were discussed with staff experts, in order that articles could be selected for inclusion or exclusion. The questions were recorded and grouped as a result of these discussions.

Characterization of the literature on soil quality indexes involved examining and indicating the following:

- Consideration of what characterizes any index, what is involved in the indexing process in general, and provision of examples of other indices -- such as in econometrics -- with their background; e.g. Consumer Price Index, GDP, stocks; and other examples of indexes.
- Consideration of specific Soil Quality studies, in which an index or indices are developed or modeled, and that include all of the following:
  1. Approaches/ Methodologies used
     a. Characteristics
     b. Weighting factors
     c. How approach was developed / philosophy behind approach (derivation)
  2. Temporal & Spatial factors
     a. Whether static or dynamic
     b. How often index(es) are calculated, repeated, at what interval(s)
     c. What trends are dealt with or revealed
     d. What monitoring or forecasting uses may be involved
     e. Scale-related information; such as whether site-specific, farm-level, regional (comparative to ?what/?where), or national/international in scope
  3. Data sources
     a. Whether the study used their own, or ‘adapted’/borrowed [field-scale or theoretical?]
     b. Quantitative/qualitative
     c. Validity & verification given (verifiable data?)
     d. Accountability / tracking / forecasting (monitoring spinoffs)
     e. Data dynamics; changing?
     f. Reliability; that is, the ‘fit’ to hypotheses/investigations?
     g. Data sensitivity to the methods/tests/measurements used and results?
  4. Models & data
     a. Many or few indicators; How sensitive to change?
     b. Approach sensitive to the indicators used? / Philosophy
  5. Pros & Cons / Assessments / Results
     a. Preliminary study, or Ongoing?
     b. Final results (after what time period)? Relatable to other results & uses? That is, applicability of the research?

These five main areas were used when scanning literature citations and abstracts, introductions, or executive summaries and conclusions of the papers obtained as a result of searches, in order to (i) include or exclude them from the project, and to (ii) rate them for relevance to the project parameters. The project compiler provided comments within each database record for highly-related publications obtained for review.

SEARCHING THE LITERATURE

The databases, library catalogues, and web sites searched within the timelines for this project are presented in Appendix A. The search strategies specifically designed to meet the relevance criteria for inclusion in our databases are presented in Appendix B. This approach provided maximum coverage of the current agricultural literature available concerning soil quality indices for the past ten to fifteen years, given the project timelines. Numerous searches were crafted due to the semantics involved in defining soil quality / soil health and given a professional debate which appears within the current literature concerning the utility of the soil quality concept (Sojka & Upchurch, 1998; 2003; Karlen and others, 2003). The methods used for compiling the results of the literature searches are outlined in Appendix C.

It was confirmed that a body of literature exists for land-use planning and classification, as well as for agricultural sustainability within the broader arena of environmental research (Appendix D). A common theme in this literature is the worldwide concern to determine representative indicators of 'land quality' related to human and ecosystem health. Within these contexts, there are research results and ongoing studies involving indicators of soil quality from a number of countries. Some of the research projects do involve aggregation of indicator value ranges and means into efforts toward integration and thus toward derivation of indices of soil quality.

Various statistical methods are being used and are encountered in this literature, as attempts to quantify soil quality continue. Some examples of the statistical methods used are: analysis of variance / multivariate analysis, regression analysis, pedotransfer functions, fuzzy set theory / Gaussian mathematics, representation through variograms / spidergrams, graphing / charting, to name the majority in use. Indices in this body of literature are additive or multiplicative, and encompass both small and large data sets. Data are from a single locale as well as from large-area studies, with single-year or multiple-year sampling, and include comparisons by proxy or 'representative' ecosystems to characterize pristine vs. disturbed field conditions. Research was conducted in all types of soils under various types of 'treatments' and management practices, in varying topography or terrain and climatic regions.

Translation of the exact phrase for "soil quality indices" or "index(es) of soil quality" into other languages, such as Portuguese, Spanish, or French, yielded some interesting results and ‘leads’ as a means to discovering current soil assessment research projects in the 'grey' literature. This approach could be expanded to other languages, but was not fully possible to pursue for all languages due to time factors for the current project.

USE OF PROCITE™

In order to manage and fully survey related literature, a database had to be created in order to describe not just the publisher information in the form of bibliographic citations and abstracts, but also with the capability to compile, describe, track, and provide access to the detail of the variability involved in all of the above considerations. Therefore, a comprehensive database of related literature, compiling references of relevance, was created from September to December 2003 using a bibliographic management software product known as ProCite™ (ISI-ResearchSoft. ©1995-1999. *ProCite for Windows, Version 5.0*.). ProCite™ is available for trial or purchase via the world-wide web at URL: http://www.procite.com , has the capacities described above, so was chosen, and a main "Soil Quality Index Literature" database was created.

Another database -- the "Soil Quality Park" -- corrals other leads to more literature which occurred during the searches. The references in this secondary database may be of broader and related interest, but did not satisfy all of the criteria outlined above for this project and specific literature survey. These databases are located on a server within the Conservation and Development Branch, AAFRD, for access by AESA and Soil Quality Program staff. One copy of project files was provided on CD to the reviewer and another CD resides with the compiler.

The data occurs within the "SQI Lit" database via workforms for the types of publications encountered in the scientific literature. Primarily, these are: journal articles, conference presentations, chapters within books, scientific or government agency reports, as well as electronic citations from websites residing on the Internet.

The core scientific literature relating to soil quality indices and determined to be of relevance to the Alberta situation was thus identified (see Appendix D). Copies of articles of greatest relevance were obtained largely via interlibrary loan services of the Neil Crawford Library within AAFRD (Canadian library code = 'AEAG'; now known as one component of the 'Alberta Government Library' or AGL as of 2002). All articles were included in the database of SQI literature, using the ProCite™ 5.0 software, with input of bibliographic elements: author, title, date of publication, place of publication, publisher, journal title, volume, issue, pagination; together with conference information where relevant; electronic links; availability information; authors' abstracts, and compiler's comments (as time permitted, for the items of highest project interest) wherever possible.

An extensive subject classification was developed within the database, via keywords input within each record (per article) so that output can be generated in the form of custom-designed bibliographies or publishable bibliographic and Internet products. ProCite™ allows for 'controlled vocabulary' and standardization of subjects through a drop-down list in the Keywords field within each record, as well as allowing for the grouping of records into subject categories which may be generated by searches in all or subsets of the data within the Soil Quality Index Literature ("SQI Lit") database.

Procedures

The entire process may be summarized as follows:

- Identify the literature
  - Design, develop and document search strategies
  - Search existing document files
  - Consult staff and experts
  - Examine bibliographies and references cited

- Conduct online searches in: --
  - Library catalogues (local, regional, provincial, federal)
  - NEOS: Alberta Agriculture, Food & Rural Development Library, University of Alberta's Gate/library system, Alberta Environment Library, Alberta Research Council Library
  - National Library of Canada's CISTI-CAL, to search: Canada Agriculture Library, Canadian Institute of Scientific and Technical Information -- for Environment Canada Library, Natural Resources Canada Library, etcetera
  - Other: universities and colleges: Calgary, Lethbridge, Fairview College, Lakeland College, Olds College Library, TAL --The_Alberta_Library (+ other local libraries) etcetera
  - Databases
  - Agricola
  - CAB Abstracts
  - Conference Index
  - Internet and WWW
  - Agency websites (provincial, national, international)
  - Search engines (Google, MSN, AskJeeves, AltaVista)

- Structure the database
  - Include required bibliographic elements
  - Consult researchers re value-added fields
  - Incorporate needs
  - Develop evaluative criteria for inclusion
  - Test for data input variables

- Compile the literature
  - Obtain interlibrary loans
  - Arrange for photocopying
  - Search electronic journals online; download e-documents and print copies (where permitted by copyrights)
  - Conduct file management: coding, access, labelling, special collection retrieval processes

- Develop ranking and relevance indicators
  - Collaborate with experts
  - Test the database and ranking factors
  - Make any required modifications

- Maintain the database and library of documents
  - Continue file management: coding, labelling, filing, retrieval
  - Add citations as literature arrives, leading to more references
  - Maintain a standardized classification for the database
  - Edit records for consistency of database (error detection and correction)

- Make value-added enhancements
  - Scan and include abstracts
  - Scan references cited and bibliographies within articles
  - Add compiler's notes
  - Assign relevance to records
  - Classify the literature using keywords and subject heading assignments

- Make products available
  - Provide full records and/or database to the reviewer & AESA personnel
  - List citations; prepare subject bibliographies
  - Add recommendations or suggestions based on expert's feedback
  - Extract reviewer's notes for publication as needed
  - Prepare web-accessible groupings of the literature if desired
  - Create CD-R/W or other products as needed

- Seek client needs re further literature if necessary

It was decided to rank each publication as of Highest (H), Moderate (M), or of Lowest (L) interest in terms of its project relevance, and to delineate a status of Undetermined ('u') for those articles which needed expert review or further examination before a determination of fitness to the project criteria could be made. [See Appendix B]

RESULTS

Thousands of references were examined, from the multiple searches performed in databases, library catalogues, literature reviews, bibliographies, lists of references cited, agency web sites on the Internet, and from information provided by agronomy experts. Standardized online searches were performed in the indexing and abstracting services, publications lists, library catalogues, and on the Internet. Search strategies were documented and are on file along with the literature collection. The commercial indexing services used were Agricola and CAB Abstracts, Conference Index, Science Citation Index, and LibNet. Publications lists were from Agriculture and Agri-Food Canada, the Canadian Institute for Scientific and Technical Information, the U.S. Department of Agriculture's Agricultural Research Service and Natural Resources Conservation Service, the Soil Quality Institute, as well as the UN-FAO, the World Bank, the European Union (EU; formerly European Commission), and others (Appendix A). Online catalogues searched were the Alberta Agriculture Food and Rural Development Library; the NEOS library consortium -- Alberta research, university and college libraries; the Canadian Agriculture Library; the National Library of Canada; and the U.S. National Agriculture Library.

The search results were matched to project parameters and relevance ranking criteria developed during discussion with staff experts. The compiler provided full keyword classification on all records. Additionally, compiler comments regarding article contents were provided for a 150-sample set of records; these were provided to the reviewer for further consideration of project parameters to assist in sorting the literature during the review process.

The most significant result of the literature research was to identify the key papers of importance to the scientific study of soil quality assessment (Appendix D). The literature on soil quality indices of most relevance to Alberta were made available to the reviewer, Eric Bremer, and the AESA Soil Quality Program Coordinator, Karen Cannon, in the form of annotated bibliographies produced from the ProCite™ SQI database.

This bibliographic research also confirmed that within North America, soil quality indices have been studied primarily at federal government agencies' experimental research farms, and at universities within departments of soil science or agronomy. Recent research (within the last ten years) within forestry also shows a growing tendency to apply agroecosystem and soil quality assessment methods with regard to soil quality assessment, as an enhancement to productivity modelling. Forestry researchers and land-use planners present and publish their findings in a different forum, or set of journals (See Appendix D). Also, the indexing and abstracting services of these disciplines do not consistently overlap, so that only by comprehensively researching through references cited is it possible to become and to remain aware of the totality of soil quality indices research and development.

Ranking

The "SQ Index Lit" project database now (December 12, 2003) contains 488 citations to the soil quality assessment literature (as of December 2003). Rating of articles has resulted in the following designations:

Of Highest project interest	81 records
Of Moderate project interest	128 records
Of Least project interest	101 records
Undetermined, (pending further examination):	178 records
TOTAL =	488 records

Additionally, 150 records exist in a database for items related to soil quality assessment and monitoring; but these do not deal specifically with soil quality indexes.

Compiler comments were added to the SQI Lit database. A 150-sample set was ranked for the project, with the results that: 54 were H-, 42 were M-, 36 were L-, and 17 were 'u'-rated papers.

Of the 488 database records, 294 selections were deemed of some importance to the concept of soil quality indices (Appendix D). Keyword searches in these selections reveal the following occurrences of terms (but conclusions cannot be drawn based on the statistics, until the literature reviewer component of this project is completed):

126 "soil quality index" OR "index of soil quality" OR "soil quality indices"

75 "soil quality index"

21 "static", 31 "dynamic"

3 "point-scale", 9 "regional", 8 "farm-level", 9 "national"

79 "soil organic matter", 96 "microbial"

69 "forest", 12 "rangeland", 25 "grassland", 14 "catchment", 4 "riparian"

Of the total 488 records, 220 copies were provided for review to Eric Bremer, in December 2003, and will be housed (in 2004 following his review) in files of the Conservation and Development Branch, AAFRD. The AAFRD Library holds another 82, while other NEOS libraries have another 36, and 177 are also accessible via the World Wide Web. In all, 327 items, or 78% of the items identified for this literature project, and 100% of the Highest-Ranked items (n=81), are within the building or within a day's reach for the reviewer, project staff, or interested researchers.

Products

As a result of this literature review project, a library of scientific literature concerning soil quality indices has been compiled, building upon previous files compiled by agronomist Jody Winder. ProCite™ databases have been designed, developed, produced, and are being maintained as an integral part of the AESA Soil Quality Program. An annotated bibliography has been produced by the project's compiler. Other products, in the form of subject-classified bibliographies, lists, research groupings, or web-based information for application to other programs, can now be created from the interactive ProCite™ databases as needed.

APPENDIX A

SEARCHES DONE FOR SQI LITERATURE PROJECT
between September and December 2003

AGRICOLA (10 years retrospective)
CAB ABSTRACTS (10 years retrospective)
SCISEARCH - SCIENCE CITATION INDEX

NEOS/UNIVERSITY OF ALBERTA LIBRARY CATALOGUE
UNIVERSITY OF CALGARY LIBRARY CATALOGUE
UNIVERSITY OF LETHBRIDGE LIBRARY CATALOGUE
THE ALBERTA LIBRARY - CONSORTIUM CATALOGUE
ALBERTA AGRICULTURE, FOOD & RURAL DEVELOPMENT CATALOGUE/HOLDINGS
ALBERTA ENVIRONMENT CATALOGUE/HOLDINGS
AGRICULTURE CANADA LIBRARY, VIA CISTI-CAL
UNITED STATES DEPT. OF AGRICULTURE'S USDA-ARS TEKTRAN search
NATIONAL LIBRARY OF CANADA / Canadian Institute of Scientific and Technical Information CISTI
U. S. NATIONAL AGRICULTURE LIBRARY -- NAL CATALOGUE
LIBRARY OF CONGRESS CATALOGUE

INTERNET: ASKJEEVES, GOOGLE, MSN search engines
www AGENCIES' PUBLICATIONS: FAO, OECD, WORLD BANK
AAFRD, USDA-ARS, NRCS, Soil Tilth Laboratory --STL, Soil Quality Institute
Universities' websites: California, Idaho, Illinois, Iowa, Mississippi, Nebraska, Wisconsin
Other Countries coverage:
Germany, Italy, Poland, Portugal, Russia, Spain, Sweden, Switzerland
Australia, New Zealand, Scotland, Wales, United Kingdom
Argentina, Brazil, Ecuador, Uruguay, Paraguay, Mexico
China, Phillipines
India, Iraq, Pakistan

(The following databases could also be added to project searching, given further research/time; or if more international leads to SQI foreign-language publications and grey literature is needed:)

AGRIS INTERNATIONAL
BIOSIS
CONFERENCE PAPERS INDEX
EI COMPENDEX
ELSEVIER BIOBASE
ENVIRONMENTAL BIBLIOGRAPHY
EMBASE
ENVIROLINE
LIFE SCIENCES
PAIS
PASCAL

APPENDIX A-2

AGRICOLA -- Search History

Search History September 5, 2003 (clh)
* #6 #5 not #1 (**60** records) [saved]
#5 **'soil index* ' or 'soil indices'** (**66** records) [saved]
#4 soil* and (index* or indices) (6278 records)****[could explore further....]
#3 soil* qual* (590 records)
* #2 (SOIL-HEALTH) or (SOIL-QUALITY) or (SOIL-QUALITY-ASSESSMENT) or (SOIL-QUALITY-CLASSIFICATION) or (SOIL-QUALITY-INDEX) or (SOIL-QUALITY-INDEXES) or (SOIL-QUALITY-INDICATORS) (**49** records) [saved]
#1 **soil* qual* and (index* or indices)** (**66** records) [saved]

Search History October 18, 2003 (clh)
* #2 **'Doran-JW' in AU** (**64** records) [saved]
#1 ((AU=Doran) in AU,CA) and (English in la) (172 records)

Search History December 01, 2003 (clh)
* #3 (rangeland* or 'range land*') and #1 (**1** record) [saved]
#2 (riparian or catchment) and #1 (**1** record) [saved]
#1 **'soil quality' and assessment** (**76** records) [saved]

Search History December 01, 2003 (clh)
* #7 #5 and #2 (62 records) [saved]
#6 #2 and #5 (62 records)
#5 #4 and soil* (538 records)
#4 rangeland* or 'range land*' (2957 records)
#3 #1 and #2 (71 records) [saved]
#2 quality or assessment* (61420 records)
#1 riparian and soil* (328 records)

Search History December 02, 2003 (clh)
* #2 'soil quality' and German in LA (0 records)
#1 (('soil quality') in DE,ID) and (German in la) (0 records)

SCIENCE CITATION INDEX -- Search History

Some experts pursuing SQI research are John Doran and Susan Andrews of the USDA-ARS, Julian Dumanski for the World Bank.ONE SEARCH IN SCIENCE CITATION INDEX should get the majority of those interested in SQIndexing:

Who has been citing the article below? Published 1994 (work done in 1992).

Defining and assessing soil quality / by Doran, John W. and Parkin, T. B., Pages 3-22 IN: SSSA Special Publication no.35 entitled: Defining soil quality for a sustainable environment / edited by Doran, J. W.//Coleman, D. C.//Bezdicek, D. F//Stewart, B. A. Soil Science Society of America, Inc. "

OCT 01 '03 03:47 SEARCHED DATABASE = **Science Citation Index-EXPANDED;**

Timespan=l992-2003 **Results** (Articles 1 - **40+30**)

Cited Reference Search Results-Summary, October 1, 2003 by AAFRD Library

Cited Author-Doran J* or Doran John W AND Cited Year=1994

Translation: between 1992 and 2003, Doran & Parkin's article was cited @**70** times, according to SCIENCE CITATION INDEX (a database of ISI).

SEARCHES FROM FILE 50, DIALOG : CAB ABSTRACTS

Search #1: Soil Quality (Index(es) or (Indice(s) And pub > 1988
Not Soil Quality Monitor(ing) Not articles from Agricola

Search #2: Soil Quality Assessment OR Soil Health
And Indicator(s) or Indice(s) or Index(es) And Published after 1988
NOT Search #1 or (Soil quality monitoring)
Not articles included on Agricola

Search #3: Land Quality AND Index(es) OR Indice(s) OR Indicator(s) And Published after 1988
Not results from Searches #1 and #2
Not results from search on Agricola

Search #4: Soil quality (3n) indicator? ?

HIT RATES ON PRELIMINARY SQI (Database) Searches:

Commercial/Agricultural databases:
AGRICOLA 66 + 49 + 64 + 62 + 71 + 44 + 60 + 76 + 8 = **500** LESS OVERLAP
CAB 63 + 44 + 34 + 99 + 101 = **341** scanned, LESS OVERLAP for duplicates

LIBRARY CATALOG searches:
CISTI-CAL catalogs **87** less overlap [leads --not in SQ 'Park' but should be...]
UofA/NEOS/Alberta AG LIB catalog/ **118**
(including Olds College, Lakeland College/Alberta Environment/ARC)
UofLethbridge **12**
UofCalgary **26** ('leads', mainly mining/contamination)
LCC @ **130** less overlap (@10-15% only; the rest are 'leads' or not relevant)

Publications Lists of Agencies 100s.....from @ 12 sites...[global in scope]

People's Bibliographies/References Cited lists:
From Jody's bibliography re SQ Monitoring, incorporated **157** items on indexes/indicators.
..Davidson; others 100s...(less overlap)

INTERNET / WEB searches:

MSN Searches:

"soil quality"	=	26,004	September 7, 2003
"soil quality indicator "	=	44	
"soil quality indicators"	=	350	
"soil quality index"	=	81	
"soil quality indexes"	=	4	
"soil quality indices"	=	46	
"soil health"	=	6,513	

with some overlap of search results (to be analyzed as to percentage...)

Google Searches

"soil quality"	=	115,000	September 7, 2003
"soil quality indicator"	=	270	
"soil quality indicators"	=	1,670	
"soil quality index"	=	**478**	
"soil quality indexes"	=	**22**	
"soil quality indices"	=	**246**	
"soil health"	=	21,700	
--with @50% overlap of search results			
"soil" and within for "indices"	=	169,000	Oct.13, 2003
"suelos" and "indice*" [Spanish]	=	**13** items	
"qualidade de solo" [Portuguese]	=	@154 hits	Oct.04, 2003

AltaVista searches on "soil quality indices" (with overlap) = **117**

AskJeeves searches [tested for overlapping citations]

"soil quality index"	=	**212**
"soil quality indices" OR "indicators"	=	155 WITH OVERLAP

--Only **88** relevant to project

- **44** overlapped thereafter with above sources...

Appendix B --

Supplementary information

SOIL QUALITY INDEX LITERATURE PROJECT 2003/4

as of November 26, 2003

Total Records in SQI database = 490

Ranked Highest	H =	75	-meet all project objectives - deals with an index/indexing/indices
Ranked Moderate	M =	125	-meet some project terms - definitional, conceptual, developmental - important position papers, overviews - methodologies, statistically relevant - indicators vs. indices discussions
Ranked Least	L =	108	- not specifically SQindices - discussion papers, methods, meetings - research leads, that need more info. - Statistics explanations - Bibliographies, web lists/resources - SQ Indicators, Monitoring info.
Ranked Undetermined	U =	182	-Undetermined; L or M, unless needs Agronomic/soils/stats expertise

Total Records in SQI 'Park' / "Tom's Corral" = 150

E.g. -- heavy metal contamination
-- Soil erosion/degradation
-- Land quality, land-use/capacity/productivity studies

APPENDIX C -- USERS' GUIDE

STRUCTURING A LITERATURE DATABASE USING PROCITE™

Viewing or navigating the ProCite™ database

The ProCite™ software allows a user to change views of the database between a table of all records or an individual record. The individual record may also be viewed on a split screen, to show the workform plus the formatted reference like it would appear when cited or reported in a list.

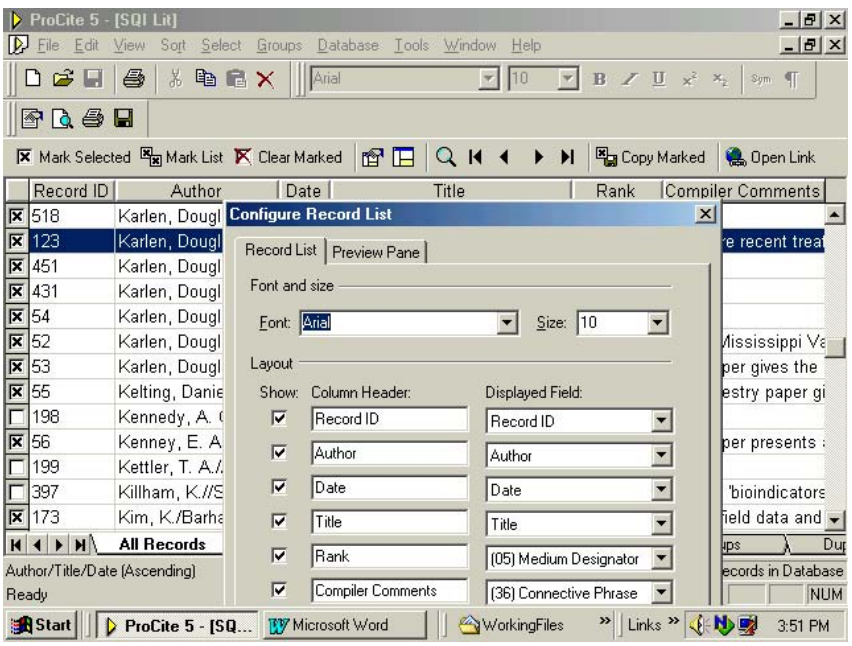

Figure 1. ProCite™ Database – showing Fields in a Record List

The tabular or "spreadsheet" view will appear when a ProCite™ database is opened, presenting columns of data. Sorting may be done by clicking on a column heading. A "Sorting Database" pop-up box will appear to show progress for the sort operation, and the rearranged data will appear on-screen after the software has performed the sort.

A standard view has been produced in the database, by selecting these fields in the following order for viewing:

Record ID number, Author, Date, Title, Rank, Compiler's Comments

The database can be manipulated to order records alphabetically by author or by title, or numerically by date or by record ID number.

The view can be changed, by going to View > Configure Record List > Record List tab, and selecting or deselecting from the check boxes and drop-down lists of fields. The order of the fields can also be changed, by retyping column headings into the template and using the drop-down lists to choose other fields to view. (ProCite™ allows only 6 columns for viewing on-screen, however.) By un-checking the check boxes, fields may be “hidden” from view (for example the Record Ids or locations may be “turned off” in this way). Lines between columns can be resized just as in any spreadsheet or database viewer, by dragging the line pointers to where you wish them to be on the viewing screen.

Searching:

There are two ways to search a ProCite™ database. The Quick Search is activated by clicking on the “Go To Record” or spyglass icon on the taskbar, where a drop-down text box will appear and give options for common ways to search (such as by Author, Date, Title, or Record ID). The full Search is activated by choosing the Search tab at the bottom of the screen, and then specifying among the multitude of fields and operators, and by typing keywords into the text box and then hitting the Search button or Enter key on your keyboard. Results for each search will be displayed on-screen immediately.

Further instructions may be found by using the Help feature within ProCite™, or through access to the database manual.

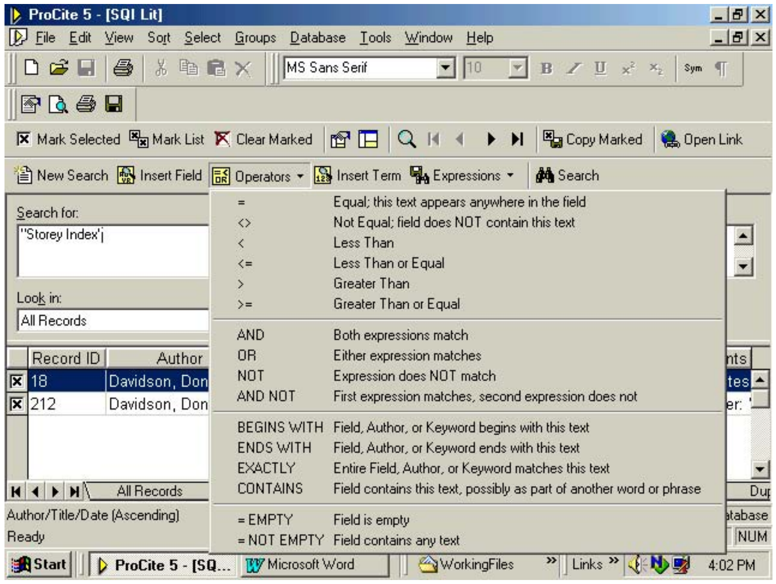

Figure 2. A ProCite™ Database – showing Search capabilities

Producing output (lists, bibliographies, subject groupings):

ProCite™ will allow for the creation of various printed products, such as lists of references cited. Basically, this is done by first identifying the records wanted and either marking or highlighting and then grouping them based upon what is wanted.
The simplest method is to perform a search, identify the records by using the Mark Selected or Mark List features on the taskbar, or by individually marking specific records by clicking on the box to the left of each one to select a subset. Next, go to the Marked Records tab at bottom of the screen, perform any sorting desired, remove by unmarking any unwanted selections. Then, go to File > Print Bibliography. A menu box opens, and it is here that you specify what is wanted in your output. You can Show All Records in List, Show Marked Records, Show Highlighted Records in the first drop-down selection box. The list may be saved as a file, or printed for proofreading, editing, or publishing.

Also, you must specify Output Style from among numerous options on the middle drop-down menu, and need to spend some time in selection among all the scientific journal options. Choose the Workform option if you want each record to appear in full; otherwise the 'ANSI standard' or the 'Chicago' styles are the most common and generic. If you need to cite in the Author-Date-Title format, with dates appearing before the title, you need to find a science title that does so, with punctuation according to your preference, or to select the pre-formatted 'Chicago B' style. The next button with three dots … selects the full output styles that the ProCite™ software contains. The next option button (on the right) labelled “Configure” allows you to further specify in Reference List, Fields, and Page Layout templates many further options. Of special note on the Reference List tab is the text box allowing you to type a TITLE for your output pages. Some time and experimentation are required, before your final product is printable. You may then Print or Save to a word-processor file for further manipulation before printing.

For publishable results, a customized output style may be necessary. See the 'Help' index and follow the directions provided within the software to pursue this option. Similarly, ProCite™ has a 'Cite-While-You-Write' option for including citations from the database and embedding or linking them directly into a word processor. Optionally, you can produce a printed bibliography, transfer it to a word-processing file, and perform any customization such as assigning a style, editing, or use the searching options (such as 'Edit > Find' in Microsoft Word) if that is appropriate. Results and products can then be converted to HTML formats for web posting, as well.

Opening Links:

Within the database, you may also automatically open web links to the Internet, if you have a browser running at the same time that ProCite™ is running. Just double-click the link in the URL field, or if this does not work, you can cut-and-paste into your browser’s Location or Address window box, or click on the
WebLink icon on the ProCite™ database taskbar. This should take you to the electronic document or link given in the database.

ProCite™ database structure

The ProCite™ software (Version 5.0) provides up to 45 fields of data presented in 39 different work-forms for bibliographic information, as follows:

Workform Fields

Figure A. Workform Template for Soil Quality Index Literature Database in ProCite 5.0.

Record Number:	Numeric, from 001 to 999. Exception: Alphanumeric, when one work is *within* another; e.g. a conference presentation published as one article within a proceedings, or one chapter within a compilation of related scientific papers on a topic or common theme, or one linked portion of a website.
Author, Analytic:	Main author responsible for a work, listed by: Surname, First name or Initial. Second Initial. Co-authors next listed in order they appear on the main title page. Separators in ProCite 5.0 are: two forward slashes between authors; Corporate author entries are preceded by an "equals" sign, so that they will format properly at output, as distinct from personal authors' names.
Author Role:	This field is usually BLANK.
Author Affiliation:	Agency, institution, or workplace of author(s).
Article Title:	Title, entered in "title case" (i.e. First significant word is capitalized, as are proper names, followed by lower case for all words) of the article, presentation, or paper. NOTE: ProCite treats this field as the primary title for viewing.
Medium Designator:	N.B.: **This field has been customized for use to indicate the RELEVANCE or significance of the article/paper/work in terms of the literature review project. RANK = H, M, L, or 'u'**
Connective Phrase:	This field is usually BLANK, but may state: "IN" if the article is from a collected work, conference, or compilation. Chapter number in a book will be given here if relevant.
Author, Monographic:	This field is used for the author of a book, editor of a proceedings or collection.
Editor/Compiler:	The field label appears as this if the workform is for a conference.
Author Role:	This field is usually BLANK, but may state: "Editor" or "Editors" where applicable.
Editor/Compiler Role:	The field label appears as this if the workform is for a conference.
Title, Monographic:	This field is used for books, and is the Main title field when a collected work or monograph is being referred to (as opposed to an "article"). Books have a separate workform, so most often this field does not appear in the record template, unless it is a book.
Proceedings Title:	Gives the name of the conference, congress, symposium, workshop, or proceeding, as it appears on the main title page. On occasions where a conference paper is (also) published as a journal article, the reprint is always treated as an Article and so should be given in that field and not in this one.
Journal Title:	Name of the periodical is given IN FULL (not abbreviated wherever possible). Use the drop-down menu to the right of the field for a full list of titles in the database.
Report Title:	This field is used for all scientific and technical, government, agency, or industry reports, and is preferred to the "Article Title" field when the item IS a report in and of itself, and NOT an article published in a journal or periodical, or an excerpt from the full report. On occasions where a portion, summary, revision, or synthesis of a report is published as a journal article, the reprint is always treated as an Article and so should be given in that field and not in this

one.

Newspaper Name: Gives the name of the newsletter, newswire service, or newspaper or newsmagazine title where applicable, for news items and not for periodical articles.

Source: This field stands in for, or replaces, the title field when the source is an Electronic Citation (workform).

Date of Meeting: Gives the start date, dash, end day, Month, Year of a conference, if it was not listed in the Proceedings Title field above; and is omitted here if it was given above, to avoid duplication upon output from ProCite. This field only appears with a conference paper workform.

Place of Meeting: Gives the location of a conference, usually city, state or province, and country(if applicable); and is omitted here if it was given as part of the title in the Proceedings Title field above, to avoid duplication upon output from ProCite. This field only appears with a conference paper workform, if in-filled.

Reprint Status: This field is usually BLANK, but may report that an item is On Request, On File, or Not on File, and gives the Date of the entry of data into the record.

Edition: This field is usually BLANK, but may indicate the date of a work, especially if it is an edition of a book or government publication that may have been revised.

Author, Subsidiary: This field is usually BLANK.

Author Role: This field is usually BLANK.

Place of Publication: City, and State or Province (abbreviated to its two-letter international code) where the article or work was published.

Publisher Name: Full name of publisher; if a government or country or institution or agency, the broadest or “highest” category is given first, followed by a comma, then the next level.

Publication: Copyright date or official Date published, year only. (Months or days are given in the Notes or Edition fields, or under Issue if a periodical).

Date of Copyright: This field is usually BLANK, but may state the year when the official copyright symbol © is present. In that case, precede the year by " c. " (without the quotation marks) or c period.

Date of Access: Appears when the main title is for a Web Page workform

Last Update: Appears when the main title is for an Electronic Citation or website workform.

Volume Identification: Number of periodical or journal volume, when the article is in a journal or serial publication.

Section: Appears when the “volume” is for a newspaper title workform.

Issue Identification: Number and/or Date given when article is published in a journal or periodical. Format used was the number, followed by a space, and abbreviated month (in brackets) where provided on the source of information.

Number: Appears when the “volume” is for a newspaper title workform.

Page(s): Start page, dash, End page of article, chapter, and presentation in printed publication or work. This field does NOT give the total length of the work (see Extent of Work field below), but is reserved for where the specific pages consulted for the literature review occur inside the whole work, such as in a periodical or as a book chapter.

Report Identification: Gives a report number where applicable.

Extent of Work: Total number of pages, or volumes, of the whole work where given in the source of bibliographic information.

Packaging Method: Use a “ p. “ to denote “pages” as in “ the total number of pages.”

Series Title: Name of a publisher’s or agency series, such as “Technical Report” series.

Series Volume ID: This field is usually BLANK, but may state the Number of the Report within a report series.

Issue ID: This field is usually BLANK

Connective Phrase: This field -- a second 'connective phrase' field, for series -- was CUSTOMIZED FOR THE SOIL QUALITY INDICES LITERATURE PROJECT, to hold "Compiler's Comments".

Address/Availability: Where to locate a copy of the article or book. AAFRD + Alberta Agriculture, Food & Rural Development Library; NEOS = Edmonton Library Consortium; CISTI = Canadian Institute of Scientific and Technical Information; CAL = Canada Agriculture Library; c&d = Conservation and Development branch files.

Location/URL: If Conservation & Development Branch of AAFRD has a copy, then this appears as "c&d". May also contain notes such as "On Request" or "AAFRD Library". Always shows the URL if the item is available on the Internet/WorldWideWeb.

CODEN: This field is usually BLANK; not used.

ISSN: International Standard Serial Number is given in this field; for periodical titles.

ISBN: International Standard Book Number is given in this field; for book or report titles.

Notes: **SQ Index Literature Review Project -- Information provided:**
Record downloaded from [database name and Date]; OR,
Reference cited in: [Title of Source article or publication, Author(s), Date: Page range]; OR,
Citation provided by AESA program staff.
Any bibliographic notes.
A Table of Contents listing is included when important to this project.

Abstract: Usually gives the Author(s) Abstract, **included when important to this project,** as all words are searchable within ProCite. Descriptive abstracts are useful for the information they can provide concerning research or literature analyses. The "author abstract" note with page number are given in italics, to denote that the abstract was, indeed, provided by the author or search service. Abstracting services are acknowledged here.

Call Number: Given when provided during searches, in order to locate the literature. DNAL = designation for the US National Agriculture Library classification; AEAG = code for the AAFRD Library within the National Library of Canada's classification system for Interlibrary Loans.

Keywords: Subject-analytic terms, classification of the soil quality assessment literature, author(s)' recommended terms when given, search engine descriptors and identifiers when the citation has been downloaded from literature indexes and search services or library catalogues' subject headings used to describe their holdings. Use the drop-down menu to the right of this field for a list of the subjects in the database.

The most commonly-used workforms for this project were Journal Article, Report, Conference, Book Chapter, Book Short form, Generic, Web site, and Electronic Citation. If a "default" is needed, prefer to use the Journal Article template.

APPENDIX D

Soil Quality Index Literature, 1992 - 2003

-- an annotated bibliography

December 15, 2003

Prepared for
Alberta Environmentally Sustainable Agriculture
Soil Quality Monitoring Program

Acton, D. F. 1993. *Soil quality evaluation report,* National Soil Conservation Program (NSCP). NCSP Monitoring, 1989-1993. 210pp. From URL: http://res2.agr.gc.ca/initiatives/manurenet/env_prog/nscp/sqep.html

In 1993, work was continuing in order to develop a soil quality index for soil organic matter.

———. 1994. *A Program to assess and monitor soil quality in Canada : Soil Evaluation Program Summary*, Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research, Ottawa, ON.

This report "identifies the requirements and provides a framework for soil quality evaluation. It summarizes the development of improved capabilities for assessing soil quality and for analyzing the impact of soil degradation on soil quality and crop productivity. It also provides insights into the status of soil quality in Canada that have been forthcoming as part of the system developments." --Quoted from: *Annotated Bibliography* in J. Dumanski, S. Gameda, & C. Pieri. 1998. *Indicators of Land Quality and Sustainable Land Management*, p.7.

Al-Dabbagh, T. H., and R. M. Al Rizzo. 1994. A Proposed soil index for soil stabilization evaluation. *Journal of Environmental Science and Health*—Part A, Environmental Science and Engineering [Monticello, NY : Marcel Dekker Inc.] 29, no. 8: 1531-1540.

A Soil Index is proposed, using the example of, or application to, soil stabilization in Iraq. This theoretical discussion paper outlines how to develop the index and sub-indices.

Alberta Environmentally Sustainable Agriculture Program (AESA), and Karen Cannon. 2003. *Alberta soil quality card,* AESA Soil Quality Monitoring Program 2003, Agdex 525-2. Alberta Agriculture, Food & Rural Development, Edmonton, AB.

Alberta Environmentally Sustainable Agriculture (AESA) Soil Quality Monitoring Program has developed an Alberta Soil Quality Card for producers. Producers can use this new tool to assess soil quality in their fields and to complete a do-it-yourself soil quality rating system. ... The Soil Quality Card uses sensible, farm level indicators and descriptions that qualitatively measure soil quality. Indicators, such as organic matter color, erosion, compaction or salinity, are ranked low, medium or preferred quality.

From URL: http://www1.agric.gov.ab.ca/$department/newslett.nsf/all/agnw3549?opendocument ; August 11, 2003.

Alonso, P., C. Sierra, E. Ortega, and C. Dorronsoro. 2003. Soil development indices of soils developed on fluvial terraces (Peńaranda de Bracamonte, Salamanca, Spain).

From URL: http://edafologia.ugr.es/comun/trabajos/catecron/catecrt.htm - 19k

The purpose of this methods paper was to rate soil horizons & describe them relative to one another. --A "soil taxonomy" study on Spanish fluvial soils, it used correlation coefficients & regression analysis; --Static; field-scale, single site studied. --Composition of soil is based on overall profile of Carbon, at all depths examined, rated using an overall Morphology Index (MI). The MI is derived by normalizing data values for properties of: structure, texture, soil class/consistency, wetness, clay film, melanization, & rubificaton (color: hue & chroma).

Amacher, Michael C., and Katherine P. O'Neill. 2003. *Soil vital signs: a New index for assessing forest soil health.* p.37. Poster [tables, figures, map] USDA Forest Health Monitoring Program.

Soil Quality Index values were developed using the entire United States Forest Inventory and Analysis (FIA) program database, "to integrate all the FIA measured physical and chemical properties of soils into a single index value as an indicator of forest soil quality or health." [quote from web site, at URL:

http://www.na.fs.fed.us/spfo/fhm/posters/ posters03/posters03.htm - 51k or http://www.na.fs.fed.us/spfo/fhm/posters/ posters03/soil_vital.pdf]
--The use of forest soil properties at a database level, and USA national scale are demonstrated. The index was developed to reduce soil physical & chemical properties to an index number relative to a critical threshold value for that property. The method then sums those values [i.e. is 'additive' index]. A higher value indicates overall higher quality soil, expressed as a percentage of the total number of measured properties. This interpretive tool is used to simplify uses/analyses of the U.S. national data set. Presentation is as a table on the Internet, and needs Acrobat Reader & Zoom capacity on a 17" color monitor for farmers to use it properly.

Andrews, Susan S., and C. Ronald Carroll. 1998. Creating a minimum data set to compare soil quality under poultry litter management alternatives. Chapter 3 In: *Sustainable agriculture alternatives: Ecological and managerial implications of composted and fresh poultry litter amendments on agronomic soils* [Ph.D. thesis]. Susan S. Andrews. Athens, GA: University of Georgia.

A Soil Quality Index is advocated. The study uses a minimum data set concept & multivariate statistical analyses to evaluate 2 fescue sites, 2 soil types (silt-loam & loamy sand), & treatments with land-applied poultry litter vs. composted poultry litter, in Georgia, USA. Andrews' method integrates soil attributes, several indicators into the SQ Index, which involves reduction of large data sets. Both fescue sites are experimental farm sites. Sampling from a randomized complete block on 4 blocks & 6 soil amendment treatments, treatments analyzed were of multiple harvests on the silt-loam site vs. no harvest/no grazing on the loamy sands. Andrews compared 2 litter applications types at 2 rates, synthetic fertilizer N/P/K, and no-amendment as a control. Samples were from the field 3 years after the amendments, were lab-analyzed from soil cores to 0-5cm depth, on 40 variables, including: total C, total N, extractable macronutrients (soluble C, mineral N, P); extractable micronutrients & heavy metals (microbial biomass C & N, soil enzyme activity, soil respiration); CEC, pH, soil moisture, plant available water, bulk density, water stable aggregates.
Methodology: The study considered management goals re crop yield; used non-parametric, uni- & multivariate statistics, plus expert opinion, to select indicators representative of a minimum data set re these goals (as the research framework); then performed Principal Component Analysis for each statistically significant variable, for each site. [PCA is summarized, p.76]; followed with transforms normalized to a value between 0 & 1, scoring as in Karlen & Stott (1994); & setting ranges of scoring functions per indicator (the 'more-is-better'/'less-is-better' scenarios); finally adding the MDS variable scores for a SQ index, for comparing the amendment treatments at each site.
Interpreted Results: --MDS scoring functions are reported, & SQI values for both sites showed compost treatments at highest index values; increases in pH & P showed need for some sort of weighting of MDS values, or changes to range values for scoring functions in the index; i.e. modifications.--ch.

———. 1998? Identifying a soil quality minimum data set for guiding poultry litter management. Abstract at http://www.nal.usda.gov/ttic/tektran/data/000009/77/0000097748.html

This single study in California is focused to reduce large data set to a representative index. Field testing at two pasture sites. " We used the index to evaluate the effects of applying either fresh broiler litter or composted litter at two different rates at two pasture sites that differed primarily by soil type and climate. A common framework was used for the index at each site but different indicator variables were used to accommodate local conditions. The common criteria for evaluating indicator performance were the management goals at each site: maximizing litter disposal, maximizing forage yield, and minimizing environmental risk. Results from soil analyses showed significant differences between management alternatives." [see abstract]. This study used different indicator variables, with conflicting results (inconclusive); it was not long-range, not dynamic; done at field scale; is a data reduction attempt, & not comparable with other studies' results.

Andrews, Susan S. and C. Ronald Carroll. 2001. Designing a soil quality assessment tool for sustainable agroecosystem management. *Ecological Applications* [Ecological Society of America] 11, no. 6: 1573-85.

Using her thesis results (Andrews 1998), Andrews & Carroll reiterate the viewpoint that "indices are specifically designed to compare management practices" (p.1573). She refined the soil quality index using regression & Principal Component Analysis (PCA) to validate the chosen minimum data set indicators as independent variables, and management goals as dependent variables; thus, achieving high correlations. SQI additive values showed that at both Georgia experimental farm sites (with different soils but similar climates), the composted litter achieved the best soil quality.

Andrews, Susan S., C. B. Flora, and J. P. Karlen D. Mitchell. 2003. Growers' perceptions and acceptance of soil quality indices. *Geoderma*—Special Issue: *The Assessment of Soil Quality* 114, no.3/4: 187-213.

This study, at field scale, used lab-analyzed soil samples for regional comparison of 12 paired sites on 11 farms in the San Joaquin Valley of Central California, comparing 'conventional' & 'alternative' treatments; with 1995 to 1998 sampling from "bulked cores" (8 to 12 per field, randomly selected). The research involved focus groups of farmers to test perceptions, compared with numeric indices derived on several SQ indicators: SOM Olsen phosphorus, exchangeable potassium, CEC, sodium absorption ratio, electrical conductivity, pH; physical properties of: soil texture, bulk density, wet aggregate stability; soil biological properties, as: potentially mineralizable n, microbial biomass Carbon (methods & results reported in a detailed paper elsewhere, 2002). A minimum data set of indicators was chosen with experts' opinions, then interpreted "based on their performance of soil functions" (p.191); then scored, summed, and scoring transformed to a value between 0 and 1. Experts rated the scoring function distribution shapes using a 'more is better' function logistic for ranking SOM, WSA, PMN; a 'less is better' for bulk density (re root growth & soil porosity); and midpoint optimum Gaussian functions (i.e. 'fuzzy set theory') for soil pH, exchangeable K/CEC; midpoint optimum curve for Olsen-P; and SAR scores dependent on EC & environmental risk (pp.193-194). --Indicator scores were summed for each, dividing by total indicators, then multiplied by 10. Farmers' questionnaire responses were compared to the SQ Index. The results on 'alternative treatments' scored higher and declined less than 'conventional treatments'. Farmers were interested in crop yields, and Radar graphs are used to present their ratings of indicators (p.205). Researchers believed the calculated SQ Index accurately reflected farmers' perceptions. According to the authors of this paper, differences were due to crops and soil types, plus statistics/data complexities.

Andrews, Susan S., D. L. Karlen, and J. P. Mitchell. 2002. A Comparison of soil quality indexing methods for vegetable production systems in northern California. *Agriculture, Ecosystems and Environment* 90: 25-45.

The abstract of this article adequately describes its purpose -- to compare methods of SQ Index development as adequate decision support tools for on-farm management practices. At the University of California-Davis' 8.11-hectare experimental farm site in Sacramento Valley, California, in September 1996, 30 soil cores were taken from 0-15 cm depth in loams/fluvisols, used for vegetable production of tomato, corn, oats, vetch, safflower, dry beans crops. The soil samples were from conventional, low-input (fertilizer & pesticides) & 'organic' treatments with 2-yr., 4-yr. & annual rotations. Samples studied in Univ. of Calif. lab analyzed these indicators of soil quality: SOM, total organic C, total N, soluble P; exchangeable K, Ca, Mg; total S, Zn, & sodium absorption ratio; electrical conductivity, pH; soil moisture; soil nitrate (NO_3-N) & ammonium (NH_4-N); potentially mineralizable N; & soil microbial communities (via phospholipid fatty acid testing). This static study used statistical methods: linear and non-linear scored multivariate analyses, ANOVA, regression, principle component analysis, Pearson correlation; and Expert Opinion decision support systems were tested and compared. Minimum data sets were attempted for establishment of data reduction technique comparisons. Results were not conclusive, as the most variability in indicators was chosen to develop the indices, and so highly correlated with high SQ Index values. Results require a statistician to verify if data/methods are truly replicable and valid [in the compiler's opinion--ch].

Andrews, Susan S., Jeffery P. Mitchell, Roberto Mancinelli, Douglas L. Karlen, Timothy K. Hartz, William W. Horwath, Stuart G. Pettygrove, Kate M. Scow, and Daniel S. Munk. 2002. On-farm assessment of soil quality in California's central valley. *Agronomy Journal [Madison, WI: American Society of Agronomy]* 94, no. 1 (Jan/Feb): 12-23.

This is a farm-level assessment, on 11 farms with intensive production practices in San Joaquin Valley, California. There were some 'conventional' & some 'organic' practices compared in 1995 through 1998. At Field scale (30- to 60-ha sites), 6 spring field-moist soils were sampled for: Electrical conductivity, soil texture, SOM, bulk density, total Kjeldahl N, NO_3-N, soluble Olsen P, exchangeable K & Ca, CEC; Zn, Fe & Mn; extractable micro-nutrients; pH; soil aggregate stability; microbial biomass. On 6 farms in 1998, performed non-parametric sum test on the data, and one-way analysis-of-variance, transformed after Student's t-test on one other farm. --The SQ Index was determined for the minimum data set on this 7th farm (one farm only) to demonstrate utility of SQI to help in management decision-making. The researchers used Stella Research software (version 5.1.1) to score the variables. Also, Principal Components on 4 significantly different eigenvalues for 1998 point-source data on Farm 7 revealed electrical conductivity, soil organic matter, pH, WSA, Zn, and bulk density as important for the minimum data set. When weighted variations were considered, EC & SOM "appear to drive the SQI results" (p.21). On-farm participatory research was used to analyze management practices.

Armstrong-Brown, Sue. 2002. Summary: Indicators for a European soil monitoring network. From URL: http://homepage.tinet.ie/~jc stie/etcs/indicsmn.htm ; Accessed Sept.10, 2002 (jw). 3pp.

Minimum data set for prediction of soil quality, based on pedotransfer functions, for soil quality monitoring, are delineated on this web site.

Arshad, M. A. 2002. Monitoring selected soil quality indicators for sustainable land management. In: *Man and soil at the Third Millennium*; Proceedings [of the] International Congress of the European Society for Soil Conservation, Valencia, Spain, 28 March 1-April, 2000; Volume 1: 861-869 . J. L. Rubio, R. P. C. Morgan, S. Asins, and V. Andreu, editors. Logrona, Spain: GEOFORMA Edicions, S.L.

This paper presents the guidelines that can be followed to identify the critical limits for the key indicators and the procedure for monitoring changes in soil quality trends. The suggested steps to monitor soil quality are as follows: (i) divide the region or the country into different ecological zones; (ii) select the ecological zone, farms or watershed with similar soil types; (iii) define the goal or requirements for sustainability; (iv) select a set of indicators for ecological zone, farms or watershed, e.g. organic matter, topsoil depth, infiltration, aggregation, pH, electrical conductivity and soil respiration; (v) select a reference point or baseline value for each indicator; (vi) specify the critical limits for selected indicators; (vii) **transform the indicators into a soil quality/sustainability index**; and (viii) test the procedure using the actual data from different soil and land management practices being used in the ecological zones, farms or watersheds. From URL: http://www.zalf.de/essc/valbook3.htm#moniqual

Arshad, M. A., and G. M. Coen. 1992. Characterization of soil quality : Physical and chemical criteria. *American Journal of Alternative Agriculture* 7, no. 1 & 2: 25-31.

Arshad and Coen (1992) examine the principle physical and chemical attributes that can serve as indicators of change in soil quality under particular agroclimatic conditions. Proposed indicators include soil depth to a root-restricting layer, available water-holding capacity, bulk density/penetration resistance, hydraulic conductivity, aggregate stability, organic matter, nutrient availability/retention capacity, pH, and (where appropriate) electrical conductivity and exchangeable sodium. They briefly touch on socioeconomic factors. They say that the absence of information on land managers' attitudes, knowledge, and practices as they affect soil quality, combined with scientists' traditional focus on the soil rather than its managers, reflect the serious state of degradation. *from Freyenberger's et al. annotated bibliography: SQI Lit.ID #214, p.9*]

Arshad, M. A., and S. Martin. 2002. Identifying critical limits for soil quality indicators in agroecosystems. *Agriculture, Ecosystems and Environment* [Amsterdam; New York : Elsevier] In the Special Issue: S*oil Health As a Indicator of Sustainable Management* 88, no. 2 (Feb): 153-160 / edited by J. W. Doran and S. I Stamatiadis. Paper presented at a workshop held June 24 -25, 1999, Athens/Kifissia, Greece**.**

This discussion paper surveys the literature in order to synthesize approaches to defining and characterizing a soil quality index. Discusses needs and ways for identifying the measurable soil attributes, key indicators, indicator critical limits, models for soil assessment, monitoring soil indicator requirements; suggests parameters for monitoring, giving guidelines and steps to take, and advocates long-term research, case studies, combination of management practices, identification of minimum data sets of soil indicators, and development of simple techniques for use by farmers and extension workers. Very good overall summary of SQI needs.

ASA-CSSA-SSSA. 2002. Soil quality as an indicator of sustainable land management: Demonstrated successes and continued needs; Papers presented at the symposium. *Agronomy Journal* 94, no. 1: 1-47.

The five papers published in this special section of *Agronomy Journal* represent a broad range of soil quality applications and geographic regions. The works encompass literature review, theory, applied research results, a report of US government agency efforts, and on Canadian regions. © *DialogWeb*

Astier-Calderon, M., M. Maass Moreno, and J. Etchevers-Barra. 2002. Derivation of soil quality indicators in the context of sustainable agriculture. *Agrociencia [Montecillo]* 36, no. 5: 605-620.

Excellent, up-to-date review of the prevailing definitions of soil quality, with a very clear discussion of what soil quality indexing requires. This paper provides 3 case studies from Mexico concerning study of soil quality indicators; presents attributes/soil properties (Table 1, p.610). It advocates a relativist position in respect to selecting which indicators are most relevant or part of a minimum data set; these authors accept the FAO framework for sustainable land use/management, but advocate using the MESMIS framework of Masera et al. (1999) instead of use of a "predetermined list of indicators" (as with Doran et al, Olson et al, Karlen et al.), so that, "the indicators are derived at the moment of study and for each system in particular." (p.612).

Australia. CSIRO. 2003. Landscape function analysis: a Systems approach to assessing rangeland condition. From URL: http://www.cse.csiro.au/Research/Program3/efa/lfa_summary.htm

We propose a procedure for the assessment of rangeland function, comprised of three components: a conceptual framework, a field methodology and an interpretive framework. The conceptual framework treats landscapes as systems: defining how landscapes work in terms of sequences of processes regulating the availability of scarce resources. The field methodology uses indicators at landscape and patch scale to provide and structure information to satisfy the needs of the conceptual framework. The interpretational framework provides a process to identify critical thresholds in landscape function and thus provide a function-based state and transition landscape assessment. The approach is quick and simple in the field, is applicable to all range landscapes and amenable for use by a wide range of end-users. -- *Online abstract.*
"**Calculation of Indices**
The soil surface data are combined in different combinations to reflect three major soil habitat quality indices: stability or resistance to erosion, infiltration/water holding capacity and nutrient cycling (Figure 2). The data are presented in percentage terms." --From URL:
http://www.cse.csiro.au/Research/Program3/efa/lfa_summary.htm

Baer, S. G., C. W. Rice, and J. M. Blair. 2000. Assessment of soil quality in fields with short and long term enrollment in the CRP. *Journal of Soil and Water Conservation* [Ankeny, Iowa: Soil and Water Conservation Society] 55, no.2:142-146.

Balota, E. L., A. Colozzi, and D. S. et al. Andrade. 2003. Microbial biomass in soils under different tillage and crop rotation systems. *Biology and Fertility of Soils* [Berlin, Germany: Springer Verlag] 38, no.1 (Jun):15-20.

Bandick, A. K., and R. P. Dick. 1999. Field management effects on soil enzyme activities. *Soil Biology and Biochemistry* [Oxford : Elsevier Science Ltd.] 31, no. 11 (Oct): 1471-1479.

Beare, M. H., K. C. Cameron, P. H. Williams, and C. Doscher. 1997. Soil quality monitoring for sustainable agriculture. *NZPPS Paper* [URL: http://www.hortnet.co.nz/publications/nzpps/proceedings/97/97_520.htm **] .**

... Farmers increasingly demand more information and better tools for monitoring the sustainability of their agricultural management. This paper describes work in progress [presenting] an overview of research and development of a Soil Quality Monitoring System (SQMS). The SQMS is designed as an on-farm tool for monitoring and interpreting changes in soil quality that reflect on the sustainability of agricultural management practices....One of the major challenges to quantifying agricultural productivity involves normalising the measurements to account for differences in land-use (e.g. arable cropping, dairy pasture, etc.), crop type (e.g. wheat, maize, asparagus) and environmental constraints (e.g. soil type, climate etc). This is particularly important in a monitoring programme where the objective is to compare year-to-year changes in paddock productivity under different crops. Our solution to this challenge is to index measures of paddock productivity against the regional (or local) average annual productivity of a specific crop (eg. pasture cover, wheat yield). Productivity threshold (PT) levels are set as a fixed percentage of the **productivity index (PI)** to denote boundaries between sustainable and unsustainable practices. Using this approach, the threshold levels for a sustainable practice can be tailored to the specific expectations of farmers, farm consultants and regional governing bodies. Depending on regional or local circumstances, PT values may be judged to be

greater than, less than or equal to one (i.e. where PT = 100% of the regional average annual productivity). Examples of productivity indices for 13 performance assessment paddocks located on the Lincoln University and Crop & Food Research farms are given. --From URL: http://www.hortnet.co.nz/publications/nzpps/proceedings/97/97_520.htm

Beinroth, Fred H., Hari Eswaran, and Paul F. Reich. 2001. Global assessment of land quality. In: *Sustaining the global farm—Selected papers from the 10th International Soil conservation Organization Meeting (ISCO99),* edited by D. E. Stott, R. H. Mohtar, and G. C. Steinhardt, Pp.569-574. West Lafayette, IN: International Soil Conservation Organization, in cooperation with the USDA and Purdue University.
--From URL: http://topsoil.nserl.purdue.edu/nserlweb/isco99/pdf/ISCOdisc/tableofcontents.htm
http://topsoil.nserl.purdue.edu/nserlweb/isco99/pdf/ISCOdisc/SustainingTheGlobalFarm/P233-Beinroth.pdf

This article follows the functional definition of 'land quality' used by Karlen & Stott.

Berkelmans, R., H. Ferris, M. Tenuta, and A. H. C. van Bruggen. 2003. Effects of long-term crop management on nematode trophic levels other than plant feeders disappear after 1 year of disruptive soil management; Application of sustainability indicators to the management of soil and catchment health. *Applied Soil Ecology* 23, no. 3: 223-235.

Nematode community analysis may provide a useful tool to quantify soil health. Nematode communities were monitored for 5 years during a 12-year period in the sustainable agriculture farming systems (SAFS) project at UC Davis, where conventional (CONV), low-input (LOW) and organic (ORG) management treatments were compared. After the completion of three 4-year crop rotation cycles, a uniform crop of oats was grown in 2001. The composition of the nematode genera was different from year to year, but there were significant management effects on genus composition in each year.... Important contributors to the differences in genus composition among treatments were plant parasitic nematodes. Nematode community indices (enrichment (EI), basal (BI) and channel (CI) indices) of the CONV treatment differed from those of the ORG and LOW treatments in 1993, 1994, 1995 and 2000 ... BI and CI appeared to be most valuable as indicators for long-term effects of management on nematode suppression. However, BI and SI may be more suitable as general indicators for the health status of a soil, since CI can be high in highly disturbed agro-ecosystems as well as in undisturbed natural ecosystems. A high BI would indicate poor ecosystem health, while a high SI would indicate a well-regulated, healthy ecosystem. For agricultural soils the presence of large populations of plant parasitic nematodes forms an additional indication of poor ecosystem health, as natural regulation is limited... . --*CAB Abstracts: Authors' abstract, p.223.*

Biederbeck, V. O., C. A. Campbell, and V. Rasiah . 1998. Soil quality attributes as influenced by annual legumes used as green manure. *Soil Biology and Biochemistry* [Oxford : Elsevier Science Ltd.] 30, no. 8-9 (Aug): 1177-1185.

Bindraban, P. S., J. J. Stoorvogel, D. M. Janse, J. Vlaming, and J. J. R. Groot. 2000. Land quality indicators for sustainable land management : Proposed method for yield gap and soil nutrient balance. *Agricultural Ecosystems & Environment [Amsterdam, New York: Elsevier]* 81: 103-112.

The required increase in agricultural production to meet future food demand will further increase pressure on land resources. Integrative indicators of the current status of the agricultural production capacity of land and their change over time are needed for promoting land management practices to maintain or improve land productivity and a sustainable use of natural resources. It is argued that such land quality indicators should be obtained with a holistic systems-oriented approach. Two land quality indicators are elaborated that deal with (1) yield gaps, i.e. the difference of actual yield and yield obtained under optimum management practices, or yields determined by the land-based natural resources, and (2) a soil nutrient balance, i.e. the rate with which soil fertility is changing. The yield gap is based on the calculation of land-based cereal productivity at three different levels in terms of potential, water limited, and nutrient limited production, considering weather, soil and crop characteristics. These modelled production levels do not incorporate socio-economic aspects, which may impede agricultural management in its effort to release stress because of inadequate soil fertility, water availability and/or occurrence of pests and diseases. Therefore, location specific actual yield levels are also considered. Besides an evaluation of the actual status of the land, it is important to consider the rate of change. The quantification of changes in soil nutrient stocks is crucial to identify problematic land use systems. The soil nutrient balance, i.e. the net difference between gross inputs and outputs of nutrients to the system, is used as measure for the changes. The indicator for the soil nutrient balance combines this rate of soil nutrient change and the soil nutrient stock. Indicators for yield gaps and soil nutrient balances are defined, procedures for their quantification are described and their general applicability is discussed. -- *Authors' abstract from © 2000 Elsevier Science B.V. All rights reserved.*

Blair, J. M., P. J. Bohlen, and D. W. Freckman. 1996. "Soil invertebrates as indicators of soil quality." In: *Methods for assessing soil quality*, J. W. Doran, and A. J. Jones, editors. Madison, WI: Soil Science Society of America Inc. Pp.273-291.

Literature covering the effect of invertebrates on soil structure and function and their contribution to soil quality is reviewed. The use of earthworms and nematodes as potential indicators of soil quality is suggested. Methods for sampling populations from both groups (hand sorting, behavioural methods, combined physical and behavioural methods) are provided and the analysis and interpretation of results is discussed. --*CAB Abstracts.*

Bloodworth, H., and T. Sobecki. 2002. Land use biodiversity index as a soil quality indicator. In *Making conservation tillage conventional: Building a future on 25 years of research*; Proceedings of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture, Auburn, AL, USA, 24-26 June, 2002, Pp.219-221. E. van Santen, editor. Auburn, AL: Alabama Agricultural Experiment Station, Auburn University.

Decreases in land cover diversity can lead to decreases in soil quality. This study proposes using the National Resources Inventory (NRI) to develop a biodiversity index as a biological indicator of soil quality. Index values for Major Land Resource Areas in the southeastern USA were calculated using land use based upon whether the Primary Sampling Unit was either: (1) all cropland; (2) multi-cropped; (3) cropland with at least one non-cropland use; or (4) cropland having some vegetative diversity (cover crop, buffer strip, etc.). Forestland and range/pasture land uses provided high biodiversity index values for most of the southeastern USA. Cropland enrolled into the Conservation Reserve Program was attributed with the increase from 1982-97 of those acres with a score of 4. Irrigated cropland tended to have lower index values than non-irrigated cropland. Maize (Zea mays) and soyabean (Glycine max) seed yields tended to decrease as index values increased. Using the NRI did show promise for developing a biodiversity index.

--*CAB Abstracts.*

Blum, W. E. H. 2002. Soil quality indicators based on soil functions. In: *Man and soil at the Third Millennium*; Proceedings [of the] International Congress of the European Society for Soil Conservation, Valencia, Spain, 28 March 1-April, 2000; Volume 1: 149-151. J. L. Rubio, R. P. C. Morgan, S. Asins, and V. Andreu, editors. Logrona, Spain: GEOFORMA Edicions, S.L.

From URL: http://www.zalf.de/essc/valbook3.htm

This paper discusses the concept of soil quality and the possibility of defining soil quality indicators for specific soil functions, ranging from biomass production, filtering, buffering and transformation activities and the soil as a gene reserve, up to soil as a memory or soil as a basis for infrastructural development and a source of raw materials.

Bolinder, M. A., D. A. Angers, E. G. Gregorich, and M. R. Carter. 1999. The Response of soil quality indicators to conservation management. *Canadian Journal of Soil Science* 79, no. 1: 37-45.

The response and consistency of different soil organic matter (SOM) attributes to changes in soil management practices were compared in eastern Canadian agroecosystems. Soil samples (0-10 cm) were obtained at sites of several replicated experiments throughout eastern Canada, and 16 paired comparisons were selected to determine the effect of conservation (no-tillage, rotations, organic amendments) vs. conventional (autumn mouldboard ploughing, continuous cropping, no organic amendments) management practices. A sensitivity index was calculated for each of the attributes by dividing the values for conservation treatments with their conventionally managed counterparts. ...--*Authors' abstract, p.37.*

Bongers, T., and M. Bongers. 1998. Functional diversity of nematodes. In: Functional aspects of animal diversity in soil; Proceedings of a workshop, Giessen, Germany, 14-20 September 1996V. Wolters, 239-251.

Since nematodes respond rapidly to new resources, and the nematode fauna can be efficiently analysed, the structure of the nematode community offers an instrument to assess (changes in) the conditions of soils. A functional grouping of nematodes is generally synonymous with allocation into feeding groups. However, **soil quality assessment indices** based on the presence of all feeding groups still provide insufficient information regarding the functioning of soil ecosystems and their threats. An alternative concept of functional groups is based on the life history of nematodes. In this paper the most recent colonizer-persister allocation and the application of this scaling in the **Maturity Index**, cp-triangles, MI(2-5) and PPI/MI-ratio is presented. It is proposed to integrate the life strategy approach and trophic group classification to obtain a better understanding of nematode biodiversity and soil functioning. Attention is given to competitive exclusion and coexistence and present concepts regarding succession and degradation are summarized.

--CAB Abstracts.

Bowman, Bruce T. 2003. FAQ - What is Soil Quality or Soil Health? Is there a difference between Soil Quality and Soil Health? From URL: http://res2.agr.ca/london/faq/soil-sols_e.htm

In a recent publication from the Research Branch of Agriculture and Agri-Food Canada entitled "The health of our soils: toward sustainable agriculture in Canada" (D.F. Acton and L. J. Gregorich, editors; 1995), the editors state that the terms Soil Quality and Soil Health can be used interchangeably. In a Statement on Soil Quality by the Soil Science Society of America [SSSA] (Agronomy News, June 1995, Page 7), the editors added the following Footnote on Soil Quality:

The terms soil quality (favored by scientists) and soil health (favored by farmers) tend to be used interchangeably, especially in the general press. Characterization of soil quality by scientists focuses on analytical/quantitative properties of soil with a separately defined quantitative link to the functions of soil quality.

Characterization of soil health by farmers focuses on descriptive/qualitative properties of soil with a direct value judgement (unhealthy to healthy)integrated into the options for a given property; in addition, interwoven into the properties of soil per se are value-based descriptive properties of plant, water, air, and animal/human systems considered by farmers to be an integral part of soil health characterization.

Soil Quality: A Conceptual Definition

(excerpted from Soil Science Society of America Agronomy News, June 1995, P.7)

Public interest in soil quality is increasing throughout the world as humankind recognizes the fragility of earth's soil, water, and air resources and the need to protect them to sustain civilization. To understand soil quality however, one must first be aware of the complexity of soil and its intrinsic value.

Soil is a living system that represents a finite resource vital to life on earth. It forms the thin skin of unconsolidated mineral and organic matter on the earth's surface. It develops slowly from various parent materials and is modified by time, climate, macro- and micro-organisms, vegetation, and topography. Soils are complex mixtures of minerals, organic compounds, and living organisms that interact continuously in response to natural and imposed biological, chemical, and physical forces. Vital functions that soils perform within ecosystems include:

--sustaining biological activity, diversity, and productivity;
--regulating and partitioning water and solute flow;
--filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric depositions;
--storing and cycling nutrients and other elements within the earth's biosphere; and
--providing support for socioeconomic structures and protection for archeological treasures associated with human habitation.

Conceptually, the intrinsic quality or health of a soil can be viewed simply as "its capacity to function." More explicitly, SSSA defines soil quality as:

The capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.

By encompassing **productivity, environmental quality,** and **health** as major functions of soil, this definition requires that values be placed on specific soil functions as they relate to the overall sustainability of alternate land-use decisions. Although unstated, the definition also presumes that soil quality can be expressed by a unique set of characteristics for every kind of soil. It recognizes the diversity among soils, and that a soil that has excellent quality for one function or product can have very poor quality for another. The functions encompassed by soil quality integrate chemical, physical, and biological properties and processes occurring within every soil and are responsive to human use and management decisions.

Bowman, R., M. Sucik, M. Rosales, and J. Saunders. 1998. Soil quality indicators for whole-farm management in the Central Great Plains. 5 pp. From URL:
http://www.akron.ars.usda.gov/fs_soilquality.html

This fact sheet speaks of 'indicators', field 'indices' by combining 3 most-easily observable, testable, on-farm, in-field soil attributes. It deals with 'Quality soil' as one that is resilient after change (sod is broken), not too sandy or clayey (loamy is best; deep loam). Texture, pH & SOM are the three main parameters used. Indicators are given: soils series/family, slope/topography, texture/particle size distribution, soil pH/reaction, SOM content/residue, presence of earthworms/macropores, depth, fertility (nitrates & SOM), salinity (electrical conductance), aggregate stability (turbidity), and infiltration. Combines SOM, soil texture and depth-to-lime for a quick field-applicable Soil Quality Index. The article makes recommendations and provides guidance for proper agricultural .management practices to achieve soil health. This is a field-scale, farm-level study, for 'awareness' of best practices and for extension purposes.

Brejda, J. J., D. L. Karlen, J. L. Smith, and D. L. Allan. 2000. Identification of regional soil quality factors and indicators: II. Northern Mississippi Loess Hills and Palouse Prairie. *Soil Science Society of America Journal* 64, no. 6: 2125-2135.

Diversity of soil series present in a region may hinder identification of soil quality factors and indicators at a regional scale. Our objectives were (i) to identify soil quality factors for a diverse population of soils at the regional scale, (ii) determine which factors vary significantly with land use, (iii) to select indicators from these factors that can be used with the US National Resource Inventory (NRI) for monitoring soil quality, and (iv) to compare these results to a similar study involving only a single soil series. One hundred eighty-six points representing 75 soil series in the Northern Mississippi Valley Loess Hills and 149 points representing 58 soil series in Palouse and Nez Perce Prairies were sampled from a statistically representative subset of NRI sample points and analysed for 20 soil attributes. Factor analysis was used to identify soil quality factors and discriminant analysis was used to identify factors and indicators most sensitive to land use within each region. In the Northern Mississippi Valley Loess Hills, five soil quality factors were identified. Discriminant analysis selected potentially mineralizable N, microbial biomass C, water stable aggregates, and total organic C (TOC) as the most discriminating attributes between land uses. In the Palouse and Nez Perce Prairies, six factors were identified. Discriminant analysis selected TOC and total N as the most discriminating attributes between land uses. The soil quality factors were similar among three of the four regions, but TOC was the only indicator common to all regions for distinguishing among land uses.

--Authors' abstract, p.2125.

Brejda, J. J., T. B. Moorman, D. L. Karlen, and T. H. Dao. 2000. Identification of regional soil quality factors and indicators: I. Central and Southern High Plains. *Soil Science Society of America Journal* 64, no. 6: 2115-2124.

Appropriate indicators for assessing soil quality on a regional scale using the US National Resource Inventory (NRI) are unknown. Our objectives were to (i) identify soil quality factors present at a regional scale, (ii) determine which factors vary significantly with land use, and (iii) select soil attributes within these factors that can be used as soil quality indicators for regional-scale assessment. Ascalon (fine-loamy, mixed, superactive, mesic Aridic Argiustoll) and Amarillo (fine-loamy, mixed, thermic Aridic Paleustalf) soils were sampled from a statistically representative subset of NRI sample points within the Central and Southern High Plains Major Land Resource Areas (MLRA) and analysed for 20 soil attributes. Factor analysis was used to identify soil quality factors, and discriminant analysis was used to identify the factors and indicators most sensitive to land use within each MLRA. In the Central High Plains, five soil quality factors were identified, with the organic matter and colour factors varying significantly with land use. Discriminant analysis selected total organic C (TOC) and total N as the most sensitive indicators of soil quality at a regional scale. In the Southern High Plains, six factors were identified, with water stable aggregate (WSA) content, TOC, and soil salinity varying significantly with land use. Discriminant analysis selected TOC and WSA content as the most sensitive indicators of soil quality in the Southern High Plains. Total organic C was the only indicator that consistently showed significant differences between land uses in both regions. *--Authors' abstract, p.2115.*

Brejda, J. J., and Thomas B. Moorman. 2001. Identification and interpretation of regional soil quality factors for the Central High Plains of the Midwestern USA. In: *Sustaining the global farm—Selected papers from the 10th International Soil Conservation Organization Meeting (ISCO99)*, Pp. 535-540. D. E. Stott, R. H. Mohtar, and G. C. Steinhardt, editors. West Lafayette, IN: International Soil Conservation Organization in cooperation with the USDA and Purdue University.

On a regional scale, representative sites from Colorado, Wyoming & Nebraska with aridic Argiustoll soils were studied. Sampling was of 64 points at 0-10cm depth, except 'native' (i.e. -non-cultivated) soils at 0-2.5cm & 2.5-10cm. Soil attributes analyzed were: microbial biomass Carbon, potentially mineralizable C,

potentially mineralizable N (by chloroform fumigation-extraction method & Drinkwater procedures, on 4mm-sieved, field-moist soil samples); water-stable aggregates by weight (air-dried), soil structure, pH, CEC; exchangeable Ca, Mg, K, & Na; acidity, and Phosphorus. Statistical methods used were: factor analysis on highly-correlated attributes used to reduce data sets, and PCA method to extract factors using software (PROCFACTOR in SAS); correlation matrix & Eigen values for variance on 18 soil attributes, to derive normalized frequency distributions for indices, & for calculation of factor index scores (explained on page 2).
--Land use practices were classified & analysis of variance was used to analyze index scores:
"Land-use practices for 1989 through 1996 from the NRI database were used to classify each sample point as: (1)wheat-fallow rotation, (2) wheat-row crop rotation, (3) conservation reserve program (crp) land, (4) grasses and legumes used for pasture and hay production, or (5) native rangeland. index scores were analyzed by analysis of variance with land--use as the independent variable. soil quality was considered "excellent" if the index score was greater than or equal to 4 but less than 5, "good" if the score was less than or equal to 3 but less than 4, "at risk" if the score was greater than or equal to 2 but less than 3, and seriously degraded if the score was less than 2." (p.2)
--Results presented as 4 "factors" of S.Q.: texture, SOM, acidity (pH & crop rotation), and phosphorus loading, as these related to 3 land-use practices. Soil component factor scores were used to examine & assess land use. The research was static, with good potential of the method for spatial & temporal comparisons. This study met its stated objectives.

Brouwer, F. M. 1995. "Indicators to monitor agri-environmental policy in the Netherlands." Agricultural Economics Research Institute, The Hague, Netherlands.

Brown, Nick, and UK. Ministry of Agriculture, Fisheries and Food. 2000. *Towards sustainable agriculture : a Pilot set of indicators*, MAFF, London, England. From URL: http://www.maff.gov.uk

Bruggen, A. H. C. van, and A. M. Semenov. 2000. In search of biological indicators for soil health and disease suppression. *Applied Soil Ecology* [Elsevier] -- Special Issue: *Soil Health—Managing the Biotic Component of Soil Quality* 15, no. 1: 13-24. Selected and edited papers of a conference held in Las Vegas, Nevada, USA, 10 November 1998; Zeiss, M. R., editor.

Position of soil health and ecosystem stability/resilience is taken, in order to discuss SH indicators as useful in disease suppression, as biological responders to stress/soil disturbance.

Bruyn, L. A. L. de, and J. A. Abbey. 2003. Characterisation of farmers' soil sense and the implications for on-farm monitoring of soil health. *Australian Journal of Experimental Agriculture* 43, no. 3: 285-305.

This study sought to collaborate with farmers in the development of a soil health checklist. The research process acknowledged the importance of local conditions, farmers' existing knowledge on soils and their preferences for delivery and presentation of the final product. The study focused on farmers located in the north-west cropping region of New South Wales, Australia. This article reports on a prototype for a farmer's soil health checklist - the features they use, how they recognise those features, especially the language they use to describe a healthy and unhealthy soil, and finally the techniques they use to determine those features.

Burger, James A., and Daniel L. Kelting. 1998. Soil quality monitoring for assessing sustainable forest management. Chapter 2 IN: *The Contribution of soil sciences to the development of and implementation of criteria and indicators of sustainable forest management;* Proceedings of a symposium sponsored by ... SSSA, USDA Forest Service NE-For. Exp. Stn., & Woods Hole Research Center, Pp. 17-52. Jerry M. Bigham, D. M. Kral, M. Viney, M. B. Adams, K. Ramakrishna, and E. A. Davidson, editors. Madison, WI: Soil Science Society of America.

Whereas in agriculture, soil quality has more recently been studied and monitored separately from crop productivity, this paper recognizes that forestry management traditionally has included soil quality as part of overall forest maturing and sustainability. Thus, soil quality analysis has more bearing on short-term forest stands where erosion, degradation, and reclamation are important. This chapter follows the philosophical positions of Doran (1994), Karlen et al. (1997), the Montreal Process (1998) re sustainability (i.e. "perpetual resource availability" (p.17)), the Santiago declaration for forest soil functions, Doran et al. (1996), Burger (1996), Parr & Papendick (1992). The authors propose use of a pie-chart model as a soil quality index, wherein 100% quality is expressed as the total area of a circle, weighted indicators are wedges, and the rated SQ Index is a fraction of 1 (the 100% total area). Indicators are to be the site-specific soil attributes applicable to the climate, soil type, and forestry practice for a particular forest soil, which is seen as dynamic, subject to human and climatic influences, and necessarily comparable to a baseline, hypothetical state for that soil (as some are of inherently poor quality for forest productivity), reflecting "natural levels in managed forests" with optimal plant growth (p.32). --Cases are examined from the Atlantic Coastal Plain, the Appalachian Piedmont, NW Florida, S Carolina, the Mobile River Delta of Alabama as examples of natural variation across landscapes, wherein soil attributes exhibit SQ as spectrum functions from High to Low based on capacity to (1) hold, supply, & cycle nutrients (soil fertility), and (2) accept, hold, & supply soil, water, & air (water-air balance) (p.34). --S.Q. monitoring will first require qualitative description of a high quality soil; then to substitute quantitative measures of attributes (that vary each within a range of 'acceptable values'). Measurable indicators are 'substitutes' (ie. pedotransfer functions), such as: organic C, pH, macro- & micro-nutrients for 'plant productivity'. The Soil Tilth Index (Singh et al., 1992) and Productivity Index (Kiniry et al., 1983) are examined as possible models, to use pH, depth to mottling, bulk density, or biomass to derive "sufficiency relationships" and values, expressed as arithmetic means, which can then be multiplied at the geometric mean by weighting factors per attribute, to derive the PI, & to produce sufficiency curves for comparison. --Karlen & Stott's (1994) soil quality model was also examined (an additive model, not multiplicative like the PI) to consider how to assign relative weights to soil attributes. --Discussion is thorough, but not definitive; investigatory and summary in approach; searching for potential models to apply to forestry, from the agricultural research literature (to 1997) on SQ monitoring. These authors conclude that forestry needs to look at multiple variable indicator transforms (MVIT) to study SQ in the future; to study FSQ, organic matter, and soil disturbance functionally.

Burger, James A., and Daniel L. Kelting. 1999. Using soil quality indicators to assess forest stand management. *Forest Ecology and Management* [Elsevier Science B.V.] -- Special Issue: *Indicators of Sustainable Forest Management* 122, no.1/2: 155-166.

Sustainable Forestry Practices are in demand, and therefore require assessments and monitoring of indicators within available SQ models. Monitoring is a process of detecting change in one or more determinants of productivity. Soil-based indicators have to be 1) soil- and site-specific; considering natural forests, plantation forests, & short-rotation woody crops (after Burger 1997); and 2) considering productivity differences among the soil orders, in terms of a) soil fertility & b) soil water/air balance; and 3) considered over time; measured at intervals, and compared. Data is stratified by these parameters. Functions, attributes, indicators selected (to measure attributes, which reflect soil functions); --indicators can be state variables, process variables, or complex constructs (such as soil tilth index); which includes bulk density, strength, plasticity, aggregate uniformity, SOM (after Singh et al 1990); which combine several soil properties into "pedotransfer functions" (after Bouma 1989. Good indicators include: --a baseline, range, sensitivity to a soil function, areal applicability, provision for continuous assessment, are easy/inexpensive/calculable, discriminate between natural or management-induced states; showing correlation to long-term response; responsive to corrective measures/treatments. [There is a companion paper: Kelting & Berger, 1999; discussion paper & review; that discusses their SQ model & Index/case study.] Results are illustrated in a pie chart, and SQ is indexed as a fraction of one (as a wedge of the total area of a circle), as weighted by the angle of the wedge to show importance of an indicator. This study identifies the minimum set of indicators to be placed in the SQ Index chart. It provides an example of combining into an overall index is given in the productivity index model of Kiniry et al (1983), which integrates field measurements for soil variables; it produces a "sufficiency curve" for each SQ attribute. Then one can monitor, and produce probability maps based upon critical thresholds.

Burrough, P. A. 1989. Fuzzy mathematical methods for soil survey and land evaluation. Pp.477-492.

Use of fuzzy-set mathematical theory to assist in soil and land classification where large & complex data sets must be reduced, but without losing the means to accurately convey information. Case studies included: --a 45ha. farm in Turen, Venezuela with a variety of soil types, as a crop yield test site for IBSNAT-CERES maize crop simulation model. 75m^2 grid, 69 soil profiles on 12 x 6 point grid were sampled at 0-20cm, 30-40cm & 70-80cm in-field, with 11 soil physical properties mapped to 25m grid using point kriging (p.485, Table 1), and variograms were produced to predict mapping minimums and maximums to locate sandy soils. A data set from Kisii, Kenya; used point kriging to map areas with potential for optimum planting, to compare Boolean vs fuzzy set approaches, and to verify using GIS. Conventional 4km soil series maps for Kenya, using standard FAO "soil characteristics" (i.e. 'land qualities') which by convex combination method confirmed the best land areas for planting maize, whereas fuzzy sets showed additional areas were possible to use, by means of a "semantic import model" (pp.489-490).

Cannon, Karen R. 2002. *Alberta benchmark site selection and sampling protocols,* AESA Soil Quality Resource Monitoring Program , Edmonton, Alberta. Alberta’s soil quality monitoring sites.

Alberta's soil quality monitoring sites are discussed.

Castillo, Xiomara, and Rainer Georg Jörgensen. 2001. Impact of ecological and conventional arable management systems on chemical and biological soil quality indices [*viz.* indicators] in Nicaragua. Presentation at: *Deutscher Tropentag 2002 Kassel-Witzenhausen: Organic Farming and Sustainable Land Use in the Tropics and Subtropics*, 1591-1597. Kassel University Press.

Lab analysis of soil samples from 25 sites in volcanic ash, vitric Andosol soils of Nicaragua: --15 sites were under conventional management, with burning of crop residue done post-harvest of cotton & sugar cane/soybean; --10 sites were under ecological management, with crop rotation & fertilizer use. Lab test methods are outlined & replicable, in this field-scale study. Soil attributes were: basal respiration, biomass C, biomass P, ergosterol (as an indicator of fungal biomass), CO_2, & qCO_2, + ratios of biomass C to P, and biomass C to total C. The study used fumigation & gas chromatography lab methods. Arithmetic means of soil properties were subjected to 2-factorial analysis of variance with subplot & soil depth, to evaluate effects of soil types & management systems. There does seem to be misuse in this study of term "index" in place of S.Q. "indicators" (--ch notes).

Castrignano, A., G. Convertini, D. Ferri, and N. Martinelli. 2001. Application of a new soil quality index based on multivariate geostatistics. From European web site for: Leibniz-Zentrum für Agrarlandschafts- und Landnutzungsforschung (ZALF) e.V. at URL: http://www.zalf.de/essc/valbook3.htm

This static, field-level study, from Italy, includes modelling and development of an integrated overall index of a complex "multiple-variable indicator transform" (MVIT) and kriging. Four soil chemical properties (N, P_2O_5, K_2O, & pH) and data from 118 sample positions, on a quadrangle grid pattern, in a 10000 x 10000 m. area, produced a probability map for landscapes, showing potential areas of high SQ and low SQ.

Castrignano, A., G. Convertini, D. Ferri, and N. Istituto Sperimentale Agronomico Via C. Ulpiani 5 70125 Bari Italy Martinelli. 2002. Application of multivariate geostatistics to develop soil quality index. In: *Man and soil at the Third Millennium;* Proceedings [of the] International Congress of the European Society for Soil Conservation, Valencia, Spain, 28 March-1 April, 2000. Volume 1:887-896. J. L. Rubio, R. P. C. Morgan, S. Asins, and V. Andreu, editors. Logrona, Spain: GEOFORMA Edicions, S.L. From URL: http://www.zalf.de/essc/valindex.htm#indexval

Awareness of the importance of soil quality for agricultural sustainability has increased in the last ten years. To quantify soil quality, specific soil indicators need to be measured spatially. The list of parameters proposed by researchers to assess soil quality is broad and includes physical, chemical and biological parameters as well as nominal variables, such as soil map unit. For a given location, however, measurements of these soil quality indicators have to be combined in a global index. Such integration is rather complex and must be made in a fashion that combines and weights each factor appropriately. We applied an approach that utilizes multiple-variable indicator system, which transforms measured data values into an overall index according to specified criteria. The criteria, developed independently for each indicator, assume the form of critical values or ranges of values representing the best estimate of good soil quality. Following this approach, soil quality is evaluated on a landscape basis as the probability of areas having good soil quality. To determine such a probability a particular technique of non-parametric geostatistics, called indicator kriging, was utilized which uses the transformed data to estimate values for locations that have not been sampled. To integrate several individual indicators into a new single indicator, we have defined 'good' soil as soil that meets all threshold criteria for all soil parameters. Thus, the integrative soil indicator is coded 0 or 1, if and only if all the individual indicator-transformed values are equal to 0 or 1, respectively. In the other cases, when one or more of the individual soil parameters fails to meet its critical threshold, the combined indicator is coded in a number varying between 0 and 1, obtained weighting each indicator according to its local importance. These weights assume the form of standardized scoring coefficients resulting from multivariate factor analysis. To illustrate the method, we present an example data set containing four soil parameters (N, P2O5, K2O and pH) for each of 118 positions located in a quadrangular grid pattern within a 10 000 by 10 000 m zone of Apulia region (south Italy). Through the estimation procedure, maps are developed that indicate the probability of meeting a specific soil quality criterion on the landscape level. The map of the overall index has allowed to indicate the areas on the landscape that have a high probability of having good soil quality according to predetermined criteria. In addition, it has allowed the identification of the indicator parameter(s) responsible for zones of low soil quality so that specific management plans or land use policies may be developed**.** *--Authors' abstract.*

Canadian Council of Ministers of the Environment (CCME), Soil Quality Task Group. 2003. *CCME Soil quality guidelines for the protection of environmental and human health* . From CCME website at URL: http://www.ccme.ca/initiatives/soil.html?category_id=44

"As part of the Canadian Environmental Quality Guidelines, CCME's soil quality guidelines are derived for the protection of environmental and human health in different land use categories. They are developed using "A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines" (CCME 1996). The CCME soil quality guidelines are derived to approximate a "no- to low-" effect level (or threshold level) based only on toxicological information and other scientific data. Nonscientific factors (socio-economic, technological, or political) are to be considered by site managers on a site-specific level as part of the risk management process. The soil quality guidelines are generic values and are not intended to be applied to all contaminated sites in Canada without a proper site characterization."

Clerck, F. de, M. J. Singer, and P. Lindert. 2003. A 60-year history of California soil quality using paired samples Additional Title: Special issue: The assessment of soil quality. *Geoderma—Special Issue: The Assessment of Soil Quality* 114, no.3/4: 215-230.

These authors recovered archived soil samples from the 1940s & 1950s, and also took 2001 samples from throughout California -- primarily the Central Valley -- and from varying land use types, to compare basic indicator measurements through lab analyses: pH, electrical conductivity, available Olsen-P, total N & C, C/N ratio, clay/silt/sand texture, % clay, chroma/color value. They used JMP version 4.0 statistical software to run parametric t-tests to compare the 1945 to 2001 values; --Found "increases, decreases, or little change in parameter values. Did not weight or score soil attributes, or combine into a SQ Index, citing Sojka & Upchurch (1999, 2003) to justify the complexities involved in soil quality indexing attempts (p.228), and so not doing so. Found "no significant decrease" in soil quality in California. This attempted a state-scale comparison, but using point samples (so no spatial variability could be tracked, nor replicable. (ch notes).

Coleman, D. C., P. F. Hendrix, and E. P. Odum. 1998. "Ecosystem health: an overview." *Soil chemistry and ecosystem health*, P. M. Huang, D. C. Adriano, T. J. Logan, and R. T. Checkai, editors. Madison , WI: Soil Science Society of America Inc. What are the "vital signs" of a healthy terrestrial ecosystem?

This discussion papers takes a soil ecology and systems approach to this topic, uses Doran & Parkin's (1994) definition of soil quality, sees soils as open systems wherein nutrients and energy flow through, enter, are replaced annually, and wherein microbial biomass communities adapt to the flow rate(s).—Roots, rhizosphere, enzymes, microbes all "interact", and **nematodes** are recognized as an indicator species for overall system health.—Section 1-5 (pp.12-17) discusses "Indexes of Soil "Quality".—Relates the Doran & Parkin (1994) major soil functions, then looks at chemical indexes of abundance/level of lignin, polyphenols, & C/N; Tian's (1993, 1995) plant residue quality index (PRQI) of C/N + lignin + polyphenol concentration of plant residues on mulching effect; enhanced macrofaunal activity (termites, earthworms); aeration; & nutrient mineralization. Next, the authors look at soil quality index extension to SOM as in Hu et al. (1995); C dynamics, soil biota effects, nutrient cycling, & carbohydrate ratios (mannose-xylose).
Methods: Field-scale, plots/subplots, root exclusion tests, in Ultisol, in SE-USA; on 40-year old mixed grass sod; used moldboard-plow, disk-harrow, rotary-till treatments, to 15cm depth; subplots sown to grain sorghum in summer & winter fallow post-tillage. Soil samples were taken in November 1990 & 1991, prior to harvest. They measured soil carbohydrates; found greater concentrations of microbial-derived carbohydrates (lab-tested samples), in ratio of mannose to xylose, as an indicator of carbohydrate origin. Microbial biomass was tested by fumigation-extraction method (after Vance et al., 1987); C & N calculated. Results: --C & N were lower in root exclusion & fungicide treatments than in control; earthworm & arthropod-inhibited treatment subplot samples.—Regression & analysis of variance were performed on the data, showing close linear relationship of biomass C & total carbohydrates in the soils.

Columbia University. Earth Institute, Center for International Earth Science Information Network (CIESIN) and Sustainable Rural Development Information System. 2002. "Land quality & sustainable land management indicators [web] sites."

Web page. Available at URL: http://www.ciesin.org/lw-kmn/slm/lqislmsites.html

Craft, E. M., R. M. Cruse, and G. A. Miller. 1992. Soil erosion effects on corn yields assessed by potential yield index model. ***Soil Science Society of America Journal*** **56: 878-883.**

The authors utilized a Potential Yield Index on corn productivity and eroded soils plus tillage; on 4 soils from 16 major "soil associations" in Iowa. Soil physical and chemicals tested were: particle-size distribution, bulk density; soil pH; available water capacity; available P & K to a depth of 1.5 m.; and in the context of available growing season data on daily soil temperature (with depth), and average seasonal rainfall, percolation, and runoff. These data were used to predict root growth potential for corn, nutrient uptake, water uptake; and compared 10-year estimates (1984).Then, they used the derived PY Index correlations to examine eroded soils, fertilizer application effects on soil fertility levels for non-eroded and eroded soils (restoration impacts), and prediction from root-growth simulations to responses to changing soil factors. This research found that erosion factors could be balanced by plow-layer soil fertility restoration.

D'Andrea, A. F., M. L. N. Silva, N. Curi, and M. M. Ferreira. 2002. Atributos de agregacao indicadores da qualidade do solo em sistemas de manejo na regiao dos cerrados no sul do Estado de Goias. ***Revista Brasileira De Ciencia Do Solo*** **26, no. 4: 1047-1054.**

Portuguese with an English abstract which explains the overall purpose of this article. --Regional scale analysis is attempted; 6 management systems, 5 soil properties, on latosols (oxisols) in Brazil; 1995/6 & 1998/9 sampling from 0-10cm, 10-20cm, & 20-40cm depths.

Dalal, R. C., P. Lawrence, J. Walker, R. J. Shaw, G. Lawrence, D. Yule, J. A. Doughton, A. Bourne, L. Duivenvoorden, S. Chow, D. Moloney, L. Turner, C. King, and A. Dale. 1999. A Framework to monitor sustainability in the grains industry. ***Australian Journal of Experimental Agriculture [CSIRO]*** **39: 605-620.**

Good 'index' information, ranking, etcetera.(jw) A clear delineation of: frameworks, indicators, sustainability, attributes, benchmarking, and monitoring; adequate review & perspective of current literature. This paper includes an awareness of land management, The Montreal Process, and complexities of decision support systems in farming. Sustainability indicators, including for soil resources, are rationalized for selection within an overall parametric framework; with soil pH, electrical conductivity, surface soil organic matter, nutrient availability, microbial biomass, surface cover extent, rooting depth, and surface crust as factors. Ranking & weighting are outlined. Multiple objectives can be accommodated by the decision support system advocated, according to these authors.

Davidson, Donald A. 2000. Soil quality assessment: Recent advances and controversies. ***Progress in Environmental Science [Arnold]*** **2, no. 4: 342-350.**

This discussion paper is an excellent perspective on soil quality assessment in the long-term context of land management and policy frameworks for land use; reviewing and summarizing soil quality research up to 2000. --Takes the soil function approach for the concept of SQ, as defined by Larson & Pierce 1996, and expanded by Karlen et al. (1997:7); --Advocates the position that since soil properties vary by soil function, selection depends upon particular land use requirements and therefore quantitative definition of soil quality is not possible "without reference to a specific objective" (p.344); --gives the Doran & Parkin (1996) minimum-data-set approach for soil quality indicators; --emphasizes need for SQ research to use comparable measures and techniques regarding these indicators in order to identify trends and change; --reports Mausbach & Tugel (1997) i.d. of a reference or "standard" conditions for sets of benchmark soils and acceptable ranges or scoring of functions to provide numerical measure.
Literature reviewed by the author:
--Karlen et al. 1994: --Crop residue management treatments on indicators on an experimental farm near Lancaster, Wisconsin, USA re removing, maintaining, or doubling crop residues for 109 years of no-till, continuous corn production; --developed scoring on indicators for an SQ Index on 0.0 to 1.0 scale; --useful sustainability assessment.
--Karlen et al. 1999: impacts on CRP land in Iowa, Minnesota, North Dakota, and Washington (state).
--Hussain et al. 1999: --computed SQ Indices to assess long-term tillage, dependent on selection of threshold values.
--Mentionns urban (Huinink 1998) and forestry (Burger & Kelting 1999) management studies also.
--Smith et al. 1993: --statistical study re MVIK to integrate a range of soil properties into an SQ Index and to predict probabilities of different land areas to meet a soil quality standard, using threshold values and coded 0 or 1 if below or above, then integrating by indicator variograms and kriging for unsampled locations.
--Oyedele et al. 1996: --Case study for maize; used pH, organic C, CEC, soil depth to plinthite, and exchangeable Al; --used kriging of integrated SQ Index values scored as 0 or 1 from threshold values to predict areas for planting, of great use to farmers/land managers; --result expressed as a map of areas.
--Liebig & Doran 1999: --Eastern Nebraska case study of farmers' perceptions of SQ.

--U.S. National and state initiatives also included, such as Ohio and Iowa with soil health cards, web site initiatives; and web-based tools such as New Zealand's SINDI (soil indicators) for soil assessment.
--Sojka and Upchurch 1999: --critical analyses of SQ concept, and rejection of a SQ Index as an impossibility.
--Harris et al. 1996//Doran & Safley 1997: --Discussion of the "soil health" concept as interchangeable with SQ. Relating to easily observable attributes, or risks, or a dynamic organism soil model, as less rigorous or consistent, Davidson sees soil quality as a valid, more viable concept, less confusing than "soil health". Score card approach allows for farmer observations to be included, but results will inevitably be "inconsistent"; so soil scientists' expert analyses, and standardized sampling must be practised and obtained, in order to identify key attributes/soil properties, to compare, and achieve results for quality land use/management decisions to be possible. All references cited in Davidson's bibliography are useful to any soil quality index literature review.

———. 2002. The Assessment of land resources : Achievements and new challenges. *Australian Georgraphical Studies -- International Review Section* 40, no. 2 (Jul): 109-128.

This paper updates Davidson 2000; is an historical overview that puts recent (1990-2001) soil quality assessments and research into the longer perspective and arena of land resource management [See Abstract[. --Section on "Parametric indices of land quality" (p.118) summarizes the literature by: --Fenton et al. 1971, as an "additive" model or index that rated land components for suitability to grow corn in Iowa soil mapping units; --Fenton et al 12975, which assigned ratings to each soil mapping unit; --the Storie Rating Index (1976) in California, of individual land properties on a scale of 1 to 100 derived into a "multiplicative index"; based on soil profile, texture of surface soil, modifying factors of slope, drainage, alkalinity; modified by Leamy (1974)(in New Zealand, and Lal (1989) in India. --There are comments on various GIS studies worldwide regarding land use assessment. The author accepts the (1996) Larson & Pierce need to consider soil functions in soil quality assessment; and Davidson presents Doran & Parkin's (1996) table of soil properties for minimum data sets, but tempered with the need to consider impossibility of a quantification of soil quality without "reference to a specific objective" (p.124). He also presents the Soil Quality Institute's standards for benchmark soils in the United States, but doubts scoring or defining acceptable ranges, optimal, or target values will be easily possible, due to the inherent variability of soil functions; and also presents New Zealand's Landcare Research web-based SINDI (Soil INDex) assessment tool for consideration. (ch) See p.118 for index method. (jw)

de-Haes, H. U., M. Nip, and F. Klijn. 1991. Towards sustainability: Indicators of environmental quality. In: *In search of indicators of sustainable development.* O. Kuik, and A. Verbruggen, editors. Boston, MA: Kluwer Academic Publishers, Pp.89-105.

A comprehensive method to assess environmental quality is proposed. The method chosen closely resembles the AMOEBA approach developed by J.J.E. ten Brink and S.H. Hosper in 1989. The method is independent of spatial scale considerations and takes into account different land uses. The parameters selected to quantify environmental quality had to meet 4 criteria: relevance, sensitivity, detectability, and appeal. A graphical representation of this quantitative method is presented within a case study of a Dutch ecodistrict.--(review by JW)

Diack, M. and Stott D. E. 2001. Development of a soil quality index for the Chalmers silty clay loam from the midwest USA. In: *Sustaining the global farm—Selected papers from the 10th International Soil conservation Organization Meeting (ISCO99)*D. E. Stott, R. H. Mohtar, and G. C. Steinhardt, 550-555. West Lafayette, IN: International Soil Conservation Organization in cooperation with the USDA and Purdue University.

.Summary Review: Long-term 16-yr field experiment in Indiana Chalmers silty clay loam; 3 tillage systems selected: conventional moldboard plowing, intermediate fall chisel plowing, and no-till system; cropping of: continuous corn, continuous soybean, 2-yr rotation between corn and soybean, and corn-soybean-wheat 3-yr rotation. Soil properties changed; data produced ranges for SQ indicators; model developed to 'score' and thus quantify soil responses to management practices.
Reviewer Comments: --S.Q. Index/model development using formulae & systems design. -- Spring sampling of a static data set (1995 samples) -- replicable -- on Indiana silty clay loam, 16-2-ha field.--Field level; 3 different tillage practices: conventional moldboard plowing of top 15-18cm soil/minimal residue/cover; intermediate chisel plowing with 30% cover, and zero tillage with 90-95% cover. 4 Crop rotation systems were used: corn, soybean, 2-yr corn/soybean, & e-yr corn/soybean/wheat, with sampling done after the corn in the 2-yr & wheat in the 3-yr rotation systems. --Infiltration rate, resistance to penetration, bulk density, aggregate stability, total C, total N, dissolved organic C and particulate organic C and microbial biomass C, flurescein diacetate (indicator for xxx). --Randomized blocks used for field sampling points on 4 cropping systems & 3 tillage types; i.e. 12 crop treatments. --S.Q. model used criteria ranking for high quality &

weighting of each soil parameter by ranked criteria; based ranking on ability of soil to resist physical and biochemical degradation, to partition water, regulate absorption/infiltration, & function to sustain plant growth. --Data reduced to a value between 0 & 1; scoring for final infiltration rate, total C, dissolved organic C, microbial biomass C & enzyme activity from "more is better" a perspective; and bulk density, penetration resistance, & sealing index as "less is better" functions; Mean values were then compared per land use practice.

Dick, R. P. 1994. Soil enzyme activities as indicators of soil quality. In: *Defining soil quality for a sustainable environment*; Proceedings of a symposium, Minneapolis, MN, USA, 4-5 November 1992; Pp.107-124. J. W. Doran, D. C. Leman, D. F. Bezdicek, and B. A. Stewart, editors. SSSA.

The importance of soil enzyme activities as a potential biochemical/biological indicator of soil quality is discussed. It is concluded that the measurement of selected soil enzymes has a good potential as soil quality indicator but also that soil sample pretreatment, assay procedures and units of measurement must be standardized in order to give the most accurate results. However systematic studies across ecosystems and long term soil management sites are also needed to identify the best soil quality enzyme assays and to provide data for calibration and interpretation of these assays as independent **soil quality indexes**. *--Author's abstract; also in CAB Abstracts.*

Dinel, H., and T. Pare. 1998. Agro-environmental indicators of soil quality in Canada // Original Title: Indicateurs agro-environnementaux de la qualité des sols au Canada. *Cahiers Agricultures* 7, no. 3: 195-200.

Indicators of agro-ecological functions were selected and measured with a wide variety of soil textures and cropping practices in Canada. Structural properties and organic matter characteristics were integrated using principal component analysis (PCA) to develop a soil quality index. The quality of organic matter, as assessed by gravimetric ratios between diethyl ether (DEE)/chloroform ($CHCl_3$) extractable lipids or $CHCl_3$/TEL (total extractable lipids), showed that physico-chemical stabilization and biochemical decomposition of soil lipids were affected by soil texture and cropping practices. The best organic matter quality and structural properties were found in forest soils and the poorest in conventional tilled soils, whereas soils under conservation tillage gave intermediate results. Integration of these indicators into a soil quality index effectively reflected anthropogenic disturbances on agricultural land. The index was sensitive to spatial and temporal variation at the field level. *--Authors' abstract.*

Doran, John W., D. C. Coleman, D. F. Bezdicek, and B. A. Stewart, editors. 1994. *Defining soil quality for a sustainable environment*. Madison, WI: Soil Science Society of America. SSSA Special Publication no.35; xxiii, 244pp.

"The papers in these proceedings contribute new perspectives on the definition of soil quality and how it may be measured and quantified." *--R.R. Janke, Rodale Institute Research Center; and R.I. Papendick, USDA-ARS; pp.ix-xi.*

Doran, John W., and Alice J. Jones. 1996. *Methods for assessing soil quality*. Madison, WI: Soil Science Society of America. Special Publication no.49; xxvi, 410 pp.

"Topics covered in the 27 chapters of this publication discuss relations between soil quality and health of plants, animals and humans, farmer-based approaches to assessing soil quality, case studies discerning land use and management impacts on soil quality, development of soil quality indices for sustainability, and techniques for understanding soil quality and its role in the biosphere." *--CAB Abstracts.*

Doran, John W., and T. B. Parkin. 1994. Defining and assessing soil quality. Chapter 1. In: *Defining soil quality for a sustainable environment*; Proceedings of a symposium, Minneapolis, MN, USA, 4-5 November 1992. Doran, John W., Coleman, D. C., Bezdicek, D. F., Stewart, B. A., editors. Soil Science Society of America - Special Publication no.35; Pp.3-22.

Doran and Parkin (1994) set criteria by which basic soil quality indicators should be selected: 1) encompass ecosystem processes and relate to process oriented modeling; 2) integrate soil physical, chemical, and biological properties and processes; 3) be accessible to many users and applicable to field conditions; 4) be sensitive to variations in management and climate; 5) where possible, be components of existing soil data bases. They then proposed seven soil physical characteristics, three chemical characteristics, and five biological characteristics to be included as basic indicators of soil quality. -- *[from Freyenberger et al. Annotated bibliography; SQI Lit.*

The 6 specific soil quality elements included in the index are: food and fibre production; erosivity; groundwater quality; surface water quality; air quality and food quality. Each soil quality element is evaluated with regard to 5 specific soil functions which indicate the capacity of soil to provide a medium for plant growth and biological activity, regulate and partition water flow through the environment and serve as an environmental filter. These specific soil functions are discussed in detail and theoretical examples are given. *--Authors' abstract excerpt, p.3.*

———. 1996. "Quantitative indicators of soil quality: a minimum data set." In: *Methods for assessing soil quality*. J. W. Doran, and A. J. Jones, editors. Madison , WI: Soil Science Society of America.

Classic article; often quoted for the basic defining attributes of 'soil quality'. (ch)

The quantitative assessment of soil quality is of great importance in determining the sustainability of land management systems. Indicators considered necessary for the assessment of soil quality must correlate well with ecosystem processes, integrate soil physical, chemical and biological properties and processes, should be easy to use under field conditions, be sensitive to variations in climate and management, and, if possible, must be components of existing soil databases. *--Authors' Introduction.*

Doran, John W., and M. Safley. 1997. Defining and assessing soil health and sustainable productivity. In: *Biological indicators of soil health; Soil resilience and sustainable land use*: Proceedings of a Symposium held in Budapest, 28 September to 2 October 1992, including the Second Workshop on the Ecological Foundations of Sustainable Agriculture (WEFSA-II). Pp.1-28. C. Pankhurst, B. M. Doube, and V. V. S. R. Gupta, editors. Wallingford; New York: CAB International.

Doran, John W., M. Sarrantonio, and M. A. Liebig . 1996. Soil health and sustainability. *Advances in Agronomy* [San Diego, Calif.: Academic Press] 56: 1-54.

Doran, John W., and Stamatis I. Stamatiadis, editors. 2002. *Agriculture, Ecosystems & Environment*—Special Issue [entitled]: *Soil Health as an Indicator of Sustainable Management;* Summary Findings of an International Workshop, GAIA Environmental Research and Education Center, Kifissia, Greece, 24-25 June 1999 88, no. 2: 107-193. -- *Preface;* Pp.107-110.

In the preface to a conference re soil health, the authors identified the "need to standardize key soil attributes in a multifunctional and multidimensional sustainability index" with associated arising complications (p.109).

Dumanski, Julian, Samuel Gameda, and Christian Pieri. 1998. *Indicators of land quality and sustainable land management: an Annotated bibliography*. Washington, DC: The World Bank.

Excellent example of an annotated bibliography; --land use and quality indicators for sustainability; --includes references to titles dealing with soil quality and assessment; --useful model for project to characterize the SQI literature.

Dunjo, G., G. Pardini, and M. Gispert. 2003. Land use change effects on abandoned terraced soils in a Mediterranean catchment, NE Spain. *Catena* 52, no. 1: 23-37.

A catchment in NE Spain, in semiarid environment, has been progressively abandoned by farmers during the last century. ... Along two altitudinal gradients, we selected 11 random environments representative of the current land uses, in sequence from cultivated to early abandonment. ... Erosion plots were installed in selected environments for soil physico-chemical characterisation, throughout 1-year observation, monitoring nutrient losses, runoff volume and sediment yield data. Analysis of variance (ANOVA) indicates significant differences in the main soil quality parameters such as soil organic matter (SOM), total nitrogen (N), water holding capacity (WHC) and pH, among the selected environments under different land use conditions. Factor analysis of the principal components (PCA) enabled the identification of three soil quality indices: index of soil erosion and nutrient losses (SENL), **index of soil quality and fertility (SQF)** and index of vegetation cover and soil protection (VCP). *--Authors' abstract excerpt*.

DUX, and Umweltbundesamt für mensch und umwelt. 2002. German Environment Index (DUX) // Deutscher Umweltindex (DUX). From URL: http://www.umweltbundesamt.de/dux-e/

For the first time, the Federal Environmental Agency (UBA) has calculated a characteristic value which reflects developing trends in German environmental protection in a single figure—the German Environment Index, or DUX (*Deutscher Umwelt Index*) for short. The DUX is comprised of various values stemming from the Environment Barometer for Germany on climate, air, soil, water, energy and raw materials. Each environmental field may score a maximum of 1,000 points. If the set environmental political goals were achieved in all fields, the DUX would amount to **6,000 points**.

How is the DUX calculated?

The values of the six indicators of the Environment Barometer are fed into the DUX (from the fields of climate, air, soil, water, resources: energy/raw materials). In order to make these very different values comparable, it is not the absolute indicator values that are used, but rather a calculation of each individual indicator's relative achievement of target. This means a calculation of the indicator's stage of development relative to its actual point in the base year (values of the base year) and its theoretical target point (target values in target year). Complete achievement of targets is valued at a maximum of 1,000 points, the base year value at 0. Should development worsen as compared to the base year, the outcome is a negative value. " The Environment Barometer and its six indicators can not include all fields of environmental policy." *--From URL:* http://www.umweltbundesamt.de/dux-e/ ; *Accessed Nov.18, 2003.*

Ericksen, P. J., and K. McSweeney. 1999. Fine-scale analysis of soil quality for various land uses and landforms in central Honduras. *American Journal of Alternative Agriculture* 14, no. 4: 146-157.

20 sites in a catchment ar4ea of Honduras (Central America) were sampled at field scale, 100 to 400 m^2 plots, along within-site transects aligned with surface water flow direction, at intervals of 0, 5, 10, 15, & 35m. to test land form, land use, and 5 main soil functions from 14 attributes: (Table 1, p.149): infiltration rate, bulk density, microtopography & vegetative cover, soil structure, soil macrofauna, % clay, SOC, surface stoniness, soil N, P & K, pH, and A horizon 'thickness' (dsepth?). --Soil attributes were scored & weighted by function, following Karlen et al. (1997); summing scored attributes to a "value of unity". (for assignment of weights, see p.151.) --Used analysis of variance and means; land use, landform were important qualitatively but noty quantitatively (p.153). --Scoring soil quality functions displayed complexities and diversity; study's SQIndices were inconclusive & did not account for the variability found (p.154).

Farquharson, R. J., G. D. Schwenke, and J. D. Mullen. 2003. Should we manage soil organic carbon in Vertosols in the northern grains region of Australia? -- Application of sustainability indicators to the management of soil and catchment health. *Australian Journal of Experimental Agriculture* 43, no. 3: 261-270.

"... the results and associated discussion give some support to the use of soil organic carbon as a sustainability indicator for soil health. There was a consistent correlation between crop input decisions (fertilisation, stubble management, tillage), outputs (yield and profits) and outcomes (change in soil organic carbon content) in the short and longer term. And this relationship depended to some extent on whether the existing soil organic carbon status was low, medium or high. A stock dynamics relationship is one where the change in a stock (such as soil organic carbon) through time is related not only to the management decisions made and other random influences (such as climatic effects), but also to the concentration or level of the stock itself in a previous time period. Against such a requirement, soil organic carbon was found to be a reasonable measure. " *--Authors' abstract excerpt.*

Fernandez-Pozo, L., J. Labrador, A. Florentino, and R. Ballesteros. 2002. Agroecological indicators to evaluate soil quality under Mediterranean conditions. In: *Man and soil at the Third Millennium;* Proceedings [of the] International Congress of the European Society for Soil Conservation, Valencia, Spain, 28 March 1-April, 2000; Volume 1: 1911-1922. J. L. Rubio, R. P. C. Morgan, S. Asins, and V. Andreu, editors. Logrona, Spain: GEOFORMA Edicions, S.L.

This abstract discusses the need for soil quality assessment based upon soil functions, and a philosophy re crop productivity. A project in Spain exists, to examine farmer perceptions re SQ in the context of sustainability.

Filip, Z., and J. Berthelin. 1999. Development and application of ecologically based indicators of soil quality. *Scientia Agriculturae Bohemica* 30, no. 3: 209-223.

This article provides a summary/overview of a project by five European Community countries to derive comparisons from 49 sites for soil quality in undisturbed vs. 'anthropogenically-stressed' soils, by laboratory testing of established indicators. Field samples were taken from 5 countries, 49 locations (See Table 1 on p.170). The study is dynamic, with ongoing tests/comparisons. Parameters were: microbial biomass, composition and abundance of microbial communities (bacteria, fungi, microbes), and biochemical activities (respiration (CO_2 release-0ATP, substrate, & post-fumigation), ammonification (NH_4 release--cations), nitrification/denitrification, dehydrogenase, and humification (humic & fulvic acids); also some aquatic testing). Graphs of results are presented. Findings include wide variability across test sites, which points to need to establish critical limits of soil quality. The article gives the preliminary results, with more to be reported by individual authors from the five countries (gives names of involved researchers in bibliography).

Firestone, Mary K., Teri C. Balser, and Donald Herman. 1998. Defining soil quality in terms of microbial community structure. From URL:
http://www.cnr.berkeley.edu/~gsposito/Kearney/Proposals/firestone.html

The purpose of this work was to refine the methods used to determine microbial diversity and community structure in soil and to begin to establish a relationship between microbial community composition and soil function. We investigated the usefulness of a commercially-prepared substrate utilization profile method (BiOLOG indices) in providing a functional index of microbial community processes. We find that the method correlates very well with observed soil processes. --*Authors' Introduction.*

France. 2002. Mesures de la qualite des sols: la France se dote d'un reseau. *Chambres D'Agriculture* 908: 37-39.

Factors that can influence soil quality are discussed, and elements involved in the French Soil Quality Measurement System are outlined. ... A systematic network has been established to provide measurement of soil quality indicators... The national system is based on routine testing of soil samples taken from approximately 2000 sites spread uniformly across France in a 16 km grid pattern. The sampling and testing mechanisms used as part of this national system are described. --*CAB Abstracts.*

Francis, G. S., and M. H. Beare. 2002. The Land Management Index: A potential pressure indicator [progress report]. In: *Soil Quality and Sustainable Land Management Conference Proceedings*; Pp.87-93*.* Peter Stephens, Jemma Callaghan, and Anne Austin, editors. Wellington, NZ: Ministry of Agriculture and Forestry.

Regional councils in New Zealand have a statutory obligation to ensure that the life-supporting capacity of soil is maintained. Councils undertake state of the environment monitoring and reporting to meet this obligation, using a number of soil state indicators. However, councils may prefer to use a pressure indicator. ... This paper contains results from work aimed at developing an improved pressure indicator -- the land management index. --*Authors' Introduction, p.87*

Franco-Vizcaino, E. 1997. Comparative soil quality in maize rotations with high or low residue diversity. *Soil Biology and Biochemistry -- Biology and Fertiliity of Soils* [Oxford : Elsevier Science Ltd.] 24, no. 1 (Jan): 32-38.

This study assessed differences in soil quality linked to differences in the diversity of residues returned to the soil in nine pairs of farm fields in central Michigan. To assure that management was the main difference within pairs, study sites were selected that mapped to the same soil series. Analysis of variance using subsamples as replicates for all nine comparisons revealed significantly higher maize (Zea mays L.) yield and total and mineralizable N for the high diversity fields. Manuring history reported by farmers was difficult to reconcile with levels of total C and extractable P. To account for uncertainty in manuring histories, comparisons were separated into four subsets on the basis of residue diversity (DVS) and extractable P (high DVS high P, low DVS low P, high DVS low P, and low DVS high P). For these segregates, analysis of variance (ANOVA) using subsamples as replicates revealed significant improvements in 6 of 21 soil quality indices in the high DVS P subset. For all nine comparisons, correlation analysis revealed moderately strong relationships between total C, extractable P, as well as their ratio (Ctot/Pext), and both bulk density and log (infiltration time). When the data were segregated as before, these relationships were much stronger for the high DVS high P subset. and their slopes differed significantly from those of the other subsets, indicating that the data points originated from different populations. These results suggest a strong interaction between residue diversity, and P likely applied in manure, that influenced soil quality. --*Authors' Abstract, from Science Citation Index and from Agricola databases.*

Freudenschuss, Alexandra, Sigbert Huber, Martin Schamann, and Martha Wepner. 2001. "EIONET technical workshop on indicators for soil contamination." *Workshop proceedings*, Technical report no.79. European Environment Agency, 2002 Project Report. From URL:
http://www.reports.eea.eu.int/technical_report_2002_78/en/technical_report_78.pdf

Freudenschuss, Alexandra, Sigbert Huber, Martin Schamann, and Martha Wepner. 2002. Assessment of data needs and data availability for the development of indicators on soil contamination. [8pp.]. Technical report no.81. European Environment Agency, 2002 Project Report. From URL: http://www.reports.eea.eu.int/technical_report_2002_81/en/tech_81.pdf

Freyenberger, Stan, Rhonda Janke, and David Norman. 1996? "Indicators of sustainability in whole-farm planning: Literature review." Kansas State University, Kansas Sustainable Agriculture Series, Paper no.2. From URL: http://agecon.uwyo.edu/wire/Reports/KSUSustAgPaper2.htm

This Kansas State University extension paper surveys the 'grey literature' for indicators of agricultural sustainability; reviews several 'framework' conferences and biophysical indicator papers (pp.8-11), as well as papers on socio-economic and international-scale indicators. Soil quality studies are primarily in the biophysical category.—Advocates a whole-farm planning model.

Frielinghaus, M., H. Petelkau, D. Deumlich, R. Funk, L. Muller, and B. Winnige. 2001. Soil indicator system to minimize the risk of soil degradation in northeastern Germany. In: ***Sustaining the global farm—Selected papers from the 10th International Soil conservation Organization Meeting (ISCO99.).*** **D. E. Stott, R. H. Mohtar, and G. C. Steinhardt, editors. West Lafayette, IN: International Soil Conservation Organization in cooperation with the USDA and Purdue University. From URL:** http://topsoil.nserl.purdue.edu/nserlweb/isco99/pdf/isco99pdf.htm/

A reference cited by the OECD, at URL: http://www.oecd.org/dataoecd/28/27/1890358.htm

Fu, Bo Jie, Shi Liang Liu, Yi He Lu, Li Ding Chen, Ke Ming Ma, and Guo Hua Liu. 2003. Comparing the soil quality changes of different land uses determined by two quantitative methods. ***Journal of Environmental Sciences*** **15, no. 2: 167-172.**

Sichuan Province in SW China, on Wolong Nature Reserve land, this study examined land use changes and effects upon soil quality through use of an integrated SQ Index, from principal components analysis and analysis of variance, using field-level data. Compared 79 soil samples collected from 6 land use types at 0-30cm depth on soil properties of: bulk density, SOC, total N, P, K, available N, K, P using the "China Standard method" (1996); and also considered land use succession. Assumed forested soils were in the most 'natural' state and other land uses had caused 'deterioration'; developed a Deterioration Index. But, static study and land use types used to 'represent' land use succession/change (ch notes). Findings were that cultivation caused disturbance and loss of soil nutrients at statistically significant levels. Sampling details are not given (ch notes). SQ Indices values are compared here as "membership functions" of land use type (p.170).

Gadem, Abu-Elgassim-Y. 2000. "Land resources evaluation: an approach for soil qualtiy assessment and mapping of riparian areas using GIS. Master's thesis, University of Nebraska-Lincoln. 96pp.

Gale, M. R., D. F. Grigal, and R. B. Harding. 1991. Soil productivity index: predictions of site quality for white spruce plantations. ***Soil Science Society of America Journal*** **55, no. 6 (Nov/Dec) : 1701-1708.**

Field tests on 76 plots of forest "plantations" of white spruce, red pine, jackpine, trembling aspen, red maple, in young (19-34 yr.), and old (35-43 yr.) stands of trees; fields were plowed or furrowed. --comp0ared above-ground biomass with forest site index vs PI models to test index sensitivity. --Soil texture, pH, bulk density, available water capacity, porosity, topography (percent slope), climate, limits to root growth analyzed; --Cultural practices influenced the results; --Static data (although age of stands varied); grouped age-related sites & cultivation practices, to find higher correlations of PI & SI to productivity.

Garcia, S. 1997. Indicators for sustainable development of fisheries. In: "Land quality indicators and their use in sustainable agriculture and rural development." *FAO Land and Water Bulletin* [United Nations Development Programme (UNDP)]***;*** **Pp. 131-155. Rome, Italy: UN-FAO.**

This is a discussion paper outlining what considerations need to be included in sustainability indicators (p.134-135). Pressure, state, response are socio-economic indicators requiring sustainability research/study. Level, change, and structure indicators allow dynamic views and functional approaches. The Matrix approach integrates PSR indicators, allowing for development of "Sustainability Reference Systems (SRSs) "such as the Prescott-Allen (1996) "sustainability barometer" -- a normalized PSR index on a scale between 0 and 1, which can be depicted in value-tabular or graphic (e.g. Kite diagram) forms for comparison purposes, can then be scaled or weighted, and attributes targetted (e.g. spawning biomass of a fishery), to demonstrate "ecological well-being." PSR provides a framework for a systems approach to sustainability variables and study of indicators.

Gardi, C., M. Tomaselli, V. Parisi, A. Petraglia, and C. Santini. 2002. Soil quality indicators and biodiversity in northern Italian permanent grasslands. *European Journal of Soil Biology* 38, no. 1: 103-110.

Permanent grasslands represented a common type of land use in northern Italy traditional agriculture, but its area has been constantly declining over the last 50 years. Three permanent grasslands of the Po valley (northern Italy) were characterized in terms of biodiversity and soil quality and were compared with other agricultural land uses. Two indicators of biological soil quality (BSQ-ar, based on arthropods; and BSQ-c, based on Collembola species) were also applied and validated. Soil in the study area were classified as Fluventic Ustochrepts. Results demonstrate the importance of permanent grasslands as biodiversity 'hot spots' within the intensive agroecosystems. The quality of soils was higher in permanent grasslands with respect to the arable lands, as evidenced by the standard soil quality indicators (organic carbon, aggregate stability) and confirmed by BSQ. This research proposes BSQ as a synthesizing soil quality indicator. *--CAB Abstracts.*

Garlynd, M. J., A. V. Karakov, D. E. Romig, and R. F. Harris. 1994. Descriptive and analytical characterization of soil quality/health. Chapter 10. In: *Defining soil quality for a sustainable environment;* Pp.159-168. J. W. Doran, D. C. Coleman, D. F Bezdicek, and B. A. Stewart, editors. Soil Science Society of America.

Geomatics International Inc. 1999. Selecting core variables for tracking ecosystem change at EMAN sites; Final report. 1 v. Environment Canada, Ecological Monitoring and Assessment Network (EMAN). From URL: http://www.eman-rese.ca/eman/reports/publications/d000_eman_core_variables/variables.pdf

Germany. Leibniz-Zentrum für Agrarlandschafts und Landnutzungsforschung (ZALF) e.V. 2002. Traditional soil and water conservation // Soil functions and Soil quality // Soil indicators > Keynotes—valbook3 [web page]. Leibniz-Zentrum für Agrarlandschafts und Landnutzungsforschung (ZALF) e.V. From URL: http://www.zalf.de/essc/valbook3.htm

Gil-Sotres, F., M. C. Leiros-de-la-Pena, and C. Trasar-Cepeda. 2003. A comment on the article by de la Paz-Jimenez et al., "Soil quality: a new index based on microbiological and biochemical parameters." *Biology and Fertility of Soils* 37, no. 4 (Apr): 260.

Comments are made on the previous article by De la Paz-Jimenez et al. (see Biology and Fertility of Soils (2002) 35 302-306) which aims to assess soil quality by some chemical, physical, biological and enzymatic parameters and to determine a minimum set of these parameters capable of detecting management-induced changes in soil quality after deforestation. The comments point out the errors in the combination of soil properties which do not constitute a suitable soil quality index as it does not distinguish between the influence of soil use and management of soil quality (results and discussion section), and the errors in considering each one of the eight plots per treatment as individual samples, when they actually correspond to eight replicates of the same treatment (materials and methods section). *--CAB Abstracts.*

Girardin, P., C. Bockstaller, O. Perler, and F. Hani. 1994. Agri-environmental evaluation of arable farms by means of agroecological indices. In: *Proceedings of the Third Congress of the European Society for Agronomy,* Padova University, Abano-Padova, Italy, 18-22 September 1994; Pp.694-695. M. Borin, and M. Sattin, editors. Colmar , France: European Society of Agronomy.

Uses a pie chart and 10 factors to discuss/display "agroecological indexes"; gives 'Nitrogen Index' as an example. Indices set ranges from 0 to 10, and increase in value as a farmer uses 'sustainable practices' (but, considers pesticides & N fertilizers as 'sustainability'; i.e. productivity). --Explanation of weighting is unclear (See p.695).

Glover, J. D., P. K. Andrews, and J. P. Reganold . 1998. Applying a soil quality index to conventional, integrated, and organic apple production systems. *Acta Horticulturae [ISHS]* , no. 525: 217-228.

Four 0.14ha plots, on 3 treatments, in Washington State apple orchards were sampled, and a soil quality index developed for soil properties was modified from Karlen et al, 1994. (See p.219).

"The **soil quality index** used was a weighted additive model of the soil's capacity to accommodate water entry, facilitate water transfer and absorption, resist degradation, and sustain crop productivity and quality.

Critical threshold values and relative importance for each soil property based on published data and soil conditions in adjacent permanent grass sites were determined. Soil quality was higher under both the integrated and organic apple production systems, as these systems resulted in increased surface water infiltration, higher microbial biomass carbon and nitrogen, greater surface aggregate stability, and more earthworms than the conventional system." --*Authors' abstract.*
"Our goal for developing such **site-specific soil quality indices** is to assist researchers, consultants, and producers in ... " http://www.actahort.org/books/525/525_26.htm -- *MSN online abstract.*

Glover, J. D., J. P. Reganold, and P. K. Andrews . 2000. Systematic method for rating soil quality of conventional, organic, and integrated apple orchards in Washington state. *Agriculture, Ecosystems & Environment* 80, no. 1/2: 29-45.

Washington State, apple orchards; compared 3 management systems on 4 different 0.14ha fields; 1998 samples; indexing as Karlen & Stott's 1994 approach assigning numerical weights to soil functions, multiplying by normalized, standardized scoring of indicators (more is better, less is better, or optimum function curves); and use of SQ scoring cards; values between 0 and 1. Attributes were: aggregate stability, bulk density, earthworms, pore spaces, porosity, organic C, microbial biomass processes, CEC, pH, total N, nitrate nitrogen, extractable phosphorus, and electrical conductivity. Conventional, integrated, and organic soil management systems were sampled, with soil cores taken from 0-7.5cm, 7.5-15cm depths 4 days post-irrigation on experimental plots in May 1998 at random. Scoring functions of (modified) Karlen et al. 1994 SQ Index presented in table form (p.3;6). --Integrated plots scored significantly higher overall than conventional and organic systems. The SQ Index approach was found to be very useful in this study, which is replicable, field-scale, but static.

Goh, K. M., D. R. Pearson, and M. J. Daly. 2000. Effects of apple orchard production systems on some important soil physical, chemical and biological quality parameters. *Biological Agriculture & Horticulture* 18, no. 3: 269-292.

Three different grassed-down apple orchard production systems (organic or biological, BFP; conventional, CFP; and integrated, IFP) in New Zealand were compared for their effects on some important soil physical, chemical and biological quality parameters. A total of 17 grassed-down apple orchards with alley and treeline areas from BFP, CFP and IFP systems in experimental sites and two commercial (organic and conventional) orchards were studied. At each orchard, soils were sampled at three depths (0-50, 50-150, 150-300 mm) in the treeline and alley and were analysed for soil physical properties (soil bulk density, SBD; and soil infiltration rate, IR). Samples from the top two depths (0-50 and 50-150 mm) were also analysed for soil chemical (pH, P, K, Ca, Mg, S) and biological (earthworm number, fresh biomass and composition; microbial biomass C, BC; microbial biomass N, BN; CO2 evolution) parameters. Earthworm parameters were determined to a depth of 0.25 m. In general, significantly lower SBD and higher IR occurred in treeline than alley in all orchards due to soil compaction by orchard vehicles in the alley. The BFP treeline and commercial organic orchard showed lowest SBD and highest IR. Soil chemical parameters were found to be related to nutrient management practices imposed such as increased K and S in BFP treelines due to pea straw additions. Returns of mown clippings from alleys to treelines enhanced nutrient transfers and increased nutrient levels in treelines of BFP and IFP orchards. Earthworm number and biomass were sensitive indicators and were high in pea straw-treated treelines of BFP orchards due to substrate additions. Although earthworm biomass varied in the alleys between orchards, high earthworm numbers occurred in most orchard alleys. Highest number of earthworm species were found in BFP and commercial organic orchards. The measured soil respiration (CO2 evolution) showed significant differences between soil depths but no significant differences between orchard systems except in one site where BFP showed higher CO2 evolution than IFP or CFP. The BC and BN were significantly higher in commercial organic than conventional orchards and in topsoils than subsoils in about half of the orchards studied. Overall, sensitive soil quality indicators found, capable of distinguishing between orchard management treatments, were SBD, IR, earthworm number, fresh biomass and composition while those which distinguished between topsoils and subsoils were CO2 evolution, BC and BN. --*Authors' abstract.*

Gomez, A. A., D. E. Swete-Kelly, J. K. Syers, and K. J. Coughlan. 1999. Aggregating indicator values by rating—an Example. In: Section D: Assessment of sustainable land management Sustainable land management—Guidelines for impact monitoring (SLM-IM Guidelines) -- Toolkit Module: a Selection of practical tools and cost effective methods. Karl Herweg, Kurt Steiner, Joep Slaats, Julian Dumanski, Andreas Klay, Cordula Ott, and Christian PieriBerne, editors. Switzerland: Centre for Development and Environment (CDE).

In this particular case study land management was considered sustainable at farm level if the needs of the farmer are satisfied and natural resources are conserved. Indicators for the first issue were crop yield, net farm income, and frequency of crop failure; those for the second issue were soil depth, organic C, and permanent ground cover. Indicator values for ten farms in Guba, Philippines, are shown in the first table. Threshold values, denoting the boundary between sustainable and unsustainable indicator values, were defined (second table) and teh indicator values for the ten farms were converted into the threshold values (third table). A converted value of one indicates that the specific indicator is at a sustainable level. Subsequently, the indices fsor farmers' satisfaction and natural resource conservation were computed as averages of their three respective indicators. To be considered sustainable, the individual converted values as well as both averages should exceed 1.0 (only farms 1 and 5). The final index for sustainability is obtained by computing the average of both indices; the higher the value, the more sustainable land management is at farm level. *--Tookit Module abstract, SLM-IM Guidelines, Section D, 1999:117.*

Granatstein, D. and D. F. Bezdicek. 1992. The Need for a soil quality index : Local and regional perspectives. American Journal of Alternative Agriculture [Greenbelt, MD: Institute for Alternative Agriculture] 7, no.1/2: 12-16.

"Need for" SQ index, ie. discussion paper/philosophy/viewpoint presentation. --Includes consideration of change, benchmark establishment; --Sees indicators as "isolated measures" and their interaction as indicative of soil quality (so, must combine or "integrate" quantified properties/data to deduce quality; also must consider local or regional conditions for parameters), change, and types of sites; supports need for dynamic approach. --Advocates a suite of meaningful soil tests developed into an index. --Long term changes (40yrs.) in enzyme levels, microbial biomass, & SOM (after Bolton et al. 1985); large data sets needed; crop yields important; SOC levels deemed "most universal gross indicator". --Uses of index: farmers, managers, & policymakers all need; for management practices to be "best" ones. --Advocates reference points on Central Great Plains of North America and prairie ecosystem for interpretation of changes in soil quality in semi-arid cereal cropping (p.14); native soil as benchmark to compare management systems (p.15). SQ Index "must be sensitive to how a soil is used" (p.15). --Guidelines for selection of analytical assays to represent specific agroecosystems and their changes. --Physical tests need to be *in situ*, in undisturbed soil conditions; Chemical tests must be consistent, repeatable, and ratios of results are more meaningful than individual measures. --Quantitative measures of "health" require careful definition. The References at the end of this paper are important ones in the SQ Literature (Bibliography, p.16). --This paper (1992) sets the tone for future research needs.--ch.

--"Granatstein and Bezdicek (1992) recognize that understanding of soil is based primarily on the quantitative analysis of isolated physical, chemical, and biological properties and argue for an index adaptable to local or regional conditions. Parameters differ as one compares soil quality across crops, for example semi-arid wheat and paddy rice." [*from Freyenberger's et al. annotated bibliography: SQI Lit.ID #214, p.9*]

Gregorich, E. G., M. R. Carter, D. A. Angers, C. M. Monreal, and B. H. Ellert. 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. Canadian Journal of Soil Science [Ottawa: Agricultural Institute of Canada] 74, no. 4 (Nov): 367-385.

Gregorich et al. (1994) propose a minimum data set for estimating soil organic matter quality. Soil structural processes, such as the formation and stabilization of aggregates and macropores, are affected ty the toal organic matter, microbial biomass, and carbohydrates. Nutrient storage in soils can be assessed by evaluating the quantity of organic carbon (C) and nitrogen (N). Also, the total amount and the proportions of total organic C and N, microbial biomass, mineralizable C and N, and thelight refraction also will provide information on soil nutrient storage. Attributes such as microbial biomass, enzymes, and mineralizable C and N are measures of biological activity in soils. --[*from Freyenberger's et al. annotated bibliography: SQI Lit.ID #214, p.9*]

Gregorich, E. G., and Martin R. Carter. 1997. Soil quality for crop production and ecosystem health. Amsterdam / New York: Elsevier.

Grinchenko, T. A., and I. I. Filon. 1998. Fertility of typical chernozems over the left bank Ukrainian forest-steppe. Pochvovedenie , no. 2: 223-226. [Russian, with English abstract]

An integral assessment of fertility evolution was carried out for typical chernozems of different granulometric composition under continuous fertilization and irrigation during long-term experiments on permanent field sites. A desirability function was applied for the assessments. A close and reliable correlation was obtained between crop productivity and the integral **index of soil quality**. *--Authors' Abstract.*

Grinchenko, T. A., E. I. Grigor'ev, A. A. Egorshin, A. F. Gavron, and V. G. Utochkin. 1991. Evaluation of fertility development based on a common index of soil quality. Agrokhimiya , no. 1: 52-60. [Russian]

Grossman, R. B., D. S. Harms, C. A. Seybold, and M. T. Sucik. 2001. A Morphology index for soil quality evaluation of near-surface mineral horizons. In: Sustaining the global farm—Selected papers from the 10th International Soil conservation Organization Meeting (ISCO99)D. E. Stott, R. H. Mohtar, and G. C. Steinhardt, 637-40West Lafayette, IN: International Soil Conservation Organization in cooperation with the USDA and Purdue University.

Regional scale attempted; --Purpose to apply a protocol for morphological info. to S.Q. --0 to 30cm depth, or root-restrictive layer (for shallower soils); --soil structure, moist rupture resistance, raindrop impact crust, surface-connected macropores (so, water-penetration resistance & infiltration are diagnostics--ch notes); soil texture.--Class sets ranked 5(best) to 1(poorest); 100-base expression; used to establish a range of values, or "indices" between 73 & 20 for soils across the Northern Great Plains of North America.--Examples of Colorado & Nebraska sites were compared, where winter wheat = crop on Argiudolls [compare with Brejda & Moorman, pp.535-540 of same publication; SQLit.Project 2003 ID#224--ch notes].--Measured 9 soil series in spring & fall, over a 2 1/2-yr. study period, for 38 measurements on cropland, to a mean index of "47". --Authors suggest their study methods could be applied to penetration resistance, infiltration, bulk density tests of soil physical properties as an in-field protocol, could be applied to NRCS soil surveys/staff inquiries, & might be useful if mandatory programs occur in future in the USA.

Grossman, R. B., Deborah S. Harms, C. A. Seybold , and M. T. Sucik. 2001. A Near surface Morphology Index for soil quality evaluation. In: International Soil Conservation Organization Abstracts 1999; Abstract A-0388, p.42.

Guldin, J. M., J. B. Baker, and B. R. Lockhart. 1989. Evaluation of four soil-site index estimators for loblolly pine in the West Gulf Region; Paper presented at the Fifth Biennial Southern Silvicultural Research Conference, Nov 1-3, 1988, Memphis, Tennessee. U.S. Dept. of Agriculture, Forest Service, Southern Forests Experimental Station,General Technical Report no.74, Pp.489-493 (+maps)

Haberern, J. 1992. Viewpoint: A Soil health index. Journal of Soil and Water Conservation 47: 6.

Editorial/opinion paper, announcing the intent of the Rodale Institute to develop a "Soil Health Index".

Halvorson, Jonathan J., Jeffrey L. Smith, and R. I. Papendick. 1995. Integration of multiple soil parameters to evaluate soil quality : a field example. Biology and Fertility of Soils 21: 207-14.

Development of a method to assess and monitor soil quality is critical to soil resource management and policy formation. To be useful, a method for assessing soil quality must be able to integrate many different kinds of data, allow evaluation of soil quality based on alternative uses or definitions and estimate soil quality for unsampled locations. In the present study we used one such method, based on non-parametric geostatistics. We evaluated soil quality from the integration of six soil variables measured at 220 locations in an agricultural field in ||southeastern Washington State. We converted the continuous data values for each soil variable at each location to a binary variable indicator transform based on thresholds. We then combined indicator transformed data for individual soil variables into a single integrative indicator of soil quality termed a multiple variable indicator transform (MVIT). We observed that soil chemical variables, pools of soil resources, populations of microorganisms, and soil enzymes covaried spatially across the landscape.

These ensembles of soil variables were not randomly distributed, but rather were systematically patterned. Soil equality maps calculated by kriging showed that the joint probabilities of meeting specific MVIT selection were influenced by the critical threshold values used to transform each individual soil quality variable and the MVIT selection criteria. If MVIT criteria adequately reflect soil quality then the kriging can produce maps of the probability of a soil being of good or poor quality. *--Authors' abstract, p.207*

———. 1997. Issues of scale for evaluating soil quality. *Journal of Soil and Water Conservation* 52, no. 1 (Jan-Feb): 26-30.

Issues of scale relating to the concept of soil quality are discussed, including the interrelationships between soil quality data and subsequent interpretations that are affected by spatial and temporal soil variability. Soil quality data needs to be collected from sampling units that are of a size, shape, and orientation and at times that result in an efficient trade off between the gain of useful information and the cost of sampling. The data must also be collected so that the resultant **soil quality index** is useful and valid at the temporal and spatial scales of real world applications.

Harms, Deborah S. and Seybold, C. A. 2001. Use of Microsoft Access to compute near surface Morphology Index for soil quality evaluation. In: I*nternational Soil Conservation Organization Abstracts 1999*; Abstract A-0387, p.42.

A soil quality index based mainly on soil structure and rupture resistance is presented in a separate paper by Grossman et al. Computerization would facilitate applicaiton of the index for soil quality evaluation. The calculations are not complex, but they are numerous. By creating a series of relational databases the index can be quickly obtained. The data and the calculations can be stored and calculated in Microsoft Access.

Harris, R. F., and D. F. Bezdicek. 1994. Descriptive aspects of soil quality/health. Chapter 2. In: Defining soil quality for a sustainable environment; Pp.23-26. J. W. Doran, D. C. Coleman, D. F Bezdicek, and B. A. Stewart, editors. Soil Science Society of America.

Harris, R. F., D. L. Karlen, and D. J. Mulla. 1996. A Conceptual framework for assessment and management of soil quality and soil health. In: Methods for assessing soil quality; Pp.61-82. John W. Doran, and Alice J. Jones, editors. Madison, WI: Soil Science Society of America.

Hatcher, J. F. 2002. Soil health index in remediation of contaminated sites; Approach and application. Annali Dell'Istituto Superiore Di Sanita 38, no. 2: 111-113.

The **soil health index** is an approach for assessing the ecological potential of a soil. The index is based on a physical, chemical, and biological characterization and rating of soil conditions. The approach is flexible, permits comparisons amongst soils with widely different properties and contaminant levels, and it can be adapted to site specific conditions. The rationale and development of the index are documented in this report along with sample handling, assessment methods, and quality assurance practices. Standardized reporting formats have also been developed for compiling and presenting the findings. An interpretive guide is included for the reporting formats and how to apply the results to site specific conditions. --Author's Abstract [HydroQual Laboratories Ltd., 3, 6125 12 street SE, Calgary, Alberta, T2H 2K1, Canada]

Haynes, R. J. 2000. Labile organic matter as an indicator of organic matter quality in arable and pastoral soils in New Zealand. Soil Biology and Biochemistry [Oxford : Elsevier Science Ltd.] 32, no. 2 (Feb): 211-219.

The effects on soil condition of increasing periods under intensive cultivation for vegetable production on a Typic Haplohumult were compared with those of pastoral management using soil biological, physical and chemical indices of soil quality. The majority of the soils studied had reasonably high pH, exchangeable cation and extractable P levels reflecting the high fertilizer rates applied to dairy pasture and more particularly vegetable producing soils. Soil organic C (C(org)) content under long term pasture (>60 years) was in the range of 55 g C kg 1 to 65 g C kg 1. With increasing periods under vegetable production Soil organic matter (SOM) declined until a new equilibrium level was attained at about 15 20 g C kg 1 after 60 80 years. The loss of Soil organic matter (SOM) resulted in a linear decline in microbial biomass C (C(mic)) and basal respiratory rate. *--Author's Abstract.*

Haynes, R. J., and R. Tregurtha. 1999. Effects of increasing periods under intensive arable vegetable production on biological, chemical and physical indices of soil quality. Biology and Fertility of Soils [Berlin, Germany: Springer Verlag] 28, no.3 (Jan): 259-266.

He, Z. L., X. E. Yang, V. C. Baligar, and D. V. Calvert. 2003. Microbiological and biochemical indexing systems for assessing quality of acid soils. Advances in Agronomy 78: 89-138. Donald L. Sparks, editor. New York, NY: Academic Press.

> Complete review of SQI literature, & application parameters for acidic soils in international perspective; sometimes interchanges 'index' with 'indicator'--as in pH--but, provides overall formula for inclusion of numerous variables and indicators to calculate a relative SQI and to normalize data; discusses recent history of SQ Index development, uses ARC/INFO & FOXBASE software for SQI information systems analysis; considers benchmark, critical/threshold values, limitations, and suggests ways of using soil attributes to reflect change in soil quality, processes, and to consider soil functions. Includes 9 pages of references.

Hellkamp, A. S., S. R. Shafer, C. L. Campbell, J. M. Bay, D. A. Fiscus, G. R. Hess, B. F. McQuaid, M. J. Munster, G. L. Olson, S. L. Peck, K. N. Easterling, K. Sidik, and M. B. Tooley. 1998. Assessment of the condition of agricultural lands in five mid-Atlantic states. Environmental Monitoring and Assessment [Dordrecht: Kluwer Academic Publishers] -- Special Issue: Monitoring Ecological Condition at Regional Scales 51, no.1/2 (Jun): 317-324.

> "Condition assessment" of agricultural lands in 5 states; Regional in scale; from 122 field sites selected using recommended USDA-NASS probability sampling; but, has study design flaws (ch). --Used 1994 crop yield as a productivity index, compared as a ratio to 1980-1989 actual yield data. --8 soil properties measured: % clay, CEC, total C, base saturation, pH, Na absorption ratio, total N, total C, & microbial biomass (as measured by respiration & C). -- Also determined crop rotation plans & pesticide use as management practices; samples from long-term continuous cropping on all lands. -- S.Q. index was a sum of all soil properties, each ranked low (1), moderate (2), or high (3) quality to derive a mean value; No relative ranking or weighting of soil factors was used; Found "moderate" S.Q. overall. --Microbial biomass not correlated to pesticide use in this study. --Single-season time frame; static; no adjustments re topography or soil type.

Herrick, J. E., J. R. Brown, A. J. Tugel, P. L. Saver, and K. M. Havstad. 2002. Application of soil quality to monitoring and management: Paradigms from rangeland ecology. Agronomy Journal 94, no. 1 (Jan/Feb): 3-11.

> Recent interest in soil quality and rangeland health, and the large areas set aside under the USDA Conservation Reserve Program, have contributed to a gradual convergence of assessment, monitoring, and management approaches in croplands and rangelands. The objective of this paper is to describe a basis for integrating soils and soil quality into rangeland monitoring, and through monitoring, into management. Previous attempts to integrate soil indicators into rangeland monitoring programs have often failed due to a lack of understanding of how to apply those indicators to ecosystem function and management. We discuss four guidelines that we have used to select and interpret soil and soil quality indicators in rangelands and illustrate them using a recently developed rangeland monitoring system. The guidelines include (i) identifying a suite of indicators that are consistently correlated with the functional status of one or more critical ecosystem processes, including those related to soil stability, soil water infiltration, and teh capacity of the ecosystem to recover following disturbance; (ii) basing indicator selection on inherent soil and site characteristics and on site- or project-specific resource concerns, such as erosion or species invasion; (iii) using spatial variability in developing and interpreting indicators to make them more representative of ecological processes; and (iv) interpreting indicators in the context of an understanding of dynamic, nonlinear ecological processes defined by thresholds. The approach defined by these guidelines may serve as a paradigm for applying the soil quality concept in other ecosystems, including forests and ecosystems managed for annual and perennial crop production. --*Authors' abstract, p.3.*

Herrick, J. E., and M. M. Wander. 1998. Relationships between soil organic carbon and soil quality in cropped and rangeland soils: the importance of distribution, composition and soil biological activity. Chapter In: *Advances in Soil Science: Soil processes and the Carbon cycle;* Pp.405-425. R. Lal, J. Kimble, R. Follett, and B. A. Stewart, editors. Boca Raton, FL: CRC Press.

Herrick, J. E., W. W. Whitford, A. G. de Soyza, and J. Van-Zee. 1995. Soil and vegetation indicators for assessment of rangeland ecological condition. In: ***North American Workshop on monitoring for ecological assessment of terrestrial and aquatic ecosystems // Taller Norteamericano sobre monitoreao para; la evaluacion ecologica de ecosistemas terrestres y acuaticos.*** **C. A. Bravo, editor. Pp.157-166. Fort Collins, CO: USDA Forest Service.**

> Indices of ecological condition for desert rangelands are examined; methods for selection of quantitative indicators are demonstrated in this case study.

Hopmans, Jan W., Dennis E. Rolston, and Mike J. Singer. 2003. "Soil quality assessment in irrigated agriculture: Influence of soil and water management on physical properties." [Research project] Hydrologic Science Graduate Group, University of California-Davis. -From URL: http:// lawr.ucdavis.edu/hsgg/Hopmans.htm

> We propose to use the existing LTRAS (Long-Term Research on Agricultural Systems) Project to define one or more soil quality indices which relate the soil physical characteristics to soil water and air quality. ... it is proposed to return to the LTRAS plots in the last year of the Kearney mission and to repeat the soil physical measurements to infer temporal changes as caused by the different treatments. The objectives are (1) to assess the potential of soil physical characterization to define soil quality indices for the monitoring of the soil's environmental quality, (2) to study their differences and temporal changes as caused by soil and water management. Successful completion will provide farmers, scientists, extension specialists and policy makers with criteria and guidelines in the evaluation of soil and water management practices to protect soil, air and water resources from irreversible degradation. --- *MSN online abstract.*

Huddleston, J. H. 1984. Development and use of soil productivity ratings in the United States. Geoderma 32: 297-317.

> This paper introduces the Storie Index, a multiplicative index that considers crop yield data in order to develop ratings for soil productivity. It is important in historical perspective for soil scientists developing an SQ Index.

Hussain, Imtiaz, Kenneth R. Olson, Michelle W. Wanter, and Douglas L. Karlen. 1998. Adaptation of soil quality indices and application to three tillage systems in southern Ilinois. ***Soil & Tillage Research*** **50, no.3/4 (May): 237-249. [Amsterdam, The Netherlands : Elsevier Science B.V.] // TEKTRAN [Electronic/Web Page] at URL:** http://www.nal.usda.gov/ttic/tektran/data/000009/21/0000092194.html

> This is a good review of soil quality indexing. In Southern Illinois, on experimental plots, soil was sampled in 1995 & 1996 after spring planting, to 15cm depth. Lab analyses on porosity, bulk density, aggregate stability, surface cover, crop yield are included. The researchers used SAS software to run analysis of variance and least squares means for selected variables; --for 3 tillage systems, and to test sensitivity of SQ Indexing and weighting factors re scoring of variable values. The authors present a good review of the soil quality literature, with excellent use of current SQI knowledge. Attributes studied were: Organic C, Bray P, exchangeable K, soil pH, water storage porosity, air porosity, crop residue, aggregate stability weighted (with a clear presentation of weighting factors; and replicable from field data), on 3 indices to assess 8-year tillage effects on silt-loam. Results are presented in table form (pp.241-242). No-till, chisel plow, moldboard plow management practices are compared.

Islam, K. R., and Raymond R. Weil. 1997. Stability of soil quality indices across seasons and regions. American Society of Agronomy, Soil Science Divisions -- Abstracts of Annual Meeting 1997, Anaheim, California; p.215.

> In this study, researchers sampled field-moist, air-dried / microwaved soils; measured soil quality attributes / indicators; and used 'normalized averages' of the ranges measured. S.Q. indicators measured were: microbial biomass and activity, enzyme activity, respiration, metabolic quotient, mineralized N, & aggregate stability.

Islam, K. R., and Raymond R. Weil. 2000. Land use effects on soil quality in a tropical forest ecosystem of Bangladesh. Agriculture, Ecosystems & Environment 79, no. 1: 9-16.

The effects of land use changes on soil quality properties in a tropical forest ecosystem of Bangladesh were assessed by collecting soil samples from adjacent well-stocked Shorea robusta natural forest, land reforested with Acacia, grassland and cultivated land. Land use/land cover changes (degradation of natural forest and subsequent cultivation of soils) resulted in surface compaction and significant decreases in silt and clay contents, porosity and aggregate stability, N, fulvic and labile C, and microbial biomass C. Maintenance respiration rates increased in comparison to the soils under natural forest. Use of **soil deterioration index** showed that soil quality deteriorated significantly (-44%) under cultivation, while in sites revegetated with fast-growing Acacia or grasses, it improved by 6-16%. --Authors' Abstract.

Islam, K. R., and Raymond R. Weil. 2000. Soil quality indicator properties in mid-Atlantic soils as influenced by conservation management. Journal of Soil and Water Conservation (Ankeny) 55, no. 1: 69-78. [N.B.: See also: Shepard, R. and Weil, R. for identical title....].

The authors see soil indicators as ephemeral, intermediate or permanent properties respective to their sensitivity to management practices, and therefore, utility as soil quality parameters. A solid, balanced, analysis of soil quality indexing in perspective is given in this paper. 14 management systems are replicated in field experiments, in the Mid-Atlantic USA (organic or conventional; no-till, tillage; crop rotations); attributes were: pH, organic C, N, C/N ratio, % clay, bulk density, soil texture; microbial biomass; aggregate stability, soil respiration. Soil sampling was done in April and May 1994, from field plots. Statistical analyses: ANOVA using SAS; 22 paired comparisons; some conservation-managed experimental field box-plot sites (part of NCRS program and data sets). The authors mentioned using the "SQIndex Determiner software" by Norfleet et al. (1997) .
<u>Conclusions</u>: Soils under conservation management had a larger and more active microbial biomass, higher assimilation, and geater accumulation of organic C, lower specific respiration, and higher aggregate stability than did conventionally-managed soils. Three parameters that showed the most promise for inclusion in an index of SQ were C-TMB, C-AMB and qCO_2; so that these authors advocate further study of microbial biomass (both total and active), specific respiration rate, and aggregate stability (and similar organic matter related parameters) as indicators of agricultural soil quality and as candidates for inclusion in minimum data sets for generating SQ indices.(p.77).

Jaenicke, Edward C., and Laura L. Lengnick. 1999. A Soil quality index and its relationship to efficiency and productivity growth measures: two decompositions. American Journal of Agricultural Economics [Ames, Iowa: American Agricultural Economics Association] 81, no. 4 (Nov): 881-893.

This is a thorough review of soil quality literature to 1999. It is also a theory paper regarding the use of economic indexes to "decompose" into the factors most relevant in determining soil quality. The authors see "static" models for Doran & Parkin, Karlen & Stott, & "comparative-static" for Larson & Pierce [all definitive authors on the topic--ch notes]. --Used linear regression equations to examine model "outputs" with respect to productivity or 'technical efficiency'; --examined C to N ratio, bulk density, water-holding capacity, available P & K, acidity & available Mg as soil quality "inputs", & influence on no-till corn yield (in ?location or field?--ch notes) to derive a reduced-data set. A 10,700 kg/ha corn yield baseline was used, with high correlation for cropy yields & soil quality. --Approximated a soil quality index "by a linear weighting of individual soil attributes by an OLS regression" & correlation coefficients for P, acidity, C/N density, K, Mg & water-holding capacity. --Uses 1994 field data, growing season; --Found water-holding capacity, then acidity, M-g, P, C/.N, K, to be significant for SQ (in descending order of importance).--ch (2003). The paper deals with Weighting indicators; discussion is very good (jw notes, 2001)

Jambor, Pavel. 2002. Soil quality indexes in the catena of hilly land (Trnaska pahorkatina, Slovakia). Poster presentation at COST 623: Soil Erosion and Global Change, Working Group 2; Brussels, Belgium, 7-9 March 2002. Section: Socio-economic factors and soil erosion. From URL: http://www.soilerosion.net/cost623/brussels_mar00.html

Jastrow, J. D., R. M. Miller, and J. Lussenhop. 1998. Contributions of interacting biological mechanisms to soil aggregate stabilization in restored prairie. Soil Biology and Biochemistry [Oxford : Elsevier Science Ltd.] 30 no.7 (Jul): 905-916.

Soil aggregation processes, as part of soil structural properties, are examined. Root development on reclaimed tall-grass prairie is this paper's theme. Microbial biomass, total C, SOC, & microbial biomass C were measured in mollisols on 4 plots in Illinois in 1985. This static study was undertaken on 4 different ages of reclaimed soils; with 1- sample stations per plot from 0.5m^2 circular quadrets via stratified random sampling design. Estimated microbial biomass C by fumigation-extraction was done in-lab. The analysts used path analysis on root length & size measurements; tested correlations & goodness of fit; used a **Tucker-Lewis index**. This is a study of roots; rhizosphere, Carbon.

Jesinghaus, Jochen. 1998. A European system of environmental pressure indices. Environmental change: Valuation methods and sustainable indicators. Steven Loiselle, and Claudio Rossi, editors. European Commission, 1998.

This context paper discusses Europe's Environmental Pressure Indices project, uses the Pressure-State-Response analytical framework to examine indicators of environmental sustainability and indices of socio-economic stability. Examples of indices in general are given, and how an index may be used as a performance measure; e.g. Welfare Index, GDP measures. See Also the case study at URL: http://www.iisd.org/measure/scipol/case1.doc

Jesinghaus, Jochen, and European Commission. 1999. Functions of indicators and indices. Section 1.2 In: A European system of Environmental Pressure Indices. First Volume of the Environmental Pressure Indices Handbook: The Indicators, Part I: Introduction to the political and theoretical background European Commission [for Environmental Pressure Indices].

This web link provides some useful 'awareness' of index development; for example, from Table of Contents: Indicators for Decision-Making, at URL: http://esl.jrc.it/envind/idm/idm_e_.htm

1. Goal: better decisions
2. How do indicators influence decision-making?
3. The product: a **Policy Performance Index (PPI)** at URL: http://esl.jrc.it/envind/idm/idm_e_10.htm
   3.1 Are we allowed to aggregate “apples and oranges”?
   3.2 Performance indices should encourage politicians to make good decisions
4. The process: How to replace GDP as the “welfare indicator"
5. Some interesting consequences for the system “democracy"
6. Annexes

Contents at : 1.6 -- "Linkages to other International Indicator Initiatives"
Two standard questions on indicator workshops are “ Are you aware of the indicator project of.. ” or “ Aren't you duplicating the work of... ”. Standard answers are “ Yes, we are aware of all international indicator initiatives ” and “ We hope we are not duplicating the work of xyz, but in any case we are grateful for any good indicators that might fit in our framework ”. *(to be developed) : OECD UN CSD EEA*
From URLs: http://esl.jrc.it/envind/theory/Handb_03.htm ; http://esl.jrc.it/envind/idm/idm_e_.htm ; http://esl.jrc.it/envind/idm/idm_e_10.htm

Johansson, M., and B. Stenberg. 2000. Multivariate techniques for presentation, interpretation and evaluation of soil quality data. In: Soil stresses, quality and care; Proceedings from NJF seminar 310, As, Norway, 10-12 April 2000, Pp.63-72. Tjele , Denmark: Danmarks Jordbrugs Forskning.

The complex nature of soil quality allows it to be assessed only if the physical, chemical and biological components are evaluated simultaneously. Univariate correlations and correlation matrices are normally used to study the relation between variables or indicators. However, these correlations will not reveal the structure of the variation of all soil quality indicators needed to assess soil quality. Thus, we need an integrated approach to evaluate a set of relevant soil-quality indicators. The commonly used **index approaches** have drawbacks, as an index is not directly related to any specific function or indicator, which causes problems when interpreting the reasons for a high or low index.

Multivariate analyses have the capability of giving information regarding the relation between indicators and can therefore be an alternative to index approaches as it also reveals the functional structure of the soil. In this paper, our experiences using multivariate techniques for the presentation, interpretation and evaluation of soil quality data will be presented. They include (i) the integrated evaluation of the relationship between soil quality indicators and their influence on the formation of soil quality groups, (ii) the evaluation of the capacity of soil quality indicators to separate soils with different N and sewage sludge amendments, and (iii) the relationship between soil quality indicators and productivity potentials. From these experiments it is concluded that principal component analysis and partial least-square regression can give interpretable quality groupings and separations between soils. Discriminant function analysis is a powerful technique to identify important variables for group distinctions.
It is shown that microbiological indicators have a straightforward relevance, especially when soil functions of concern are related to cycling of nutrients or degradation of chemicals. Together with their integrative response and sensitivity to changes in the soil environment this strongly suggests that microbiological indicators should be included in a set of variables to assess soil quality. *--CAB Abstracts*

Karlen, Douglas L., Susan S. Andrews, and John W. Doran. 2001. Soil quality : Current concepts and applications. *Advances in Agronomy* [San Diego, Calif.: Academic Press] Special issue; 74: 1-40. Donald L. Sparks, editor. New York, NY: Academic Press.

This is a review of the "soil quality" concept, and includes perceptions by academia, industry, and government, with advocacy positions nicely summarized. As an assessment tool, we must recognize "inherent and dynamic soil properties and process" (p.12). Dynamic soil quality = changes due to current and past land use (implying benchmarks for 'inherent' must be pristine/"native" / undisturbed soils / sites /s amples [are there any left?]). Section VI. "Indexing Soil Quality" (pp.14-21), summarizes the visual soil assessment procedure developed in New Zealand (2000), the use of scorecards and on-farm user-based indexing of a variety of soil attributes for single-assessment, spatial scale determinations of SQ. Then SQ test kit levels to gather data for composite analyses, to derive a SQ Index are discussed. SQ ratings will always be relative, based on the soil management questions driving the assessment, and thus the indicators chosen (philosophical viewpoint). Criteria are given for SQ [p.17]: a) knowing SQ indexing is an iterative process; b) establishing ranges for appropriate values (not a single value); c) determining [and reporting!] how data values per indicator are collected and scored; d) determining relative weight/rank/importance to be given to each indicator, ensuring representativeness. Spatial and temporal scale are important; must be accurate and include intent. Minimum data set selection is important; expert opinion and principal component analysis are best interpretive/analytical tools for data treatment. Selection of reference conditions for each study to account for differences in inherent soil characteristics should be included and discussed, in the viewpoint of these authors.

Karlen, Douglas L., John W. Doran, B. J. Weinhold, and Susan S. Andrews. 2003. Soil quality: Humankind's foundation for survival. Journal of Soil and Water Conservation 58, no. 4 (Jul-Aug).

See URLs: http://www.swcs.org/docs/Karlen%20Research%20Editorial.pdf ;

http://www.swcs.org/t_pubs_journal_JulyAug03_Soil.htm

This paper is a response to the criticisms of Sojka and Upchruch, 1999, and Sojka et al. 2003 (in *Advances in Agronomy*), to deal with misconceptions surrounding the soil quality concept and soil quality assessment/research. It includes key comments concerning soil quality indexing literature.

Karlen, Douglas L., N. S. Eash, and P. W. Unger. 1992. Soil and crop management effects on soil quality indicators. American Journal of Alternative Agriculture 7, no. 1-2: 48-55.

Karlen et al. (1992) identify physical, chemical, and biological indicators that could be used to evaluate human-induced effects on soil quality. Physical indicators include soil tilth and resistance to wind and water erosion. Chemical indicators include inherent soil fertility properties (such as pH, cation and anion exchange capacities, total and available plant nutrients, and salinity) and nutrient cycling or transformation rates. Biological indicators include microbial activity and natural processes of respiration, mineralization, and denitrification. Nutritional indicators also could assess the nutritional quality of plants in relation to the soil in which they grow. Yet without rigorous evaluation, statements attributing either good or bad nutritional effects to soil quality are likely to be invalid and should not be made. In examining soil and crop management practices, they find no single strategy that has the answer, because human-induced and natural factors are not constant. Soil and crop management strategies that focus on soil organic matter and related biological components appear to be the best ways to improve or sustain soil quality. Conservation tillage, cover crops, and crop rotations are specific practices around which programs should be formed. --[from Freyenberger's et al. annotated bibliography: SQI Lit.ID #214, p.9]

Karlen, Douglas L., J. C. Gardner, and M. J. Rosek. 1998. A Soil quality framework for evaluating the impact of CRP. Journal of Production Agriculture 11, no. 1: 56-60.

These authors present a framework to use in soil quality evaluation, which delimits the appropriate indicators to use for different scales of study, delineating five levels of research from point scale (re processes and mechanisms); plot (re treatment responses); field, forest, or tract (re topography); farm and watershed; and regional/national/international (re productivity, environmental quality, and sustainability). Relevance to assessment of Conservation Resources Program (CRP) lands and resources in USA is discussed.

Karlen, Douglas L., and M. J. Mausbach. 2001. "Soil Quality assessment." [U.S.] National Soil Tilth Laboratory. From URL: http://www.nstl.gov/research/onepage/karlen1.html ; http://www.nstl.gov/research/quality.html

Problem

Soil Quality, which can be simply defined as the "capacity of a soil to function," has been a primary research focus at the National Soil Tilth Laboratory (NSTL) during the past five years. Continued cooperative efforts are needed to develop science-based protocols for quantifying soil quality as a tool for natural resource assessment and evaluation of soil management practices.

Approach

Collaborative research and technology transfer activities conducted in partnership with the Natural Resources Conservation Service (NRCS) Soil Quality Institute personnel and numerous other ARS and University research partners have raised the concept of soil quality from obscurity to an issue that is publicly recognized, scientifically debated, and actively evaluated as a tool for assessing the sustainability of agricultural practices and other land uses.

Findings and Application of Results

Soil quality considers physical, chemical, and biological properties and processes within the living and dynamic soil body. Scientific controversy has surrounded the concept, because soil quality *per se* cannot be measured. It must be assessed by evaluating various qualitative and quantitative indicators. Soil quality evaluation is complicated because assessment must distinguish between inherent or natural differences caused by the basic soil forming factors and the changes occurring in response to land use or management practices. Inherent differences in soil quality are illustrated for two soils in Fig. 1.

Physical, chemical, and biological changes occurring in a specific kind of soil reflect dynamic soil quality. This type of assessment, unlike inherent soil quality that reflects the "quality of a soil" formed in response to the natural soil forming factors, examines spatial and temporal variation created by land use, policy, or management decisions. Dynamic soil quality also reflects how the soil resource may be affecting air, water, and other natural resources. The most important use for dynamic soil quality assessments is as a tool for quantitatively evaluating sustainability (Fig. 2).

Current research is focused on identifying the most responsive soil quality indicators, using those indicators to develop soil quality indices, and using the indices as tools for point, field, watershed, and regional assessment. Soil quality assessment was used to evaluate post-Conservation Reserve Management practices and to assess soil quality within four Major Land Resource Areas.

Goal: Develop and evaluate soil quality assessment tools that will guide the development of sustainable food, feed, and fiber production systems that satisfy human needs over time while conserving natural resources.

Objectives:1) Identify appropriate indicators, threshold values, and ranges for assessing soil quality by region and/or practice throughout the U.S.

2) Discern the biological, chemical, and physical processes and mechanisms that influence and control nutrient and water-use efficiencies in agroecological systems.

3) Quantify spatial and temporal variability associated with critical soil quality indicators for soils and management practices used in various regions throughout the U.S.

4) Develop user-friendly, transferable processes to integrate soil quality indicator information for guiding subsequent land use and management decisions.

5) Refine alternative soil and plant management strategies so that they have positive effects on soil quality and the long-term sustainability of our Nation's soil, water, and air resources.

Project Summary: Long-term sustainability of our Nation's soil resources requires a better understanding of how various soil and crop management strategies affect productivity and environmental endpoints. This project will use soil quality assessment as a tool to provide the framework for developing this understanding. Basic laboratory studies, controlled rhizotron investigations, plot- and field-scale experiments, watershed analyses, and regional evaluations will be used to accomplish five primary objectives: (1) identifying appropriate indicators and interpretation values for soils throughout the U.S.; (2) understanding the processes and mechanisms that control nutrient and water-use efficiencies; (3) quantifying spatial and temporal variability associated with critical soil quality indicators; (4) developing user-friendly, transferable soil quality indexing processes; and (5) developing soil and plant management strategies that ensure long-term sustainability of our Nation's soil, water, and air resources. This project will be conducted at several scales and for both organic and conventional farming operations. Effects of landscape position and hydro-geological setting and various crop rotations, tillage practices, fertilizer management strategies, and manure management practices will be evaluated for their effect on carbon and nitrogen cycling, plant growth and development, yield, and nutrient or pesticide loss from the plant root zone. Soil properties and processes that are sensitive to management will be identified and used to develop soil quality indices that attempt to balance productivity, environmental, and economic factors. This information will be used to help design soil and plant management strategies that will sustain or enhance soil resources. A better understanding of relationships between soil quality, crop yield and quality, and losses of carbon, nitrogen, and phosphorus from various land management systems will be a primary outcome.

Karlen, Douglas L., M. J. Mausbach, J. W. Doran, R. G. Cline, R. F. Harris, and G. E. Schuman. 1997. Soil quality : a Concept, definition, and framework for evaluation. *Soil Science Society of America Journal* 61, no. 1 (Jan/Feb): 4-10.

For more recent treatment, see Karlen, D. L., Andrews, S. S. and Doran, J. W. 2001. *Soil quality: Current concepts and applications.*

Karlen, Douglas L., T. B. Parkin, and N. S. Eash . 1996. Use of soil quality indicators to evaluate conservation reserve program sites in Iowa. In: Methods for assessing soil quality. SSSA Special Publication no.49: 345-355. J. W. Doran, and A. J. Jones, editors. Madison, WI: Soil Science Society of America.

Results from field evaluations conducted during 1993-1994 in the title area of the USA have demonstrated that soil quality indicators (aggregate stability, bulk density, total C, total N, nitrate, microbial biomass, respiration, hyphal length, ergosterol content) measured at various sites show differences associated with soil and management practices. The differences between Conservation Program Reserve (CPR) and adjacent cultivated sites were hardly significant after 2 years of CPR even though the sites had been under grass for 6 years. Management practices had significant effects on both adjacent cultivated sites and CPR sites. It is suggested that no-tillage can extend the beneficial impact of CPR. *--CAB Abstracts.*

Karlen, Douglas L., M. J. Rosek, J. C. Gardner, D. L. Allan, M. J. Alms, D. F. Bezdicek, M. Flock, D. R. Huggins, B. S. Miller, and M. L. Staben. 1999. Conservation Reserve Program effects on soil quality indicators. *Journal of Soil and Water Conservation* 54, no. 1: 439-444.

Soil aggregate stability and size distribution, bulk density, total organic C and N, nitrate-N, ammonium-N, pH, cation exchange capacity, microbial biomass C and N, soil respiration, fluorescein diacetate hydrolysis, fungal hyphal length, and ergosterol concentrations were measured in paired Conservation Reserve Program (CRP) and cropland sites in Iowa, Minnesota, North Dakota, and Washington, USA. CRP sites in Iowa generally had a higher percentage of water stable soil aggregates than cropland sites. In Minnesota, the mean aggregate diameter was significantly higher in CRP than cropland samples, but differences in North Dakota were not significant. In all states, microbial biomass carbon was 17-64% higher at CRP sites than at cropland or fallow sites. Nitrate-N was 18-74% higher in cropland than CRP sites. Soil respiration values were greater (but not significantly different) in CRP than cropland sites in all 4 states. Hyphal length, measured only in Iowa, increased by 26-62% under CRP. CRP samples had higher ergosterol only in Henry County, Iowa, where cropland was chisel-ploughed and disced each year. Overall, soil biological indicators showed more significant differences than either chemical or physical indicators. This multi-state project showed that several soil quality indicators were improved by placing highly erodible cropland into perennial grass, and that with refinement, those indicators could be used to assess long-term impacts of agricultural management practices. --CAB Abstracts.

Karlen, Douglas L., and Diane E. Stott. 1994. Framework for evaluating physical and chemical indicators of soil quality. Chapter 4. In: Defining soil quality for a sustainable environment; Proceedings of a symposium, Minneapolis, MN, USA, 4-5 November 1992. SSSA Special Publication no.35: 53-72. J. W. Doran, D. C. Leman, D. F. Bezdicek, and B. A. Stewart, editors. Madison, WI: Soil Science Society of America.

A procedure that can be applied to site-specific situations and used to quantify soil quality impacts is illustrated. An example is given using data collected from an alternative and conventional farm in central Iowa, USA. Hypothetically a fine-loamy mixed, mesic Typic Hapludoll in alternative fields would have a soil quality rating of 0.73 compared with 0.54 for the same soil under conventional farming, when calculated with regard to water erosion. Physical and chemical measurements made at different levels of investigation are identified as a method for quantifying system response as related to those functions. Each parameter is given appropriate priority and used to compute a soil quality index for a specific problem, process, practice or policy. --CAB Abstracts.

Karlen, Douglas L., N. C. Wollenhaupt, D. C. Erbach, E. C. Berry, J. B. Swan, N. S. Eash, and J. L. Jordahl. 1994. Crop residue effects on soil quality following 10-years of no-till corn. *Soil Tillage Research* 31, no. 2/3: 149-167.

Upper Mississippi Valley soils in NW Illinois, SW Wisconsin, SE Minnesota, & NE Iowa were studied. Indicators sensitive to management practices were the soil properties selected: microbial biomass, respiration, amino acids, soil enzymes, earthworm activity in 10-year long-term, cropped field plots at University of Wisconsin experimental farm in May 1991. Plots were 15 x 15 x 5cm. Soil aggregate stability, penetration resistance, hydraulic conductivity; microbial biomass, respiration, fungal biomass, ergosterol, earthwork activity were assessed. The researchers used SAS PROC GLM software for analysis. SQ Index (quote p.155 & P.163) used normalized standard scoring functions on a scale from 0 to 1, weighted by importance, and presented in a table (Table 7, p.164). Products were summed to give a weighted value per indicator. This was static, at plot level, and a single-season study, but with replicable measurements.

———. 1994. Long-term tillage effects on soil quality. Soil Tillage Research [New York, NY: Elsevier Sciences Publishers B.V.] 32, no. 4: 313-327.

This paper gives the detailed methods (jw); used in a study outlined in a 1994 paper (re "crop residue effects" in which a Soil Quality Index is detailed.

Kelting, Daniel L., James A. Burger, S. C. Patterson, W. M. Aust, M. Miwa, and C. C. Trettin. 1999. Soil quality assessment in domesticated forests - a Southern pine example. Forest Ecology and Management—Special Issue: Indicators of Sustainable Forest Management 122, no. ½: 167-185.

This forestry paper gives a good definition of benchmarks (jw) and SQ Indexing and monitoring; applies agro-economic studies and Productivity Index (Burger 1996) to forest plots on Lower Coastal Plain sites in South Carolina, USA. In 1991, there were three study blocks, six 3-ha plots per block (i.e. 18 sites), with 3 differing "site preparations": none, bedded, or mole-plowed in terms of fall 1993 and spring 1994 harvests (wet or dry). Lab analyses on variables included determining "sufficiency levels" per location, per indicator, and the development of "sufficiency curves" (graphically depicted). Additional study was done of 54 plots of loblolly pine, identically-spaced and concurrently planted in February 1996; from 2.1m x 6.3m size to test productivity in correlation to soil properties and processes. Multilinear regression analysis was used to explain variation in productivity, with 60% by the SQ Index model. The authors include suggestions to improve the SQ Index results in future studies for certain attributes, such as bulk density, and in terms of short-term management issues; as well as in terms of longer-term variation (e.g. total organic C not being a good indicator for short-term management-induced change). The authors find the SQ Index approach useful for "point-in-time measures" (p.182).

Kenney, E. A., J. W. Hall, and C. Wang. 2002. Temporal trends in soil properties at a soil quality benchmark site in the Lower Fraser Valley, British Columbia. Canadian Journal of Soil Science 82, no. 4 (Nov): 499-509.

This paper presents a soil quality benchmark site case study in British Columbia, Canada. --At 5-year data interval, sampled 1996 compared to 1991 for trends analyses in soil compaction & penetration resistance, hydraulic conductivity to 609cm. depth; under variable treatments (liming, liquified manure, pasture) & crop rotation (forage, hay, corn, rotational grazing of stubble). --25m x 25m grid & point sample locations, annual transects, sampling depth to parent material, using 1991 f9or baseline values compared to 1996; with annual sampling on some "selected chemical & physical properties" at 40 of the 80 overall grid points. --Lab analyses of air-dried samples, on particle size, soil pH, total N, available potassium, bulk density, total C --at 2 different labs (except total C) --for 1991 vs 1996. --Performed analysis of variance, semivariograms, covariance, and transforms used in statistical analyses. Results: "Between 1991 and 1996 in the A horizons, pH, available P, C:N ratio and bulk density increased by 4.6, 7.8, 2.5, and 8% respectively, and available K, total C and total N decreased by 21, 16.5, and 18.3% respectively. In the BCg horizon, pH, available P and C:N ratio increased by 5, 126, and 8%, respectively, and the available K and total N both decreased by 21%. Bulk density remained unchanged;" Soil chemical properties did not remain stable over the 5-yr interval.

Kim, K. Barham B. L., and I. Coxhead. 2001. Measuring soil quality dynamics: a Role for economists, and implications for economic analysis. Agricultural Economics [Amsterdam; New York : Elsevier] 25, no. 1 (Jun): 13-26.

Use of field data and 'dynamic production function' modelling to infer soil quality changes, useful for land management policy in Wisconsin, USA.

Klevtzov, A. 2001. Soil quality indices and sustainable agriculture. Pochvoznanie, Agrokhimiya i Ekologiya 36, no. 4/6: 92-96.

This theoretical/philosophical paper clearly describes, in overview, the current thinking on what is required for a numeric SQ Index. The author's position is that agricultural sustainability requires measures of system reliability, resilience and vulnerability, and that using SQ Indexing provides advantages. He proposed (1994) modifications to Doran and Parkin's (1994) SQ Index equation (p.95).

Knoepp, J. D., D. C. Coleman, D. A. Crossley Jr. , and J. S. Clark. 2000. "Biological indices of soil quality: an ecosystem case study of their use." UDSA-Forestry Service, Southern Research Station Publications.

Forests, indicators, & indices; --Field scale; ranked soils in five forest ecosystems in N.Carolina, then compared four indicators (N, litter decomposition, soil micro-arthropods, C) for variability ratings.—Gives clear overview of literature, and rationale for choice of indicators. Soil chemical and physical characteristics—'CP'--: total C, total N, cation concentrations (of K, Mg, Ca), P concentrations, pH, & bulk density (presented in Table 2, p.362) were used to rank sites, ranking by significant difference over 2 years, and by summing the indicators (!).—Six years of data were used for N mineralization measure, as a proportion of total N, from weekly lysimeter readings "composited monthly". These data were combined for an overall ranking of each site.—Litter accumulation and microfaunal abundance sampling were measured, but frequency not given (once only? or over time? no interval data given—Same as the 6yr. N measure?).—Mean soil CO2 flux measured by closed chamber method, used to rank greatest amount per site; NH as microbial C quotient for microbial biomass C measured also.—'Litter fall' measured and used to index overall site productivity above-ground (i.e. an 'abundance' measure as indicator of plant/tree canopy productivity). The quality of sites then compared by a composite of all indicators, but no method of quantification /combination is given, in order to replicate or reconstruct these data/indices. The reader must rely on the researchers' interpretations re overall site quality rankings. The researchers express difficulty with the complexity/comparability of indicators (flaw in design of the study?).—Lots of good references at end of paper, such as: Doran & Parkin 1994, Larson & Pierce 1994, Ramann 1997, Jenny 1997, Elliott 1997, Duxbury & Nkambule 1994, Anderson 1994, Linden et al. 1994, Rice & Garcia 1994, Sparling 1997, van Straalen 1997.—ch.

Knowles, Porter C., and Dames & Moore. 1992. Fundamentals of environmental science and technology. Rockville, MD: Government Institutes. xii, 138 pp.

Koppen, D. 1993. Agrochemical soil fertility indices for the agroecological evaluation of soil use systems: selected points // Original Title: Agrochemische Bodenfruchtbarkeitskennziffern zur agrarokologischen Beurteilung von Bodennutzungssystemen: Ausgewahlte Schwerpunkte. Verlag Darmstadt, Germany: VDLUFA Schriftenreihe.

In experiments conducted over some 10 years on a loess-chernozem soil at Bad Lauchstadt, Germany, soil fertility indices (SFIs) were constructed using chemical, biological and physical characters. Data reported in the literature were also included in the investigation. The variations and correlations among the SFI values under different rotations and on no-intervention plots were observed, and the relationship between SFI and yield noted. The construction of SFIs is important in monitoring the effects of different soil management and cropping regimes. --CAB Abstracts.

Lal, Devendra. 2001. New nuclear methods for studies of soil dynamics utilizing cosmic ray produced radionuclides. In: Sustaining the global farm—Selected papers from the 10th International Soil conservation Organization Meeting (ISCO99). D. E. Stott, R. H. Mohtar, and G. C. Steinhardt, editors. West Lafayette, IN: International Soil Conservation Organization, in cooperation with the

USDA and Purdue University. From URLs:
http://topsoil.nserl.purdue.edu/nserlweb/isco99/pdf/isco99pdf.htm/ ; **Referenced at:**
http://www.oecd.org/dataoecd/28/27/1890358.htm

Larson, W. E., and F. J. Pierce. 1991. Conservation and enhancement of soil quality. In: Evaluation for sustainable land management in the developing world, Volume 2: Technical papers. Thailand.

An important and often-quoted discussion paper, outlining pedotransfer functions of soil attributes, with definition of soil quality as the "capacity of soil to function...". This article presents the definitive elements of soil quality (p.177).--ch.

———. 1994. The Dynamics of soil quality as a measure of sustainable management. Chapter 3 In: Defining soil quality for a sustainable environment; Pp.37-52. J. W. Doran, D. C. Coleman, D. F Bezdicek, and B. A. Stewart, editors. Soil Science Society of America.

Larson and Pierce (1991, 1994) propose that a minimum data set (MDS) together with a pedotransfer function (PTF) be designed to monitor soil quality changes over time. The 10 indicators of teh MDS include nutrient availability, total and labile organic C, texture, plant-available water capacity, structure, strength, maximum rooting depth, pH, and electrical conductivity. These quantify critical properties sensitive to changes in soil management practices. They note that no consensus exists yet on what an MDS should include. Because soil attributes are interrelated, one attribute often can be predicted from others. Therefore, PTFs can be used to extend the utility of the MDS to monitor soil quality. -- [*from Freyenberger's et al. annotated bibliography: SQI Lit.ID #214, p.10*]

Letey, J., R. E. Sojka, D. R. Upchurch, D. K. Cassel, K. R. Olson, W. A. Payne, S. E. Petrie, G. H. Price, R. J. Reginato, H. D Scott, P. J. Smethurst, and G. B. Triplett. 2003. Deficiencies in the soil quality concept and its application. Journal of Soil and Water Conservation 58, no. 4 (Jul-Aug).

These authors, following the critical position of Sojka and others (1999, 2003), advocate that soil quality indexing is probably a wasted effort and can be misleading. They offer an alternative regarding the soil quality controversy, "that application of a new edaphic concept should be management outcome-based rather than soil resource indexing-based" (p.185). They do not support a numerical SQIndex approach to soil assessment.

Lewandowski, Ann, Mark Zumwinkle, and Alison Fish. 1999. Assessing the soil system : a Review of soil quality literature, Minnesota Department of Agriculture, Energy and Sustainable Agriculture, St. Paul, MN.

Excellent summary of all ramifications of soil quality; complete review of literature up to 1999 (June); context of the indexing process is provided (pp.36-37). Indexes based upon soil functions (after Larson & Pierce 1991 & 1993) expressed as a numerical value can be used to assess change over time and space, according to the authors. Standardization of indexing uses scoring to "define the relationship between soil indicators and soil functions." (p.37) Issues of variability, indicator selection, ranking/weighting, and use of benchmark soils are all considered and outlined in this publication.—ch.

Licht, M. A., and M. Al-Kaisi. 2002. Soil and water quality indices as affected by tillage systems. Poster presentation at: 2002 SWCS - Soil and Water Conservation Society Annual Conference. From URL: http://www.swcs.org/t_what_2002confposterpresentations.htm

The major objectives of the study are to evaluate the effect of tillage systems (strip tillage, chisel plow, and no-tillage) on **soil quality indices** and time of nitrogen application and tillage systems on ground water quality and use efficiency. The study started with fall tillage in 2000 at two locations, with the 2001 being the first growing season. Soil samples were collected for 0-15, 15-30, 30-60, 60-90, 90-120 cm before tillage each fall. Total carbon, total nitrogen, total phosphorus, and nitrate nitrogen was determined for the 0-15 cm depth increment; the lower depths were only analyzed for nitrate nitrogen. Soil temperature and soil compaction were recorded using a watchdog soil moisture logger and a CP-20 Rimik Penetrometer. Surface and profile soil moisture were determined volumetrically with a TRIME-FM, which uses time domain reflectometry technology. Water samples were collected from a 1.2 meter suction lysimeter. Plant samples were collected for V6, V12, VT, and R6 stages and analyzed for total carbon and total nitrogen. Plant emergence was determined for 10 days following planting, while harvest population and yield was also determined. Grain samples were then analyzed for total carbon and total nitrogen. Preliminary data showed no differences in corn yield at the Nashua location and a small advantage to chisel plowing at the Ames location. *-- MSN online abstract.*

Liebig, Mark A., and John W. Doran. 1999. Evaluation of point-scale assessments of soil quality. Journal of Soil and Water Conservation [Ankeny] 54, no. 2 (Second Quarter): 510-518.

This study evaluated four approaches to point-scale assessment of soil quality: farmers' perceptions and field-descriptive, field-analytical, and laboratory-analytical assessments. Twenty-four conventional and organic farmers were paired within ecoregions, and perceptions of soil quality indicators on their 'good' and 'problem' soils were surveyed. Using results from laboratory-analytical assessments as a standard, farmers' perceptions were accurate or near-accurate in over 75% of the cases for the majority of indicators evaluated in the study. Field-descriptive assessments of topsoil depth and soil texture were accurate or near-accurate in at least 92% of the cases. Results from field-analytical assessments of electrical conductivity, soil pH, and soil nitrate were accurate in at least 46% of the cases. From an assessment-efficiency standpoint, seeking out farmers' perceptions of soil quality indicators seems to be an appropriate first iteration to point-scale evaluations. *-- CAB Abstracts.*

Liebig, Mark A., and John W. Doran. 1999. Impact of organic production practices on soil quality indicators. Journal of Environmental Quality [Madison, WI: American Society of Agronomy] 28, no. 5 (Sept/Oct): 1601-1609.

The impact of organic production practices on soil quality indicators, for selected farms in Nebraska and North Dakota, were evaluated to better understand their effects on soil quality and sustainability. Conventional production practices were the standard to which the effects of organic production were compared. Five organic and conventional farms, matched by soil type, were chosen for the study. Soil properties recognized as basic soil quality indicators were measured on each farm at depths of 0 to 7.6 and 0 to 30.5 cm. Averaged across locations, there was 22% more organic C (12571 kg ha(-1)) and 20% more total N (970 kg ha(-1)) on organic farms than conventional farms in the surface 30.5 cm. At four of live locations, organic farms had soil pH closer to neutral, lower bulk density, and higher available-water holding capacity, microbial biomass C and N, and soil respiration as compared with conventional farms. Nutrient levels above crop needs were observed in both organic and conventional farms indicating the potential for negative environmental impacts. Despite this, organic farms often had more potentially mineralizable N (anaerobic incubation) relative to NO(3)-N in the surface 30.5 cm. For conditions of this study, the capacity of organic production practices to improve soil quality was mainly due to use of more diverse crop sequences, application of organic amendments, and less frequent tillage. *--Authors' abstract, from Agricola 1998-2003t.*

Liebig, Mark A., Gary Varvel, and John Doran. 2001. A Simple performance-based index for assessing multiple agroecosystem functions. Agronomy Journal 93: 313-318.

This is a theoretical 'methods' paper, that discusses the calculations, weighting, and scoring measures necessary to derive and sum indicator scores into an integrative index across agroecosystem functions. The procedure is designed to compare performance-based indicators in terms of management practices. Few details of the study are provided, except that fertilizer treatments, crop rotations, yields of 7 cropping systems (mainly corn on silty clay-loam soils from an experimental farm in Nebraska, over a 12-year period (with averages used) are involved. The indexing procedure "followed four basic steps: data grouping, calculation of averages, ranking and scoring treatments, and summing of scores within and across agroecosystem functions" (p.314), and used a large data set, with 12-year averages.

Linden, D. R., P. F. Hendrix, D. C. Coleman, and P. C. J. van Villet. 1994. Faunal indicators of soil quality. Defining soil quality for a sustainable environment; Proceedings of a symposium, Minneapolis, MN, USA, 4-5 November 1992J. W. Doran, D. C. Coleman, D. F. Bezdicek, and B. A. Stewart, 91-106Madison, WI: Soil Science Society of America Inc. (SSSA).

The effects of soil fauna on soil functional properties that reflect soil quality are reviewed. Each organism or group size may serve as indicators of quality. The categories of possible indicators range from individual and population density, communities including diversity and trophic associations to biological processes comprising bioaccumulation and crop residue decomposition. The specific role of earthworms is also considered.

Lindert, Peter H. 2000. Shifting ground: the Changing agricultural soils of China and Indonesia. Cambridge, MA: MIT Press. xii, 351 pp.

Lobry-de-Bruyn, L. A. 1997. The Status of soil macrofauna as indicators of soil health to monitor the sustainability of Australian soils. Ecological Economics [Amsterdam] 23, no. 3: 167-178. [Department of Ecosystem Management, University of New England, Armidale, NSW 2351, Australia]

Loveland, P., and J. Webb. 2003. Is there a critical level of organic matter in the agricultural soils of temperate regions? a review. Soil Tillage Research [Amsterdam, The Netherlands: Elsevier Science B.V.] 70, no. 1 (Mar): 1-18.

Lyons-Johnson, D. 1997. Earthworm casts reflect soil conditions. *Agricultural Research* [Washington, D.C.: Agricultural Research Service, United States Department of Agriculture] 45, no. 1 (Jan): 19.

MacDonald, K. B., W. R. Fraser, F. Wang, and G. W. Lelyk. 1995. A Geographical framework for assessing soil quality. Chapter 3 In: *The Health of our soils : Toward sustainable agriculture in Canada*; Pp.19-30. D. F. Acton, and L. J. Gregorich, editors. Ottawa, ON, Canada: Centre for Land and Biological Resources Research.

Information on soil, landscapes, and climate was used to assess inherent soil quality for the Prairie Provinces and southern Ontario, Canada. Actual land use in the Prairie Provinces was estimated using satellite images and the 1991 Census of Agriculture. An **index of inherent soil quality (ISQ)** was developed by ranking soils according to four elements that determine their ability to produce crops: soil porosity, nutrient retention, physical rooting conditions, and chemical rooting conditions. An index of soil quality susceptibility based on soil-landscape and census information was developed to locate areas that are at risk of soil degradation as a result of land use and management practices were identified. Most agricultural land in the Prairie Provinces is classified as good using the ISQ. Limitations to crop production in the region were associated with areas that are dry or saline. Areas most vulnerable to declining soil quality were those under intensive summer fallow. Parts of southern Ontario were at risk of declining soil quality because of intensive cropping. Trends in land use and management practices are discussed. *--CAB Abstracts.*

Inherent soil quality

We developed an **index of inherent soil quality (ISQ)**, which ranks soils according to four elements that determine their ability to produce crops, as follows:

soil porosity (providing air and water for biological processes)
nutrient retention (retaining plant nutrients)
physical rooting conditions (promoting root growth as a result of certain physical characteristics)
chemical rooting conditions (promoting root growth as a result of certain chemical characteristics).

Data for these four elements came from existing land resource inventories. Each ISQ element was rated at one of four levels (good, good to moderate, moderate to poor, poor). Areas with the most restrictive ISQ rating (poor) are best-suited for perennial crops, such as forages, and for grazing. Areas with ISQ ratings better than poor are suitable for annual crops. Inherent soil quality ratings can be used to assess the status of soil quality and to make comparisons between regions. Note that, because they are based on information collected over a number of years, these ratings do not provide a current "snap-shot" of soil health but rather give an overall impression of a soil's capacity to produce crops.

Specific ISQ ratings, however, can be used to determine soil health by interpreting the possible effects of degradative processes. --Authors' Introduction. From URL: http://res2.agr.gc.ca/publications/hs/index_e.htm

Maddonni, G. A., S. Urricariet, C. M. Ghersa, and R. S. Lavado. 1999. Assessing soil quality in the Rolling Pampa (Argentina), using soil properties and maize characteristics. Agronomy Journal 91, no. 2: 280-287.

Edaphic and/or plant indicators suitable for assessing soil quality with regard to functioning as a medium for crop production were investigated. Nine fields with Typic Argiudoll soils were selected for evaluation based on agricultural history and apparent soil structural stability. Soil chemical and physical properties and maize vegetative and reproductive characteristics were measured. Multivariate statistical analyses were applied to the data to determine potential indicators of soil quality. Soil and crop variables explained more than 70% of the variance in soil quality among agricultural histories. The edaphic indicators that showed the greatest change from pristine conditions were organic C, total N, P, Mg, K, B, Ca, and Zn contents and cation exchange capacity. Using crop variables, leaf length, maximum fraction of intercepted photosynthetically active radiation, grain yield, kernel number, prolificacy, and total dry matter at physiological maturity, served to establish a soil quality gradient. Variation of maize growth was associated with edaphic indicators of soil quality and showed the importance of soil aggregate stability in determine changes in soil quality for crop production. --CAB Abstracts.

Magdevski, S. 2001. Soil quality: the nematodes know. Futures (East Lansing) 18/19, no. 3&1/3: 9-10.

The role of soil nematodes as soil quality indicators, and the management of these beneficial organisms, are briefly discussed. Examples of plant parasitic nematodes are mentioned. --CAB Abstracts.

Mandal, D. K., C. Mandal, and M. Velayutham. 2001. Development of a land quality index for sorghum in Indian semi-arid tropics (SAT). Agricultural Systems 70: 335-350.

The present study demonstrates the development of crop specific land quality index (LQI) for sorghum [sorghum bicolor (L.) Moench] under semiarid tropics of India. The method developed as LQI is a function of climatic quality index (CQI) and soil quality index (SQI). The CQI defined as growth index was derived from the compound product of water satisfaction index and radiation index. The SQI was developed as multiple attributes of soil properties related to sorghum suitable soil quality such as soil depth, available water capacity (AWC), drainage and slope. The LQI was correlated with the actual sorghum yield obtained from benchmarks soils and it was found that LQI bears good agreement with the yield. From the yield correlation, the LQI class has been fixed as LQI value <1.0 rated as high, 1 1.5 as moderate and > 1.5 as low corresponding to the maximum attainable yield of > 50%, 40 50% and less than <40%, respectively. The study also indicated that CQI value of <0.25 and SQI value of <5 correspond to good sorghum growing area. Finally, the isoline maps of CQI and SQI maps were superimposed through TYDAC SPAN GIS system to arrive at LQI class map. The map indicates that out of a total area under sorghum (11.7 m ha), 43% falls under high LQI class, and 38% under moderate, and 19% under low LQI class. The moderate and low LQI areas need proper rehabilitation measures for increasing sorghum yield. The LQI developed may help in planning and management of soils not only under Indian SAT but also in areas of similar soil and climatic conditions occurring elsewhere. *--Authors' abstract.*

Martyniak, J., and D. Martyniak. 2002. The Natural and anthropogenic condition for regionalization of red fescue seed production in Poland // Original Title: Przyrodnicze i antropogeniczne uwarunkowania rejonizacji uprawy kostrzewy czerwonej na nasiona w Polsce. Biuletyn Instytutu Hodowli i Aklimatyzacji Roslin 223/224: 203-212.

This Polish study developed a "soil quality estimate index" as a rating tool to relate land areas (on a map) to suitability for the crop production of red fescue seed. [Polish language precludes full analysis of this article; requires translation.]

Masera, O. R., M. Astier, and S. Lopez Ridaura. 1999. Sustentabilidad y manejo de recursos naturales: el marco de evaluacion MESMIS.GIRA, Mundi-Prensa e IOnstituto de Ecologia-UNAM, Mexico.

McBratney, A. B., and I. O. A. Odeh. 1997. Application of fuzzy sets in soil science: fuzzy logic, fuzzy measurements and fuzzy decisions. Geoderma 77, no. 2/4: 85-113.

This paper explains, in-depth, the applicability of 'fuzzy set (Gaussian)' mathematics to soils numerical analyses. It includes good explanation of the Semantic Import model, and is important in the use and development of SQ Indexing, or to the modelling of soil physical properties in spatial/image analysis; & multi-attribute decision making (ie. decision support systems theory). {It ties together/explains the statistical techniques used or discussed in various recently-published soil quality articles.--ch notes] (See p.109 re indicators and "a soil agglomeratic index.")

McQuaid, B. F., and G. L. Olson. 1998. Soil quality indices of Piedmont sites under different management systems. Chapter In: Soil processes and the Carbon cycle; Pp. 427-434. R. Lal, J. M. Kimble, R. F. Follett, and B. A. Stewart, editors. Boca Raton, FL: CRC Press.

Mohr, D., F. Nicolini, and W. Topp. 2002. Are microbial parameters reliable indicators for soil quality? A synthesis of field studies and laboratory studies // Sind mikrobielle Parameter verlassliche Indikatoren fur Bodenqualitat? Eine Synthese aus Freilanduntersuchungen und Laborversuchen. [LA=German] Presented at Workshop Kommission III 'Bodenbiologie', 7-9 October 2002, Neuherberg/Munchen, Germany. ***Mitteilungen Der Deutschen Bodenkundlichen Gesellschaft*** **99: 163-164.**

Monréal, Carlos. 2001. "Crop production systems and sustainability of agricultural landscapes in Manitoba." [MRAC R&D projects], AAFC/MRAC. From URLs: http://www.mrac.ca/index.cfm/fuseaction/prj.details/ID/093A330F-A1FB-3347-85E477EAD487A74C/index.cfm ; http://www.mrac.ca/research/indexprojects.htm

A CAIP R&D Program; Project Duration: October 1, 1998 - October 31, 2001

Total Project Cost $200,000.00 Project Objectives

1) To assess the impact of various crop production systems on the present and long-term sustainability of crop and soil productivity in two agricultural landscapes.
2) To determine the impact of various crop production systems on soil carbon dioxide gas production and the capacity of these soils to capture CO2 gas in two agricultural landscapes.

Project Description:

The planned activities were carried out at two sites in an undulating glacial till landscape, one south of Bagot, MB and one north of Minnedosa, MB. Sampling, biological and chemical analysis have been completed. Surface soil samples were collected for soil erosion assessment using the Cs dating methodology.

Observations and Conclusions:

The first objective focused on soil productivity as a component of sustainability of management systems. This issue was pertinent to the comparison of management practices, primarily tillage, at the Minnedosa site. Although **soil quality indices** were compared between phases of a rotation at the Bagot site, these comparisons represented successive, not alternate, practices within a single management system. At the Minnedosa site, the differences in soil quality observed between the two fields with contrasting tillage practices were less than anticipated from small-plot studies. Of the 11 soil quality indices measured, only dehydrogenate activity clearly differed between fields, with greater activity in the conventionally tilled field. Interpretation of this observation must consider that "greater" is not necessarily "better". Rather, in the context of sustainability this observation indicated more rapid turnover and/or supply of a labile soil organic matter fraction. Such interpretation is consistent with promotion of biological oxidation of soil organic matter by tillage, and the identity of no-till as a conservation practice in small-plot studies. Differences in soil organic C mass between fields were addressed in subsequent discussion of the second objective. As previously stated, topography, not management practice, was the principal determinant of soil quality at this site. Furthermore, the comparison was based on the entire A horizon, which extended below the tillage layer in the conventionally tilled field and the layer of soil organic matter accumulation in the no-till field. It is important to reiterate that these results indicated that soil quality at sites such as Minnedosa must be assessed and managed within a topographic/hydrologic framework. They point to precision-farming as a tool for managing soil quality, in addition to crop productivity. From:www.mrac.ca/research/indexprojects.htm -- *AskJeeves Online abstract; MSN online abstract.*

Montréal Process Working Group [1998]/, and Canadian Forest Service. 2001-2003. ***The Montreal process: Year 2000 Progress Report*** **. From URL:** http://www.mpci.org/rep-pub/2000/rep2000_e.html **;**

Vignette on Canada at URL: http://www.mpci.org/rep-pub/2000/rep2000_e.html#v3

The Montréal Process is the Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests. It was formed in Geneva, Switzerland, in June 1994 to develop and implement internationally agreed criteria and indicators for the conservation and sustainable management of temperate and boreal forests.

"Criterion

· A category of conditions or processes by which sustainable forest management may be assessed.

· A Criterion is characterized by a set of related indicators which are monitored periodically to assess change.

Indicator

A measure (measurement) of an aspect of the criterion. A quantitative or qualitative variable which can be measured or described and which, when observed periodically, demonstrates trends.

Montréal Process Criteria

The Montréal Process Working Group agreed on a framework of criteria and indicators that provide member countries with a common definition of what characterizes sustainable management of temperate and boreal forests. The framework identifies seven criteria that are further defined by 67 associated indicators which are aspects of the criteria that can be identified or described. "
--URL: http://www.mpci.org/whatis_e.html accessed Sept.09/03 --clh.

Mueller, Paul, Nancy Creamer, Mike Linker, Frank Louws, Mary Barbercheck, Cavell Brownie, Michael Wagger, Michele Marra, Shuijin Hu, Charles Raczkowski, and Joan Ristaino. 2001. Federal projects: Long-term, Large-scale systems research directed at Agricultural sustainability. $230,000. USDA SARE.

Projects implemented by CEFS Faculty since 1997 [PDF/Adobe Acrobat]
This project is the second, three-year grant for the major farming systems experiment at CEFS. Initiated in 1998, the farming systems project encompasses 200 acres, and compares five diverse systems: a BMP short-rotation cash-grain system, an organic production system, an integrated crop/ animal system with a 15 year rotation, a forestry/woodlot system, and a successional ecosystem. The experiment is slated to continue in perpetuity. A wide range of parameters is being measured. These include: above-ground biomass of cover and cash crops, nutrient/energy flows, decomposition, **soil quality indices (physical, chemical, biological)**, soil microbiology, microarthropods, entomopathogens, insects, weeds, disease, crop yield and quality; and, economics."
--*Web resource at URL: http://*www.cefs.ncsu.edu/federalprojects-COLOR1.pdf -- *MSN online abstract.*

Murage, E. W., N. K. Karanja, P. C. Smithson, and P. L. Woomer. 2000. Diagnostic indicators of soil quality in productive and non-productive smallholders' fields of Kenya's Central Highlands. *Agriculture, Ecosystems & Environment* 79, no. 1: 1-8.

A study was conducted to identify indicators of soil fertility status that are consistent with farmers' perceptions of soil fertility. Physical, chemical and biological properties of soils (Kikuyu red clay, Humic Nitisols) were measured from paired fields identified as either productive or non-productive by 12 farmers and compared to findings of a household survey on soil fertility management. Special attention was given to the potential of different soil organic matter fractions to serve as diagnostic indicators of soil fertility. Farmers' criteria for distinguishing soil productivity included crop performance, soil tilth, moisture and colour and presence of weeds and soil invertebrates. All farmers attributed low fertility to inadequate use of organic and inorganic fertilizers (100%) and removal of crop residues (100%). Other causes included continuous cropping (83%), lack of crop rotation (66%) and soil erosion (42%). Productive soils had significantly higher soil pH, effective cation exchange capacity, exchangeable cations, extractable P and total N and P than non-productive soils. Total organic C and several estimates of soil labile C including particulate organic C (POC), three Ludox density separates of POC, KMnO4-oxidizable C and microbial biomass C were significantly greater in productive soils. Soil microbial biomass N, net N mineralization and soil respiration were also significantly higher in productive soils. Soil microbial biomass N, net N mineralization and soil respiration were also significantly higher in productive soils. Farmers' perceptions of soil quality were substantiated through soil chemical analyses and soil organic matter fractions provided precise information on these differences. The similarity of soil physical properties in productive and non-productive fields suggests that differences in chemical and biological indicators may have resulted, in part, from smallholders' management and are not inherent properties of the soils. *--Authors' abstract.*

Nambiar, K. K. M., A. P. Gupta, Fu QingLin, and S. Li. 2001. Biophysical, chemical and socio-economic indicators for assessing agricultural sustainability in the Chinese coastal zone. *Agriculture, Ecosystems & Environment*—Special Issue: Papers From the European Union Concerted Action conference: *Unification of Indicator Quality for the Assessment of Impact of Multidisciplinary Systems (UNIQUAIMS)*, January 1998 - March 2001 87, no. 2: 209-214.

Agricultural sustainability depends to a great extent upon the maintenance of soil health. There is no single measurement that can be made for its quantification although certain soil biophysical and chemical characteristics are found to be key potential indicators of soil health. An agricultural sustainability index is proposed to measure agricultural sustainability as a function of biophysical, chemical, economic and social indicators. It was tested on a regional dataset from China. It showed marked changes in sustainability over a 9-year period and between regions within the coastal zone. This index appears promising for assessing agricultural sustainability. It permits the comparison of relative sustainability of different agroecosystems and can be used to compare agricultural sustainability across regions, although care must be taken in the choice of rating scale for the component indicators. --*CAB Abstracts.*

Neher, Deborah A. 2001. Role of nematodes in soil health and their use as indicators. 39th Annual Meeting of The Society of Nematologists, June 24-28, 2000, Quebec City, Quebec Canada. At URL: http://www.eeescience.utoledo.edu/Faculty/Neher/Publications/01JON_manuscript.doc

Running Head: "Nematodes and Soil Health: Neher". Source: Cornell University's Soil Health Information Gateway, at URL: http://mulch.mannlib.cornell.edu/TSSearch.html ; Accessed Sept.17, 2003. "This downloadable Symposium paper was presented at the 39th Annual Meeting of the Society of Nematologists (June 2000) in Quebec, Canada. It discusses using nematode communities as bioindicators of soil health."

New Zealand. Environment Waikato, Regional Council. 2003. *Environment Waikato - Soil quality - Key points*. Waikato Regional Council, NZ.

Environmental indicator information about soil quality in the Waikato Region [of New Zealand]. This Key Points page presents bullet points and graphed data for this indicator. More information is available in the Report Card and Technical Information pages; found at **URL:** http://www.ew.govt.nz/ourenvironment/indicators/land/soil/land6/keypoints.htm -- *MSN online abstract..*

New Zealand Institute for Crop and Food Research Limited. 2002. Soil Quality Management System (SQMS), SQMS decision support system, SQMS test kit. From URLs:
http://www.crop.cri.nz/psp/sqms/section1.htm ; http://www.crop.cri.nz/psp/sqms/decision.htm
SQMS is a decision support system designed to help farmers monitor and manage changes in soil quality to enhance the productivity and environmental sustainability of mixed-crop farms on the Canterbury Plains of New Zealand.

The SQMS web site provides:
confidential storage and retrieval of SQMS test results and management history information for each registered paddock
detailed interpretation of indicator results based on management history information
comprehensive crop and soil management recommendations to assist farmers to maintain or improve soil quality and crop performance
How does the SQMS decision support system work?The soil quality indicator data collected using the SQMS test kit and user manual are entered by a registered user into the confidential website. This data is stored for each registered paddock and remains confidential to the user and Crop & Food Research.
Once the indicator data have been entered and accepted by the system, the user can request:
a summary of the indicator results for a given paddock over the life of their monitoring programme
detailed interpretations of indicator results for the current monitoring year
recommendations to assist with soil management decisions

--From URL: http://www.crop.cri.nz/psp/sqms/decision.htm -- *MSN online abstract.*

New Zealand. Manaaki Whenua Landcare Research. 1999-2003. *SINDI: Soil quality indicators on the web ;* a web-based tool to measure soil quality [web site at URLs: http://sindi.landcareresearch.co.nz/ ; http://www.landcareresearch.co.nz/research/rurallanduse/soilquality/SINDI.asp **].**

This web tool summarizes 7 indicators from soil attributes, aggregated in 4 groupings of soil characteristics: soil fertility--as indicated by Olsen Phosphorus; soil acidity--as indicated by pH; organic resources--as indicated by anaerobic mineralizable Nitrogen, total Carbon, total Nitrogen; and soil physical properties--as indicated by bulk density and macroporosity.

———. 2001. Normal ranges for soil indicators. From URL: http://www.landcareresearch.co.nz/

3 types of limits initially proposed for interpretation of indicators are discussed: Level of concern, Environmental bottom line, and Recommended limits for crop productivity.

Norfleet, M. L., D. Dirlam, and B. F. Hajek. 1997. Properties, distribution and land use of soil quality reference soils. American Society of Agronomy Abstracts, no.258.

Use of SQIndex Determiner software, mentioned from Islam and Weil, 2000.

Nortcliff, Stephen. 2002. Standardisation of soil quality attributes. In: *Selected papers from the International Workshop on "Soil Health as a Indicator of Sustainable Land Management"* held at the Goulandris Natural History Museum/Gaia Environmental Research and Education Center, Athens/Kifissia, Greece, 24-25 June 1999John W. Doran, and Stamatis I. Stamatiadis, 161-168.

Preliminary discussion paper; Viewpoint is that soil functions should be the key to researching which indicators are most suitable in developing a soil quality index, and that standards are required at international level; thus advocates ISO methods as they are being developed (Abstract provides philosophical position of author). Discusses physical, chemical, biological, visible soil attributes, and SOM, indicator selection parameters, the issues of scale, sampling, data representativeness, definition of methods, as all necessary to include. Provides a process toward steps to follow to achieve standardization at international level. Concludes that more awareness and co-operation will lead to a "suite of standard procedures" [in] establishing indices of soil quality. (p.167).

Oberholzer, Hans-Rudolf, J. Rek, P. Weisskopf, and U. Walther. 1999. Evaluation of soil quality by means of microbiological parameters related to the characteristics of individual arable sites // .Agribiological Research "Im Druck". [LA=German] From URL: http://www.aramis-research.ch/e/671.html#0810EN [Citation from Swiss Research Information System, accessed Nov.23, 2003.]

Oberholzer, Hans-Rudolf, and Swiss Research Information System. 2003. Kriterien, methoden und iundikatoren zur beurteilung der bodenfruchtbarkeit. // Criteria, methods and indicators for the assessment of soil quality. [LA=German] From URL: http://www.aramis-research.ch/e/671.html

Project begins 20.10.1999 -- Project ends 31.12.2003

Ontario Soil Management Research and Services Committee (OSWARSC). 2002. 2002 report, Ron Bayert, principal researcher. From URL: http://www.gov.on.ca/OMAFRA/english/research/oascc/oswarsc/soil.htm

Recommendation 5: Soil Management and Soil Quality Research leading to determining the effects of soil management practices on chemical, biological and physical soil quality. The present threat of global climate change and soil management issues dealing with carbon sequestration and the reduction of greenhouse gas emissions, warrants a better understanding of the effects of soil management on soil processes. As such, soil management practices, such as tillage, cropping pattern, and fertilization influence soil, water, and air quality. Assessing soil quality and its impacts on productivity and the environment is complicated since research must consider the multiple functions of soil and integrate the physical, chemical and biological soil attributes that define soil function. However, to achieve the goals of high crop yields and quality with minimal environmental impact requires reliable research information that assesses the impact of management on soil quality and on soil use. In addition, the fundamental requirements of profitability and competitiveness must be incorporated into the overall soil management strategy. -- *Online summary.*

Orellana, J. A. de, M. A. Pilatti, and D. A. Grenon. 1997. Soil quality : an approach to physical state assessment. *Journal of Sustainable Agriculture* [Binghamton, NY : Food Products Press] 9, no. 2/3: 91-108.

Organisation for Economic Co-operation and Development (OECD). 1999. *Environmental indicators for agriculture—Volume 1: Concepts and framework.* **Paris, France: Organisation for Economic Co-operation and Development.**

Little quantitative information is available to assess the impacts, both harmful and beneficial, of agriculture on the environment ... http://www.oecd.org/searchResult/0,2665,en_2649_201185_1_1_1_1_1,00.html ; accessed September 09, 2003.

———. *Environmental indicators for agriculture—Volume 2:* "Issues and design". -- *"The York Workshop" [1998],* Paris, France: Organisation for Economic Co-operation and Development (OECD).

Need for soil quality indices was recognized in 1998. Indicators were then developed for OECD use, termed "agri-environmental (AEI) are truly socio-economic factors needed for international policy framework development, and therefore fall within political & socio-economic parameters. Soil quality is examined only in terms of potentials for soil erosion. National bases exist for comparison purposes between/among nations.

———. 2001. Environmental indicators for agriculture—Volume 3: Methods and results. Paris, France: Organisation for Economic Co-operation and Development (OECD).

"During the completion of the OECD (2001) publication Environmental Indicators for Agriculture Volume 3: Methods and Results, an extensive bibliography was established covering the main agri-environmental indicator themes." --From URL: http://www.oecd.org/htm/M00009000/M00009689.htm -- *MSN online abstract.*

"The impacts of agriculture on the environment and the achievement of sustainable agriculture are of major public concern in the context of agricultural reform, trade liberalization, and multilateral agreements...." --From URL: http://www.oecd.org/searchResult/0,2665,en_2649_201185_1_1_1_1_1,00.html ; accessed September 09, 2003.

Pankhurst, C. E., B. G. Hawke, H. J. McDonald, C. A. Kirkby, J. C. Buckerfield, P. Michelsen, K. A. O'Brien, V. V. S. R. Gupta, and B. M. Doube. 1995. Evaluation of soil biological properties as potential bioindicators of soil health. Australian Journal of Experimental Agriculture 35, no. 7: 1015-1028.

Two long-term field trials in South Australia were used to detect and characterize changes in soil biological properties that were a consequence of different agricultural management. The sensitivity of these biological properties was assessed to no-tillage vs. conventional cultivation, stubble management (stubble retained vs. stubble harvested), crop rotation (continuous wheat vs. wheat-sown pasture), and N fertilization (0 and 80 kg N/ha applied during the crop phase). Tillage, stubble management, crop rotation, and N fertilization significantly ($P<0.01$) affected C mineralization and microbial biomass. Tillage with stubble management significantly affected root pathogenic fungi, protozoa, collembola, earthworms, and cellulose decomposition. Crop rotation affected mycorrhizal fungi, protozoa, and soil peptidase activity, and N fertilizer had a significant effect on mycorrhizal fungi, protozoa, and cellulose decomposition. As these biological properties are responsive to agricultural management, thay may have potential as bioindicators. Total bacteria, fungi, and actinomycetes, cellulose-decomposing bacteria and fungi, soil phosphatase and sulfatase activity, and N mineralization were less affected by these treatments and may therefore have limited potential as bioindicators. --*CAB Abstracts.*

Pankhurst, Clive E. 1994. Biological indicators of soil health and sustainable productivity. In: *Soil resilience and sustainable land use*: Proceedings of a Symposium held in Budapest, 28 September to 2 October 1992, including the Second Workshop on the Ecological Foundations of Sustainable Agriculture (WEFSA-II); Pp.331-351. D. J. Greenland and I. Szabolcs, editors. Wallingford, UK: CAB International.

This conference discussed: (1) types of bioindicator; (2) bioindicators of soil productivity and sustainability; (3) bioindicators of soil pollution; and (4) role of bioindicators in sustainable land use. Research needs are briefly outlined.

Pankhurst, Clive E., and Australia. CSIRO Land and Water, Davies Laboratory. 1998. Bioindicators of soil health: Assessment and monitoring for sustainable agriculture. From URL: http://www.csiro.au/research/mdb/biodbiot.html

Soil Processes and Indicators for Land Management
-- Project Leader: Doug Reuter.
-- Project Objective: Development of generic indicators of landscape health.

Biodiversity and Management of the Soil Biota for Sustainable Rural Production
-- Project Leader: Pankurst, Clive.
Project Objectives:
To develop and apply new techniques for the rapid diagnosis of the biological status of soils. To develop methods to characterise and quantify the biodiversity of soil microbial populations. To determine the impact of agricultural practices on the biological health and functioning of soils and define the linkages between soil biology, soil functioning, soil health and sustainable crop production. To provide strategies, based on soil biology assessment, that will improve soil health and sustainable crop production. To use soil biodiversity as a tool to facilitate and monitor bioremediation of contaminated soils.
Main Deliverables:
Biological Indicators of Soil Health
Identification of four soil biological properties as having high potential as bioindicators of soil health. Report to GRDC(95), publication in AJEA (95), 4 conference presentations (93-95).
Evaluation of biological indicators of soil health. Review in Adv. Pl. Pathol. (95) Chapters in books (96-one), (97-four), (98-two); Editors of book "Biological Indicators of Soil Health" (CABI).
Assessment of soil health indicators at 10 long-term trials across Australia - demonstration that sustainable crop yield significantly related to soil biology (Waite long-term trial). Progress reports to GRDC (96,97); 2 conference presentations (96,97), consultations with GRDC representatives.
Soil Biodiversity
Establishment of GC-FAME technology as a tool to investigate soil microbial diversity (95).
Establishment of metabolic profiling (BIOLOG) as a tool to investigate the functional soil microbial diversity (96).
Capacity to predict the quantity fatty acid methyl esters (FAMEs) in soil s that are signatures for bacterial and fungal biomass, from mid-infrared soil analysis.
Development of DNA markers for identification of two cereal root pathogens.

Papendick, R. I., and J. F. Parr. 1992. Soil quality—the key to a sustainable agriculture. *American Journal of Alternative Agriculture* 7, no. 1-2: 2-3.

This paper provides a general introduction to the papers presented in this Special Issue on Soil Quality. The themes discussed in the individual contributions include: the need for developing a soil quality index based on local and regional considerations; recent international activities directed toward assessing and monitoring soil degradation; soil crusting: its effects and control; soil biological criteria as indicators of soil quality; the physical and chemical attributes needed for proper characrerization of soil quality; the effect of soil and crop management practices on different soil quality indicators; and factors that can affect the nutritional quality of crops. *--CAB Abstracts.*

Papritz, A. 1993. Interference between spatial variability and the detection of temporal changes in soils. *Soil monitoring: Early detection and surveying of soil contamination and degradation*; Pp.309-328. R. Schulin, A. Desaules, R. Webster, and B. von Steiger, editors. Basel, Switzerland: Birkhauser Verlag.

Temporal changes; spatial variability.--jw.

Parr, J. F., R. I. Papendick, S. B. Hornick, and R. E. Meyer. 1992. Soil quality: Attributes and relationship to alternative and sustainable agriculture. American Journal of Alternative Agriculture 7, no. 1-2: 5-11.

This macro-political discussion paper adopts Haberern's (1992) notion of a "Soil Health Index" re soil capability for crop production, taking the position that "no single reliable index of S.Q. has been developed" (p.7); --surveys the philosophy of S.Q. & conceptual framework for its study. --SQ improvements indicated by Granatstein's (1990) soil properties/attributes approach, according to these authors. --SQI = f(SP,P,E,H,ER,BD,FQ,MI) : SQ Index is a function of: soil properties, potential productivity, environmental factors, health, erodibility, biological diversity, food quality/safety, & management inputs. --Interaction of these indicators has to be determined; then lists all socio-economic & political factors of influence on purposes of soils analysis (all-things-to-all-people-approach is advocated.--ch notes). --Emphasizes need to monitor & assess, provide baselines for degradation & erodibility in soil quality studies/research.--ch.
--Parr et al. emphasize that attributes of soil quality (increased infiltration, aeration, macropores, aggregate size stability, soil organic matter, decreased bulk density, soil resistance, erosion, and nutrient runoff) should

not be limited to productivity but must include the more dynamic environmental (species diversity or genetic diversity) and social qualities. [*from Freyenberger's et al. annotated bibliography: SQI Lit.ID #214, p.9*]

Paz-Jimenez, M. de la, A M. de la Horra, L. Pruzzo, and R. M. Palma. 2002. Soil quality : a new index based on microbiological and biochemical parameters. Biology and Fertility of Soils [Berlin, Germany : Springer Verlag] 35, no. 4 (Jun): 302-306.

Agroforestry analysis in Argentina, precursor minimum data set analysis for establishing a soil quality index. This short communication of research results from La Paz summarizes the soil properties (organic C, soil respiration, enzyme activity, total N, P, pH) found to be of interest on lands with 4 treatments (native forest, pasture deforested 8-10yrs, no-till 6yrs & deforested 26 yrs, & conventional tillage on deforested 40 yrs.). --Used ANOVA, Turkey's test, correlation and multiple regression analyses; results presented in table form (p.304). --Organic C & enzyme variables were the focus; extractable P & pH were excluded as not sensitive indicators of management practices (although 'highly correlated').

Pembina Institute for Appropriate Development. 2003. Sustainability measurement: Genuine Progress Indicators [web site at URL: http://www.pembina.org/sustainability_mea.asp]

The Sustainability Measurement team researches and develops practical tools that can be used by organizations to measure, monitor and report on their progress towards economic, social, and environmental sustainability.

The Genuine Progress Indicators (GPI) is a measurement system for use by nations, states and communities to determine their progress towards a sustainable future. The GPI provides a comprehensive account of sustainable development - including economic, social and environmental factors - as compared to a more narrow and traditional measure of development, such as Gross Domestic Product (GDP), which considers only economic growth.

As advisors to the National Round Table on the Environment and the Economy, the Sustainability Measurement team is developing national environmental and sustainable development indicators. The team is also working closely with others, including Canadian Policy Research Networks and GPI Atlantic, to develop a Canadian **index** of well-being and sustainability. -- *Pembina Institute web site at URL:* http://www.pembina.org/sustainability_mea.asp

Pennock, D. J., D. W. Anderson, and E. de Jong. 1994. Landscape-scale changes in indicators of soil quality due to cultivation in Saskatchewan, Canada. Geoderma 64, no. 1/2: 1-19.

This paper builds on the relationship which has been demonstrated to exist between small (5 m by 5 m) slope segments and soil distribution in order to define larger landform element complexes in till landscapes of Saskatchewan, Canada. Distinctive pedogenic regimes are associated with these complexes. These complexes were then used to stratify the landscape at four conterminous sites with different cultivation histories and to assess changes in indicators of soil quality. Soil redistribution (as assesed by 137Cs redistribution) has had a major impact on these landscapes. The shoulder and level summit complexes have experienced continued high rates of soil loss. The shoulder complexes have lost 55% of their original soil organic carbon (a loss of 64 mg ha-1) over 80 years and 70% of this loss is attributable to net soil export from these positions. The portions of the footslope complexes dominated by Orthic Black Chernozemic soils initially act as sediment deposition sites in the first 22 years of cultivation, but ultimately this soil is removed from these positions and a moderate decline in soil quality occurs. The Gleysolic-dominated portions of the footslopes and the level depressional complexes occupy 15% of the landscape and are the major long-term sediment depositional sites; the biochemical indicators of soil quality (soil organic carbon and total soil nitrogen) show a major and beneficial increases in these positions.

The relationship which exists between small (5 m x 5 m) slope segments and soil distribution was built on to define larger landform element complexes in till landscapes of southern Saskatchewan, Canada. Distinctive pedogenic regimes associated with these complexes were used to stratify the landscape at four conterminous sites with different cultivation histories and to assess changes in soil quality indicators. Soil redistribution (assessed by 137Cs redistribution) has had a major effect on these landscapes. The hill shoulder complexes have lost 55% of their organic soil carbon (a loss of 64 mg/ha) over 80 years and 70% of this loss is attributable to net soil export from these positions. The footslope complexes dominated by Orthic Black Chernozemic soils acted as sediment deposition sites in the first 22 years of cultivation but ultimately the soil is removed and a moderate decline in soil quality occurs. The Gleysolic-dominated portions of the footslopes and the level depressional complexes occupy 15% of the landscape and are major long-term sediment depositional sites; the biochemical indicators of soil quality (soil organic carbon and total soil nitrogen) show a marked and beneficial increase in these positions.

Pierce, Francis J., and W. E. Larson. 1993. *Developing criteria to evaluate sustainable land management. Utilization of soil survey information for sustainable land use*; Proceedings of the 8th International Soil Management Workshop, May 1993., 7-14. Lincoln, NE: USDA-SCS, National Soil Survey.

Development of land quality indicators is discussed in this summary, presented at the 89th International Soil Management Workshop. The position paper maintains that quantification of quality involves pedotransfer functions of soil attributes, collection of minimum data sets, development and establishment of quality standards that include threshold levels, benchmark soils, productivity considerations, acceptable performance limits, and adequate statistical assessment methods, including trends analysis for comparative, meaningful evaluation. Control charts, variability, and system design using process control models for soil quality monitoring are discussed.

Pinzari, F., A. Trinchera, and A. Benedetti. 1996? Soil quality indicators for the assessment of the risk of desertification in Mediterranean ecosystems. --From URL:
http://www.desertification.it/asv/doc/ASINARA%20WEB/34pinzari.htm

"This study was carried out to compare soils undergoing the pressure of a range of different degenerative processes that increase the risk of erosion. The aim is to test microbial biomass activity and organic matter quality parameters as both indicators of disturbance, and soil-state descriptors of natural systems." *-- Online abstract.*

Popp, Jennie, Dana Hoag, and James AscoughII. 2002. Targeting soil conservation policies for sustainability : new empirical evidence. *Journal of Soil & Water Conservation* [Ankeny, Iowa: Soil and Water Conservation Society] 57, no. 2 (Mar/Apr): 66-74.

Sustainable resource management is one of the most complex concerns today. Society has spent billions of dollars conserving soils in production, yet it is unclear whether these efforts buy sustainability, or even what sustainability is. Further study about which soils need conservation merits consideration. We use a simulation model, regression and optimization analysis to examine the sustainability of resource management in objective, measurable ways Soil quality, represented by a new index, and other non-irrigated corn production data are placed into a dynamic model to identify: 1) the conditions where soil conservation is efficient, and 2) under what definitions conservation is sustainable. Results show that decisions to use or conserve soil and the impacts of these decisions are highly dependent upon soil type and how sustainability is defined. In general, while soil conservation slowed degradation on erodible soils, it seemed to be more effective and economically efficient the better the initial quality of the soil. This calls into question whether U.S. conservation policy that focuses on marginal soils supports sustainability. Economic research was undertaken to study which soils might best be targeted for conservation, using economic and sustainability criteria. An economic model of non-irrigated corn production was created to determine nder requirements of maintaining a certain level of production or maintaining soil qualityif, when, and where it was best to apply conservation practices. Results show that decisions to use or conserve soil and the impacts of these decisions are highly dependent upon the characteristics of the soil and how sustainability is defined. In general, while soil conservation slowed degradation on erodible soils, it seemed to be more effective and economically efficient the better the initial soil quality. *--Authors' abstract, p.66.*

Renger, M., O. Strebel, and W. Giesel. 1974. Evaluation of soil, cultural and hydrological problems by using the climatic water balance and physical soil indices. 1. Need for sprinkler irrigation : Beurteilung bodenkundlicher, kulturtechnischer und hydrologi scher Fragen mit Hilfe von klimatischer Wasserbilanz und bodenphysikalischen Kennwerten. [LA=German] Beregnungsbedurftigkeit. Z-Kulturtech-Flurbereinig 15, no. 3 (May/Jun): 148-160.

Rhoton, F. E., and D. L. Lindbo. 1997. A Soil depth approach to soil quality assessment. *Journal of Soil & Water Conservation* [Ankeny, Iowa: Soil and Water Conservation Society] 52, no. 1 (Jan/Feb): 66-72.

Philosophical viewpoint: depth influences productivity & erodibility of soils, so must assess soil properties based upon ESD (effective soil depth) as an "integrative" factor in S.Q. index development. --(Page 66 quote:) "A soil quality index cannot be based solely on the analysis of a few arbitrarily-chosen soil properties from a single soil type and location, because of inherent and artificial differences among soils." --Lower Mississippi Valley, fragipan soils, eroded sites; 69 randomly-selected points per site were sampled (12 plots, over 3 years); --Tests replicable (p.68). --soybean yields measured. --Soil physical & chemical properties (Table 1, p.68): Bulk density, aggregate stability, mod. of rupture, available water, clay content, extractable Fe, SOM, pH, CEC; grouped by degree of P erodibility. --Correlations with soil depth worked out for A horizons; --Productive-erodibility indices related to ESD were graphed, & compared to 1984-1986 yield data from these plots. --Advocates of the position that a single indicator, such as SOM, is not adequate for soils with limited depth (p.72).

Rienzi, E. A., M. Rorig, S. Navone, A. E. Maggi, and C. P. Movia. 2001. Indicadores de calidad de la tierra en distintas posiciones de la cuenca del rio Santa Maria // Soil quality indicators in landscape position of Santa Maria river basin [Argentina] [LA=Spanish, with English summary] *Revista De La Facultad de Agronomia* [Universidad De Buenos Aires] 21, no. 2: 111-115.

Results of a study on the behaviour of soil (sandy soil) quality indicators (electrical conductivity, sodium adsorption ratio, soil pH and organic carbon content) in the Santa Maria river basin, Catamarca, Argentina, due to changes in the landscape position, land use and measurement depth, are presented. *--CAB Abstracts.*

Rodale Institute. 1991. International Conference on the Assessment and Monitoring of Soil Quality; Proceedings of a conference hosted by the Rodale Institute, July 11-13, 1991, Emmaus, PA. John Haberern, editor. Emmaus, PA: Rodale Press.

"This conference report documents the first steps of a national effort to define and describe methods of enhancing soil quality."

Rodriguez, A., J. L. Mora Hernandez, and C. D. Arbelo Rodriguez. 2002. Variation of soil quality in plant succession of the coastal scrub of Tenerife (Canary Islands, Spain). In: Man and soil at the Third Millennium; Proceedings [of] International Congress of the European Society for Soil Conservation,Volume 2: 1185- . J. L. Rubio, R. P. C. Morgan, S. Asins, and V. Andreu, editors. Logrona , Spain: GEOFORMA Edicions, S.L.

The successional processes of degradation and regeneration of ecosystems are necessarily associated with variations of soil quality. Moreover the reference soils, from the point of view of quality, must be associated with the climax vegetation. A study is presented in this paper of the Relationship between the different plant communities characteristic of the succession in the coastal scrubland of the Canary Islands (Spain) and the quality of the soils (Leptosols, Regosols, Eutric Cambisols, Luvic Calcisols and Petric Calcisols) associated with them, to **attempt to establish a soil quality index that is valid for the ecosystem studied**. To this end, intensive sampling was carried out of both soils and plants in a large arid zone located in southeast Tenerife. Up to 60 properties of the soil and land were analysed. Plant communities were delimited by means of multivariate analysis of classification and ordination. Uni- and multivariate statistical techniques were applied to establish which of the variables studied were relevant in determining the vegetation. The most significant characteristics were those related to the saline-sodic state of the soils and the degree of human intervention in the area. The general characteristics of the soils associated with the different plant communities are presented and the role of each of these communities in the process of plant succession is analysed.

Rogers, T., J. Krebsbach, and Laura L. Jackson . 1994. On-farm measurements of soil quality indices : a class experience. Presentation at: Upper Midwest Organic Farming Conference 1994. From URL: http://www.bio.uni.edu/department/faculty/jackson.html

Romig, D. E., M. J. Garlynd, and R. F. Harris. 1996. Farmer-based assessment of soil quality: a soil health scorecard. In: *Methods for assessing soil quality*; Pp. 39-60. J. W. Doran, and A. J. Jones,editors. Madison, WI : Soil Science Society of America.

Farmers' knowledge of soil health (in Wisconsin, USA), was analysed through structured interviews. All responses were coded and a database characterizing the main soil health properties was created. The identified properties were used to produce score cards containing the following scale: healthy (optimal function); impaired (abnormal function or structure); unhealthy (function severely restricted, deformity). A numerical scale (0.1; 1.5 and 3-4) grades each indicator with a degree of sensitivity, but this rating is ordinal. A detailed description of the scorecard used as a field tool to assess and monitor soil quality and health is presented. *--CAB Abstracts.*

Rubio, J. L., R. P. C. Morgan, S. Asins, and V. Andreu, editors. 2002. *Man and soil at the Third Millennium*; Proceedings [of the] International Congress of the European Society for Soil Conservation, Valencia, Spain, 28 March-1 April, 2000. Volume 1. Logrona, Spain: GEOFORMA Edicions, S. L. ["This publishing company has stopped its activities."--web note Oct.14, 2003]; 1115 p.

***Book of Abstracts* is available [web page] at URL: http://www.zalf.de/essc/valindex.htm#indexval ; edited by: Rubio, José L.//Asins, S.//Andreu, V.//Paz, J. M. de//Gimeno, E.**

This book has 2 volumes which are divided into 10 sections. Section 1 is on soil and society. Soil and water cycle are discussed in Section 2. The inter-linkages between biodiversity, climate change and soil resources are dealt with in Section 3. Section 4 presents the traditional soil water conservation systems. Section 5 is devoted to soil indicators. Soil functions and soil quality are described in Section 6. Section 7 tackles desertification and soil degradation processes. A discussion on soil contamination is presented in Section 8. New technologies and soil assessment are given in Section 9. And Section 19 is on soil conservation.

Rust, R. H., R. S. Adams, and W. P. Martin. 1972. Developing a soil quality index. IN: *Indicators of environmental quality*; Proceedings of a symposium held during the AAAS meeting in Philadelphia, Pennsylvania, December 26-31, 1971; Pp.243-247. William A. Thomas, editor. New York, London: Plenum Press.

General discussion (academic, theoretical review) of the factors possibly necessary to develop a Nitrogen soil quality 'index' in terms of retention in soils amended for cropping; considers the Smith & Wischmeier soil-loss prediction equation as an analogy. Also uses pesticide residues as one example of crop residue estimation as a complex expression of an SQ Index.

Sands, Gary R., and T. H. Podmore. 1993. Development of an environmental sustainability index for irrigated agricultural systems. In: Integrated resource management & landscape modification for environmental protection; Proceedings of the International symposium; Pp. 71-80. Kent J. Mitchell,editor. St. Joseph, MI: American Society of Agricultural Engineers.

Sustainability is one of the premier issues currently being faced by agriculture. While qualitative definitions of sustainability abound, quantitative definitions and measures have a scant presence in the literature. This paper presents the conceptual framework for the development of an environmental sustainability index for irrigated agricultural systems. The objective of the proposed index is to quantify, from an environmental prespective, the sustainability of irrigated agricultural systems.
A systems approach is a prerequisite for tackling the issue of sustainability. A three-pronged framework for characterizing environmental sustainability is conceptualized and discussed herein. The framework comprises: (i) indicators of inherent soil productivity of the system; (ii) indicators fo the agricultural system's potential to degrade the surrounding environment, and; (iii) indicators of ecosystem stability, from an energetic standpoint. The selection of various sustainability indicators within the aforementioned framework is outlined. Development and testing of aggregation schemes, leading to the design of the overall index is discussed. Anticipated results of application of the index are hypothesized. *--Authors' abstract, p.714.*

Sands, Gary R., and Terence H. Podmore. 2000. A Generalized environmental sustainability index for agricultural systems. *Agriculture, Ecosystems and Environment* 79: 29-41.

This paper presents the design and development of an Environmental Sustainability Index (ESI) and describes a case study used to evaluate the performance of the index. The objective of the index was to provide a modelling-based, quantitative measure of sustainability from an environmental perspective, comprising both on- and off-site environmental effects associated with agricultural systems. A performance approach was utilized for the ESI, having inputs that were derived from long-term simulations of crop management systems with the EPIC model (Erosion Productivity Impact Calculator). 15 sub-indices for representing sustainability were chosen employing a dual framework for characterizing environmental sustainability, embodying the agricultural system's: (i) inherent soil productivity and groundwater availability; and (ii) potential to degrade the surrounding environment. A case study was developed based on prevalent corn and wheat agricultural production systems in Baca County, located in southeastern Colorado. Principal components analysis was employed to assess the information content of the 15 sustainability sub-indices. Sensitivity analysis was performed to evaluate the effects of model input uncertainty on the index. The effect of the time frame over which the index is computed was also examined for time frames ranging from 50 to 300 years. Results show that the ESI is capable of demonstrating clear differences among crop management systems with respect to sustainability. *© 2000 Elsevier Science B.V. All rights reserved.*

Sarrantonio, M., J. W. Doran, M. A. Liebig, and J. J. Halvorson. 1996. On-farm assessment of soil quality and health. In: Methods for assessing soil quality; Pp. 83-107. J. W. Doran, and A. J. Jones,editors. Madison, WI: Soil Science Society of America.

Saviozzi, A., R. Levi-Minzi, R. Cardelli, and R. Riffaldi. 2001. A Comparison of soil quality in adjacent cultivated, forest and native grassland soils. Plant and Soil 233, no. 2: 251-259.

"In Italy, there is a growing interest in estimating the cropping-induced changes in soil fertility parameters. The objective of this study was to identify soil properties that can be used as indicators for evaluating changes in soil quality after 45 years of continuous production of corn by the conventional tillage method as compared with adjacent forest and native grassland sites." (p.252).
There are problems with the methods used in this study (--ch notes). The 1997 data is from 3 plots, each 0.1ha area; (cropped, forest, and supposedly 'virgin' grassland soils compared); measured: organic C, SOM, microbial biomass, respiration, enzyme activity (protease, Beta-glucosidase, urease, alkaline phosphatease, dehydrogenase, catalase); Results from all sandy-loam soils; texture & pH, subalkaline not much 'changed' (i.e. differing); organic C showed "significant change", & C/N ratio of cropped land lower than forested or grassland soils. This is an attempt at Trends Analysis in organic carbon; but not appropriate for single-season testing. Methods useful only if follow-up tests done over subsequent years (need a 'baseline'; must argue 'change' is equivalent to different ecosystem soils as different temporal representatives; flaw in logic, as soil chemistry and soil physical properties will be variable and different from within each ecosystem in a given year; --Static study.--(ch notes).

Schenck, R. C. 2001. Land use and biodiversity indicators for life cycle impact assessment. International Journal of Life Cycle Assessment—Special Issue [of the]:International Conference and Exhibition on Life Cycle Assessment: Tools for Sustainability, Arlington, Virginia, USA, 25-27 April 2000 6, no. 2: 114-117.

A workshop was conducted in July 2000 by the Institute for Environmental Research and Education and its partner, Defenders of Wildlife, to develop a preliminary list of life cycle indicators for land use impacts. The preliminary list of impact indicators includes: protection of priority habitats/species; soil characteristics; soil health; proximity to and protection of high priority vegetative communities; interface between water and terrestrial habitats/buffer zones; assimilative capacity of water and land; hydrological function; per cent coverage of invasive species within protected areas; road density; per cent native-dominated vegetation; restoration of native vegetation; adoption of best management practices linked to biodiversity objectives; distribution (patchiness, evenness, etc.); and connectivity of native habitat. It is concluded that the list of indicators conforms well to other efforts in developing indicators. *--CAB Abstracts.*

Schoenholtz, S. H., H. van Miegroet, and J. A. Burger. 2000. A Review of chemical and physical properties as indicators of forest soil quality: Challenges and opportunities. *Forest Ecology and Management* 138, no. 1/3: 335-356.

Complete literature review and discussion of the concept of soil quality, indicators (See Tables), and applicability of agricultural studies to forest soils and forestry research/models. Literature is usefully presented with soil quality indicators and soil properties in table format, to assist readers.

Schwenke, G. D., D. J. Reuter, R. W. Fitzpatrick , J. Walker, and P. O'Callaghan. 2003. Soil and catchment health indicators of sustainability: case studies from southern Australia and possibilities for the northern grains region of Australia ; Application of sustainability indicators to the management of soil and catchment health. Australian Journal of Experimental Agriculture 43, no. 3: 205-222.

During the last decade, a range of indicators has been advocated for assessing soil, farm and catchment health. This paper assembles some recent experiences of the authors in developing and using indicators from paddock to national scales. Indicators are merely a subset of the attributes that are used to quantify aspects of catchment or farm health. Their selection and use in the past has led to criticism of indicators, but, given an explicit approach, most of the criticisms can be overcome. Reliable indicators provide positive and negative signals about the current status of natural resources and how these properties have changed over time. They are used both to identify potential risks and to confirm that current farming practices and systems of land use are effective in maintaining the resource base or economic status. They should be precursors for change and future on-ground investments when problems are observed or identified. A structured approach is needed to ensure indicators are selected and used efficiently. This approach involves: deciding local issues and selecting the most appropriate indicators to reflect those issues; interpreting both positive and negative signals from the monitoring process; taking appropriate action to resolve problems; and, using indicators to monitor the outcomes from the action taken. Finally, we have drawn on these and other experiences to compile a list of indicators that may be used to address sustainability issues associated with farm productivity, soil health and catchment health identified in recent strategic plans developed for the northern grains region of Australia, the focus of this special journal issue. *--CAB Abstracts.*

Scottish Environmental Protection Agency (SEPA). 2001. Soil Quality Report 2001 -- a State of the Environment report. From URL: http://www.sepa.org.uk/publications/stateoftheenvironment/soil/index.htm

Publication Announcement : State Of The Environment : Soil Quality Report...
Launch of the SEPA State of the Environment: Soil Quality Report [was] 4 April 2001.
--From URL: http://www.sepa.org.uk/publications/stateoftheenvironment/soil/index.htm -- *Online abstract.*

Scrivner, C. L. 1999. "Soil productivity indices and soil properties of some major soil series of the Missouri Ozarks." Report no.EC955. Columbia, MO: University of Missouri-Columbia, University Extension. From URL: http://muextension.missouri.edu/explore/extcirc/ec0955.htm

This publication provides information and tables for estimating the potential productivity of several soils in the Ozarks. The system, designed by three soils scientists, is based on a productivity index (PI). It uses three properties — the potential available water capacity, bulk density and soil acidity (pH) — to determine the PI. Each of the 11 major Ozarks soil series is outlined in this publication. *--From URL:* http://muextension.missouri.edu/explore/extcirc/ec0955.htm ; accessed Oct.15, 2003.

Scrivner, C. L., B. L. Conkling, and P. G. Koenig. 1999. "Soil productivity indices and soil properties for farm-field sites in Missouri ." Report no.EC947. Columbia, MO: University of Missouri-Columbia, University Extension.

Farm-level field plots and soils testing in Missouri; tabular presentation of results; designed for on-farm use. " This report summarizes soil data collected from 500 field plots in Missouri." --From URL: http://muextension.missouri.edu/explore/extcirc/ec0947.htm

Seybold, C. A., and J. E. Herrick. 2001. Aggregate stability kit for soil quality assessments. Catena—Special Issue [of the] Workshop on Soil Aggregation in Arid and Semi-Arid Environments, Las Cruces, New Mexico, USA 8-10 May 1997 44, no. 1: 37-45.

Aggregate stability affects soil strength, and the soil's ability to transmit liquids and gases, which are important functions for crop production and ecosystem health. Aggregate stability can be used to assess soil quality because it is an indicator of vital soil functions. For soil quality assessments, there is a need for a quantitative field method for measuring aggregate stability that is simple to perform, low cost, and available for routine assessments by land managers. A method that follows the commonly used or standard single-sieve wet-sieving method for aggregate stability is presented. *--Authors' abstract.*

Seybold, C. A., M. J. Mausbach, D. L. Karlen, and H. H. Rogers. 1998. Quantification of soil quality. IN *Soil processes and the carbon cycle*. R. Lal, J. M. Kimble, R. F. Follett, and B. A. Stewart, 387-404. Boca Raton , FL: CRC Press Inc.

The five soil functions of Karlen et al. (1997), as well as of Larson and Pierce (1991), and the functional definition for soil quality by Doran and Parkin (1994) are all outlined, in this solid review and discussion of frameworks for soil quality assessment.

Sherwood, Stephen, and Norman Uphoff. 2000. Soil health: research, practice and policy for a more regenerative agriculture. Applied Soil Ecology [Elsevier Science B.V.] 15, no. 1: 85-97.

Sikora, L. J., C. A. Cambardella, V. Yakivchenko , and J. W. Doran. 1996. Assessing soil quality by testing organic matter. IN Soil organic matter : Analysis and interpretation; Pp.41-50. F. R. Magdoff et. al. editors. Madison, WI: Soil Science Society of America.

Singh, K. K., T. S. Colvin, D. C. Erbach, and A. Q. Mughal. 1992. Tilth Index : an Approach towards soil condition quantification // Tilth Index : an Approach to quantifying soil tilth. Transactions of the ASAE—ASAE Meeting Papers, American Society of Agricultural Engineering, 6 (Nov-Dec) St. Joseph, MI: ASAE.

Classic paper which sets out to quantify 5 soil physical properties: bulk density, cone index, aggregate uniform coefficient, organic matter content, and placticity index; and combine into a single index so as to characterize soil tilth from a value of 0 (unusable by plants) to 1 (non-limiting for crop growth). The Soil Tilth Index is a multiplicative combination of coefficients for the soil properties. This developed from 1989 July tests from 4 locations in field plots of corn with chisel-plow, moldboard plawing and slot plant ridge systems. Crop yields were measured 9189 and 1990. A corn-soybean rotation was used in 1990. The study compared mean values of crop yields and tilth indices for a Waseca, Minnesota Webster clay-loam soil, finding positive correlation.

Smart, Peter, and International Standards Organisation. 2003. ISO 10381: Soil quality: sampling. Peter Smart. From URL: http://www.eng.gla.ac.uk/~gnca11/sme/isotc190.html The international standards for soil quality are listed on this useful web link.

Smith, Jeffrey L., Jonathan J. Halvorson, and Robert I. Papendick. 1993. Using multiple variable indicator kriging for evaluating soil quality. Soil Science Society of America Journal 57, no. 3 (May/Jun): 743-749.

———. 1994. Multiple variable indicator kriging : a Procedure for integrating soil quality indicators. Chapter 9. IN Defining soil quality for a sustainable environment; Proceedings of a symposium. Pp.149-158. J. W. Doran, D. C. Coleman, D. F Bezdicek, and B. A. Stewart, editors. Soil Science Society of America.

"Kriging" is a statistical method to transform values above or below arbitrarily-selected data thresholds in multivariate non-ranked data sets, in order to examine correlations of variables. It is not easily replicable or applicable by farmers without expertise/assistance (--ch notes). Soil indicators for 3 parameters from 60 locations in a triangular grid on a 100m x 100m field, measured in millograms per kilogram, labelled A, B & C. (Not told where or what these were!--ch notes). Maps of probability are then "kriged" from data; the result is a probability index and not a unit index. Field level, small-scale, of "risk-qualified" parameters is given; but, a complex method for farmers to apply (--ch notes). Presence/absence around a 'critical threshold' used to derive data, which are replicable, but measurement methods are not apparent from this published presentation of the research. (--ch notes).

Soil Quality Institute. 2001. “What is soil quality?” Web page, Available at URL: http://www.statlab.iastate.edu/survey/SQI/sqw.html ; Accessed September 11, 2003.

Soil Quality Institute. 2003. “About soil quality [NRCS SQI web site].” Web page, Available at http://soils.usda.gov/sqi/soil_quality/index.html ; Accessed September 11, 2003.

Sojka, R. E., and D. R. Upchurch. 1999. Reservations regarding the soil quality concept . Soil Science Society of America Journal 63, no. 5 (Sept-Oct): 1039-1054. This discussion paper presents the viewpoint that 'soil quality' is conceptually flawed.

Sojka, R. E., D. R. Upchurch, and N. E. Borlaug. 2003. Quality soil management or soil quality management: Performance vs. semantics. Advances in Agronomy; Vol. 79: 1-68. Donald L. Sparks, editor. New York, NY: Academic Press.

This comprehensive 'philosophy of science' review of the soil quality concept (2003) expresses serious reservations, opposes the position of Karlen et al. (1997) categorically, advocates dangers of the 'soil functionalism' and reductionist paradigms, and 'quality soil management' versus 'soil quality management'. These authors take the position that current efforts at soil quality index development, application, and interpretation are flawed, require deconstruction to make sense of their data, are not indicative of management needs, do not accurately reflect reality, are impossibly complex for farmers and managers to use, and are paradigmatically a wasted effort in agricultural science. The paper is an excellent summary of the current issues related to soil quality indexing, esp. the "institutional definition of soil condition or health (Mausbach & Tugel 1995), and definition issues re SQ, soil health, 'transient soil status' (p.45). "Integrated indexing of simultaneous functions has not been achieved" according to the authors (p.52); they advocate management solutions, not indexing efforts, in further soils research endeavours. This will continue to be an important position paper in the 'soil quality vs. quality soil' debate for some time to come.

Southorn, Neil, and Stephen Cattle. 2000. Monitoring soil quality for Central Tablelands grazing systems. Communications in Soil Science and Plant Analysis 31, no. 11-14: 2211-2229.

Southourn, N. J. 2002. The Role of soil quality criteria in assessing farm performance . Proceedings of the International Farm Management Congress.

The environmental impact of industrial agriculture is under close scrutiny, by Governments, concerned citizens, and farmers. This paper discusses the need to incorporate environmental factors in measures of farm performance, as part of the continuous review of long term sustainability. The concept of natural capital allows natural resources to be considered in similar ways to other assets of the farm business. It is suggested that soil quality criteria, selected to match the site characteristics and purpose of the landowner, be included in these measures, despite continuing disagreement about the conept and difficulties in its applicaiton. The intuitive appeal of a soil quality paradigm is the potential to integrate the many dimensions of sustainability, encouraging responsible land management. It is further suggested that soil sturcture is a key indicator of soil quality, and methods for its assessment are summarized. --*Author's abstract, p.1.*

Sparks, Donald L., editor. 2001. Advances in Agronomy., Vol. 74. New York, NY: Academic Press.

Volume 74 contains six excellent cutting-edge reviews detailing advances in the plant and environmental soil sciences. Chapter 1 is an extensive review on soil quality.[by Karlen, Douglas L.//Andrews, Susan S.//Doran, John W.]. Chapter 2 covers recent advances in understanding the formation of metal hydroxide precipitates on soil surfaces and their implications on metal sequestration and soil remediation. Chapter 3 is a timely review on effects of organic acid exudation from roots on phosphorus uptake and aluminum tolerance of plants in acid soils. Chapter 4 discusses bamboo production and management, including manipulation of growth and development and environmental aspects of bamboo production. Chapter 5 addresses a significant worldwide issue - management of soils for food security and environmental quality. Chapter 6 is a comprehensive review on the management of wheat, barley, and oat root systems. *-From the Advances in Agronomy website at URL:* **http://www.harcourt-international.com/catalogue/title.cfm --Accessed Sept.09.2003.**

Sparling, Graham P. 2002. Soil quality assessed at 500 sites nationwide. Soil Horizons , no. 7 (Mar): 1-2. This article is about the '500 soils project' of New Zealand.

Sparling, Graham P., Wim Rijkse, Hugh Wilde, Tony van-der Weerden, Mike Beare, and Glyn Francis. 2002. *Implementing soil quality indicators for land*. Research Report for 2000-2001 and Final Report for MfE Project Number 5089, Landcare Research Contract Report: LC0102/015. Ministry for the Environment Sustainable Management Fund, New Zealand.

This article is about the '500 soils project' of New Zealand. From URL: http://www.smf.govt.nz/results/5089_report00_01.pdf ; Accessed February 4, 2002.

Sparling, Graham P., and L. A. Schipper. 1998. *Final Report: Trialing soil quality indicators for state of the environment reporting* (SMF Project 5001), Landcare Research Contract Report: LC9798/146 for SMF Project 5001. Landcare Research, New Zealand.

The 500 soils project of New Zealand is discussed. Soil quality indicators that are required, at minimum, and paired soil types, are identified for the development of a soil quality monitoring program for New Zealand; semantically, aggregates of indicators are called 'indices'.

———. 1998. Soil quality monitoring in New Zealand : Concepts, approach and interpretation, Technical Report LCR 9798/060. Landcare Research, New Zealand, 500 soils project, New Zealand. From URL: http://www.smf.govt.nz/results/5001_handbook.pdf ; Accessed February 4, 2002

———. 2002. Soil quality at a national scale in New Zealand. Journal of Environmental Quality—Ecological Risk Assessment Section 31, no. (Dec): 1848-1856.

The 500 soils project of New Zealand is discussed. Researchers used their own sources to produce quantitative, valid, & verifiable data. This New Zealand study of 222 sites is an overall soil survey in 5 regions, at regional scale for a national assessment. The article abstract provides details of soil attributes compared. Field data for standard soil chemical properties (total C, total N, CEC, base saturation, Olsen Phosphate, pH) was collected. Applied analysis of variance and principal component analysis statistical methods to soil properties; frequency analysis compared to national '500 Soils' data set was used to determine representativeness of soil samples, and to rationalize data over land use, soil type, and eco-region variables. Data value ranges are reported and graphed using box plots. Data interpretation is presented by land use category. Report is for 2/3rds of project completion; included finding similar SQ patterns across similar land use, in all regions, despite different soils and climates (p.1856). "Suite of indicators" approach--No single index developed or applied to the data interpretation.

Steiner, Kurt G., Heidrun Traeger, and Anna Haering. 2001. Indicators of sustainable land management, Deutsche Gesellschaft fur Technische Zusammenarbeit, Eschborn, Germany. From URL: http://www.gtz.de/soil-management/english/english/publik.htm

Stenberg, Bo. 1999. Monitoring soil quality of arable land : Microbiological indicators ; Review article. Acta Agriculture Scandanavia—Section B: Soil and Plant Science 49, no. 1: 1-24.

This review discusses the soil quality concept, indicators of soil quality and ways for selecting, sampling to monitor SQ, with a framework developed for Sweden, based on microbiological indicators.--ch. Comment on paper: "Informative notes, very good information."--jw.

Stenberg, Bo, Mikael Pell, and Lennart Torstensson. 1998. Integrated evaluation of variation in biological, chemical and physical soil properties. Ambio [Royal Swedish Academy of Sciences] 27, no. 1 (Feb): 9-15.

Sweden, Bavaria; --1995 spring samples were collected from an experimental farm in Sweden to 10 cm depth, from point samples on mesh grid with intersects resampled spring 1996 to a 90cm depth at 3 intervals; moldboard plowing & crop rotations in fields, for total C, N & S. --1991 to 1993 samples randomly selected from among 228 air-dried samples of 26 soils from throughout Sweden, for pH, infrared reflectance -- to represent CEC, SOM, & clay content. Then in 1995 resampling in late winter/early srping in-field on these selections, at 290cm depth from a 10 to 50 m^2 area; sieved, stored in labs/frozen, and analyzed within one yhear for soil microbial biomass. --High variability, high pH in most soils. (PCA analyses seem disjointed--ch notes).

Stephens, Peter R. 1999-2003. Soil quality and functioning of ecosystems: Research outline for Soil quality programme. Manaaki Whenua Landcare Research, New Zealand.

The programme [by LandCare Research in New Zealand] will develop critical thresholds of soil quality indicators, and an associated regional scale monitoring system for their use, to determine trends in soil quality and soil ecosystem health. The programme also includes research investigating the response of soil ecosystems to urbanisation.
The underpinning research has been realigned to focus on determining the impact of land-use pressures on resistance and resilience of key soil orders, and, in later years, soil ecosystem functioning. Land uses comprise grassland, forestry, arable, urban and organic farming. Investment is being made to better understand and facilitate the interaction between researchers and end-users, and how knowledge and information are used for sustainable management of soil ecosystems. Key end-users comprise regional councils and government agencies concerned with environmental issues. -- **From URL:** http://www.landcareresearch.co.nz/research/rurallanduse/soilquality/ProgOutline.asp

Stephens, Peter R., A. E. Hewitt, G. P. Sparling , R. G. Gibb, and T. G. Shepherd. 2003. Assessing sustainability of land management using a risk identification model. Pedosphere 13, no. 1: 41-48.

New Zealand is highly dependent on its soil resource for continued agricultural production. To avoid depleting this resource, there is a need to identify soils and associated land management practices where there is a risk of soil degradation. Environmental integrity and ecosystem services also need to be maintained. Accordingly, to ensure sustainable production, the on- and off-site environmental impacts of land management need to be identified and managed. We developed a structural vulnerability index for New Zealand soils. This index ranks soils according to their inherent susceptibility to physical degradation when used for agricultural (pasture, forestry and cropping) purposes. We also developed a rule-based model to assess soil compaction vulnerability by characterizing the combined effects of resistance and resilience. Other soil attributes have been appraised using seven chemical, physical and biological indicators of soil quality (total C, total N, mineralizable N, pH, Olsen P, macroporosity and bulk density). These indicators have been applied in a nation-wide project involving data collection from over 500 sites for a range of land uses. These soil quality data can be interpreted through the World Wide Web - through the interactive decision-support tool SINDI. The land use impact model is a framework to assess agricultural land management and environmental sustainability, and may be applied to land units at any scale. Using land resource data and information, the model explicitly identifies hazards to land productivity and environmental integrity. It utilizes qualitative expert and local knowledge and quantitative model-based evaluations to assess the potential environmental impacts of land management practices. The model is linked to a geographic information system, allowing model outputs, such as the environmental impacts of site-specific best management practices, to be identified in a spatially explicit manner. The model has been tested in New Zealand in an area of pastoral land use. Advantages of this risk identification model include: utilizing current knowledge of the causes and effects of land management practices on soil degradation; linking land management practice to both on- and off-site environmental consequences; identifying important gaps in local knowledge; and providing spatially explicit information on the environmental impact of land management practices. *--Authors' abstract, p.41.*

Stockle, C. O., R. I. Papendick, K. E. Saxton, G. S. Campbel, and van-Evert F. K. 1994. A Framework for evaluating the sustainability of agricultural production systems. American Journal of Alternative Agriculture 9, no. 1&2: 45-50.

[In this discussion paper, we learn that:] Sustainable agriculture has gained acceptance as a conceptual approach for shaping farming systems of the future. All definitions of sustainable agriculture include food productivity, food safety, resource protection, quality of life and environmental quality. However the sustainability of a wide range of farming systems has been judged only subjectively. Currently there are no scientific criteria to evaluate the sustainability of a specific farming system. We propose a framework for evaluating the relative sustainability of a farming system using nine attributes: profitability, productivity, soil quality, water quality, air quality, energy efficiency, fish and wildlife habitat, quality of life, and social acceptance. Each attribute is scored and then weighted in a way that is subjective and dependent ont he judgment of the evaluating team, but that must be expressed numerically. The scoring must be based on quantifiable constraints within each attribute. Constraints can be quantified by direct measurement, which is already true for those related to profitability, productivity, water quality and energy efficiency. Constraints that are not readily measurable will need other evaluation techniques, including expert opinion and computer simulation models. *--Authors' abstract, p.45*.

Stott, D. E., R. H. Mohtar, and G. C. Steinhardt , editors. 2001. Sustaining the global farm—Selected papers from the 10th International Soil Conservation Organization Meeting (ISCO99), 24-29 May 1999, West Lafayette, Indiana. West Lafayette, IN: International Soil Conservation Organization in cooperation with the USDA and Purdue University. 688pp. From URL: http://topsoil.nserl.purdue.edu/nserlweb/isco99/pdf/ISCOdisc/tableofcontents.htm ; Accessed Oct.17.2003 (ch).

Straalen, N. M. van. 1997. Community structure of soil arthropods as a bioindicator of soil health. Biological indicators of soil health; Pp. 235-264. C. Pankhurst, B. M. Doube, and V. V. S. R. Gupta, editors. Wallingford, UK: CAB International.

The concept of community bioindicators for soil health is outlined. Possible microarthropod community indicators are considered based on a classification after species abundance, dominance, life histories, feeding types and physiotypes. The stability of soil microarthropod communities is discussed. Ways in which the ecology of the species can be exploited to optimize the indicator value of the microarthropod community are examined. The indicator value of ecological groupings is discussed. The soil factors for which microarthropod community indicators may be useful include soil type, humus type, microbial populations, pH, humidity, temperature, nutrient status, heavy metals, and pesticide residues. --*CAB Abstracts.*

Straalen, N. M. van. 2002. Assessment of soil contamination—a functional perspective. *Biodegradation*—Special Issue on *Resilience of the Subsurface Ecosystem to Anthropogenic Disturbances*; OECD Meeting, Amsterdam, Netherlands, 27-28 August 2001 13, no. 1: 41-52.

In many industrialized countries the use of land is impeded by soil pollution from a variety of sources. Decisions on clean-up, management or set-aside of contaminated land are based on various considerations, including human health risks, but ecological arguments do not have a strong position in such assessments. This paper analyses why this should be so, and what ecotoxicology and theoretical ecology can improve on the situation. It seems that soil assessment suffers from a fundamental weakness, which relates to the absence of a commonly accepted framework that may act as a reference. Soil contamination can be assessed both from a functional perspective and a structural perspective. The relationship between structure and function in ecosystems is a fundamental question of ecology which receives a lot of attention in recent literature, however, a general concept that may guide ecotoxicological assessments has not yet arisen. On the experimental side, a good deal of progress has been made in the development and standardized use of terrestrial model ecosystems (TME). In such systems, usually consisting of intact soil columns incubated in the laboratory under conditions allowing plant growth and drainage of water, a compromise is sought between field relevance and experimental manageability. A great variety of measurements can be made on such systems, including microbiological processes and activities, but also activities of the decomposer soil fauna. I propose that these TMEs can be useful instruments in ecological soil quality assessments. In addition a "bioinformatics approach" to the analysis of data obtained in TME experiments is proposed. Soil function should be considered as a multidimensional concept and the various measurements can be considered as indicators, whose combined values define the "normal operating range" of the system. Deviations from the normal operating range indicate that the system is in a condition of stress. It is hoped that more work along this line will improve the prospects for ecological arguments in soil quality assessment. *--CAB Abstracts.*

Suyundukov, Y., and S. Yanturin. 2000. Agroecological optimization of Bashkir Trans-Ural soil utilization. Mezhdunarodnyi Sel'Skokhozyaistvennyi Zhurnal, no. 3: 41-46.

Agroecological indexes (e.g. humus, organic fertilizers in soils, erosion risk) associated with various tillage methods (terracing and non-terracing plough, zero tillage) were examined in the optimization of the fallow system, rotational structure with conservation and reproducibility of fertility by soil tillage in the title area of Russia. Soil restoration was possible with the planting of mixed grass, and the use of ecological organic irrigated farming. -- *CAB Abstracts.*

Switzerland. SAR. 2003. SAR research projects : 1.1 Natural resources, environmental protection in agriculture. From URL: http://www.sar.admin.ch/en/research/subject_area/1_1.html

We links to the Research projects of the six Swiss federal research stations in the field of agriculture [regarding] soil quality, soil fertility, soil analytical method, soil quality indicator, sustainability ... SAR - Forschungsprojekte - Projektsuche über Schlagwörter Sitemap Copyright © 1999 SAR http://www.admin.ch/sar/ Forschungskatalog 2000 - 2003 Projektsuche überwww.sar.admin.ch/de/research/keyword_index.html

Taiwan. Food and Fertilizer Technology Center (FFTC). 2002. *Soil chemical and biological indicators selected for assessing the soil quality of Taiwan soils* [Table 5. Soil biological indicators selected for assessing the soil quality of Taiwan soils [Tables on web site]. --From URL: http://www.fftc.agnet.org/library/image/eb473t5.html

Table 4: Soil chemical indicators selected for assessing the soil
Table 4 Soil chemical indicators selected for assessing the soil quality of Taiwan soils. E-mail:From:www.fftc.agnet.org/library/image/eb473t4.html
Table 5: Soil biological indicators selected for assessing the soil
Table 5 Soil biological indicators selected for assessing the soil quality of Taiwan soils.

Thomas, R., and M. A. Ayarza. 1999. Sustainable land management for the Oxisols of the Latin American Savannas: Dynamics of soil organic matter and indicators of soil quality. Cali, Columbia: Centro Internacional de Agricultura Tropical (CIAT).

This book contains the following chapters: (1) sustainable land management for the Oxisols of the Brazilian cerrados; (2) Oxisol development along a compound catena of the Araguari River, Central Brazil; (3) agropastoral systems based on legumes: an alternative for sustainable agriculture in the Brazilian cerrados; (4) physical and chemical properties of selected Oxisols in the Brazilian cerrados; (5) distribution of water-stable aggregates and aggregating agents in Oxisols of the Brazilian cerrados; (6) aggregation studied by laser diffraction in relation to ploughing, soil organic matter, and lime in the Brazilian cerrados; (7) short-term variation in aggregation and particulate organic matter under crops and pastures; (8) soil organic matter in Oxisols of the Brazilian cerrados; (9) soil organic carbon, carbohydrates, amino sugars, and potentially mineralizable nitrogen under different land-use systems in Oxisols of the Brazilian cerrados; (10) carbon fractions as sensitive indicators of quality of soil organic matter; (11) labile N and the nitrogen management **index** of Oxisols in the Brazilian cerrados; (12) characterizing labile and stable nitrogen; (13) phosphorus fractions under different land-use systems in Oxisols of the Brazilian cerrados; (14) phosphorus pools in bulk soil and aggregates of differently textured Oxisols under different land-use systems in the Brazilian cerrados; (15) acid monophosphatase: an indicator of phosphorus mineralization or of microbial activity?A case study from the Brazilian cerrados; (16) microbial biomass, microbial activity, and carbon pools under different land-use systems in the Brazilian cerrados; (17) organic matter in termite mounds of the Brazilian cerrados; (18) pesticides in soil, sediment, and water samples from a small microbasin in the Brazilian cerrados; and (19) general conclusions. *--CAB Abstracts.*

Torri, D. 2001. Land use, soil qualities and soil functions: Effects of erosion [Italy]. **Source, from: valbook3 [European web site for: Leibniz-Zentrum für Agrarlandschafts- und Landnutzungsforschung (ZALF) e.V.] at URL:** http://www.zalf.de/essc/valbook3.htm

Scientists cannot evaluate soil quality in eroded/degraded areas until soil functions are determined, processes are modelled, and impacts assessed. W.E.H. Blum (Austria) maintains soil quality definitions must be function-based; SQ parameters must be defined by specific land use/function/ SQ indicators must be in framework of the OECD's "Driving Force>Pressure>State>Impact>Response" relationship or model (after the European Environmental Agency), for use by all socio-economic stakeholders involved in land management.

Trasar-Cepeda, C., C. Leiros, F. Gil Sotres, and S. Seoane. 1998. Towards a biochemical quality index for soils: an expression relating several biological and biochemical properties. *Biology & Fertility of Soils* [Berlin, Germany: Springer Verlag] 26, no. 2: 100-106.

Soil biological and biochemical properties are highly sensitive to environmental stress and thus can be used to assess quality. Any soil quality index should include several biological and biochemical variables so as to reflect better the complex processes affecting soil quality and to compensate for the wide variations occurring in individual properties. Many authors recommend the use of a native soil supporting climax quality reference soil. In this study which examined three such native soils of Galicia (N.W. Spain) bearing Atlantic oakwood as the climax vegetation, biological and biochemical properties were found to vary widely seasonally and with sampling site and depth. These variations were closely correlated with the total carbon (C) and/or total nitrogen (N) contents of the soils. The following equation: Total N=(0.38x10(3)) microbial biomass C +(1.4x10(3)) mineralized N +(13.6x10(3)) phosphomonoesterase +(8.9x10(3)) beta glucosidase + (1.6x10(3)) urease explained 97% of the variance in total N for the soils studied, suggesting that a balance exists between the organic matter content of a soil and its biological and biochemical properties. A simplified expression of the above equation may be useful as a biochemical quality index for soils. *Agricola 1998-2003 abstract*.

Truman, C., W. Reeves, J. Shaw, A. Motta, C. Burmester, R. Raper, and E. Schwab . 2003. Tillage impacts on soil property, runoff, and soil loss variations from a Rhodic Paleudult under simulated rainfall. Journal of Soil and Water Conservation 58, no. 5 (Sep-Oct).

These researchers did not attempt a SQ Index, but this is the type of study which could include SQI for testing.

Tugel, A. J., S. Seiter, D. Friedman, J. Davis, R. P. Dick, D. McGrath, and R. R. Weil. 2001. Locally led conservation activities : Developing a soil quality assessment tool. In: Sustaining the global farm—Selected papers from the 10th International Soil conservation Organization Meeting (ISCO99)D. E. Stott, R. H. Mohtar, and G. C. Steinhardt, 529-34West Lafayette, IN: International Soil Conservation Organization in cooperation with the USDA and Purdue University.

This paper presents the positive aspects of developing soil quality cards as assessment tools for use by farmers. Using the Wisconsin model, the USDA-NRCS 7 CES, 7 SQI developed 43 indicators of soil quality through farmer inputs, held workshops in 1997 & 1998 in Oregon & Maryland, USA; developed soil quality cards, tested their validity, & further applied the techniques across Illinois, Maryland, Montana, North Dakota, Ohio, & New Mexico, as well as Oregon (7 cards).

Turco, R. F., A. C. Kennedy, and M. D. Jawson. 1994. Microbial indicators of soil quality. Defining soil quality for a sustainable environment; Proceedings of a symposium, Minneapolis, MN, USA, 4-5 November 1992: 73-90. J. W. Doran, D. C. Coleman, D. F. Bezdicek, and B. A. Stewart, editors. Madison, WI: Soil Science Society of America.

Aspects of groundwork for selecting proper indicators to estimate the microbial component of soil quality are discussed. Methods addressing the size and diversity within the soil microbial community, especially bacteria, are considered. Generally microbial form and function in soil should use methods that estimate the diversity between ecosystems and/or estimate the community structure within ecosystems. The need to identify the minimal number of biological parameters that consider both processes and community diversity for estimating the role of the biotic component in determining soil quality is emphasized.

United Nations. Food and Agricultural Organisation (FAO). 1997. Land quality indicators and their use in sustainable agriculture and rural development, UN-FAO, Rome, Italy.

The Title page states: "Proceedings of the Workshop organized by the Land and Water Development Division, FAO Agriculture Department and the Research, Extension and Training Division, FAO Sustainable Development Department, 25-26 January 1996; Paper prepared under the Land Quality Indicators (LQI) initiative." Sponsored by UN-FAO, UN Development Programme (UNDP), UN Environment Programme (UNEP), and the World Bank.

United Nations. Food and Agricultural Organisation (FAO). 2003. Data sets, indicators and methods to assess land degradation in drylands ; Report of the LADA Email Conference 9 October - 4 November 2002, UN-FAO, Rome, Italy. From URL: http://www.fao.org/ag/agl/agll/oldocsl.jsp

This report summarizes the findings of the e-mail conference that took place from 9 October to 4 November 2002 and which was organized by the Land Degradation Assessment in Drylands (LADA) project. The report contains exchanges of views on data sets and methods that may be used to assess land degradation and a discussion on the biophysical, socio-economic and institutional indicators that explain the root causes, driving forces, status, impact and responses to land degradation at various scales.

United Nations. Food and Agricultural Organisation (FAO). 2003. Use of indicators in sustainable agriculture and rural development / Tschirley, Jeff. UN-FAO FAO Research, Extension and Training Division. Rome, Italy. From URL: http://www.fao.org/sd/epdirect/epan0001.htm

Institutional indicators
Although indicators of sustainable development pose an enormous challenge to develop, there are a number of entry points to begin work. For example, the governments of most countries already influence land use through their agriculture, forestry and fisheries policies and planning processes; they use various kinds of information to arrive at their decisions. But, traditional environmental indicators that focus on the use of pesticides and fertilizers, crop productivity, land conservation and so on, ignore human and institutional performance even though it is often the critical factor in success.
--From web site at URL: http://www.fao.org/sd/epdirect/epan0001.htm

United States Department of Agriculture, Natural Resources Conservation Service (NRCS). 2003. Soil Conditioning Index for cropland management systems. USDA-NRCS; at URL: http://soils.usda.gov/sqi/soil_quality/land_management/sci.html and ftp://ftp.nssc.nrcs.usda.gov/pub/agronomy/scifiles/latest_revisions

A tool to rate trend in SOM, in consideration with cropping systems and tillage practices; field scale; dynamic; reliable (Microsoft Excel spreadsheet products); part of standards of practice/best practices. Evolving; used 2-3 years; is incorporating soil databases in 2003 for modelling purposes. [See web page summary for details.]

United States Department of Agriculture, Technical Soil Services. 2000. Technical Soil Services [handbook]. From URL: http://soils.usda.gov/procedures/handbook/content/608ex7.txt

["indices" search results:]
NSSH Part 621 (Exhibits 1-5) | NRCS Soils
http://soils.usda.gov/technical/handbook/contents/part621p2.html
NSSH Part 622 (Exhibit 2) | NRCS Soils
http://soils.usda.gov/technical/handbook/contents/part622p2.html
Soil Quality Assessment | NRCS SQ
at URL: http://soils.usda.gov/sqi/soil_quality/assessment/
NSSH Part 608 (Exhibits 2-7) | NRCS Soils
http://soils.usda.gov/technical/handbook/contents/part608p3.html
NSSH Part 621 (00-11) | NRCS Soils
at URL: http://soils.usda.gov/technical/handbook/contents/part621.html
Soil Quality Concept Articles | NRCS SQ
http://soils.usda.gov/sqi/soil_quality/what_is/sqconcept.html
NSSH Part 601 | NRCS Soils
http://soils.usda.gov/technical/handbook/contents/part601.html
NSSH Part 614 (Exhibit 2) | NRCS Soils
http://soils.usda.gov/technical/handbook/contents/part614p2.html
Examples:
NSSH Part 608 (Exhibits 2-7) | NRCS Soils
Workload Analysis -- Annual Plan of Operations (Exhibit 608-2)
INTERPRETATIONS [form] -- includes:
"In a narrative, describe: What soil performance data (e.g. crop yields, site **indices**) are collected and how?"
--From URL: http://soils.usda.gov/procedures/handbook/content/608ex7.txt
NSSH Part 622 (Exhibit 2) Ecological and Interpretative Groups (Part 622) Land Capability Classification (Agriculture Handbook 210) (Exhibit 622-2). CONTENTS includes:
"Soil-woodland **site index** correlations are essential for interpreting the potential wood production of the individual soil units that are mapped. Woodland-site indices are commonly developed for individual kinds of soils. Soil-mapping units can be placed in woodland groupings according to **site indices** for adapted species and other responses and limitations significant to woodland conservation. Such groupings do not necessarily parallel those for capability units or range sites; however, in some areas capability units may be grouped into range sites and woodland-suitability groups."

--From: soils.usda.gov/procedures/handbook/content/622-ex2.htm --*Online excerpts.*

United States Department of Agriculture (USDA). National Soil Survey Center. 1996. Indicators for soil quality evaluation. *USDA Soil Quality Information Sheet*, Apr 1996: 2pp. From URL: http://soils.usda.gov/sqi and http://www.ftw.nrcs.usda.gov/ "Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA."

United States Department of Agriculture (USDA). Natural Resources Conservation Service. 2001. Rangeland soil quality—Indicators for assessment and monitoring. *USDA Soil Quality Information Sheet*: *Rangeland Sheet no.2*, May 2001; 2pp. From URL: http://soils.usda.gov/sqi **and** http://www.ftw.nrcs.usda.gov/glti

United States Department of Agriculture (USDA). Natural Resources Conservation Service (NCRS). 2001. *Guidelines for soil quality assessment in conservation planning*. From URLs: http://policy.nrcs.usda.gov/scripts/lpsiis.dll/TN/TN_SOI_1_1.htm and http://www.statlab.iastate.edu/survey/SQI/catalog.html

The publication provides guidelines for assessing soil quality in the context of the nine-step conservation planning process. It compliments the material taught in the National Employee Development Center (NEDC) course, "Soil Quality Assessment and Application for Field Staffs." It also illustrates the practical use of tools and information developed by the Soil Quality Institute and provides information relating specific practices in the Field Office Technical Guide to solving soil quality problems. The information is primarily intended for use in the planning process, but can also aid with conducting informal soil quality assessments, or as an educational resource for teaching about soil quality. The guide is intended for as wide an audience as possible. --Accessed Sept.09.03,clh.

United States. National Soil Tilth Laboratory. 2000. Soil quality information sheets. USDA-NRCS. From URLs: http://www.nstl.gov/pubs/reprintlist.html ; http://library.ncsu.edu/MARION/ANA-9776

United States. Natural Resources Conservation Service, Soil Quality Institute. 1996. *The Soil quality concept booklet.* From URL: http://soils.usda.gov/sqi/soil_quality/what_is/sqconcept.html

The Soil Quality Concept Booklet is **a** set of reprints compiled by the NRCS Soil Quality Institute in 1996. Preface: Eight key papers on soil quality (as judged by the Soil Quality Institute staff) were selected for inclusion in this volume. The authors of the papers present the concept of soil quality from several different perspectives:

Aldo Leopold (1933), as a forester with the US Forest Service, was one of the first to envision conservation of the land. He discusses the fundamental concept of conservation and provides the theoretical foundation for the concept of soil quality.

Larson and Pierce (1991) were the first to write a comprehensive paper on soil quality that established the theory and concepts on which soil quality is currently based.

Karlen et al. (1997) describe the background and development of the concepts of soil quality and discuss the theoretical reasoning and rationale for its existence in soil science. They also provide the current thinking on the definition and vital functions of a soil.

Warkentin (1995) focuses on soil functions, describing them from an ecological perspective. Soil function is a major conceptual component in understanding and assessing soil quality.

Seybold et al. (1997) reviewed the literature on the concepts of soil quality, soil quality indicators and indices, and issues of scale. They also present a theoretical framework for assessing soil quality.

Kennedy and Papendick (1995) give a good overview of the soil biological component of soil quality. Soil biology has not been emphasized in the past because of its dynamic nature, but it is a major driving force behind the soil quality concept.

Parr et al. (1992) discuss the relationship between soil quality and sustainability in agricultural systems, and the need for a soil quality index and monitoring programs at national and global scales.

Doran et al. (1994) apply the concept of soil quality to real situations, and provide some strategies for maintaining or enhancing the quality of soils in agricultural systems.

Leopold, Aldo. 1933. The Conservation Ethic. *J. Forestry* 31:634-647.

Larson, W.E. and F.J. Pierce. 1991. Conservation and Enhancement of Soil Quality. In: *Evaluation for Sustainable Land Management in the Developing World.* P. 175-203. Int. Board for Soil Res. and Management, Bangkok, Thailand.
Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman. 1997. Soil Quality: A Concept, Definition, and Framework for Evaluation. *Soil Sci. Soc. Am. J.* 61(1):4-10.
Warkentin, B.P. 1995. The Changing Concept of Soil Quality. *J. Soil Water Cons.* 50:226-8.
Seybold, C.A., M.J. Mausbach, D.L. Karlen, and H.H. Rogers. 1997. Quantification of Soil Quality. In: B.A. Stewart and R. Lal (eds.) *Advances in Agronomy*. Proceedings from an International Symposium on Carbon Sequestration in Soil. Lewis Publishers.
Kennedy, A.C. and R.I. Papendick. 1995. Microbial Characteristics of Soil Quality. *J. Soil Water Cons.* 50:243-8.
Parr. J.F., R.I. Papendick, S.B. Hornick, and R.E. Meyer. 1992. Soil Quality: Attributes and Relationship to Alternative and Sustainable Agriculture. *Am. J. Altern. Agric.* 7:5-11.
Doran, J.W., M. Sarrantonio, and R. Janke. 1994. Strategies to Promote Soil Quality and Health. In: C.E. Pankhurst, B.M. Doube, V.V.S.R. Gupta, and P.R. Grace (eds.) *Soil Biota: Management in Sustainable Farming Systems.* P. 230-237. CSIRO, Australia.

University of Illinois at Urbana-Champagne. ACES. 2000? Illinois participatory research programs. University of Illinois. From URL: http://www.aces.uiuc.edu/~IPRP/illinois1.html

Agro-Ecology/Sustainable Agriculture Program -- The sustainable agriculture program at the University of Illinois, College of Agricultural, Consumer and Environmental Sciences.
Illinois Soil Quality Initiative -- ISQI participants include individual farmers and various organizations and associations who are working together to identify **soil quality indices** farmers can use to make decisions about their own stewardship goals.
Partnership Illinois -- A new initiative at the University of Illinois at Urbana-Champaign, designed to coordinate public service and outreach efforts, increase their impact, and create new opportunities to serve the state.
On-Farm Research @ UIUC -- Participatory on-farm research projects conducted by farmer-cooperators have addressed primarily nitrogen fertilizer reduction in corn, reduced herbicide use, and tillage and rotation systems and their impact on soil tilth and root growth.
--*From web site at URL:* http://www.aces.uiuc.edu/~IPRP/illinois1.html *-- MSN online abstract.*

University of Illinois at Urbana-Champaign. Department of Natural Resources and Environmental Sciences (NRES). 1998. *Illinois Soil Quality Initiative (ISQI).* University of Illinois. From URLs: http://www.ag.uiuc.edu/~vista/ ; http://www.agr.state.il.us/C2000/fy98/97-62.html **;** www.agr.state.il.us/C2000/fy97/96-40.html **; http://web.aces.uiuc.edu/vista/pdf_pubs/ISQI97.PDF**

Valarini, P. J., M. S. Garrido, A. Fernandez Santander, and C. Romero. 2002. Evaluation of biological parameters as indicators of the integral soil health after organic treatments; Comparison with physico-chemical parameters. In: Man and soil at the Third Millennium; Proceedings [of the] International Congress of the European Society for Soil Conservation, Volume 1: 923-928. J. L. Rubio, R. P. C. Morgan, S. Asins, and V. Andreu, editors. Logrona , Spain: GEOFORMA Edicions, S.L.

The purpose of the paper was to study the influence of different types and doses of organic matter incorporated in one soil sample from lower terraces of Tajo river (Spain) on physico-chemical and biological properties. The treatments were: (1) soil samples plus 25 and 50 t/ha of composted animal manure (E25 and E50); (2) soil samples plus 15 and 30 t/ha of several green crop residues and weeds (RC15 and RC30); (3) soil samples plus plant leaf residues of Platanus hispanica (P. acerifolia) (HP15 and HP30); (4) without organic matter addition (control, T); bean seeds (Phaseolus vulgaris) were sowed in every treatment. The physico-chemical and biological parameters were evaluated at the beginning of the experiment and after three months. Results showed considerable increases in the microbiological (exopolysaccharides and alkaline phosphatases and esterases enzymes), chemical (organic matter and cation exchange capacity) and physical properties (field capacity). There is a significant correlation between biological activity parameters (alkaline phosphatases, esterases and polysaccharides) and chemical parameters (cation exchange capacity and oxidizable organic matter). This fact points to the use of those biological parameters as integral soil health indicators. *--CAB Abstracts.*

Vigier, B., E. G. Gregorich, D. Kroetsch, and D. King. 2003. Soil Quality Evaluation Program: Soil quality benchmarks sites: Sites 14 ON & 44 ON - Rockwood; Site description report (Revised edition 2003). From URL: http://res2.agr.gc.ca/ecorc/r1444/index_e.htm

Soil quality has been defined as "***the soil's fitness to support crop growth without becoming degraded or otherwise harming the environment*** " (Acton and Gregorich, 1995). However, no quantitative methods to determine soil quality at the farm or regional level are available at the present time. The absence of methodologies to evaluate soil health is in part associated with a lack of understanding of the soil ecological processes in sustaining plant growth and environmental quality (Hatfield and Stewart 1994).

The Research Branch of Agriculture and Agri-Food Canada initiated a pilot project in eastern Canada to establish benchmark sites to monitor trends in soil quality. This study was adopted nationally in 1990 by the National Soil Conservation Program (N.S.C.P.) as part of the Soil Quality Evaluation Program (S.Q.E.P.).

By 1992, a network of 23 benchmark monitoring sites had been established across Canada for assessing trends in soil quality change within existing farm management systems. Various land, soil, and crop characteristics were to be monitored for at least 10 years and characterization of baseline soil and site conditions were to be completed. By 1994, the reporting of baseline datasets was completed for fourteen sites across Canada (Wang *et al.* 1994). However the Rockwood site in Ontario was completed in 1995 and was used as part of a complementary study, through the Ontario-Canada Green Plan program. Studies carried out at the Rockwood site include data collection on microbial biomass and organic carbon, soil enzyme activity, soil organic matter components and spatial variation analyses.

Objectives:

A "case study" approach is used for the benchmark study to monitor the trends in soil quality change. **Two basic assumptions underlie this approach:**

Landscapes of the benchmark sites are representative of major agroecosystems and are managed under typical farm production systems and could be characterized in detail to create baseline data sets to make soil quality assessments; and

Monitoring selected soil variables within these landscapes (benchmark sites) for 10 or more years would allow for the evaluation of trends in soil quality change.

In addition, it was anticipated that benchmark site information could be used to support expert systems research and development for making general statements on soil quality trends regionally and nationally.

National objectives for establishing benchmark sites were the following:

To provide baseline and reseampling data sets for assessing changes in soil quality and productivity indicated by typical farm production systems.

To provide data to test and validate simulation models that predict soil degradation and productivity.

To provide a way to evaluate whether farming systems in the major agricultural regions of Canada are sustainable with respect to soil quality.

To provide a national network of sites that can be used by government and non-government groups to conduct cooperative research.

Virginia Polytechnic Institute and State University, Virginia Cooperative Extension, and Diane Relf. 2001. *Building healthy soil.* From URL: http://www.ext.vt.edu/pubs/envirohort/426-711/426-711.html

This extension material covers basic soil attributes: --

"Caring for the garden soil should be as important to home gardeners as it is to farmers. Improving the soil structure is one of the most important aspects of soil care, and adding organic matter is the most effective way to accomplish this. Organic matter also helps maintain the pH balance of the soil and adds nutrients. Good topsoil is

relatively dark in color

active with microorganisms, plant nutrients, and organic matter, and

usually has a pH between 5.5 and 7.5 (for non-acid loving plants).

Improve the Soil Structure

As the structure of a soil is made more granular and crumbly by decomposing organic matter, the soil absorbs moisture that would otherwise run off, causing erosion and a loss of nutrients in the process. Good soil structure provides channels through which water and air can filter to greater depths. When rain comes after a dry spell, soil that is hard on the surface is much more subject to rapid runoff and erosion than one that is loose and crumbly.

Organic matter in the soil also ensures a continuous food source for soil organisms. As the organisms decompose the organic materials, they help maintain good soil structure, making the soil a more favorable place for root development. The decomposition process improves the soil structure by developing compounds that cement small soil particles together into aggregates, allowing for both increased drainage and moisture retention. Decomposition also changes the organic matter into inorganic nutrients that can be used by growing plants.

Incorporating organic matter aids in sustaining the organic content of the soil. However, organic matter cannot be built up permanently in the soil because it continually decomposes and disappears; soil building must be a continual process in the garden."

Visser, S., and D. Parkinson. 1992. Soil biological criteria as indicators of soil quality : Soil microorganisms. American Journal of Alternative Agriculture 7, no. 1-2: 33-37.

Visser and Parkinson (1992) review microbiological studies that had been done at a species population level and a community structure level and soil process at the ecosystem level. They argue for an indicator focus at the soil process level (i.e., decomposition rates, soil respiration, microbial biomass carbon, nitrogen cycling, and soil enzyme measurement). --[*from Freyenberger's et al. annotated bibliography: SQI Lit.ID #214, p.9*]

Wagenet, R. J., and J. L. Hutson. 1997. Soil quality and its dependence on dynamic physical processes. Journal of Environmental Quality 26:41-48.

This position paper advocates consideration that "soil is a dynamic system" and SQ indexing has two major shortcomings: "First there is always the question of the functional relationships of the components of the index. Should they be additive, multiplicative, or some more complicated combination of the assumed soil characteristics? How should they be weighted, and what influences the weighting? Esentially, any index of soil quality is limited by the attempt to represent a complex, interacting system as a composite of discrete parts. This fundamental difference between reality and the index seems to be almost forgotten.
Second, soil quality indices are estimators of changes in the soil condition that have occurred since the last time the index was measured. They use soil characteristics measured at several times to estimate long-term trends. The characteristics are static, instantaneously measured (by comparison with a process, which operates continuously over time) manifestations of soil quality. Using indices, trends in soil quality are thereby estimated by looking from the current condition backward to the previous conditions. This retrospective approach allows estimation of the impact of previous management practices upon the current soil characteristics, but does not indicate future soil conditons that may result from the accumulative effects of those management practices over time ...." (p.42).

Walker, J., and D. J. Reuter. 1996. Indicators of catchment health: a technical perspective, CSIRO Publishing, Collingwood , Australia.

This publication gives information for the identification of the most useful indicators for assessing the impact of farming practices on catchment health. The 4 sections (12 chapters) deal successively with: the indicator approach (1 paper); key indicators (1 paper); the report card (a case study from New South Wales, Australia, 1 paper); and technical considerations (9 papers covering indicators of farm productivity, product quality, soil health, water quality, landscape integrity). --*CAB Abstracts.*

Wander, Michelle M., and G. Bollero. 1999. Soil quality assessment of tillage impacts in Illinois. *Soil Science Society of America Journal* 63: 961-971.

36 sites of ND, CT & NT practices in Illinois are compared, at Field-scale; tested in the 1995 & 1996 growing seasons. Soils were sampled from 100m x 100m plots, & lab-tested on 23 parameters, using analysis of variance (ANOVA) & principal component analysis (PCA). A detailed outline of tests is given, so the research demonstrates reliable & replicable testing, in this static study. It identifies minimum data sets for analysis of the most significant parameters: SOM (as C) & practices = No-till. There is rational use of numerical indexing methods, & complex data sets analyses. It would be difficult for farmer-based use (needs expertise to interpret & apply the statistical procedures.--(ch notes).

Wander, Michelle M., and L. E. Drinkwater. 2000. Fostering soil stewardship through soil quality assessment. Applied Soil Ecology 15: 61-73.

Wander, Michelle M., Gerald L. Walter, Todd M. Nissen, German A. Bollero, Susan S. Andrews, and Deborah A. Cavanaugh-Grant. 2002. Soil quality: Science and process. Agronomy Journal 94, no. 1 (Jan/Feb): 23-32.

This paper provides an outline/summary of the Illinois Soil Quality Initiative. Inputs, (corn) crop yield responses, minimum data sets, soil attribute selection for SQ indexing, & monitoring of soil ecosystem functions are discussed. On-farm research occurred in 1995 & 1996 on 36 farms, with conventional tillage & no-till practices were compared to adjacent benchmark samples from grassways, roadways, woodlots, or yards. --Multivariate analysis to data grouping/ranking; Vertical sampling on multiple soil properties;

incorporated farmer SQ assessments (Table 12, p.28). --Focus groups of farmers used to determine soil functions to rank measures on: available N, available P, K, SOC, & pH, soil water retention, residue, porosity, aggregate stability, C, macropores, POM/SOC ratio, bulk density, penetration resistance, C & pH. --Ranges of scores summed & treatments (CT, NT or ND) presented (Table 2, p.29). --Then radar graphs are used to represent the scores, to represent SQ indices for inherent soil properties & SOM, with each axis depicting a soil indicator & showing mean scores. -- "Index" = mean score from data range of individual samples, aggregated & summed; No indication how data sets were normalized in this paper, except graphically (--ch notes).

Wang, C., B. D. Walker, and H. W. Rees. 1997. Establishing a benchmark system for monitoring soil quality in Canada. Chapter 15 In: *Soil quality for crop production and ecosystem health*. E. G. Gregorich, and M. R. Carter, 323-337. Amsterdam: Elsevier.

Wang, C., B. D. Walker, H. W. Rees, L. M. Kozak, M. C. Nolin, W. Michalyna, K. T. Webb, D. A. Holmstrom, D. King, E. A. Kenney, and E F. Woodrow. 1993. Benchmark sites for assessing soil quality change. Section 5 In: *A Program to assess and monitor soil quality in Canada: Soil quality evaluation program summary (Interim report)*; Pp. 5-1 to 5-8. D. F. Acton, editor. Ottawa: Centre for Land and Biological Resources Research, Research Branch, Agriculture Canada.

Wang, XiaoJu, and ZiTong Gong. 1998. Assessment and analysis of soil quality changes after eleven years of reclamation in subtropical China. *Geoderma* 81, no. 3/4: 339-355.

A method for assessing and mapping soil quality changes in time and space in small watersheds is presented. It was developed and used to evaluate the changes in soil quality after 11 years of reclamation at Qian-Yan-Zhou experimental station (QYZES) in subtropical China. Changes in soil quality were assessed and analysed for cropland, citrus orchards, pasture land, grassland, sparse weed land, artificial forests, natural forests, bare land, and other land uses. The Qian-Yan-Zhou Soil Quality Information System (QYZSQIS) was developed using ARC/INFO and FOXBASE software. Two concepts of **Relative Soil Quality Index (RSQI)** and its difference (DELTA RSQI) were introduced and used in the evaluation and analyses. By combining the QYZSQIS with databases of soil properties for different time periods, the system provided an effective method for evaluating soil quality changes in time and space in small watersheds. The RSQI provided a standard for comparing regional soil quality and the DELTA RSQI a standard for evaluating soil quality changes over time. After 11 years of reclamation, there was a decrease in the area of both low quality and high quality soils, while medium quality soils increased. In terms of land use systems, the soil quality in paddy fields, vegetable fields, and citrus orchards was mainly improved, whereas fuel woods, sparse weed land, and bare land were mainly degraded. Annual grass played an important role in the conservation and improvement of soil quality in the area. These results also showed that it was of equal importance to improve soil quality in degraded locations and to sustain it in high quality areas. *--CAB Abstracts.*

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> We evaluated the temporal variation of microbial biomass C, beta-glucosidase, acid phosphomonoesterase (acP), alkaline phosphomonoesterase (alP), and protease activity over 18 consecutive months. The likely causes for the seasonal variability at a non-degraded and a degraded site in south-western Nigeria were identified. Microbial biomass, alP, and beta -glucosidase activity were sensitive indicators of soil quality changes over time. Microbial biomass C correlated significantly with soil moisture conditions and soil organic matter-related parameters. AlP and beta -glucosidase activities were not controlled by climatic conditions over the course of two rainy seasons and one dry season but were temporally related to microbial biomass C and total C and N. Due to the steadiness of the alp activity over time the enzyme is considered a suitable indicator with which to monitor long-term changes of soil quality. Single sampling during the course of a year is adequate. *--CAB Abstracts, excerpt.*

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> Agriculture at Ibadan, Nigeria, on a well-drained Alfisol belonging to the Egbeda-Iwo series. Sampling sites were selected with varying degrees of degradation from 3 long-term experiments (WB1, D2 and WB3 in order of degradation severity). Soil microbiological and soil biochemical parameters (pH, exchangeable basic cations, inorganic and organic phosphorus pools, total organic carbon and total nitrogen, microbial biomass carbon, acid and alkaline phosphatase, beta -glucosidase and protease activity) were identified as indicators of soil quality under improved fallow management systems. *--CAB Abstracts, excerpt.*

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> "**Sensing Soil Quality** is a technological approach for rapid assessment and large area surveillance of soil condition. The technology is based on rapid screening of soil quality using a portable reflectance spectrometer. Soil properties and soil quality indices are predicted from spectral libraries, using calibrations based on few samples. Spectral libraries constructed from soils sampled from geo-referenced locations are then used in conjunction with remote sensing imagery to map out soil quality and soil constraints over entire river basins. We also present spectral libraries for African soils and organic (plant litter) resources." Includes Links to: Sensing Soil Quality in Lab and Field; Spectral Library of African Soils; Spectral Library of

Organic Resources; Sensing Soil Functional Attributes; Sensing Organic Resource Quality

World Bank. 2003. World Development Indicators 2003. From web site at URL: http://www.worldbank.org/data/

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Soil quality indices are attempts to classify soil conditions and to compare these conditions to their historical use. From this information it may be possible to determine which uses of soils are better for the long range goals of agriculture and society. With many factors involved in the profitable production of safe foodstuffs without significant degradation of the environment and soils, an indicator that represents a broad biological perspective of quality is appropriate. Among a group of biological indicators, the ratio of crop N uptake to mineralized N as determined by microbial respiration plus net mineralized N found over a growing season is an useful indicator of soil quality. An evaluation of the 12 year old Farming Systems Trial at the Rodale Institute Research Center indicated that soils in plots that had been conventionally managed were of lower quality than soil treated with manure or planted with legume cash grain crops. *--Agricola 1998-2003 database.*