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)