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Soil Quality Index of land impacted by anthropogenic activities in coastal Ghana

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Abstract
The excessive use of weedicide and fertilizer by farmers, indiscriminate waste disposal as well as unregulated and pervasive chemical use for mining and industry has huge impacts on the sustainability of soil resource. However, land use-specific characterization of soil has not been extensively studied. The soil quality of 4 different land use classes-cultivated soils, industry, decommissioned waste dump and forest reserve that depict different anthropogenic effect in urban and rural settings were assessed. Twelve composite samples were taken per site at a depth of 30cm with an auger, air dried and sieved with 2mm mesh and portions used for analysis. Soil mineral parameters analyzed include bulk density, reaction pH, organic carbon, total nitrogen, phosphorus, exchangeable cations: sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), and extractable trace elements: manganese (Mn), nickel (Ni), iron (Fe), cadmium (Cd), copper (Cu), zinc (Zn) and lead (Pb). The mean %SQIs for soil samples collected from cultivated soils, decommissioned dump, industrial and forest reserved sites are 54.9%, 57.6%, 60.6% and 61.4% respectively. Mean concentrations of Cd, Pb and Ni are 0.020 mg/kg, 1.301 mg/kg and 0.213 mg/kg, respectively. There were significant variations pairwise between cultivated soil and forest reserve soil and then cultivated and industrial soil ($p < 0.05$). Assessing soil quality (SQ) through evaluation of changes in soil properties across different land use classes is an essential tool for proper management to promote sustainable use to sustain life.

Keywords
soil, pesticide, waste, heavy metal, Ghana.

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Introduction

Flora and fauna derive their very existence from soil hence soil quality is very important for sustainability of the earth. It is apparently clear that proper land use practices have not been adhered to by mankind thereby creating problems for many communities. Upholding soil quality is the most effective means of ensuring food security to support life (de la Guardia & Garrigues, 2012). Man typically satisfies the basic physiological needs of air, water, and food before considering issue of safety (Block, 2011) and other qualities of life, such as the environment in which they live. The increase in anthropogenic influence on the soil resource globally is largely contributed by climate change and the phenomenon of agriculture and industry. The increase inappropriate land use practices on soil resource has necessitated the need to measure the effects on the soil resource in order to provide solutions to ensure sustainability of the practices (Oliver, Bramley, Riches, Porter, & Edwards, 2013). Generally soil quality will have to take into account societal goals for a specific ecosystem and land use (Doran & Parkin, 2015). There is also the need for a concerted effort to permanently prevent further environmental degradation of soil resource by applying sound and effective management strategies to soils that are prone to contamination (Sims, Cunningham, & Sumner, 1997).

Varied definitions are given to soil quality and the key phrase that runs through most of the definitions is the concept of specific function of the soil that is critical to meet management goals (Andrews, Karlen, & Cambardella, 2004; Carter, 2002).

Similarly, Karlen et al. (1997) proposed that soil quality be defined 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." Soils have various functions that are inextricably linked to its quality. As mankind becomes more aware of the environment, soil quality definitions have expanded from the simple association with production and serving as an environmental buffer to protection of watersheds and ground waters from agricultural chemicals, industrial and municipal wastes and sequestering carbon that would otherwise contribute to global climate change (Reeves, 1997).

Soil is an important source of nutrients in food supply and plant based medicines however poor soil fertility and high levels of potential toxic compounds, heavy metals and antibiotics pose threat to these vital resources. Contributing to these is the excessive use of weedicide by farmers, indiscriminate waste disposal along with unregulated and pervasive chemical use for mining and industry. Soil properties and conditions are critical in the production of sufficient and nutritious crops. Contaminated soils may be toxic and can transfer those substances to humans through crop uptake, leading to contaminated foods that compromise food security (Steffan, Brevik, Burgess, & Cerdà, 2018). In Africa, most people rely on plants as a source of medicine besides food which makes it imperative to maintain proper soil quality to avoid exposure to contaminants through soil.

Till date, there has been no systematic assessment of heterogeneities in soil quality index in Ghana across land use types (cultivated soil, industry, decommissioned waste dump and forest reserve). This is a fundamental motivation for this study. In assessing the quality on the backdrop of the possible physical and chemical changes in soil properties, Visual soil quality assessment and interpretation is vital, but visual soil assessment alone cannot be used to assess effectively the status of ecosystem services determined by biological and chemical soil processes (Ball et al., 2017). Since visual soil assessment gives different information than laboratory approaches (Emmet-Booth et al., 2016) and its assessment by semi-quantitative visual soil evaluation (VSE the combination of both is imperative. Visual soil assessment is important in yield gap analysis and land management programs (McKenzie et al., 2015) it is expedient to develop soil quality index (SQI) that integrates the specific measured soil properties into a single parameter that could be used as an indicator of soil quality (Amacher, O'Neill, &

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Perry, 2007). Human practice regarding land use in rural settings may differ from that of the urban in relation to agriculture production, waste disposal and industrial use. However, the soil quality index of agricultural soils could be compared with soils under different land uses. This study is aimed at analyzing the physical and chemical properties of soils with different uses to generate a soil quality index data.

Materials and Methods

Soil sample locations

Soil sampling was conducted in four sites within Greater Accra and Central Regions of Ghana. Three of the sampling sites are in the Greater Accra and one site in the Central Region. The sampling sites represent four land use classes-cultivated soil, industry, waste dump and forest reserve that depict different anthropogenic effect in urban and rural settings. The sites in Accra are within an urban area and separated about 9km apart and 140km from the last location in the Central Region. Cultivated soils were sampled from the environs of the Council for Scientific and Industrial Research (CSIR) head office within an urban setting. The area remains a major vegetable growing site all year for over 50 years and the continuous application of pesticides, organic and inorganic fertilizer. Soil from the dump was taken within 200m from the Adenta decommissioned dump that received all manner of solid waste from most part of the capital for many decades. The industrial soils were taken from Accra North industrial area that has most of the companies that make plastic products and samples from the forest reserve were taken from Kakum National Park, in the Central Region. The park is located in the rural coastal environs of the Central Region and covers an area of 375 square kilometres with tropical forest.

Soil sample collection

Soils were randomly sampled with auger at a depth of 30 cm from four (4) different locations to represent decommissioned dump, agricultural soils, industrial and forest reserved soils. Composite soil samples were generated by physically mixing soil samples taken within an area of a location into one homogenous sample. Twelve (12) of such

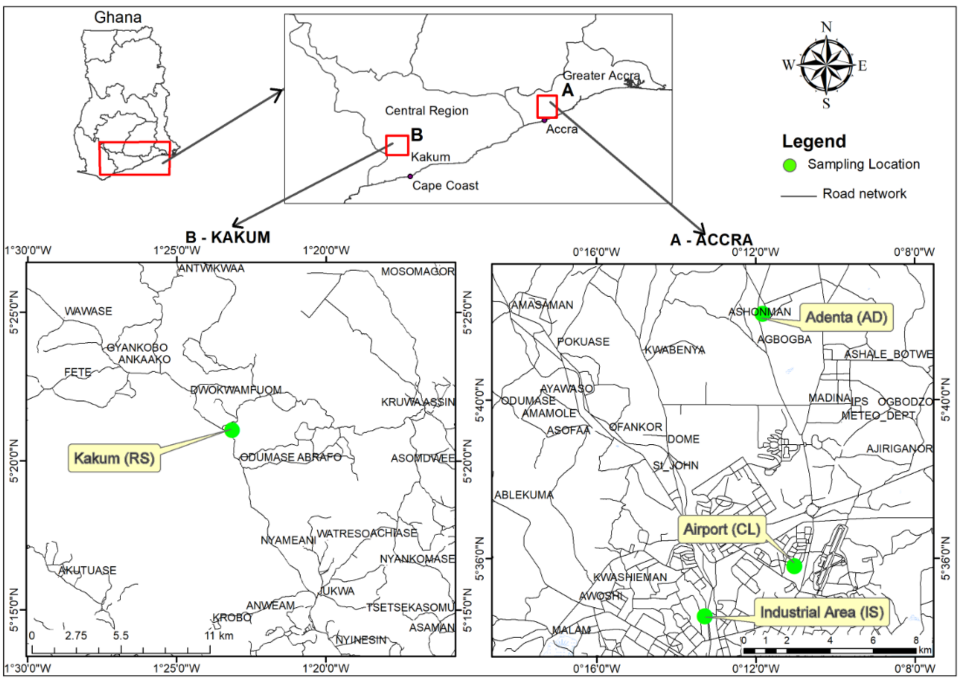

Figure 1. *Map of geographical location of sampling areas.*

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homogeneous samples were made per location, initially stored in aluminum foil and taken through preparatory procedures. The samples were air dried at room temperature, homogenized and sieved (2mm mesh) before use to determine the physicochemical characteristics properties of the soils.

Physicochemical analysis of soil samples

Soil particle size analysis was carried out using the pipette method as described by (Rowell, 1994). Soil reaction pH and electrical conductivity (EC) were measured in 1:2.5 soil: water suspension. Total nitrogen was determined by the Kjeldahl method (Sparks et al., 1996). Available phosphorus contents in soils were extracted by Bray's P1 solution and measured on Genesys 20 spectrophotometer (Bray & Kurtz, 1945). Organic carbon was determined by the wet oxidation method (Nelson & Sommers, 1996). Analyses of the exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were done by the method described by (Rowell, 1994) and determined with Jenway PFP7flame photometer. Heavy metals were extraction using aqua regia according to (Verloo and Demeyer 1997) and determined with Atomic adsorption spectrophotometer (AAS), Agilent Technologies 200 series 240FS AA and Graphite Tube Atomizer 240ZAA.

Mineral soil property threshold values shown in table 1 (Amacher et al., 2007) were used as basis for the determination of the SQI. The individual index values for all the mineral soil properties are computed to give a total SQI: The SQI which was originally developed by Amacher et al 2007 was meant to assess forest soil quality and establish baseline levels for different soil.

$$\text{Total SQI} = \sum \text{individual soil property index values} \qquad [1]$$

Parameter	Level	Index
Bulk density (g/cm³)	> 1.5	0
	1.5	1
pH	<3.0	-1
	3.01 to 4.0	0
	4.01 to 5.5	1
	5.51 to 6.8	2
	6.81 to 7.2	2
	7.21 to 7.5	1
	7.51 to 8.5	1
	> 8.5	0
Total organic carbon in mineral soils (percent)	> 5	2
	1 to 5	1
	< 1	0
Total nitrogen in mineral soils (percent)	> 0.5	2
	0.1 to 0.5	1
	< 0.1	0
Exchangeable Na percentage (exchangeable Na/ECEC x 100)	> 15	0
	≤15	1
0.03 M NF4 + 0.025 M HCl (Bray 1) P (mg/kg	> 30	1
	15 to 30	1
	< 15	0
K (mg/kg)	> 500	2
	100 to 500	1
	< 100	0
Ca (mg/kg)	> 1000	2
	101 to 1000	1
	> 10 to 100	0
	< 10	-1

Parameter	Level	Index
Mn (mg/kg)	50 to 500	1
	< 50	0
	> 100	0
	< 1	0
Fe (mg/kg)	> 10	1
	0.1 to 10	1
	< 0.1	0
Ni (mg/kg)	> 5	0
	0.1 to 5	1
	< 0.1	1
Cu (mg/kg)	> 1	0
	0.1 to 1	1
	< 0.1	0
Zn (mg/kg)	> 10	0
	1 to 10	1
	< 1	0
Cd (mg/kg)	> 0.5	0
	0.1 to 0.5	1
	< 0.1	1
Pb (mg/kg)	> 1	0
	0.1 to 1	1
	< 1 0.	1

Table1.
Soil quality index values and associated soil property threshold values (Amacher et al., 2007).

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The maximum value of the total SQI is 26 if all 19 soil properties are measured however 16 properties were measured with a total SQI value of 22. The total SQI is then expressed as a percentage of the maximum possible value of the total SQI for the soil properties that are measured:

% SQI = (total SQI / maximum possible total SQI for properties measured) ×100 [2]

Results and Discussion

The results of table 2 show the variations in soil mineral parameters of the study sites, indicating high variation in iron levels. Manganese level of dump soils was about 3 fold that of industry and cultivated soil while zinc level was about 8 fold that of cultivated and reserved soils. The high levels of zinc and manganese in the dump soils originate from combustion and decay of waste products containing these metals. Soil exchangeable cations are important nutrient parameter and they remain fairly distributed across sites.

Table 2. *Statistical results of mean soil quality parameters and threshold*

Parameter	Dump	Agricultural	Industrial	Reserve	Threshold	
					CEC 1986	(MEF, 2007)
Fe (mg/kg)	361.338 ± 61.97	165.506 ± 62.01	549.426 ± 49.31	605.845 ± 36.12	NA	NA
Mn (mg/kg)	11.713 ± 1.17	3.373 ± 1.53	4.049 ± 0.68	2.501 ± 0.49	NA	NA
Cd (mg/kg)	0.035 ± 0.01	0.002 ± 0.00	0.041 ± 0.05	0.002 ± 0.00	3.0	1
Pb (mg/kg)	2.693 ± 0.66	0.309 ± 0.18	1.766 ± 0.49	0.436 ± 0.03	300.0	60
Ni (mg/kg)	0.367 ± 0.10	0.154 ± 0.06	0.177 ± 0.01	0.153 ± 0.04	75.0	50
Cu (mg/kg)	2.787 ± 1.23	0.143 ± 0.02	0.910 ± 0.30	0.157 ± 0.03	140.0	100
Zn (mg/kg)	9.939 ± 0.61	0.652 ± 0.13	4.806 ± 1.62	1.244 ± 0.28	300.0	200
OC (%)	1.272 ± 0.297	1.174 ± 0.432	1.046 ± 0.476	0.913 ± 0.471	NA	NA
N(%)	0.106 ± 0.030	0.098 ± 0.038	0.088 ± 0.041	0.076 ± 0.039	NA	NA
Ca (mg/kg)	3.559 ± 1.227	3.309 ± 1.450	3.032 ± 1.557	2.558 ± 1.399	NA	NA
Mg(mg/kg)	0.534 ± 0.184	0.496 ± 0.218	0.455 ± 0.234	0.384 ± 0.210	NA	NA
Na (mg/kg)	0.177 ± 0.054	0.160 ± 0.066	0.147 ± 0.072	0.124 ± 0.064	NA	NA
K (mg/kg)	0.012 ± 0.003	0.010 ± 0.004	0.009 ± 0.004	0.008 ± 0.004	NA	NA
P (mg/kg)	2.566 ± 0.782	2.187 ± 0.744	1.885 ± 0.780	1.662 ± 0.808	NA	NA
pH	4.668 ± 1.689	4.193 ± 1.897	3.731 ± 1.949	3.196 ± 1.817	NA	NA
BD	1.413 ± 0.039	1.472 ± 0.019	1.466 ± 0.028	1.336 ± 0.023	NA	NA

The SQI is a tool for determining baselines and classifying soil health trends. Soil quality index for the various sites are shown as plotted bars to allow for sites comparisons of the different SQI values (fig2). The mean SQIs for soil samples collected from cultivated soils, decommissioned dump, industrial and forest reserved sites are 12.08, 12.67, 13.33 and 13.5 representing 54.9%, 57.6%, 60.6% and 61.4% quality, respectively. The distribution of SQIs for soil samples collected from the different sites shows that there were variations in individual mineral soil property among sites.

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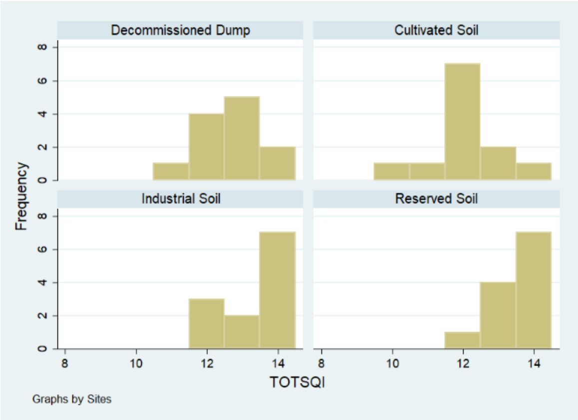

Figure 2 *Comparison of total soil quality index of twelve samples among locations.*

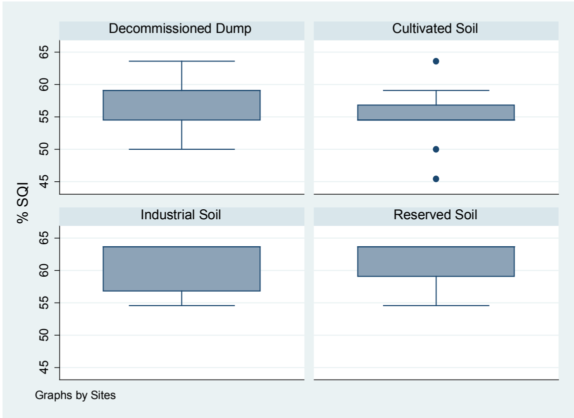

Figure 3. *Percentage SQI of analyzed parameters among sites.*

The observed percentage SQI values are shown for each site in box plots (Fig. 3). The results in figure 2 and 3 indicates that forest reserve soils have the highest quality index (QI) which is due to the less human influence while cultivated soil is least as a result of continuous cultivation and application of pesticides and fertilizers.

Decommissioned soils also had lower SQI compared to industrial soils due to the substantial anthropogenic influence with regards to waste management. Substantial quantity of waste generated are left unattended to and eventually end up in the environment and this supports the observation by (Abalo, Peprah, Nyonyo, Ampomah-Sarpong, & Agyemang-Duah, 2018). The QI of decommissioned soils and industrial soils are however below the reserved soils. Table 3 shows that there were significant variations pairwise between cultivated soil and reserved soil and then cultivated and industrial soil ($p < 0.05$).

Table 3. *Multiple Comparisons of analyzed parameters among sites*

(I) Sites	(J) Sites	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Decommissioned Dump	Cultivated Soil	.583	.355	.365	-.36	1.53
	Industrial Soil	-.667	.355	.252	-1.61	.28
	Reserved Soil	-.833	.355	.103	-1.78	.11
Cultivated Soil	Decommissioned Dump	-.583	.355	.365	-1.53	.36
	Industrial Soil	-1.250*	.355	**.005**	-2.20	-.30
	Reserved Soil	-1.417*	.355	**.001**	-2.36	-.47
Industrial Soil	Decommissioned Dump	.667	.355	.252	-.28	1.61
	Cultivated Soil	1.250*	.355	**.005**	.30	2.20
	Reserved Soil	-.167	.355	.965	-1.11	.78
Reserved Soil	Decommissioned Dump	.833	.355	.103	-.11	1.78
	Cultivated Soil	1.417*	.355	**.001**	.47	2.36
	Industrial Soil	.167	.355	.965	-.78	1.11

Dependent Variable: TOTSQI. *.The mean difference is significant at the 0.05 level.

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Cultivated soil showed more variation with lower SQI compared to the others that have reduced variations with higher SQI values. Soil mineral parameters that significantly predict SQI are manganese, iron and cadmium as indicated in table 4. Unit increases in manganese, iron and cadmium affects soil quality index by -0.254, 0.003 and 12.544 respectively indicating that cadmium influences soil quality the most followed by iron then Manganese.

Total organic carbon and nitrogen are highly related and also correlate to exchangeable cations (K, Mg, Ca) except bulk density. Individual indicators of soil health are correlated with a range of soil physical and chemical properties in an effort to identify which property or properties are linked with soil health. Soil physical and chemical properties were measured as part of the soil health indicators to evaluate the position of the developments in soil quality.

Table 4. *Parameter estimates of soil mineral variables and total SQI*

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	8.510	3.657		2.327	.027
BD	3.657	2.765	.207	1.322	.196
OC	-.447	.415	-.794	-1.076	.290
N	7.118	4.419	.768	1.611	.117
Ca	-.064	.042	-.716	-1.529	.136
Mg	.403	.229	.657	1.764	.088
Na	.566	.934	.219	.606	.549
K	-40.475	23.561	-.687	-1.718	.096
P	-.113	.166	-.163	-.678	.503
pH	-.288	.341	-.358	-.846	.404
Fe	.003	.001	.541	2.209	**.035**
Mn	-.254	.117	-.905	-2.164	**.038**
Cd	12.544	4.233	.340	2.963	**.006**
Pb	-.700	.358	-.688	-1.956	.059
Ni	5.540	2.831	.555	1.957	.059
Cu	.219	.336	.247	.651	.520
Zn	.191	.125	.673	1.526	.137

Dependent Variable: Total SQI

Conclusions

In this study, however 16 measured soil physical and chemical properties were used to assess the SQI of the selected soils. Generally, all the sites were deficient in some of the chemical properties studied making the soils less fertile for optimum crop growth and support essential environmental benefits. The cultivated soil showed more variation with lower SQ compared to the others that have more points with higher SQI values. Continuous cultivation of land without proper agronomic

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management has a lot of adverse effect on soil quality. Similarly proper waste management is critical to ensure soil quality. We recommend above 70% SQI for agricultural soils that are not sodic, strongly acidic or strongly alkaline as well as forest soils this is because SQI is highly sensitive to these parameters. Again industrial and decommissioned dump soils must have above 60% SQI when all heavy metals are within recommended acceptable limit. Soils have various functions therefore it is exceedingly important to make conscious effort to protect the soil resource to enhance the protection of watersheds and ground waters from agricultural chemicals, industrial and municipal wastes and sequestering carbon that would otherwise contribute to global climate change to ensure sustainability. Protection of soil resource for optimum function is vital and requires individual conscious effort to achieve it. Proper soil quality indicative tools such as visual soil assessment and laboratory approaches must be used to determine soil quality since many soil properties are related with each other to the extent that using a single dependent variable may not offer a comprehensive assessment of soil health.

Data Availability

The data that support the findings of this study are available on request from the corresponding author.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contribution statement

Benjamin Ason. Conceptualization, Investigation, original draft

David Kofi Essumnag Supervision, review & editing

Frederick Ato Armah Supervision, review & editing

Samuel Obiri. Resources

References

ABALO E.M., PEPRAH P., NYONYO J., AMPOMAH-SARPONG R., AGYEMANG-DUAH W. (2018) A Review of the Triple Gains of Waste and the Way Forward for Ghana. Journal of Renewable Energy, 1–12. https://doi.org/10.1155/2018/9737683

AMACHER M.C., O'NEILL K.P., PERRY C.H. (2007) Soil vital signs: A new soil quality index (SQI) for assessing forest soil health. USDA Forest Service - Research Paper RMRS-RP, (65 RMRS-RP), 1–14.

ANDREWS S.S., KARLEN D.L., CAMBARDELLA C.A. (2004) The Soil Management Assessment Framework. Soil Science Society of America Journal, 68(6):1945–1962. https://doi.org/10.2136/sssaj2004.1945

BALL B.C., GUIMARÃES R.M.L., CLOY J.M., HARGREAVES P.R., SHEPHERD T.G., MCKENZIE B.M. (2017) Visual soil evaluation: A summary of some applications and potential developments for agriculture. Soil and Tillage Research, 173:114–1244. https://doi.org/10.1016/j.still.2016.07.006

BLOCK M. (2011) Maslow's Hierarchy of Needs. In Encyclopedia of Child Behavior and Development (pp. 913–915).

BRAY R.H., KURTZ L.T. (1945) Determination of total, organic, and available forms of phosphorus in soils. Soil Science, 59(1):39–45. http://dx.doi.org/10.1097/00010694-194501000-00006

CARTER M.R. (2002) Soil quality for sustainable land management: Organic matter and aggregation interactions that maintain soil functions. Agronomy Journal, 94(1): 38–47.

de LA GUARDIA M., GARRIGUES S. (2012) Handbook of Green Analytical Chemistry. In Handbook of Green Analytical Chemistry. https://doi.org/10.1002/9781119940722

DORAN J. W., PARKIN T.B. (2015) Quantitative Indicators of Soil Quality: A Minimum Data Set.

DOI: 10.6092/issn.2281-4485/14197

EMMET-BOOTH J.P., FORRISTAL P.D., FENTON O., BALL B. C., HOLDEN N.M. (2016) A review of visual soil evaluation techniques for soil structure. Soil Use and Management, 32(4):623–634.
https://doi.org/10.1111/sum.12300

KARLEN D.L., MAUSBACH M.J., DORAN J.W., CLINE R.G., HARRIS R.F., SCHUMAN G.E. (1997) Soil Quality: A Concept, Definition, and Framework for Evaluation (A Guest Editorial). Soil Science Society of America Journal, 61(1):4–10.
https://doi.org/10.2136/sssaj1997.03615995006100010001x

McKENZIE D.C., PULIDO MONCADA M.A., BALL B.C. (2015) Reduction of yield gaps and improvement of ecological function through local-to-global applications of visual soil assessment. In Visual soil evaluation: realising potential crop production with minimum environmental impact (pp. 31–48).

MEF (2007) Government Decree on the Assessment of Soil Contamination and Remediation Needs. Ministry of the Environment Finland, 6.

NELSSON, D. W., & SOMMERS, L. E. (1996). Total carbon, organic carbon, and organic matter. BT - Methods of soil analysis. Part 3. chemical methods. In Methods of soil analysis. Part 3. chemical methods (pp. 961–1010).

OLIVER D.P., BRAMLEY R.G.V., RICHES D., PORTER I., EDWARDS J. (2013 June). Review: Soil physical and chemical properties as indicators of soil quality in Australian viticulture. Australian Journal of Grape and Wine Research, 19(2):129–139.
https://doi.org/10.1111/ajgw.12016

REEVES D.W. (1997) The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil and Tillage Research, 43(1–2):131–167.
https://doi.org/10.1016/S0167-1987(97)00038-X

ROWELL D.L. (1994) Soil science: Methods and applications. Longman Group UK Ltd., London.

SIMS J.T., CUNNINGHAM S.D., SUMNER M.E. (1997) Assessing Soil Quality for Environmental Purposes: Roles and Challenges for Soil Scientists. Journal of Environmental Quality, 26(1):20-25.
https://doi.org/10.2134/jeq1997.00472425002600010004x

SPARKS D.L., PAGE A.L., HELMKE P.A., LOEPPERT R.H., TABATABAL M. A., SUMNER M.E. (1996) Methods of soil analisys. Part 3 Chemical Methods. Soil Science Society of America.
STEFFAN J. J., BREVIK E C., BURGESS L.C., CERDÀ A. (2018) The effect of soil on human health: an overview. European Journal of Soil Science, 69(1):159–171.
https://doi.org/10.1111/ejss.12451

THE COUNCIL OF THE EUROPEAN COMMUNITIES (1986) Council Directive of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (86/278/EEC). Official Journal of the European Communities, L(181/6).

VERLOO M., DEMEYER A. (1997) Soil preparation and analysis – A practical guide. Department of Applied Analytical and Physical Chemistry, Coupure Links 653, B-9000 Gent, Belgium