Suitability of ^{137}Cs Redistribution as an Indicator of Soil Quality

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ABSTRACT

Despite its great relevance as an indicator of change in soil quality conditions, ^{137}Cs redistribution has not been widely suggested for inclusion in minimum data sets for soil quality evaluations. In part, this is due to a perception that its high variability precludes its use. ^{137}Cs typically has a coefficient of variation of about 20% in the reference sites used to estimate redistribution in disturbed landscapes. Recent studies on changes in soil quality indicators (including ^{137}Cs) in Saskatchewan, Canada and northeastern Ghana indicate that the variability associated with ^{137}Cs in both reference and cultivated sites is very comparable to that for other, commonly measured indicators of soil quality such as organic carbon and soil nitrogen. The sampling requirements for ^{137}Cs are very similar to these other properties (i.e., 15-30 samples per sites are required for accurate estimates of central tendency) and hence its variability should not preclude its adoption as a soil quality indicator.

Key Words: Soil variability. Coefficient of variation. Sampling.

INTRODUCTION

The concept of sustainability has become pervasive in the current research (and funding) environment. After the adoption of the concept as a "guiding" principle, a need arose to develop quantitative measures of progress towards (or away from) sustainability. In agriculture and related natural resource areas, the emergence of the concept of soil quality has been a major step in the development of these quantitative measures. Soil quality (like sustainability) has many definitions, but is defined for this paper as the capacity of a soil to function both within its ecosystem boundaries and in relation to the environment external to that ecosystem (Larson and Pierce, 1994). Improvements in (or at least maintenance of) soil quality is viewed as positive step towards sustainability, whereas deterioration of soil quality clearly militates against the achievement of sustainability.

Considerable effort has been spent on the development of quantitative indicators to assess changes in soil quality. ^{137}Cs is, in many respects, ideally suited to be an indicator of changes in soil quality. The specific process that it measures (soil redistribution) is a major determinant of changes in other significant soil quality indicators, such as organic carbon and nutrient status. Moreover, it can be directly used to assess the effect of terrestrial erosion on adjacent aquatic systems, as the work of the IAEA Co-ordinated Research Project continues to demonstrate. Hence it appears to be a very logical inclusion in any listing of key indicators of changes in soil quality.

Table 1. Mean values and coefficient of variation for soil quality indicators measured at the Lanigan, Saskatchewan research sites.

Soil Property	Measurement Unit	0-Year Site (N=47)		80-year Site (N=42)	
		Mean	CV	Mean	CV
^{137}Cs	Bq m^{-2}, 0-45 cm	2194	23.7	1995	53.8
Soil Organic Carbon	Mg ha^{-1}, 0-15 cm	68.2	15.6	46.6	31.5
Soil Nitrogen	Mg ha^{-1}, 0-15 cm	11.0	14.5	8.4	61.9
pH		6.84	8.6	7.58	6.1
A horizon Thickness	cm	20.5	53.5	15.9	50.9
Depth to CaCO$_3$	cm	35.1	73.8	34.9	106.5
Sand	%, 0-15 cm	42.3	11.3	47.0	7.1
Silt	%, 0-15 cm	19.6	19.2	18.8	12.2
Clay	%, 0-15 cm	38.0	14.8	34.1	9.9
Bulk Density	g cm^{-3}, 0-15 cm	1.05	11.3	1.39	7.1

Lists of minimum data sets of soil quality indicators have been developed by many authors (summarised by Carter et al., 1997) but the ^{137}Cs technique is generally not listed despite its apparent utility. In part, this may reflect that it is not as widely available as other, more basic, techniques but it also reflects a lingering perception that ^{137}Cs is highly variable and hence unreliable for these measures. Recent summaries by authors such as Higgitt (1995) and VandenBygaart et al. (1999) have correctly pointed out the untested (and, in many cases, untestable) assumptions that underlie the technique, but also act to reinforce the perception of its unreliability.

Clearly the assumptions behind the use of this technique should be continually addressed, but its suitability as an indicator should not be assessed in isolation from the other common indicators. The purpose of this report is to address the question: What is the variability of ^{137}Cs concentrations relative to other, more common, indicators of soil quality?

The simplest index of variability is the coefficient of variation (CV), which is equal to the sample standard deviation/sample mean multiplied by 100 (to express it as a percent). The CV can also be readily used to calculate the number of samples required to estimate the mean within given confidence limits. Wilding and Drees (1983) examine a range of pedological characteristics and place them into three arbitrary categories: least variable (CV's < 15%), moderate (CV's 15-35%), and most variable (CV's > 35%).

Several authors have examined the CV's of ^{137}Cs reference sites (i.e., sites that have experienced no or very minimal soil loss or gain since the 1950's) and the CV's at these sites have generally fallen into the moderate category. In an extensive literature review of ^{137}Cs variability for reference sites in over 70 published studies, Sutherland (1996) found a range of CV's from 1.5 to 86.4%. The median CV for the sites was 19.3% Certainly the higher values for CV are less typical. For example, at 13 reference sites in New Zealand, Basher (1998) found a range of CV's from 7 to 45 percent, but with a median value of 17%.

STUDY AREAS

The comparison between the variability of ^{137}Cs and other indicators of soil quality is assessed in this paper using data sets on the effects of agriculture on soil quality indicators from two highly contrasting locations. The first is a previously published examination at two research sites (51°52'N, 104°55'W) in Saskatchewan, Canada (Pennock et al., 1994). The second is an ongoing Ph.D. research project of Bertha K. Gana on changes in soil quality due to farming practises in the semi-arid environment of northeastern Ghana (10°45'N, 0°30'W).

The climate of the northeastern Ghana study area is semi-arid with a total annual precipitation of 150 cm. It has one rainy season and a marked growing season moisture deficit (Adu, 1969). The soils of the study region show a definite relationship to topography. The oldest sur-

faces occur on the uplands and are dominated by Alfisols with ferruginous concretionary B-horizons. On younger surfaces, Alluvisols or colluvial soils occur those have weakly expressed profile characteristics. The soils of the youngest surfaces are dominantly gray, poorly drained alluvial clays.

The agriculture in the area is mainly subsistence. There are two types of farms - compound farms located around the house and bush farms located 2 to 10 kilometers away from the village. The compound farms are small (about 1 ha or less) and are continuously cultivated with fertility being maintained by use of household refuse and human and animal wastes. Bush farms are between 1 - 2 ha. On the bush farms, no manure is applied and the fertility is (ideally) restored naturally through fallow. Crops grown include early and late millet, sorghum, cowpeas, vegetables and rice.

The sampling sites were located at or near the village of Kugri. One uncultivated site (UC) was located and used as the primary reference site. A site that had not been cultivated for 50 years (LTF1) was also used as a reference site. For this report one compound farms (CF2) and one short-term fallow bush farm (STF3) are presented. These two sites had CV's in the mid-range for their land use group of sites.

The two reference sites were sampled with a 4 x 3 grid with a spacing of 25 m between sampling points. At the cultivated sites a 3 x 3 sampling grid was laid out with the same sample spacing. A topographic survey of each site was completed with an Abney level. A soil observation pit was dug at each sampling point, and soil samples were taken using a fixed volume sampler in 5-cm deep increments. Bulk horizon samples were also taken for horizons beneath the main sampling layers.

The two sites used in used for the southern Saskatchewan study area are from a gently rolling, hummocky till surface. The two sites are located 1.5 km from each other on a continuous till surface. The reference site has never been cultivated (0-year site), and the cropped site had been cultivated in a wheat-fallow rotation for 80 years at the time of sampling (80-year site). Complete site descriptions and methodology is contained in Pennock et al., 1994.

At each of sites, a 400 m by 400 m section of the field was selected and a square or rectangular grid with a set spacing of 20 m between sample stations was laid out on the surface. At each of the sampling stations a soil column was described and a truck-mounted hydraulic coring device was used to extract three 7.2-cm-diameter soil cores. Three samples were taken from each core (0 to 15 cm, 15 to 30 cm, and 30 to 45 cm) and were then bulked to make a composite sample for that depth increment. Grain size was assessed using the modified pipette technique.

The soils at each sampling point were described and classified using the Canadian System of Soil Classification. The Canadian classes can for the most part be directly correlated with an appropriate Soil Taxonomy class. The dominant soil order at the study sites is the Chernozemic Order, which is equivalent to the Boroll sub-order of the Mollisol Order. The Regosolic Order co-

Table 2. Mean values and coefficient of variation for soil quality indicators measured at the northeastern Ghana research sites.

Soil Property	Measurement Unit	UC (n=12)		LTF1 (n=12)		CF2 (n=9)		STF3 (n=9)	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV
^{137}Cs	Bq m^{-2}, 0-25 cm	925.1	21.3	901.4	22.7	466.9	20.0	524.6	41.2
Soil Organic Carbon	Mg ha^{-1}, 0-10 cm	23.0	33.9	11.0	37.6	4.7	49.0	6.96	41.2
Soil Nitrogen	mg kg^{-1}, 0-10 cm	1549	33.2	743.1	25.2	432.3	29.5	499.8	18.0
pH	0-10 cm	7.4	4.1	7.3	5.4	6.9	10.1	7.0	1.4
Base saturation	%, 0-10 cm	92.3	5.2	75.5	11.2	82.4	3.7	77.2	24.0
Percent concretions	0-10 cm	7.4	64.9	24.0	34.2	12.6	16.8	21.0	90.1
Sand	%, 0-10 cm	69.0	9.1	75.0	7.1	85.0	3.3	77.0	3.9
Silt	%, 0-10 cm	19.0	10.2	17.0	23.1	12.0	25.1	18.0	16.8
Clay	%, 0-10 cm	12.0	32.6	8.0	25.0	3.0	23.1	5.0	8.3
Bulk Density(soil fines)	g cm^{-3}, 0-10 cm	1.45	8.1	1.27	6.9	1.52	5.9	1.37	5.1

rrelates to the Entisol Order. Soils of the Gleysolic Order are influenced by reducing conditions for at least part of the year, and no direct equivalent at the Order level exists in Soil Taxonomy.

MATERIALS AND METHODS

Each soil sample was air-dried, weighed, and the aggregates were broken using a mortar and pestle. For the Ghanaian samples, the larger concretions were removed by hand and the smaller ones were separated after passing the soil through a 2 mm mesh sieve. The concretions were weighed and the percentage of concretions in each sample was calculated on a weight basis. The bulk density and porosity of the concretions were determined using a pycnometer. The bulk density of the concretions was used to correct the whole-soil bulk density for the presence of concretions using the method of Vincent and Chadwick (1994).

Particle size analysis was completed using a modified pipette method. Soil pH and electrical conductivity were determined on a 1:2 water ratio sample using standard equipment. Total carbon was measured by a LECO CR 12 Carbon determinator at 1100ºC and organic carbon was determined at 840ºC on the same equipment; inorganic carbon was calculated as the difference between the two methods. Base (Ca, Mg, K, Na, Mn) and acid (Al) cations were extracted using unbuffered 1.0 M NH_4Cl (at pH 5.0) and effective cation exchange capacity was calculated by the summation of base and acid cations. Atomic absorption spectrophotometry was used to measure Ca, Mg, Mn, and Al and exchangeable Na and K were measured by flame spectrophotometry. Total N and P were extracted by H_2SO_4-H_2O_2 digestion and P and N measured by colorimetry.

[137]Cs was measured by gamma spectroscopy. Soil samples were put into 1-L Marinelli beakers for equilibration and placed over a high-purity coaxial germanium crystal enclosed in a 10-cm Lucite-lined castle connected to a Canberra Series 35 Plus Multi-Channel analyzer. [137]Cs activity concentration per unit mass (Bq kg^{-1}) was determined by counting the 662 keV gamma emissions after a 2 to 21 hour counting interval. Total activity of the sample was converted to total areal activity using the corrected bulk density and the sampling depth. For the Ghanaian samples, a series of ^{137}Cs analysis were run on different sized fractions of the concretions; no measurable ^{137}Cs was detected for the concretions.

RESULTS AND DISCUSSION

The CV's for ^{137}Cs at the three reference sites (0-year site, Table 1 and UC and LTF2, Table 2) are only slightly higher than the median value of 19.3% CV's assessed by Sutherland (1996) in his literature review. The CV's increase greatly for the cultivated site in Saskatchewan (Table 1) and for site STF3 in Ghana (Table 2). This increase is typical for a surface undergoing redistribution of soil - soil loss extends the ^{137}Cs range towards lower values, whereas the concentration of sediment in a limited area of the field causes a few sampling points to have concentrations significantly higher than those found at the reference site. This increase does not occur at CF2. In this case, the values for ^{137}Cs at all sampling points were well below the values of both reference sites, indicating that all sampling points experienced soil loss. The net export from the field was very high, and the spread of values was correspondingly low.

For the sites in Saskatchewan, the CV for ^{137}Cs is marginally higher than those for the soil biochemical (SOC, nitrogen) and physical (particle size and bulk density) but well below those for the soil morphological properties (depth to calcium carbonate and A horizon thickness). Both of the latter have been used as surrogates for soil erosion but their use has been justifiably criticized (Pennock, 1997).

The CV of ^{137}Cs at the reference sites in northeastern Ghana is well below that for the soil biochemical properties (Table 2). A major soil morphological property of interest in soil quality investigations in these soils is the concretion content of the upper soil and again this has a CV substantially greater than that for [137]Cs. The great variation in concretion content indicates the very complex geomorphic history of land surfaces in this area. The variability in soil pH and base saturation of these soils is very low and the levels of both properties are anomalously high for sub-tropical soils generally. The soils of the study area receive annual inputs of bases from the Harmattan dusts and this maintains the base content and buffering capacity at high levels. The soils throughout the study region are dominated by sand, and the CV for the sand fraction and the soil bulk density are very low.

CONCLUSIONS

Overall the CV's for the major indicators of soil quality at both study areas fall into the moderate class of Wilding and Drees (1983) (i.e., between 15-35%). Hence the-

re is no evidence that the variability of ^{137}Cs is any greater than for the other commonly measured soil indicators, and its variability should not preclude its inclusion as an indicator of soil quality. Wilding and Drees (1983) suggest that between 10 to 25 samples must be taken for properties in the moderately variable group for a 95% confidence interval within ±10% of the mean. Hence the sampling requirements for ^{137}Cs are no different than for the other major indicators. Indeed, given its usefulness as an indicator of trends and patterns in soil erosion (perhaps the major determinant of soil quality changes in many environments), its inclusion in regional and national programs should be strongly advocated.

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