Canadian Journal of Soil Science
Revue canadienne de la science du sol

**The potential to regain organic carbon in degraded soils: A
boundary line approach**

Journal:	<i>Canadian Journal of Soil Science</i>
Manuscript ID	CJSS-2016-0008.R1
Manuscript Type:	Short Communication
Date Submitted by the Author:	09-Jun-2016
Complete List of Authors:	VandenBygaart, A.J.; Agriculture & Agri-food Canada, Research Branch
Keywords:	Carbon, Conservation tillage, Cropping system, Environmental health, Erosion

SCHOLARONE™
Manuscripts

Only

Short Communication

The potential to regain organic carbon in degraded soils: A boundary line approach

A.J. VandenBygaart

Ottawa Research and Development Centre
Agriculture & Agri-Food Canada, KW Neatby Building, 960 Carling Avenue, Ottawa, Ontario,
Canada K1A 0C6

Email: Bert.VandenBygaart@canada.ca

Phone: 613 759 1836

Abstract

There is a physical limit to the storage capacity of SOC that is dependent on fine particles in arable soils. Here it is demonstrated that a ceiling of SOC storage can be identified utilizing a boundary line approach relating SOC to the clay fraction of soils in Ontario. The method can determine the deficit of SOC in order to establish the potential to regain SOC and ameliorate eroded landscape positions.

Key words: Soil organic carbon; soil erosion; boundary line analysis

Introduction

Multiple studies have demonstrated that the soil organic carbon (SOC) concentration in surface arable soils is texture-dependent and highly correlated with fine mineral particles (Hassink 1997; Six et al. 2002). The theory implies that there is a physical limit to available mineral surface area for protection from microbial decomposition (Hassink 1997). Hassink (1997) proposed that the quantity of stable SOC has a ceiling or saturation limit determined by the amounts of fine silt- and clay-sized particles in the soil. Determining the capacity of a soil to gain SOC provides an opportunity to determine the potential to sequester carbon (C) with management practices that can reduce C decomposition and/or increase litter inputs.

Examining large data sets with scatter plots can be valuable in determining an upper limit or maximum potential between dependent and independent variables. In particular boundary line analysis can establish an upper limit of the data cloud which can identify the maximum functional dependency between two variables (Schmidt et al. 2000). If an upper limit can be shown to exist then the upper boundary represents the maximum response to an independent variable, whereby points below the boundary line denote situations where other factors have

limited the response to the independent variable (Schmidt et al. 2000). In agronomy boundary line analysis has been used in identifying yield responses to multiple factors (Shatar and McBratney 2004).

In this paper it is proposed that the boundary line approach can be used as a tool to determine the C deficit and define the potential to gain back lost C due to soil erosion. Utilizing the boundary line concept here, a potential for C amelioration in eroded soils can be determined, by relating clay content to the SOC concentration and defining the upper boundary.

Methods

A large data set (n=433) relating SOC concentration and clay content for well-drained *Ap* horizons in southern Ontario was used to define an upper boundary or saturation limit for carbon as a function of clay content (<0.002 mm). The dataset was compiled from many studies that the author had conducted on soils of southern Ontario (n=367), along with data collected from papers published in the Canadian Journal of Soil Science where research was conducted in southern Ontario (n=66). The data were derived from multiple soil types, textures, landscape positions, and management practices. It is acknowledged that the broad uniform representation of all factors was assumed but weightings may have been greater for certain factors that may have imposed a bias. The histogram distributions of both clay and SOC content showed a skewed distribution toward lower values (Fig.1).

The boundary could also be determined for a clay plus fine silt relationship as was defined by Hassink (1997) but the database used here lacked the characterization of the fine silt fraction thus limiting the analysis to clay and SOC. About 1/3 of the SOC measurements were made utilizing the Walkley-Black method (Nelson and Sommers 1996), while the remainder were measured via dry combustion in Leco induction analyzers. A conversion factor of 1.25 X

the Walkley-Black analyzed SOC measurement was applied to account for differences in the laboratory techniques (Grewal et al. 1991). Nelson and Sommers (1996) determined C conversion factors ranging from 1.16 to 1.59 for a range of soils. It is acknowledged that the lack of a more precise conversion factor used here will increase the uncertainty of the results. When inorganic carbon was present as carbonates it was subtracted from the SOC measurement made by dry combustion.

Many different approaches have been utilized to determine boundary lines, some arbitrary or even drawn free-hand (Black and Abrams 2003). However, one more quantitative approach is to divide the independent axis into equal increments such that maximum values for the independent variable are identified within the intervals (Schmidt et al. 2000). This approach was utilized by dividing the independent variable (clay content) into equal divisions of 50 g kg^{-1} and identifying maximum values in these increments. A regression line is then calculated for the points for which the equation represents the upper boundary line. This approach is still somewhat arbitrary but is seen as more appropriate than simply drawing a line free-hand. An attempt at nonlinear fits to the maximum points identified by this method yielded logarithmic, power and exponential fits that were not satisfactory in supporting the upper boundary.

Results and Discussion

Figure 2 shows the scatterplot relating SOC to clay content. For clay contents below approximately 200 g kg^{-1} there is a clear upper boundary with a positive slope, whereas beyond about 200 g kg^{-1} the relationship reaches a maximum such that change in clay content does not affect the C concentration (Fig. 2). More than half of the points in the data cloud are situated at clay concentrations below about 200 g kg^{-1} clay. The upper limit supports the concept that clay

content correlates to available surface area for reactions between mineral surfaces and organic molecules (Hassink 1997) coupled with physical protection by aggregation (Six et al. 2002).

Linear regression analysis on the uppermost points within the 50 g kg⁻¹ intervals of clay content yielded two distinctive lines: For clay < 200 g kg⁻¹ the upper limit is defined as:

$$\text{SOC} = 0.15(\text{Clay}) + 5.94$$

And for clay > 200 g kg⁻¹:

$$\text{SOC} = 34.7.$$

The two regression lines intercept at a value of 192 g kg⁻¹ clay. In theory the maximum concentration of SOC is about 35 g kg⁻¹ or 3.5 %, for soils with > 19% clay, while below 19% clay the maximum SOC concentration is a function of the clay content. Logarithmic, power and exponential fits were attempted but none fit as well as the two linear estimates.

It is germane to point out that although there appears to be a clear upper limit in SOC concentration, in particular for soils with < 19 g kg⁻¹ clay, other factors could limit the maximum potential to gain SOC. Soils high in sand and low in clay can result in reduced water retention and nutrient limitations that could limit the C inputs necessary to reach the maximum indicated by the upper boundary. Furthermore, organic amendments such as manures could enhance the SOC concentration on sandy soil types but the SOC may be physically-unprotected and thus more susceptible to decomposition with physical disturbance (Six et al. 2002). Also, heavier-textured soils may also inhibit plant growth necessary for sufficient C inputs to reach the saturation level noted in this study due to structural issues such as compaction and saturation.

Quantifying the potential to gain C in eroded soils is an obvious utility of the boundary line analysis. For example, VandenBygaart et al. (2012) showed that tillage and water erosion has resulted in vast quantities of C being redistributed to lower landscape positions for multiple

field locations in Canada. For a site in southern Ontario they showed that an eroded shoulder had lost a large mass of SOC to a footslope landscape position. The footslope location had more than twice the SOC stock compared to the eroded shoulder, and the buried soil had maintained the SOC mass for several decades since its deposition (VandenBygaart et al. 2012). The concentrations of clay and C in the *Ap* horizon of the eroded shoulder position were 198 g kg^{-1} and 22.7 g kg^{-1} respectively. Utilizing the upper boundary for $> 192 \text{ g kg}^{-1}$ the potential C gain on the eroded shoulder slope is simply: $34.7 \text{ g kg}^{-1} - 22.7 \text{ g kg}^{-1} = 12 \text{ g kg}^{-1}$. Bulk density of this horizon was about 1.6 g cm^{-3} and thus to a depth of 20 cm the maximum potential C stock gain on this shoulder slope would be about 38 Mg ha^{-1} via improved management practices that favour SOC storage. This level of increase could be realized within one to two decades with some management practices such as converting to perennial from annual cropping or manure amendments (VandenBygaart et al. 2008).

In summary there is a clear upper boundary in the relationship between clay and SOC concentrations in cultivated, well-drained soils of southern Ontario. Boundary line analysis provides a simple tool for determining the potential to regain lost SOC due to decades of soil erosion.

References

- Black, B.A. and Abrams, M.D. 2001. Influence of Native Americans and surveyor biases on metes and bounds witness tree distribution. *Ecology*. **82**: 2574-2586.
- Grewal, K.S., Buchan, G.D. and Sherlock, R.R. 1991. A comparison of three methods of organic carbon determination in some New Zealand soils. *J. Soil Sci.* **42**: 251-257.

Hassink, J. 1997. The capacity of soils to preserve organic C and N by their association with clay and silt particles. *Plant Soil* **191**: 77-87.

Nelson, D.W. and Sommers, L. 1996. Total carbon, organic carbon, and organic matter. Pages 539-579 in D.L. Sparks, A.L. Page, P.A. Helmke and R.H. Loeppert, eds. *Methods of Soil Analysis. Part 3. Chemical Methods*. Soil Science Society of America.

Schmidt, U., Thoni, H., Kaupenjohann, M., 2000. Using a boundary line approach to analyze N₂O flux data from agricultural soils. *Nutr. Cycl. Agroecosys.* **57**:119–129.

Shatar, T.M. and McBratney, A.B. 2004. Boundary-line analysis of field-scale yield response to soil properties. *J. Agric. Sci.* **142**: 553-560.

Six, J., Conant, R.T., Paul, E.A., and Paustian, K. 2002. Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. *Plant Soil*. **241**:155–176.

VandenBygaart, A.J., Kroetsch, D., Gregorich, E.G., and Lobb, D.A. 2012. Soil C erosion and burial in cropland. *Glob. Change Biol.* **18**: 1441–1452.

VandenBygaart, A.J., McConkey, B.G., Angers, D.A., Smith W., de Gooijer, H., Benthams, M. and Martin, T. 2008. Soil carbon change factors for the Canadian agriculture national greenhouse gas inventory. *Can. J. Soil Sci.* **88**:671-680.

Figure 1. Histogram distributions of clay (< 0.002 mm) and SOC data used in the analysis.

Figure 2. Relationship between clay (g kg^{-1}) and soil organic carbon (SOC) (g kg^{-1}) for well drained *Ap* horizons of southern Ontario.