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Soil Organic Carbon and Silt-Clay Relationships in the Soil Orders of Northern Agriculture Region (NAR), Western Australia

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ABSTRACT

There are no recognized data about the relationships between soil organic carbon and soil texture in Northern Agriculture Region (NAR), Western Australia (WA). Such information is central in understanding the impact of silt and clay content of soil profile soil organic carbon. In order to describe mathematically this relation, twenty-one soil orders highly weathered soils (mostly sandy soils) in Northern Agricultural Region, Western Australia under similar climate, vegetation and topography were sampled at 120 cm depth and analyzed for texture and total SOC concentration. The SOC concentration was directly and linearly correlated with the combined clay + silt (but not to clay alone) content for all depths. The intercept and slope of these linear relations decreased with depth following exponential and logarithmic functions ($P < 0.001$, $R^2 = 0.81$ and 0.76, respectively). These mathematical functions permitted the adjustment of the intercept and slope parameters of a SOC = a + b (clay + silt) function for any depth in the 0-120 cm interval. This profile pedotransfer function precisely estimated SOC concentration ($P < 0.0001$, $R^2 = 0.90$) up to 120 cm of the studied soils. Using data from different soil orders, estimated vs. measured SOC relations with similarly high R^2 values were obtained, despite slopes and intercepts were different than 1 and 0. This indicates that for the NAR, WA the textural control of SOC varies predictably with depth, and the proposed model can be calibrated to estimate SOC in subsurface layers of highly weathered soils.

INTRODUCTION

The most studied abiotic factor affecting soil organic carbon (SOC) concentration is climate, more particularly temperature and precipitation (Jenny 1941, Parton et al. 1987, Burke et al. 1989 and Hasson et al. 2013). Within the same climatic zone, however, the dominant effect on SOC concentration is that of soil moisture regimes (Davidson & Lefebvre 1993) or poor drainage (Tan et al. 2004), followed by soil texture. There exists ample evidence based on local or regional data sets that point to a direct relationship of clay and SOC concentrations with similar soil moisture regimes in temperate (Kay et al. 1997, Tan et al. 2004) and tropical regions (Feller et al. 1991, Bernoux et al. 2002). However, other researchers question the validity of this relationship, because of low correlation of SOC with clay concentrations (McDaniel & Munn 1985, Lugo & Brown 1993 and Percival et al. 2000), probably due to the use of clay content as the sole measure of texture, limited textural ranges, and wide variation of environmental factors. Indeed, a proper approach to this issue must be a ceteris paribus, as used by Jenny (1941) to study how variations in a single soil-forming factor would genetically control soil properties. Likewise, Kay (1998) proposed to select soils developed from similar parent material and under similar climate, in order to better predict effects of management, drainage and topography on SOC concentration.

Pedo-transfer functions (PTFs) are mathematical functions using routinely measured soil properties as inputs to predict others not so easily determined, such as soil-moisture relations (Wösten 2002). The differential physical-chemical properties of SOC and clay and the correlation of their contents in soil allow their efficient use as parameters in PTFs to predict soil structural properties (Kay et al. 1997). However, the fundamental effect of soil depth is usually ignored in PTFs, which are mostly based on surface depths or horizons. It has been known that in many cases, but not all, SOC concentrations decrease exponentially with depth (Hasson & Jweeg 2014, Webster 1978). Bosatta & Ägren (1996) included a clay content parameter in their attempt to depth-model SOC and N concentrations, but they used a rather limited textural range data set (180-300 g clay kg^{-1}). For temperate forest soils, Arrouays & Pélissier (1994) agreed that the decrease in SOC concentration with depth is better explained by an exponential function, as also reported by Bernoux et al. (1998) for a wide textural range of Amazonian forest soils. Nevertheless, these models approach solely the effect of soil depth on SOC concentration or stocks for individual pedons. In contrast, this work aims to describe the depth effect on the complex and poorly understood relationship between soil texture and SOC concentration. An additional and more applied goal is to create a depth-weighted or profile PTF, defined here as an equation predicting a soil property (SOC) as a function of depth, based on its relationship to other properties (texture).

To achieve this goal, samples were obtained from highly weathered, tropical soils derived from different parent material and with different textures, but developed under similar climate, vegetation, and topography (all located on interfluves with < 2% slope).

MATERIALS AND METHODS

Site Description

The study area lies within the northern wheat/sheep belt of Western Australia. The area received an average of 350-450 mm annual rainfall. Evaporation average is 2500 mm at the coast of the south to 2900 mm/annum in the north east of the study site. The total area of the study is more than 2 million ha mostly grown with crops mostly wheat, lubin and barley and pastures, annuals, perennials and tagasaste fodders with annual temperature of maximum is 30°C to minimum of 6°C. The effective rainfall to evaporation ratio of the region is P/E0.7 = 0.54

There are approximately 50 soil groups existing in western Australia, out of which 21 soil groups have been included in this study. The soil orders are defined by attributes such as texture and change in texture with depth. The common group of soils is yellow deep sand covering 30% of the survey area, followed by red-brown harden soil 13% and reed loam earth 12%. The other soil grouping individually less than 10%. The series spans eight soil orders of the Australian Soil Classification (Rogers 2002). Most common soil orders are the Tenosols (occupied 50%) followed by Kandosols 29%) and Calcarosols and Sodosols less than 1%.

Analytical Procedures

Disturbed soil samples were collected at 0-10, 10-20, 20-30, 30-40, 40-70, 70-90 and 90-120 cm depths. Using data from different soils orders, estimated vs measured SOC relations, the soil orders, texture and SOC were evaluated in air-dried samples (Bernoux 2002).

Various descriptive parameters of the soil C dynamics at the study sites were measured: litter-fall C inputs, C-CO_2 emissions from soil respiration, root C content (0-30 cm), SOC forms, and content and TN (at 0-15 and 15-30 cm).

For sampling soils, soil cores (10 cm diameter) were collected within each subplot from 0 to 15 cm and 15-30 cm depths, and mixed to create an average sample. Soil samples were sieved through a 2 mm sieve and stored at 4°C until analysis. To evaluate distinct functional pools of organic matter with different turnover times, the following fractions were analysed.

Total organic C (TOC) was determined using the Walkley and Black method (Walkley Black 1934). This method was preferred over high temperature combustion method due to the presence of significant amounts of carbonates in the soils of the sites. Saline soil samples were treated with a silver sulphate solution to eliminate interference by chlorides during the analysis (Quinn & Salomon 1964).

Humic substances C (HSC) was determined by 16 h of shaking with 0.1 M sodium pyrophosphate (Stevenson 1997) (proportion 1:100 soil:extractant), centrifugation at 15, 316 g and filtration through MN 640 d filter paper (Macherey-Nagel; Düren, Germany). HSC content was corrected by subtracting the contents of WSC and HWC from the result obtained. Total N (TN) was determined by the standard Kjeldahl method (Benton 1991).

The results obtained were expressed on the basis of the dried-weight area ($g.m^{-2}$ or $kg.m^{-2}$), computed using the values of bulk density, coarse fragments, and soil water content. Bulk density was determined by drying at 105°C and weighing the soil core samples of 250 cm^3. Coarse fragments were determined using soil wet sieving. Soil water content was analysed gravimetrically at 105°C.

RESULTS AND DISCUSSION

The twenty-one soil orders are widely common soils in Northern Agriculture Region, Western Australia. Silt content varied between 73 and 1019 g/kg in Arsinic Orthic Tenosol and Brown Sonoco respectively (Figs. 1-3). In all the soils, clay content varied between 39 and 2760 g/kg in Ferric Bleached Orthic Tenosol and Sub Red Sodosol respectively. In general, soil orders have increased in clay content with depth and significant differences (P<0.05) in soil organic carbon but no significant differences in silt and clay content at the soil Horizon A, 0-15 cm depth (Fig. 4).

There is no significant correlation between soil organic carbon, silt or clay but there are low to high significant correlations between soil organic carbon and both silt and clay content at all the seven depths under all soil orders of NAR, WA (Figs. 7, 8 and Table 1), this agreed with that with Lugo (1997), McDaniel & Munn (1999) and Percival et al. (1999s).

The data in Fig. 5 also show that both, the intercept and slope of the SOC vs. (clay + silt) relations, decrease with

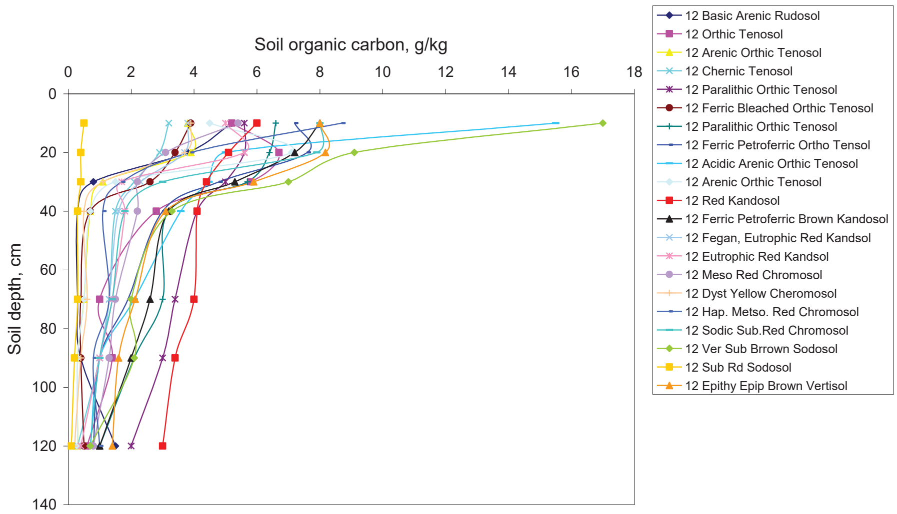

Fig. 1: Distribution of soil organic carbon with depths for the soil orders of NAR, Western Australia.

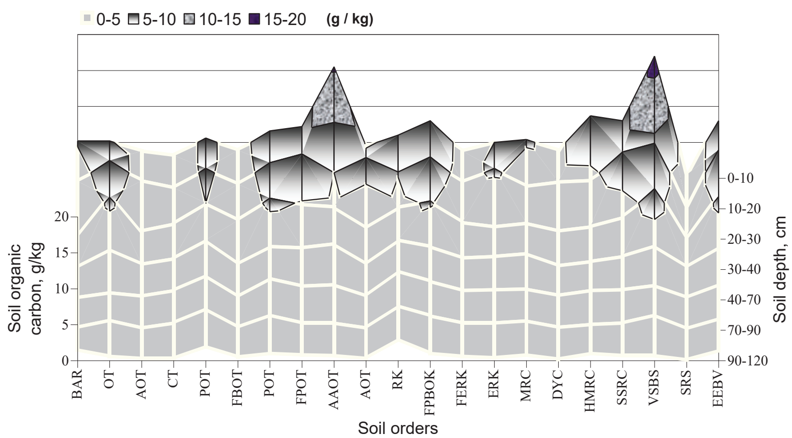

Fig. 2: The distribution of SOC with depths in soil orders.

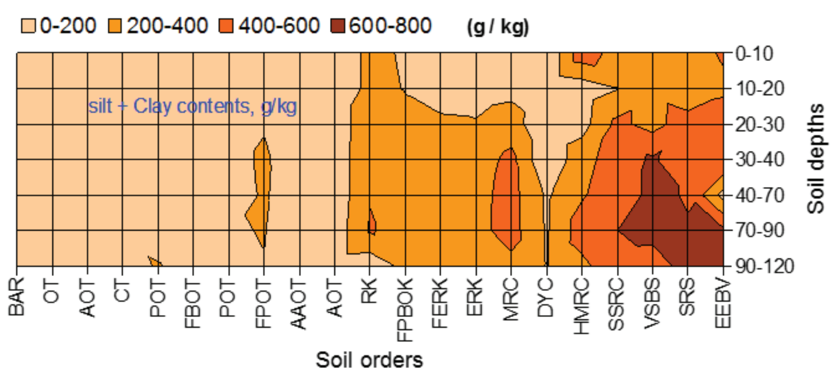

Fig. 3: The distribution of silt and clay content with depths in the soil orders.

Table 1: Relationships between SOC and clay-silt content in different soil depths.

Depth (cm)	Interception (a)	Slope (b)	R^2
0-10	0.0129	3.4541	0.8733
10-20	0.0135	2.9802	0.8009
20-30	0.0118	1.1121	0.8632
30-40	0.01	0.3391	0.7422
40-70	0.0111	0.5681	0.834
70-90	0.0076	0.3811	0.8464
90 -120	0.009	0.42640	8172

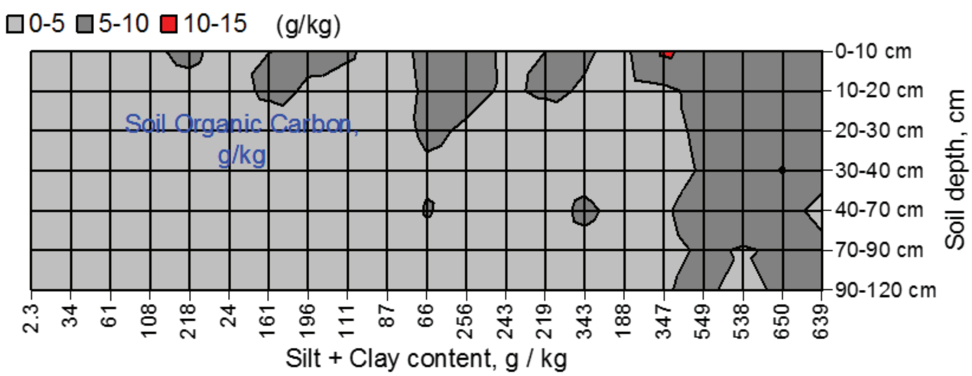

Fig. 4: The distribution of SOC with silt and clay content in depths of the soil orders.

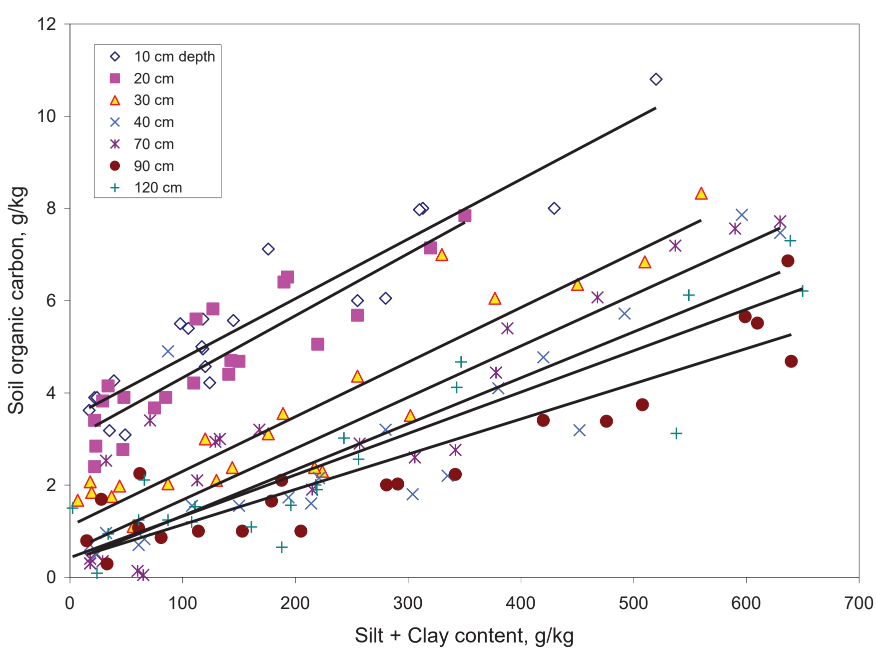

Fig. 5: The relationships between SOC and silt and clay content, g/kg of soil orders at seven depths.

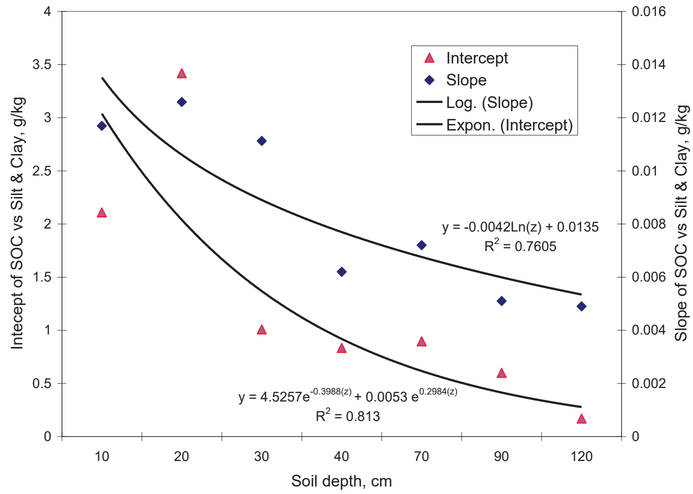

Fig. 6: The relationships between intercept A and slope b with depth z.

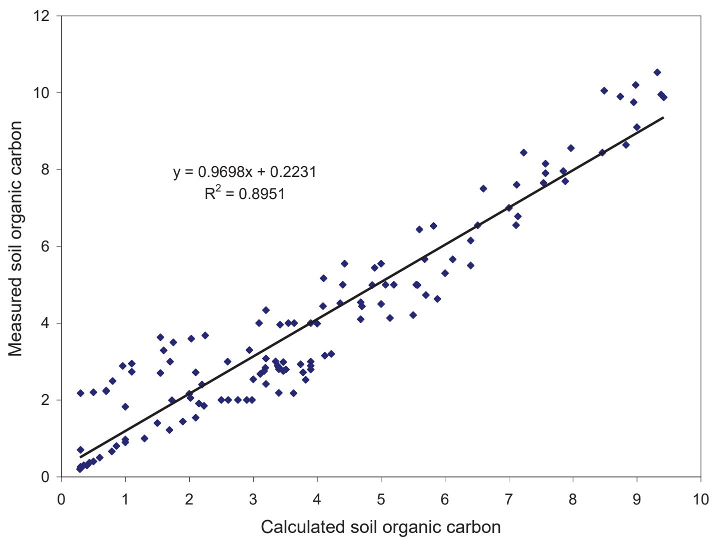

Fig. 7: The relationship between observed and calculated SOC.

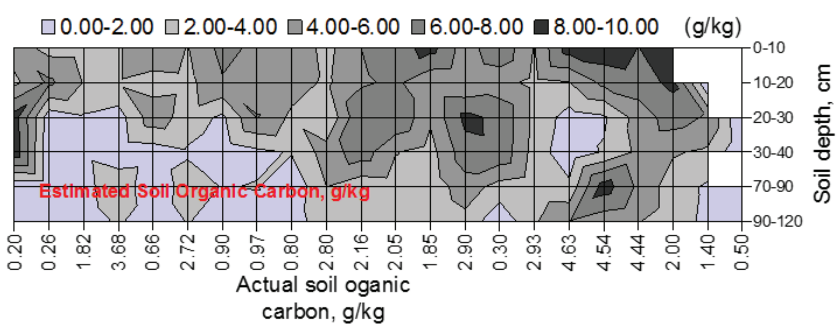

Fig. 8. The contour plots of estimated SOC at each depth of NAR. The darkest colour that show up to 8-10 g/kg and the lightest colour show up to 0-2 g/kg of SOC.

increasing soil depth, following respectively sum of exponentials and logarithmic functions (Figs. 6-7). Therefore, the intercept and slope parameters of the depth-specific relation SOC (g kg^{-1}) = a + b*(clay + silt, g kg^{-1}) can be estimated for use in a profile PTF for the 0-120 cm depth as follows:

$$SOC\ (z) = (4.5257e^{-0.3988(z)} + 0.0053e^{-0.2984(z)}) + [(-0.0042 * Ln\ (z) + 0.204 * (silt + clay)]$$

With a better fit for SOC values below 10 $g.kg^{-1}$, mostly associated with subsurface layers. However, the high determination coefficients indicate that the depth effect on the SOC vs. clay + silt relation was mathematically the same.

In this study, the strong relation between SOC vs. (clay + silt) concentrations implies an equal although negative SOC vs. sand (20-2000 µm) relation, as also reported by (McDaniel & Munn1999). Additionally, total N and SOC concentrations were strongly correlated as:

$$N = 0.143 + 0.063 * SOC,$$

P<0.0001, R^2 = 0.956. Thus, in non-amended, highly weathered tropical soils where N is mostly in organic form, total SOC and N concentrations can be simulated using textural data of subsoil layers (Fig. 8).

It is also important to note that linear SOC vs. (clay + silt) relations, or exponential and logarithmical functions for intercept and slopes, may not be the best descriptors for every region, and different functions must be tested for each region. In this study, intercepts were also well predicted by power (= $24.85D^{-0.5715}$, R^2 = 0.986, for D>0 cm) 0.0129(z) + 3.45 for z = 0 cm depth, R^2 = 0.87), which are easier to calculate than the sum of exponentials function but resulted in slightly poorer fits for the equation:

$$\text{Measured SOC} = 0.9698\ (\text{estimated SOC}) + 0.2231,\quad R^2 = 0.895$$

Additional research is currently being conducted to describe the textural and depth control on SOC partition through particle-size separates and SOC storage (mass/area).

CONCLUSIONS

Such information is central in understanding the impact of silt and clay content of soil profile on soil organic carbon. The soil organic carbon concentration was significantly and linearly correlated with the combined both elements, but not clay alone, for all depths. The intercept and slope of these linear relations decreased with depth following exponential and logarithmic functions.

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