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The use of pedo-transfer functions for estimating soil organic carbon contents in maize cropland ecosystem in the Coastal Plains of Tanzania

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ABSTRACT

Soil organic carbon (OC) plays a vital role on physico-chemical and biological properties of soils and on climate change regulation. The use of pedo-transfer functions from easily available soil properties for estimating soil OC could be fast and cheap when considering field and laboratory work implications especially in Sub Saharan Africa including Tanzania. This paper attempts to develop a model for estimating soil OC contents under maize croplands ecosystem using pedo-transfer functions from soil texture. A total of 100 epipedon data entries were randomly collected from the previous soil sampling works that were conducted under maize croplands in coastal plains of Tanzania. Eighty percent of the collected data were used for training the model by using multiple regression analysis while the remained 20% were used to validate the model. The results indicated that, clay and silt had significant ($p < 0.001$) positive correlation with soil OC while sand contents in soils had negative ($p < 0.001$) correlation with soil OC. All together clay, sand and silt were revealed powerful predictors ($p < 0.001$, $R^2 = 0.82$) of OC content in soils. On validation, the soil OC predicted agreed by 81.2% with the soil OC determined by laboratory test. These results imply that pedo-transfer functions for predicting soil OC based on soil texture is not only fast and cheap but also is an effective option for estimating OC content in soils.

1. Introduction

The soil organic carbon (OC) is the most prevalent form of C in soil and is derived from dead plant materials and remains of dead micro-organisms and animals (Lal, 2012). Soils are the biggest reservoir of organic carbon when excess atmospheric CO_2 is sequestered in soils and transferred to soil OC they thus play a big role on reducing global warming and climate change regulation (Woollen et al., 2012). The CO_2 is a greenhouse gas that traps heat in the atmosphere (Smith et al., 2010). Without CO_2 and other greenhouse gases such as nitrous oxide and methane, the earth would be a frozen planet (IPCC, 2007). However, excess CO_2 in the atmosphere leads to climate change (Woollen et al., 2012). Plants including maize use CO_2, sunlight energy and water to make their own food for their growth (IPCC, 2007). The carbon then becomes part of the plants. When the plants die, the C compounds eventually are transferred, decomposed and incorporated into the soil as soil OC. Thus, plants are the vehicle by which CO_2 is transferred from the atmosphere to soil C. It would be of interest to be able to keep more of that fixed C in the soil environment and to reduce re-emissions back to the atmosphere, where it would increase the CO_2 levels over and above normal levels, thus creating instability or change of climate (Hoffmann et al., 2014). On the other hand the content of OC in soils has direct implications to the soil physico-chemical and biological properties and thus to soil fertility for plant health (IPCC, 2007). A soil with relatively high content of soil OC has relatively higher soil fertility and tends to improve soil physical properties (Hoffmann et al., 2014). While this fact continues to be the case, a different dimension i.e. the climate change regulation dimension of soil OC has of recent come into focus. Because of the above considerations of the implications of soil OC on soil properties, and the potential for climate change regulation when sequestered in soils, there is need for estimating the contents of the OC in our soils and crop land ecosystems.

The OC content in soils varies across tropical landscapes due to a complex mix of climatic, vegetation and edaphic variables (Willcock et al., 2014). In Tanzania and coastal plains in particular, maize is the main cultivated food crop (Mwango et al., 2015a). Thus, estimating soil OC contents in maize cropland ecosystem is essential for monitoring soil health and crop yield but also for climate change regulation. These benefits of soil OC have increased the interest in quantifying the OC contents of soils at farm, regional as well as global level (Jandl et al.,

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2014). However, measuring soil OC contents especially for large tracts of land is costly when considering field and laboratory work that are involved (Jha et al., 2014; Nocita et al., 2014; Shelukindo et al., 2014a). An indirect estimation of soil properties from more easily measurable and more readily available soil properties such as particle size distribution, bulk density and soil pH are referred to as pedo-transfer functions. Studies by Minasny (2007); Bouma (1989) pointed out that the most less laborious, cheap and readily available data are such as field morphology, soil texture, structure and pH. The information on soil texture for example are said to be readily available because the data can be obtained not only from soil surveys but also from many agricultural studies, studies related to irrigation, soil moisture, hydrology and civil works. Pedo-transfer functions add value to this basic information by translating them into estimates of other more laborious and expensively determined soil properties such as soil OC. In recent years, the development of prediction methods that use pedo-transfer functions to spatially extend sparse and expensive soil measurements have been a sharpening focus of research (Keshavarzi et al., 2015).

Worldwide, the prediction of various soil properties has been possible by the use of pedo-transfer functions. Such studies include that of MacDonald (1998) developed two pedo-transfer functions to predict cation exchange capacity (CEC) based on soil organic carbon (OC) and clay (Cl) as CEC = 2.0 OC + 0.5 Cl and CEC = 3.8 OC + 0.5 Cl for Quebec and Alberta soils in Canada, respectively. Al-Busaidi and Cookson (2003) suggested a pedo-transfer function to predict soil sodium adsorption ratio (SAR) based on soil electrical conductivity (EC) as SAR = 0.464 EC + 7.077 with $R^2 = 0.83$ for saline soils in Oman. Seilsepour et al. (2008) in Iran developed a pedo-transfer function for estimating available soil phosphorus (AP) using soil OC as AP = 0.7927 $e^{4.9922OC}$ with $R^2 = 0.92$. A study by Rashidi and Seilsepour (2008) in Iran developed a pedo-transfer function to predict soil CEC based on soil organic carbon and pH as CEC = 26.76 + 8.06 OC – 2.45 pH with $R^2 = 0.77$. In Iran, Seilsepour and Rashidi (2008) also predicted soil CEC from organic carbon using a pedo-transfer function as CEC = 7.93 + 8.72 OC with $R^2 = 0.74$. Shelukindo et al. (2014b) in Tanzania developed a pedo-transfer function to predict soil organic carbon using total Nitrogen (TN) and Calcium as OC = 0.17 + 17.95TN − 0.29Ca with $R^2 = 0.99$. So far many pedo-transfer function studies including those of Cosby et al. (1984), Saxton et al. (1986), Wösten and van Genuchten (1988), Vareecken et al. (1989), Jabro (1992), Tietje and Hennings (1996) and Rasoulzadeh (2011) have been conducted for predicting hydraulic conductivity using soil texture, organic carbon and bulk density.

Pedo-transfer studies which involve the more easily measurable and readily available soil properties such as soil texture are frequently been used to predict soil moisture characteristics. Similarly soil texture could also have strong predictive potential on the status of soil properties including OC in soils. However, such pedo-transfer function studies involving particle size distribution for estimating OC contents in soils are limited and not fully understood. The current study was carried out to develop a multiple regression model for estimating soil OC contents using soil texture in maize croplands of the coastal plains ecosystem in Tanzania.

2. Materials and methods

2.1. Study area

A review was conducted in coastal plains of Tanzania covering 4 districts of Tanga and Coat regions namely Mkinga, Pangani, Bagamoyo and Kibaha districts (Fig. 1). The sampling points and salient features of the area under study are presented respectively in Fig. 2 and Table 1. The coastal plains are characterized by an area of flat, low-lying land adjacent to a seacoast and separated from the interior by other features, the plains are low altitude areas below 750 m developed on mainly marine, secondary and tertiary sediments including unconsolidated marine sediments, strongly weathered terrestrial sediments of the Karoo age, sandstone, limestone, dolomites, and gneisses of various mineral compositions (De Pauw, 1984). According to SOTER database for Tanzania as per Eschweiler, 1998, the soil coastal plains are occupied by various soils types, the major soils in the area include *Ferralic Cambisols* and *Rhodic Cambisols* which cover an area of about 4879 sq. km (66.0%), %), *Hypoluvic Arenosols* occupy 792 sq. km (11.0%), *Humi-Gleyic Fluvisols* occupy 282 sq. km (5.2%), *Chromi-Natric Vertisols* occupy 916 sq. km (12.5%) and *Calci-Hyposodic Planosols* which cover 389 sq. km (5.3%) (Hertemink and Bridges, 1995; Eschweiler, 1998).

The coastal plains of Tanzania are geographical areas exhibiting relatively similar climatic conditions. The area experience two rainy seasons with a yearly mean of 1200 mm, and is hot all year round, with a slightly hotter and wetter period from November to April, when daytime temperatures are around 30/31 °C, but with peaks of 32/34 °C, and relative humidity is high, especially in March and April, the rainiest months (De Pauw, 1984; Kanyeka et al., 2007).

The annual precipitation amounts to 1200 mm, with a maximum from March to May; April is the rainiest month receiving about 255 mm, and a secondary maximum, that of the short rains, from October to December. However, the rainfall pattern is quite irregular, so that in some years, the latter period can be very rainy as well. From June to September there is little rain; this period, in addition to being the driest, is also the coolest, with highs around 30/31 °C, and lows around 18 °C, though sometimes at night the temperature can drop to around 15 °C. The amount of sunshine in the study area is good throughout the year, except maybe in April, the wettest month.

2.2. Data collection

The soils data used in this study relied solely on the available legacy information from previous works. Top soil data from natural horizons under soil types namely *Cambisols*, *Arenosols* and *Fluvisols* were collected from the previous soil surveys that were conducted from 2010 to 2015 in smallholder maize farms in the area. This time span was chosen because it was the period when soil sampling work was conducted in the studied area. A total of 100 epipedon data entries were randomly collected from previous works that were conducted under maize croplands. Eighty percent of the collected data were used for training the model while the remained 20% were used to validate the model.

2.3. Statistical analysis

Anderson Darling test was performed to test data normality, while correlation of variables were examined by Spearman rho test under Minitab software. Analysis of variance (ANOVA) was conducted to compare the contents of soil OC, sand, silt and clay under the studied soil types. ANOVA was performed using Statistix.10 analysis software. The soil OC and particle size distribution data points were randomized by using Excel software where 80% of the data was selected to train the model and remaining 20% was used to test the developed model. The collected data on soil OC, sand, silt and clay were further subjected to regression analyses in Minitab software to develop pedo-transfer function models. Regression models are powerful tools frequently used to predict a dependent variable from a set of predictors (Rashidi and Seilsepour, 2008; Shelukindo et al., 2014b; Mwango et al., 2014). They are widely used in a number of different contexts (Minasny, 2007; Seilsepour et al., 2008). The model performance was evaluated using test data points that were not used in the regression training. The test data points were also used to predict soil OC and predicted values were plotted against measured values in a scatter plot. The coefficient of determination (R^2) and the probability levels (p) were used for evaluation of the model. Both linear and multiple regression models were used in this study. Linear regression has the limitation that it handles one dependent variable at a time. A combination of variables cannot be factored into the model. Therefore, multiple regression analysis was