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ASSESSING THE FITNESS AND VALIDITY FOR DEPTH-DISTRIBUTION PATTERNS OF AVAILABLE MICRONUTRIENTS (Fe and Mn) OVER A TOPOSEQUENCE AT LAFIA NORTH-CENTRAL NIGERIA: APPLICATION OF EQUAL-AREA SPLINES

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ABSTRACT

The study focused on assessing the distribution of micronutrients (Fe, Mn) down the profile pits by using depth function of different level of soil depths (0-5, 5-15, 15-30, 30-60 and 60-90 cm) over a toposequence in faculty of agriculture Shabu-Lafia Campus. Three soil pits were sunk using Digital Elevation Model of the study area as guide for location of soil pits (upper, middle and lower slope). The results revealed that the cations (Fe and Mn) were low across the study area and in most cases Fe and Mn tend to decrease down the profile pits with few exceptions. The fitness of the models (R^2 values) ranged from 0.88-0.99 across the pits with the exception of Mn at profile three that the fitness of the model was not biased ($R^2 = 0.11$). The spline functions were flexible and sensitive to changes (0-5 cm) of the micronutrients (Fe and Mn) movements down the profile pits therefore, they can be used in displaying the vertical variability of micronutrients within the soil of the study area.

Keywords: *Micronutrients, Equal-area spline functions, Toposequence.*

INTRODUCTION

According to Onyekwere *et al.,* (2017) micronutrients such as Fe and Mn are essential elements that are needed by plants in minute amount, with crop intake not exceeding 1.11 $kgha^{-1}$. In spite of this low requirement, important plant functions are hindered if micronutrients are limited, resulting in plant deficiencies and low yields (Onyekwere *et al.,* 2017).For effective soil management and optimum crop production, there is need for good knowledge of micronutrients distribution in the soil pit (Okoli et *al*., 2016).

Hiller (2006) reported that soils derived from shale are rich in carbonate bound trace metal fractions, while soils derived from false bedded sandstones are usually high in Fe-Mn oxides bound trace metal fractions (Gideon *et al.,* 2014) and the fraction of micronutrient is influenced by soil properties such as pH, cation exchange capacity, texture and soil organic matter (Ramzan *et al.,* 2014).

Toposequence can be described as transect (not necessarily a straight line) which begins at a hilltop and ends at a valley bottom (lower slope) or a stream (Odgers *et al.,* 2008). Topography as a key factor in soil formation may speed up or delay the work of climatic factors; topography has significant effect on soil morphological, physical and chemical properties and also affects the pattern of soil distribution in the environment even when the parent materials are of similar source (Esu *et al.,* 2008).

Soil attributes vary continuously down the profile (Ponce-Hernandez *et al*., 1986) thus, soil depth functions are created to display depth wise variation of soil attributes. Jenny (1941) made the earliest attempt of drawing free curves among soil parameters while more advanced method evolved over time of constructing continuous depth functions (Russell and Moore, 1968). A more general continuous depth function is the equal-area spline function of which is the application and mathematical expression of this function (Ponce-Hernandez *et al.,* 1986; Bishop *et al.,* 1999; and Malone *et al.,* 2009).

Obviously continuous soil depth functions like equal-area splines with an edge in predicting soil attributes at any certain depth. A robust and precise method of fitting continuous functions of soil parameters is the use of smoothing splines (Erh, 1972) and equal-area splines function (Ponce-Hernandez *et al*., 1986). Essentially, a spline function is a set of local quadratic functions tied together with 'knots' that describe a smooth curve through a set of points. Bishop *et al.* (1999) demonstrated their superiority over other continuous soil depth functions when predicting various types of soil properties (Malone *et al*., 2009).

The aim of this research work is to assess the fitness and validity of the equal-area spline functions for the distribution of soil available micronutrients over a toposequence at Lafia North-Central Nigeria.

MATERIALS AND METHODS

Description of the Study Area

The study area is located between latitude 8° 33' 22.07" N and 8° 34' 00.49" N and longitude 8°32' 37.63" E and 8° 33' 14.07" E asshown in Figure 1 (Present a map of the study area), in Shabu of Lafia metropolis, Nassarawa State, with a population of 330,712 according to National Population Commission in 2006 (Jatau, 2013). It has a perimeter of 3.13km and area of 58.29 ha. The study area has an average seven (7) months wet season (Month range) and five (5) months dry season (Nov – April) with mean annual rainfall of 1,595.7 mm and annual mean minimum temperature ranges between 21.8-22.2 and the annual maximum mean temperature 23.5℃ (Ariyo, 1987).

Environmental Data

Environmental data for digital elevation model (DEM) were generated from Google Earth Map, saved as KMZ format then converted to CSV and further transferred to Arch GIS and the sampling data were interpolated in 3D and divided into three slope classes (upper, middle and lower slope) as shown in Figure 2 (Autor's field data)

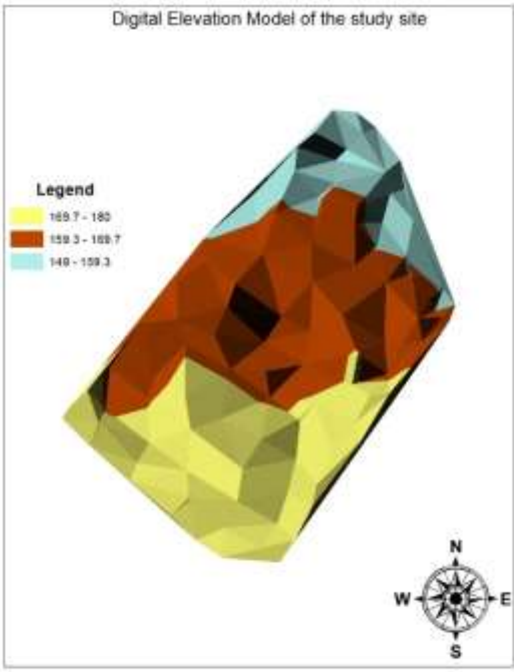


Fig. 1: Digital Elevation Model (DEM) of the Study Area showing the three slope classes

Field studies

Field studies was conducted in April 2018, the upper slope soil pit was dug at 169.71 m, middle slope was at 159.3 m and lower slope at 149 m above sea level as depicted in figure 2. Soils were sampled based on a profile depth of 5, 15, 30, 60, 90 cm (Bishop *et al.,* 1999 and Malone *et al*., 2009).

Laboratory Soil Analysis

The bulk soil samples were air-dried, gently crushed and sieved to obtain the fine soil fractions (>2 mm). The samples were labeled and stored in plastic containers and later subjected to analysis using standard methods as outlined in ISRIC/FAO (2002).

Data Analysis

R statistical software 3.6.3 was used to construct neural networks for the depth-wise modeling of micronutrients (Fe and Mn) in this study (Malone *et al.,* 2017) using the ithir package

Equal-Area Smoothing Spline Functions

The generalized equal-area spline model of Bishop *et al.* (1999) was adopted in this study and the model data are averages over horizons in a soil pit profile. According to Malone *et al.*, (2009) its assumed that true soil properties vary smoothly with depth which is translated into mathematical term. Depth is denoted by z, and the depth function describing the true attribute values by f(z); which means that f(z) and its first derivative f'(z) are both continuous and that f'(z) is square intergrable. *f*(z) represent a spline function which can be found by minimizing (Ponce-Hernandez *et al.,* 1986)

$$\frac{1}{n}\sum_{i=1}^{n}(\mathrm{C}i-\mathrm{f}i)\quad{}^{2}+\lambda\int_{\mathrm{Z0}}^{\mathrm{Zn}} f'\left(\mathrm{Z}^{2}\right)dz \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The first term describes the model fit to data and the second one measures the roughness of function *f*(z), expressed by its first derivative *f*0(z). Parameter λ controls the trade-off between the fit and the roughness penalty. The solution is a linear–quadratic smoothing spline (Bishop *et al.* 1999).

'The equal-area spline function is composed of two terms. The first term represents fidelity to the data. The second term measures roughness of the function. The parameter lambda controls the trade-off between the fidelity term and the roughness penalty. The choice of lambda is itself a non-trivial problem' (FAO, 2017).

RESULTS AND DISCUSSION

This method is based on fitting continuous depth functions for modeling the variability of soil properties (Fe and Mn) with profile depththus; it is possible to convert soil profiles to various depths. The equal-area spline function consists of a series of local quadratic polynomials that join at 'knots' located at the horizon boundaries thereby the mean value of each horizon is maintained by the spline fit. They are called equal-area splines because the area to the left of the fitted spline curve is equal to the area to the right of the curve and the value of lambda used in this work is 0.1.

Table 1: Micronutrients (Fe and Mn) of Profile 1 (upper slope)

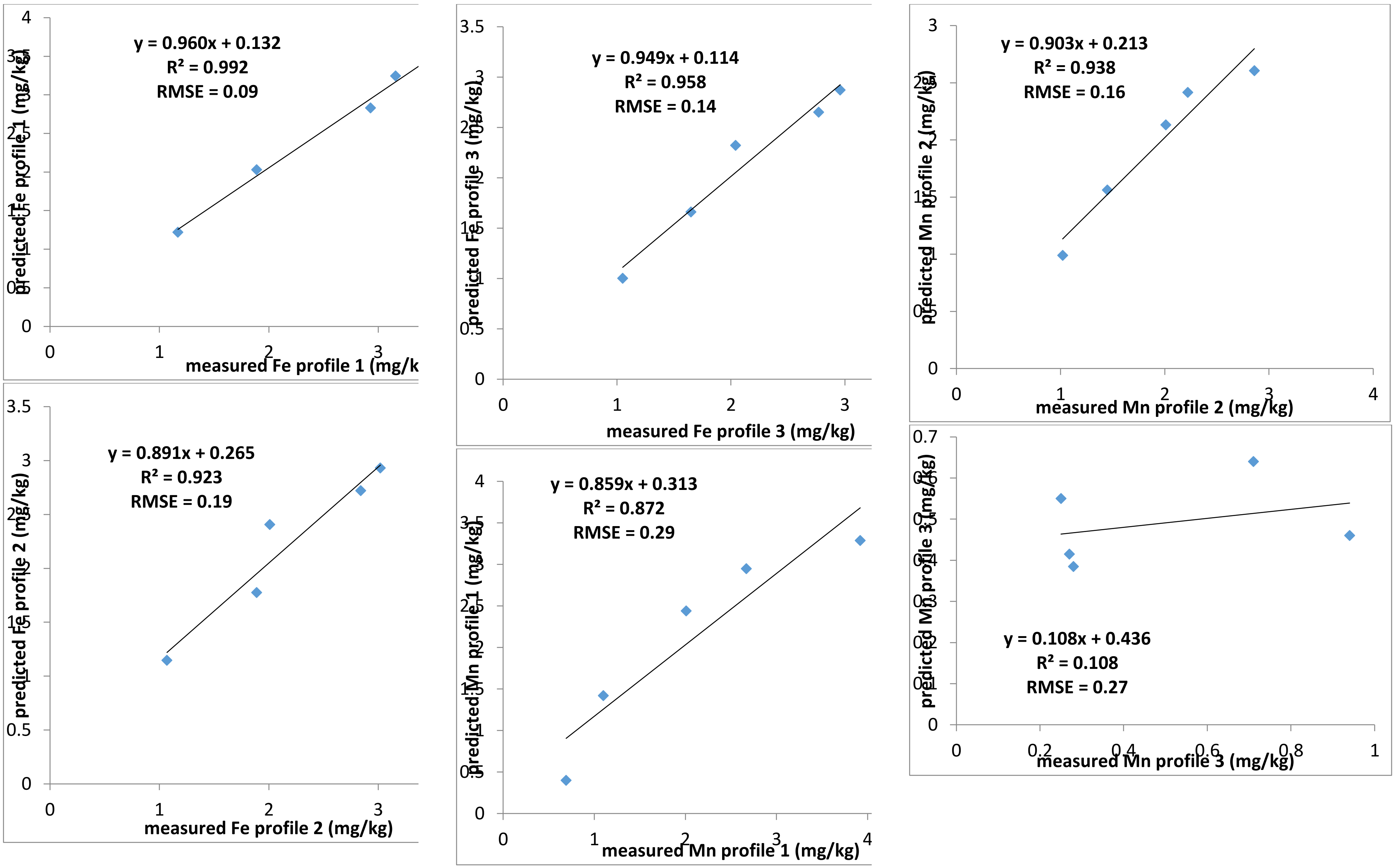
FID No.	**Depth (cm)**	**pH**	**OC gkg^{-1}**	**ECEC $cmolkg^{-1}$**	**Fe**	**Mn**
					----mgkg^{-1}---	
SHB1	0-5	5.59	24.1	4.71	3.52	3.92
SHB1	5-15	5.34	24.1	4.99	3.16	2.67
SHB1	15-30	5.0	20.7	5.23	2.93	2.01
SHB1	30-60	4.92	19.0	4.64	1.89	1.10
SHB1	60-90	4.66	14.0	5.37	1.17	0.69

Table 2: Micronutrients (Fe and Mn) of profile 2 (middle slope)

FID No.	***Depth (cm)***	***pH***	***OC gkg^{-1}***	***ECEC $cmolkg^{-1}$***	***Fe --- mgkg^{-1}---***	***Mn***
SHB2	*0-5*	*5.92*	*24.5*	*5.12*	*3.02*	*2.86*
SHB2	*5-15*	*5.78*	*17.4*	*4.97*	*2.84*	*2.22*
SHB2	*15-30*	*5.45*	*23.8*	*5.18*	*2.01*	*2.01*
SHB2	*30-60*	*5.25*	*24.3*	*5.09*	*1.89*	*1.45*
SHB2	*60-90*	*4.89*	*19.9*	*5.21*	*1.07*	*1.02*

Table 3: Micronutrients (Fe and Mn) of profile 3(lower slope)

FID No.	***Depth (cm)***	***pH***	***OC gkg^{-1}***	***ECEC $cmolkg^{-1}$***	***Fe***	***Mn***
					---mgkg^{-1}---	
SHB3	*0-5*	*4.64*	*25.7*	*5.27*	*2.96*	*0.28*
SHB3	*5-15*	*4.94*	*24.1*	*5.85*	*2.77*	*0.27*
SHB3	*15-30*	*5.52*	*18.9*	*5.49*	*2.04*	*0.94*
SHB3	*30-60*	*5.76*	*17.6*	*5.12*	*1.65*	*0.25*
SHB3	*60-90*	*5.93*	*14.5*	*5.93*	*1.05*	*0.71*


y = 0.960x + 0.132
R² = 0.992
RMSE = 0.09
predicted Fe profile 1 (mg/kg)
measured Fe profile 1 (mg/k
y = 0.949x + 0.114
R² = 0.958
RMSE = 0.14
predicted Fe profile 3 (mg/kg)
measured Fe profile 3 (mg/kg)
y = 0.903x + 0.213
R² = 0.938
RMSE = 0.16
predicted Mn profile 2 (mg/kg)
measured Mn profile 2 (mg/kg)
y = 0.891x + 0.265
R² = 0.923
RMSE = 0.19
predicted Fe profile 2 (mg/kg)
measured Fe profile 2 (mg/kg)
y = 0.859x + 0.313
R² = 0.872
RMSE = 0.29
predicted Mn profile 1 (mg/kg)
measured Mn profile 1 (mg/kg)
y = 0.108x + 0.436
R² = 0.108
RMSE = 0.27
predicted Mn profile 3 (mg/kg)
measured Mn profile 3 (mg/kg)

Scatter plots of measured data to predicted profile data

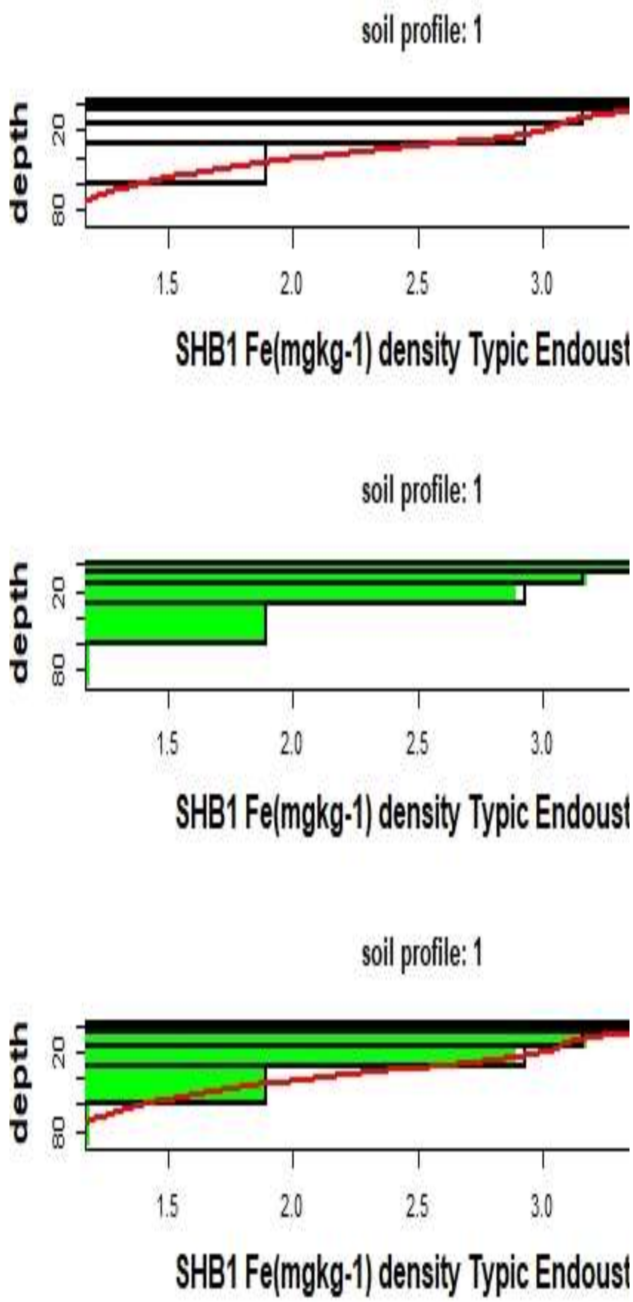


Fig. 2: Fitted splines to measured Fe data in profile 1 (upper slope)

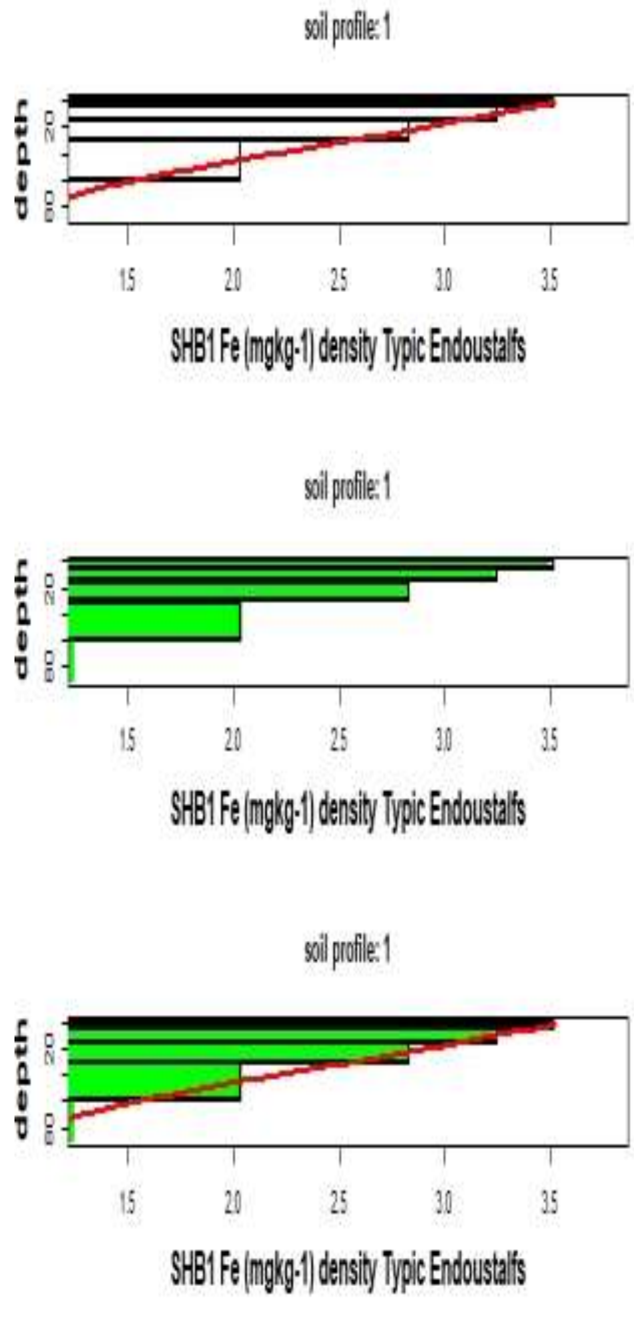


Fig. 3: Fitted splines to predicted Fe data in profile 1 (upper slope)

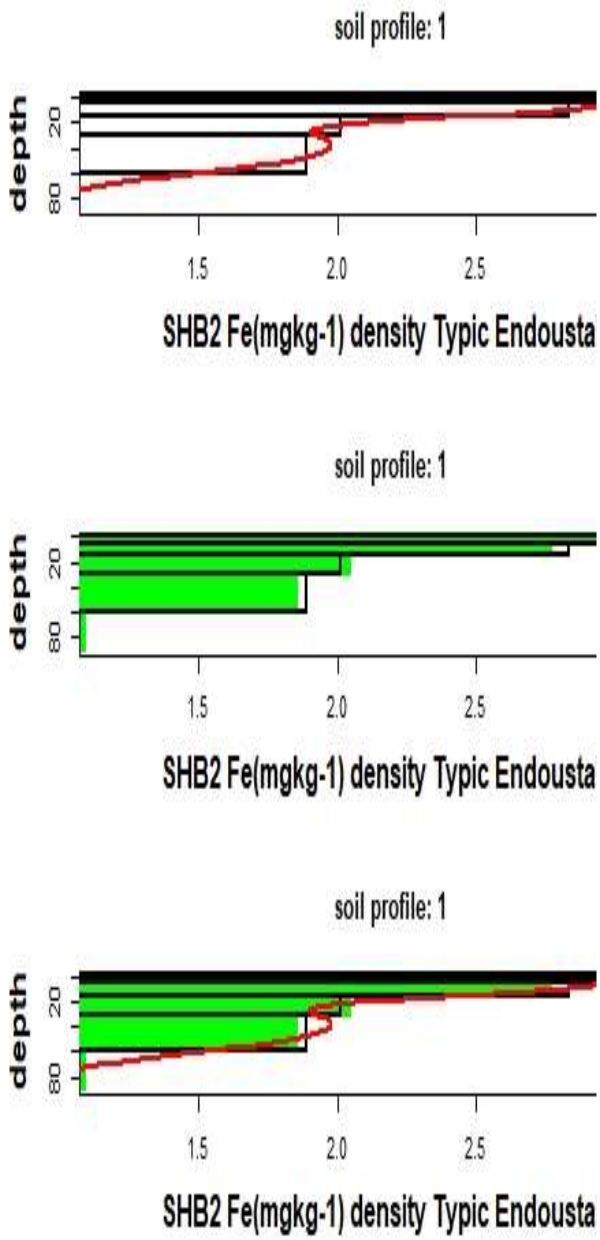


Fig. 4: Fitted splines to measured Fe data in profile 2 (mid slope).

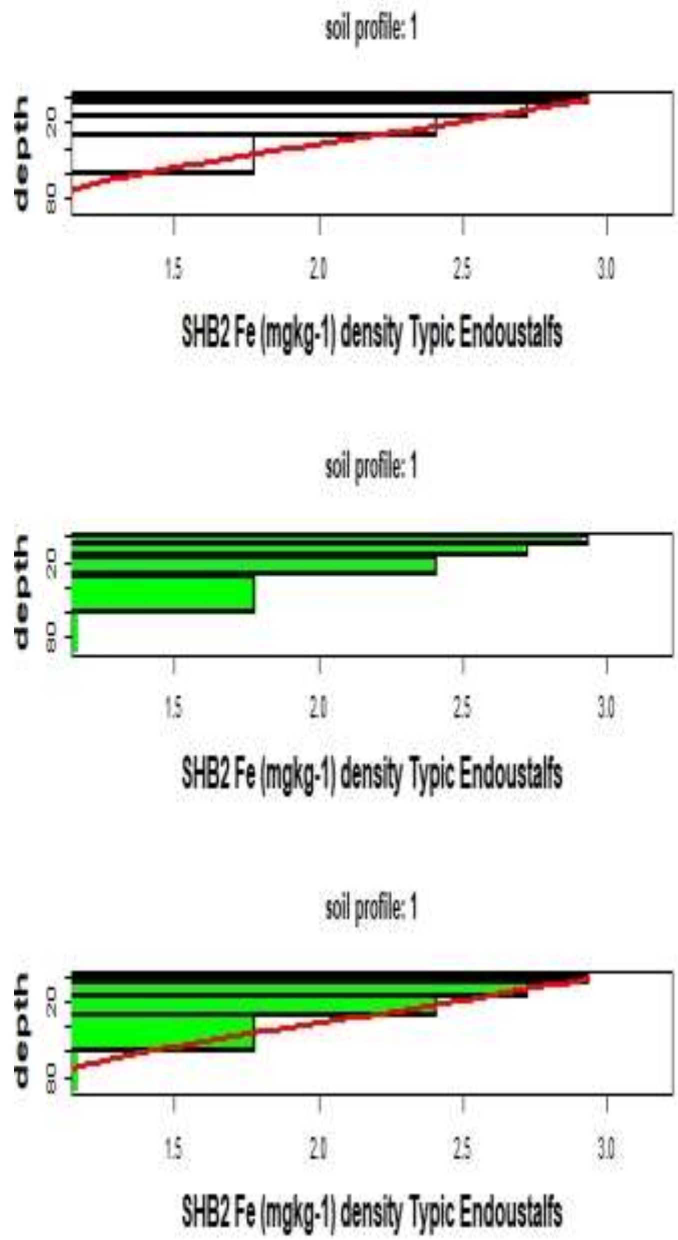


Fig. 5: Fitted splines to predicted Fe data in profile 2 (mid slope).

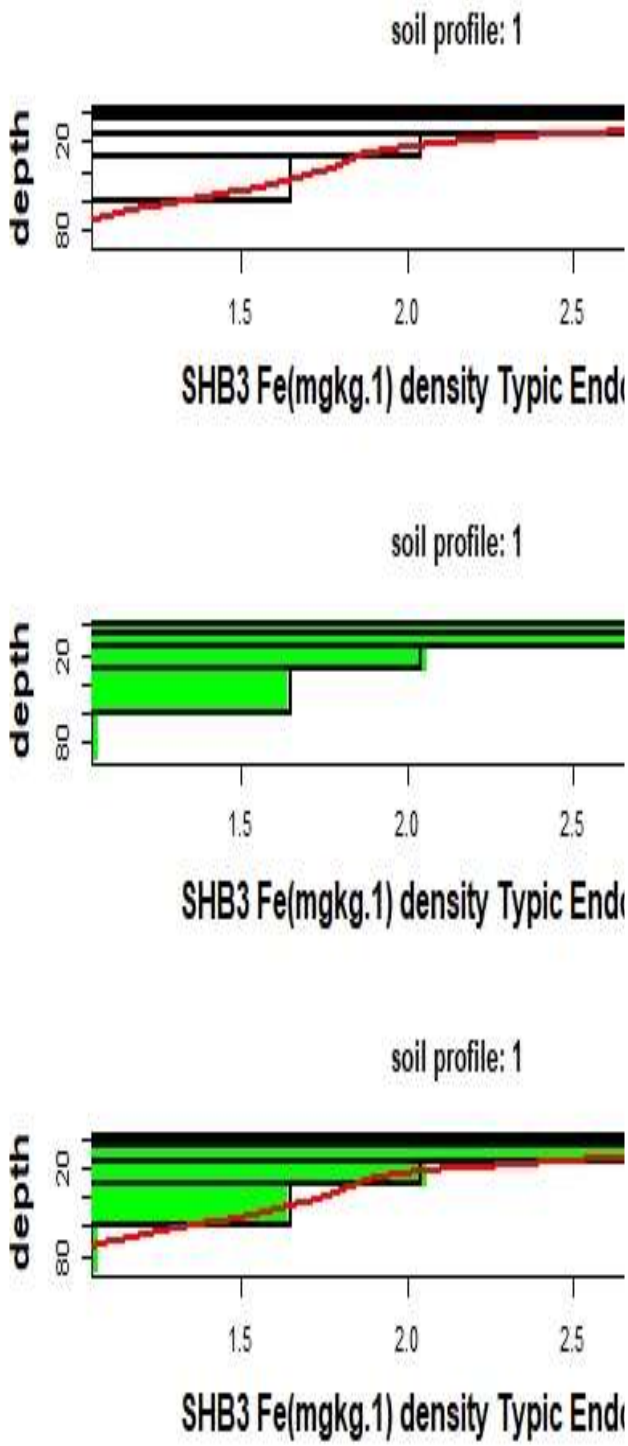


Fig. 6: Fitted splines to measured Fe data in profile 3 (lower slope)

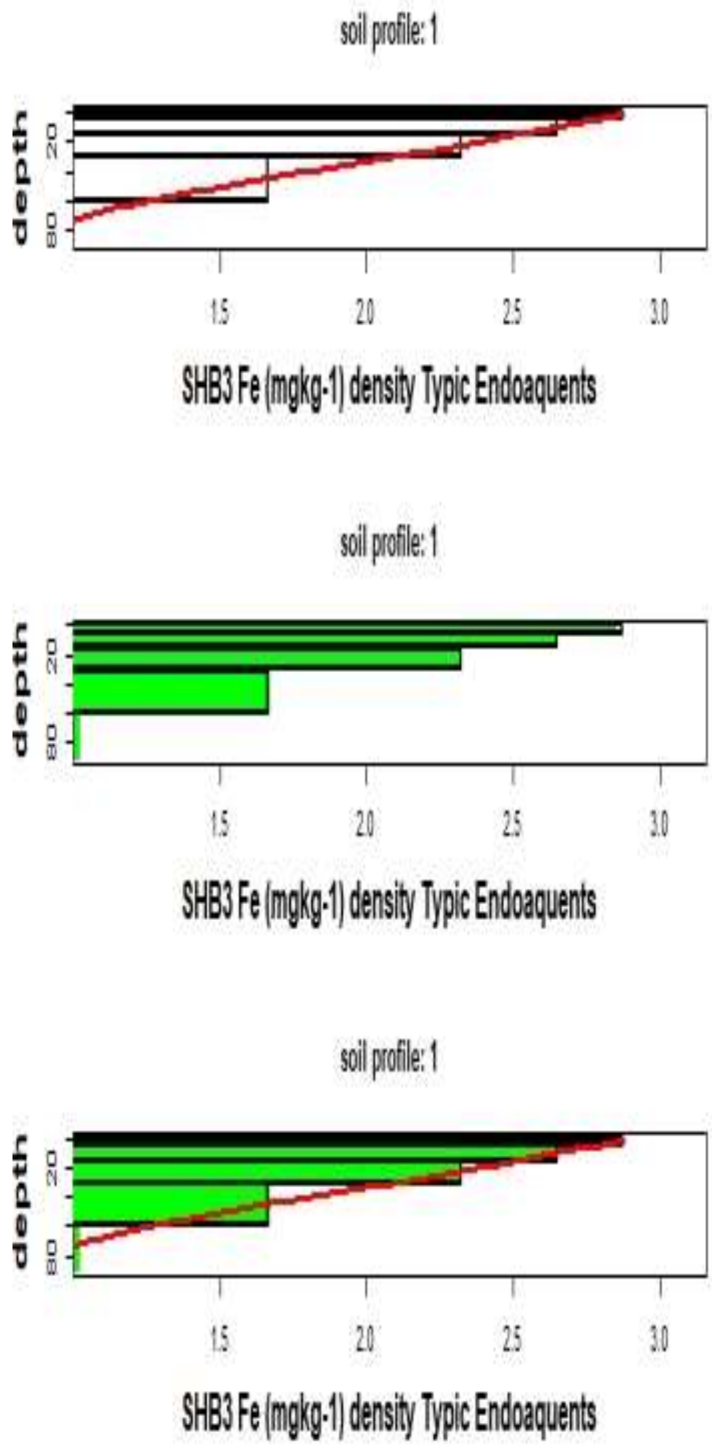


Fig. 7: Fitted splines to predicted Fe data in profile 3 (lower slope)

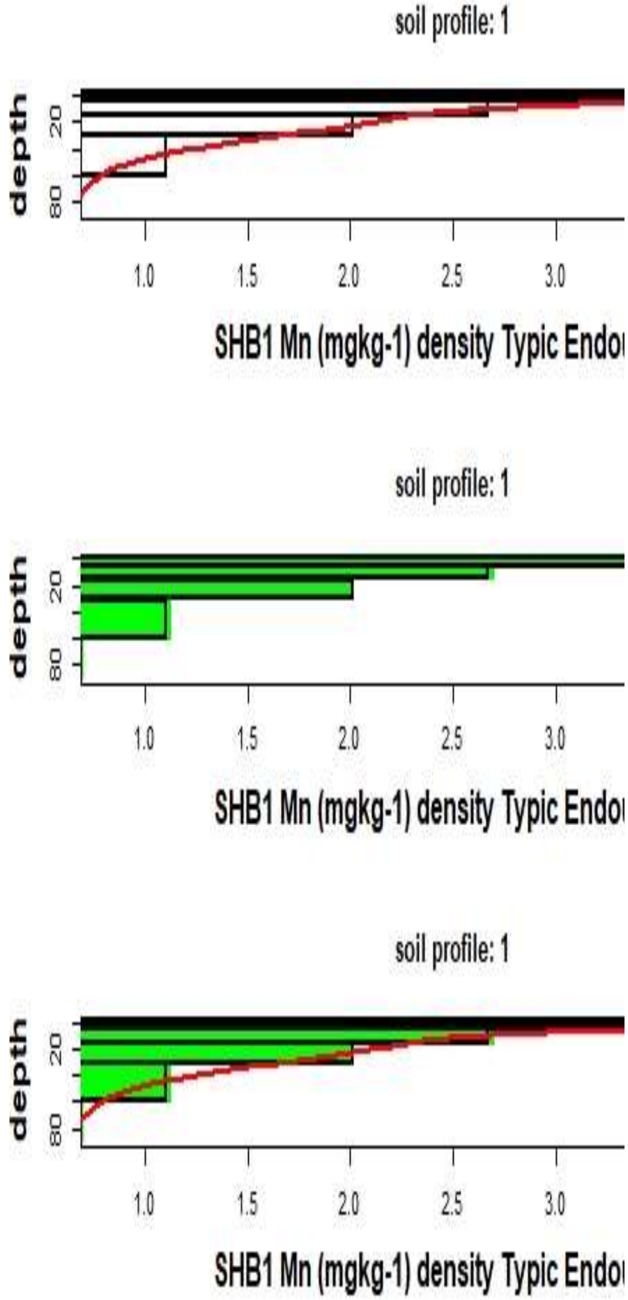


Figure 8: Fitted splines to measured Mn data in profile 1 (upper slope)

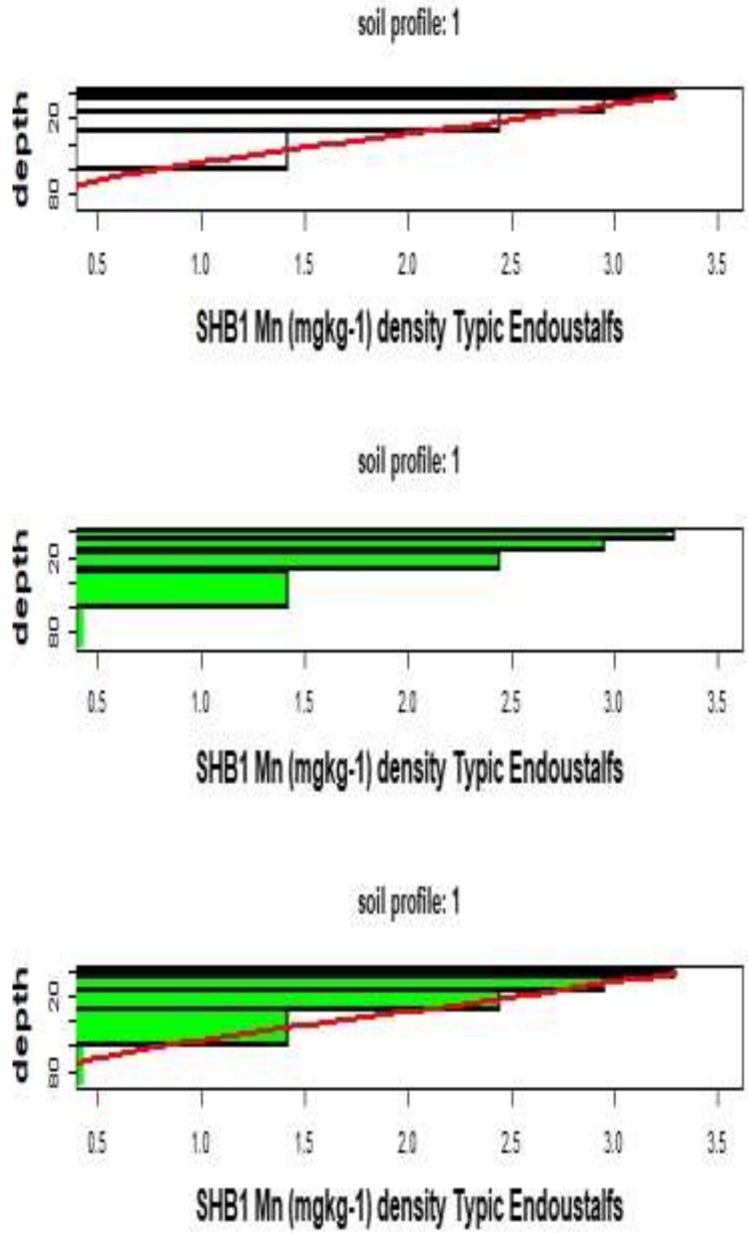


Fig. 9: Fitted splines to predicted Mn data in profile 1 (upper slope)

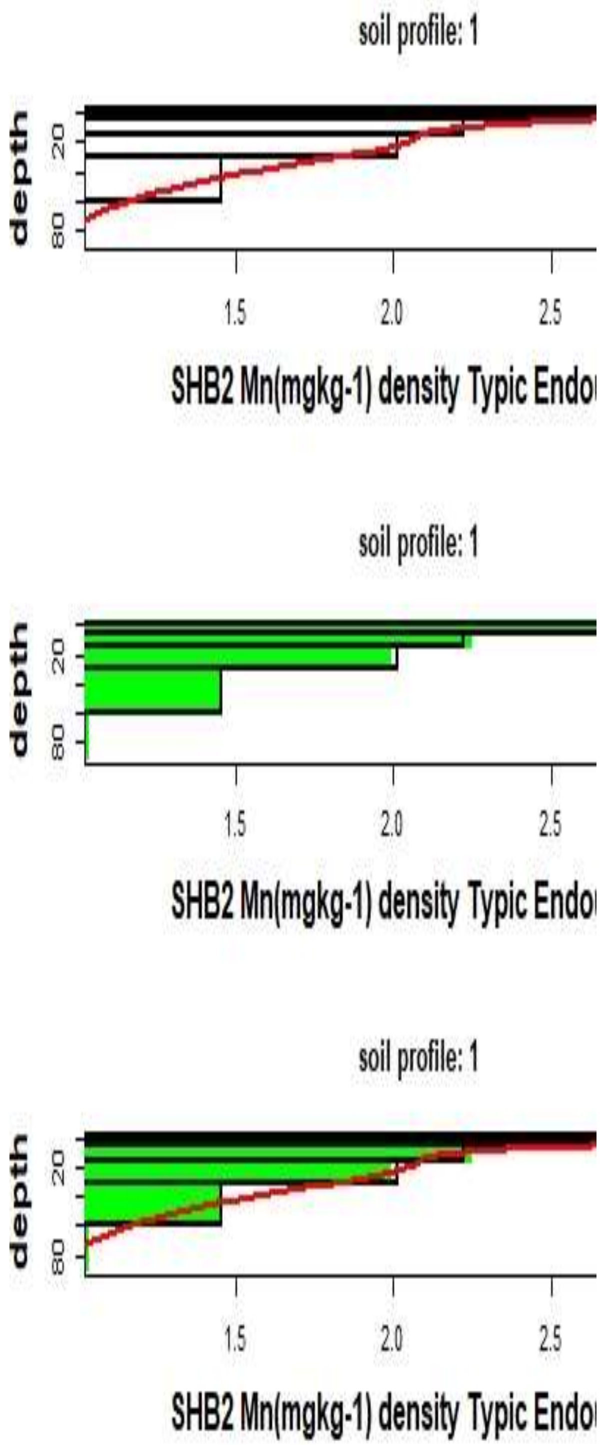


Fig. 10: Fitted splines of measured Mn data in profile 2 (mid slope).

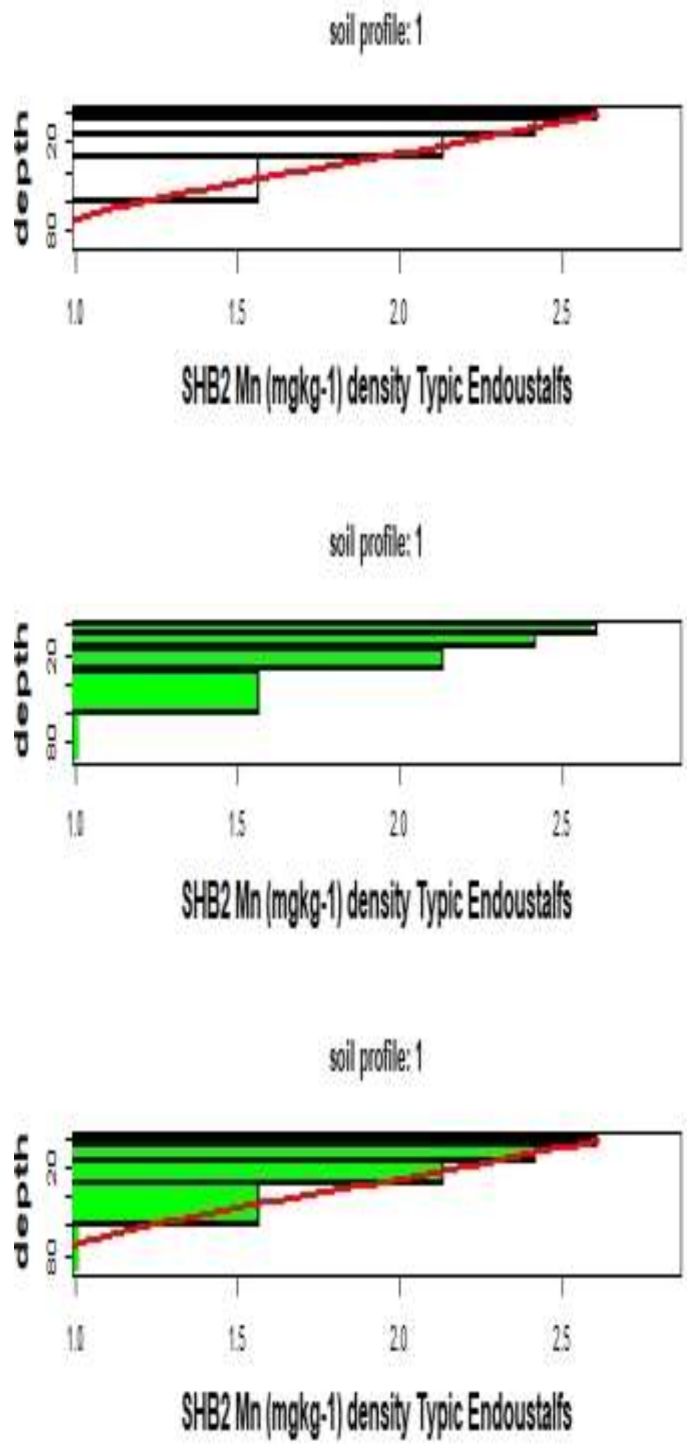


Fig. 11: Fitted splines of predicted Mn data in profile 2 (mid slope).

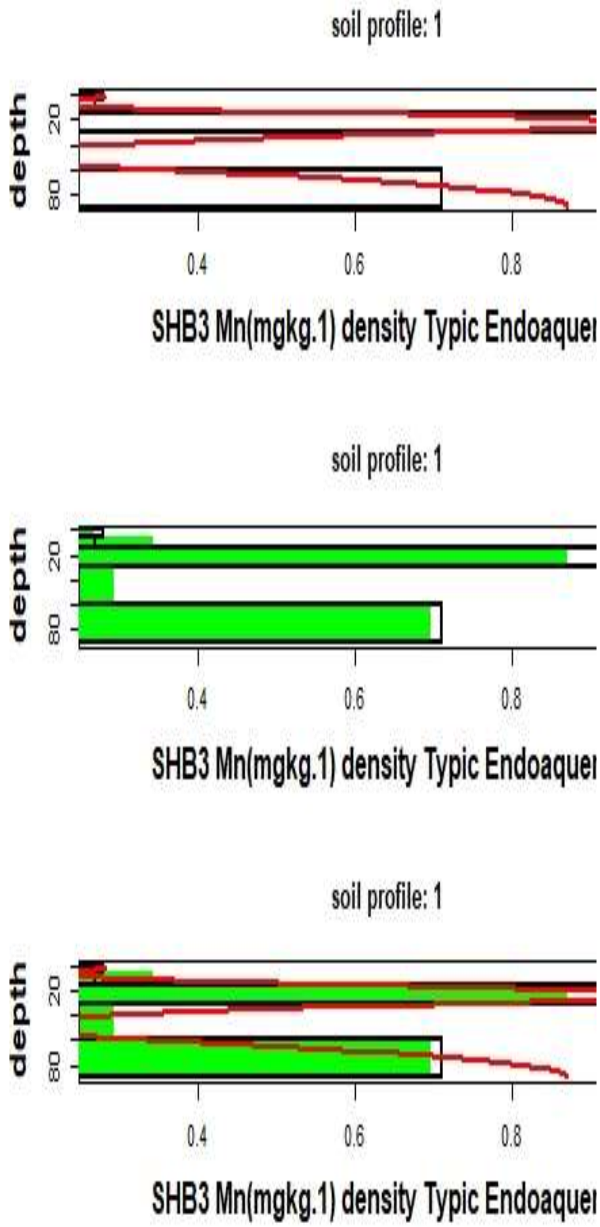


Fig. 12: Fitted splines of measured Mn data in profile 3 (lower slope).

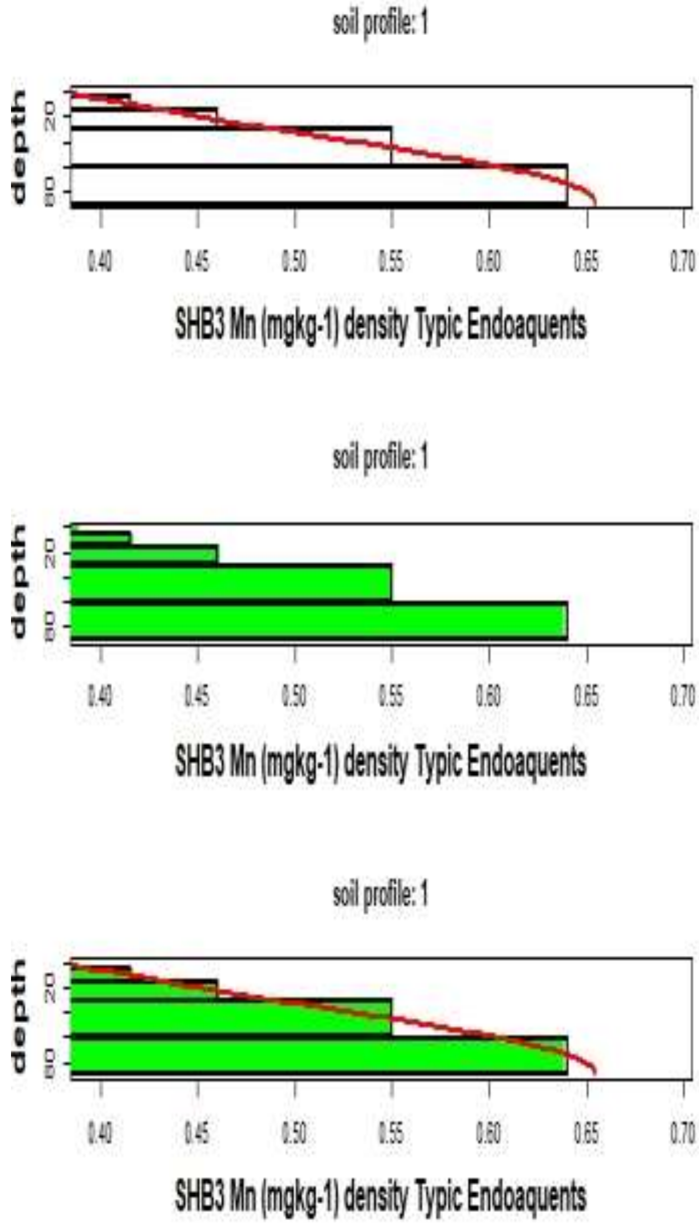


Fig. 13: Fitted splines of predicted Mn data in profile 3 (lower slope).

'The plot_ea_spline function is a basic function without too much control over the plotting parameters, there are three possible themes of plot output that one can select. This is controlled by the type parameter. Type = 1 is to return the observed soil data plus the continuous spline (default). Type = 2 is to return the observed data plus the averages of the spline at the specified depth intervals. Type = 3 is to return the observed data, spline averages and continuous spline' (Malone *et al.,* 2017).

Generally, the soils of the study area were slightly acidic inpH and micronutrients (Fe and Mn) were slightly decreasing down the profile depth in most of the soil pits and the results agrees with findings of Abubakar*et al.,* (2019) in the same study area. Results of the extractable micronutrients (Fe and Mn) have been presented in Table 1-3 and were predominantlyfar below permissible rate(low) across all the studied pits. The distribution of Fe in all the topographical locations (upper, middle and lower slope) was low (Samuel *et al*., 2003) and tend to decrease down the profile depth and tallies with the reports of Nagendran and Angayarkanni (2010). Generally, the low values of the micronutrient in the entire study area may be attributed to intensive cropping practices and the fact that micronutrients are not applied alongside NPK fertilizers (Abubakar *et al.,* 2019)

Our models for prediction of micronutrients (Fe and Mn) were capable of producing up to 99% ($R^2 = 0.99$) variation of these properties across the study area. Similar precisions of predictive models have also been reported by other researchers on organic carbon (Ryan *et al.,* 200; florinsky *et al.,* 2002). Malone *et al*., (2009) reported an R^2 value of 44% for vertical distributions of organic carbon in used in digital soil mapping. Odgers *et al.,* (2012) in their study on organic carbon which they did not include pseudo data, noticed that movements of the nutrients also tend to decrease down the soil pits using equal-area splines.

CONCLUSION

From the results obtained, it can be concluded that all the studied soils along the three topographical locations were generally low with respect to Fe and Mn and they mostly tend to decrease down the profile pits.

The spline functions were flexible and sensitive to changes or variation of the micronutrients (Fe and Mn) movements down the profile pits which can be amendable therefore, they can be used in displaying the vertical variability of micronutrients within the soil.

RECOMMENDATION

Considering the fact that in the study area (faculty of agriculture) there is a fertilizer blending plant, there is an urgent need to formulate or incorporate these limiting micronutrients (Fe and Mn) so as to avoid the low presence of these cations in the entire soils. All studies in the study area should be related to modeling in other to complement any measured data.

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