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Assessing The Fertility And Quality Of Tropical Peat (Histosols) For Sustainable Agriculture Production Based On Geostatistical Approach In An Agriculture Area In Malaysia

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Abstract: ***The decline in soil fertility is the main challenge in sustainable agriculture and the indiscriminate land use is responsible for the decline of Soil Quality. This study was conducted to assess the soil quality in an agriculture area using different soil quality indices as a tools in determining fertility status. This study was conducted in a farm located in Sepang district Selangor, Malaysia. The soil type is mainly peat and underlain by mineral soil. Soil samples were collected using a systematic grid (3 m by 3 m), 150 soil samples were collected at 5 different depths (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-00 cm) across the farm area using a hand auger. Soil analysis for chemical properties and some selected heavy metals were conducted using appropriate methods. Data obtained was used to calculate the soil quality (SFI, SQIa). Results showed that the soil in the study area is very strongly acidic to a strong acidic (pH 3.03- 4.46). Organic carbon showed a decreasing value with increasing depth (17.64-9.31 %), aluminum was high in all the sample (4.35-11.69 cmol$_+$/kg) with increasing values down the depth. SFI values showed that 75 % of the top soil (0-20 cm) in the study area has good fertility rating (S1), 10.71 % has moderate fertility rating(S2), and 14.29 % has a marginal (S3) fertility rating, and the lowest SFI was recorded at the last depth (80-100 cm). The SQIa shows that the soil at 0-60 cm has a Strong Fertility (0.61-0.71), As compared to the other depth which has moderate fertility (0.55) for 60-1000 cm. High significant correlation of soil quality indices with the soil chemical properties, indicate that these (SFI, SQIa) indices can serve or be used as an indicator of soil quality assessment and for estimating the soil fertility status.***

Keywords: Soil Fertility Index; Soil Quality; Soil Indicator; Fertility Status; Histosols.

I. INTRODUCTION

The increase in population has led to the increasing pressure on the global agricultural system to increase its food crop production in a sustainable manner. However, the decline in soil fertility and the mismanagement of plant nutrients poses a great challenge towards the attainment of this goal (Yerima & Van Ranst 2005; Hoseini & Taleshmikaiel 2013). Previous studies have shown that the indiscriminate use of the land and poor soil management practices by the farmers are among the factors responsible for the decline in soil quality (Yu et al. 2014; Hall et al. 2017; Abdalla et al. 2018). Therefore, a land used effectively will maintain not only the soil quality or the soil health, rather it would improve the quality of the soil of any type (Lal 2015; Raiesi 2017). The decline in the soil quality is of a global concern as the degraded soils have become more prevalent due to continuous mono-cropping and or poor management practices to the soil. The soil plays a vital role when determining the sustainable productivity of an agro-ecosystem and this depends mainly upon the soils ability or capability to supply nutrients to the plants. Soil is classified as a non-renewable resource which are essential of all life and cultural heritage (Lal 2015).

However, the soil quality is defined as the soils capacity or ability to carry out a given function within the agro eco-system and land-use boundaries, in order to maintain the biological productivity, to retain a quality environment, sustain the release of nutrients and water, promote the root growth, good responds to the management practice and resist degradation (Brejda & Moorman 2001). The soil quality is one of the components of environmental quality aside the water and the air quality (Andrews et al. 2002). In any given type of soil, the soil quality depends majorly on the natural composition, and also with changes related to human activities (Pierce & Larson 1994). In recent time, several methods of soil quality assessment (the card design and test kits (Ditzler & Tugel 2002), the soil quality index method (Karlen 1994; Doran & Jones 1996; Moran et al. 2000; Lu et al. 2002, Qi et al. 2009) and the geostatistical method (Sun et al. 2003)) had been developed to examine, evaluate and assess the quality of a given type of soil. Due to its flexibility, the Soil Quality Index method is the most commonly used method of all (Andrews et al. 2002).

Evaluation of the soil quality index involves certain procedures like identifying the minimum data set (MDS) of the selected soil indicator or parameter, transforming the soil quality indicators into scores and lastly, integrating all the selected indicators or parameters scores into a single value that will represent the quality of the soil tested (Andrew et al. 2004; Karlen et al. 2003). Soil parameters or soil indicators will be used to quantify the quality of a particular soil especially peat (Histosols). This present study is concerned with the quality of the soil based on its relationship to sustainable agricultural production and also its management practices. Therefore, in evaluating the soil quality, the first thing is to identify some suitable soil quality parameters that are desirous for sustainable agricultural production. The soil parameters or indicators include the chemical, physical and biological characteristics that can serve as indicators for assessing the quality of a soil. However, a single parameter cannot represent a consistent, reliable or ideal indicator for soil quality assessment, these parameters (physical, chemical, biological) can be considered in unison to assess the overall quality of a soil by quantifying the changes and the variations in the selected indicators of soil quality (Larson & Pierce 1991; Doran & Parkin 1994; Dalal & Moloney 2000; Ditzler & Tugel 2002; Sahrawat & Narteh 2002). Thereafter, the parameters would be transformed into one single value that will serve as the soil quality index or fertility index of an area. Soil quality indices were obtained from series of soil properties (physical, chemical and biological) which could be the integration of more than one soil quality indicator or parameter. Thereafter, they are used to assess, evaluate and quantify the quality of the studied soil in any given area (Pang et al. 2006).

Soil quality index serves as an important tool for evaluating agro-ecosystems and can be used to develop and produce a fertility maps, make corrections and recommendations based on soil spatial variability for fertility managements. Therefore, it is extremely important to assess the variations in the soil properties due to alterations in the land cover and to understand the influence of changes in the soil and water quality, biodiversity, and global climatic systems on natural resources and ecological processes (Houghton, 1994; Chen et al. 2001; Chaudhury et al. 2005; Abbasi et al. 2010). Susyan et al. (2011) reported that in order for soil to function well, the integration between the soil properties is essential in order to maintain soil quality for crop production.

Further, in peninsular Malaysia, peat is one type of soil in the region and they are formed through the decomposition and mixture of fragmented organic materials which has accumulated over years and this process occurs in wetlands. Tropical peats are noted to be very acidic in nature with pH value of > 4.0 (Lea 1956; Andriesse 1988), with high pH buffering capacity. The buffering capacity of the peat (Histosol) is mainly due to the carboxyl and phenolic functional groups in the humic substances of organic matter, peat has a high water capacity, poor aeration, and low bulk density which fundamentally leads to very limited crop cultivations. As such, herbicides, pesticides, fertilizers, liming materials and other cocktails of chemical are often used to produce satisfactory yield. However, such continuous practice accumulates toxic chemicals and also some heavy metals (Aikpokpodion et al. 2010; Zhou et al. 2011). This study was conducted to determine, evaluate, assess and produce a fertility map for the study area using soil quality indices such as Soil Fertility Index (SFI) and Simple Additive Soil Quality Index (SQIa) with the surface and subsurface properties employing a geostatistical approach as a tools for determining the soil fertility status in the study area. These indices can further be used as guidelines for sustainable land use for crop production on peat.

II. MATERIALS AND METHOD

This study was conducted in a farm (TKPM Ulu Chucoh) located in Sepang district in the Southern part of Selangor State, Malaysia (latitude 02°45^1 N and longitude 101°40^1 E) with an elevation of 4m above water level. According to United State Department of Agriculture (USDA, 2010) classification, the soil in this study site is classified as Histosols (Peat or Organic soils) and as observed by field and chemical properties analysis. The study was conducted on a 9 ha land and the soil type in the study area comprises of both the peat (up to 70 cm in depth) and admixture of peat and mineral soil underlying the peat (70-100 cm in depth). Soil samples were collected using a systematic grid (3 m by 3 m) across the study site. A total number of 30 grids (sample points) was identified, the georeferenced sample points (coordinates) was recorded for each sample points and soil samples was collected at five (5) different depths (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm) at each sampling points (150 soil samples) using a hand auger. The soil samples were processed for further laboratory analysis. For chemical analysis, Soil pH, Exchangeable Al, Soil Organic Matter (SOM), Soil Organic Carbon (SOC), Available P, Exchangeable Al, Exchangeable cations (Ca, Mg, K), Cation Exchange Capacity (CEC) and some selected heavy metals (Cu, Zn, Fe, Mn) were determined. Soil pH (H_2O) was determined as proposed by Jones (2002). Exchangeable aluminum was extracted with 1 N KCl according to Elisa et al. (2016), the values were determined using Inductively Coupled Plasma ICP-OES. Determination of available P was done using the Bray and Kurtz 2 method (Kuo 1996). Exchangeable cations (Ca, Mg, K) were determined by leaching method using 1 N ammonium acetate at pH 7 (Ross & Ketterings 1995; Shamshuddin 2006). Followed by removing the excess ammonium using ethanol, the soil was thereafter extracted with 0.05 M K_2SO_4 solution and the supernatant was used to determine the Cation Exchange Capacity (CEC) by titration using 0.01 N Hydrochloric acid (HCl) (Jackson 2005). The Soil Organic Carbon was determined by Walkley and Black (1934) method. The total content of heavy metals was determined by Aqua Regia method, and Inductively Coupled Plasma ICP-OES to determine the values (Gray et al. 2006). In order to evaluate the soil quality of the peat (Histosol), Soil Fertility Index (SFI) as proposed by Sağlam & Dengiz, (2014) and Simple Additive Soil Quality Index (SQIa) as proposed by Amacher et al. (2007) was implored. The SFI and SQIa indices was calculated to assess the influence of land degradation in the study site using the following equations as cited in literature:

A. COMPUTATION OF SOIL QUALITY INDICES

SOIL FERTILITY INDEX: The soil fertility index (SFI) was calculated to qualitative soil fertility classes by means of a parametric approach using twelve (12) soil quality indicators or parameters for each soil collected. The parameters or the indicators were evaluated using a factor ratings ranging between 10 and 100 (Sağlam & Dengiz 2014). The least factor value was rated 10 while the most beneficial value for plant growth was rated 100 as shown in Table 1. SFI was calculated using the value derived from the factor rating for each sample point as shown in equation 1 below:

Equation 1: Soil Fertility Index (SFI)

$$SFI = \left[R_{max} x \sqrt{\frac{A}{100} x \frac{B}{100} x \ldots\ldots} \right] x100$$

SFI= Soil Fertility Index

Rmax= Maximum Ratio, $\frac{A+B+C+\cdots.}{N}$

A, B, C…. = Rating Value for each Diagnostic Factors

N= Number of parameters or soil quality indicators

SIMPLE ADDITIVE SOIL QUALITY INDEX (SQIa): The SQIa was also calculated using twelve (12) parameters to qualitative soil fertility classes. The minimum data set was calculated, and the parameters are ranked into scores which ranged from 0 to 1 as proposed by Amacher et al. (2007). The least beneficial is ranked 0, while the most beneficial is ranked 1 for plant growth. SQIa was calculated using the score rating values for each sample points based on equation 2 below:

EQUATION 2: SOIL QUALITY INDEX (SQI)

$$SQI = \sum Individual\ soil\ parameters\ index\ values$$

$$SQI = \frac{(\sum SQI - SQImin)}{SQImax - SQImin}$$

SQI_{min} means minimum value of SQI

SQI_{max} means maximum value of SQI

The two indices (SFI and SQIa) was developed to assess the soil fertility status. Sağlam & Dengiz (2014) classified the Soil Fertility Index into four groups namely S1, S2, S3 and N which is Good Fertility rating (>80), Moderate Fertility rating (50-80), Marginal Fertility rating (20-50) and Poor Fertility rating (<20) respectively. Also, INPE (2001) and Da Silva et al. (2015) classified the SQI into six categories namely None Fertility (0), Poor Fertility (0-0.19), Weak Fertility (0.20-0.39), Moderate Fertility (0.40-0.59), Strong Fertility (0.60-0.79) and Excellent Fertility (0.80-1).

B. GEOSTATISTICAL AND STATISTICAL ANALYSIS

The geostatistical method was used to produce the SFI and SQIa spatial distribution map for the study area for all the depths. Geostatistical software (ArcGis 10.7.1) was used to construct the semivariogram for the soil quality indices. Descriptive statistical measures such as Mean, Range, Standard Deviation (SD), Coefficient of variation (CV %), Skewness and Kurtosis were used. Analysis of variance (ANOVA) and the least significant difference (LSD) was used for mean separation at P≤0.05. Pearson correlation at p≤0.05 was carried out to investigate the inter-relationships among the chemical properties and the soil quality indices (Yang et al. 2011).

Depth (cm)	**0-20**	**20-40**	**40-60**	**60-80**	**80-100**
Soil Properties					
pH	4.64	4.18	3.66	3.30	3.41
SOC %	17.64	13.67	11.10	9.98	9.31
SOM %	30.52	24.04	19.21	17.52	16.10
Ca(cmol$_+$/kg)	9.49	9.11	7.48	7.29	8.11
Mg(cmol$_+$/kg)	3.05	3.99	3.54	3.64	2.95
Avail P (mg/kg)	58.36	32.95	16.90	9.16	8.33
CEC(cmol$_+$/kg)	68.40	54.20	45.70	34.20	29.60
Al(cmol$_+$/kg)	4.35	8.24	11.69	11.69	8.12
K(cmol$_+$/kg)	0.39	0.36	0.34	0.38	0.48
Zn(mg/kg)	39.69	34.34	30.69	38.30	53.59
Cu(mg/kg)	20.21	16.30	11.32	8.51	8.24
Mn(mg/kg)	38.35	32.68	29.21	37.32	52.66
Fe(mg/kg)	3583.50	5644.14	9470.75	15172.29	20487.43
SFI	141.83	102.35	24.99	23.09	20.61
SQIa	0.71	0.66	0.61	0.55	0.55
N	30	30	30	30	30

S.O.M- Soil Organic Matter, S.O.C- Soil Organic Carbon, Al – Aluminum, Mg- Magnesium, Ca- Calcium, K-Potassium, Avail P- Available Phosphorus, SFI- Soil Fertility Index, *SQIa- Simple Additive Soil Quality, N- Number of soil samples analyzed, Cu- Copper, Zn- Zinc, Mn- Manganese, Fe- Iron.*

Table 1: Selected Chemical Properties (Mean) of the peat in the Study Area across Depth

III. RESULTS AND DISCUSSION

The mean values recorded for the soil pH in the study area ranged from pH 3.30 to 4.64 with the highest value at 0-20 cm (surface layer) while the lowest mean value of pH was recorded at depth 60-80 cm with (pH 3.30), the mean value tended to rise from 80-100 cm (Table 1), indicating that the soil at this depth is a mineral soil which increases soil pH (Andriesse, 1988). The low pH (<4) recorded from 40-100 cm was related to injury caused by proton pressure to the root of the plants in the study area. The pH value was significantly different with varying depth (Table 2) at $p \leq 0.05$. It can be concluded that the peat soil in the study area is very strongly acidic to a strong acidic. The acidity of the soil in the study area indicates the presence of the exchangeable hydrogen, aluminum and organic compounds (organic acids) that contains fulvic and humic acid (Andriesse, 1974). The result also showed decreasing value as the depth increases, and is similar to report by Suhardjo & Widjaja Adhi (1976). Shamshuddin & Fauziah (2010) reported that a typical Malaysian histosols having soluble aluminum in the soil solution can cause the decrease in the pH value down the depth of the soil profile.

Depth (cm)	pH	SOC	Al	Ca	Mg	K	CEC	P	Cu	Zn	Mn	Fe
		%			(Cmol₊/kg)					mg/kg		
0-20	4.64^{a}	17.64^{a}	4.35^{c}	9.49^{a}	3.05^{a}	0.39^{b}	68.40^{a}	58.36^{a}	20.21^{a}	39.69^{b}	38.35^{c}	3583.5^{d}
20-40	4.18^{b}	13.67^{b}	8.24^{b}	9.11^{ab}	3.99^{a}	0.36^{b}	54.20^{b}	32.95^{b}	16.3^{b}	34.34^{b}	32.68^{c}	5644.14^{c}
40-60	3.66^{c}	11.10^{c}	11.16^{a}	7.48^{bc}	3.54^{a}	0.34^{b}	45.70^{c}	16.90^{c}	11.32^{c}	30.69^{b}	29.21^{c}	9470.75^{b}
60-80	3.30^{d}	9.98^{c}	11.69^{a}	7.29^{c}	3.64^{a}	0.38^{b}	34.20^{d}	9.16^{c}	8.51^{cd}	38.3^{a}	37.32^{b}	15172.29^{a}
80-100	3.41^{d}	9.31^{cd}	8.12^{b}	8.11^{abc}	2.95^{a}	0.48^{a}	29.60^{d}	8.33^{c}	8.24^{d}	53.59^{a}	52.66^{a}	20487.43^{a}
P-value	<0.0001	<0.0001	<0.0001	0.0485	0.4635	0.0071	<0.0001	<0.0001	p<0.0001	p=0.003	p<0.0001	p<0.0001

S.O.C- Soil Organic Carbon, Al – Aluminum, Mg- Magnesium, Ca- Calcium, K-Potassium, Avail P- Available Phosphorus, CEC- Cation exchange capacity, Cu- Copper, Zn- Zinc, Mn- Manganese, Fe- Iron.

Table 2: *Statistical Analysis of the selected soil properties in the Study Area*

The aluminum recorded in this study was high in all the depth of the study area ranging from 4.35-11.67 $cmol_{+}$/kg with the highest mean value at 60-80 cm depth and the lowest mean value at the top layer (Table 1). There was a significant different with varying depths at $p \leq 0.05$ test level (Table 2). The result showed that there was relationship between aluminum and the soil pH. This relationship can be explained as hydrolysis of Al^{3+} in the soil solution. The high content of aluminum in this study will possibly hinder the availability of exchangeable bases in the farm area and result in saturation of aluminum (Arifin et al. 2008; Abdu et al. 2008).

Soil organic carbon (SOC) in this study recorded a mean values which ranged from 9.31-17.64 % with the highest mean value at the surface layer (0-20 cm) and decreases down as the depth increases to the lowest value recorded at 80-100 cm, and the result was par to previous reports (Iqbal et al. 2014; Guan et al. 2015; Chen et al. 2016). The result was significantly different with varying depth down the soil profile at $p \leq 0.05$ level (Table 2). The coefficient of variation (CV%) ranged between 16.15 to 23.25 % indication a low variation (< 25 %) among the depths (Aweto 1982). The result obtained for SOC was similar to peat soils of Riau (Lucas, 1982), which shows that when the depth is getting to the mineral soil layer, the value tends to decreases to less than 12 % which is similar to the soil in the study area. The high SOC content at the surface layer was a result of cycling of plant and the carbon inputs from the plant roots same as the plant residues (which contains high nitrogen and carbon contents) in the surface layer of the study area (Jobbágy & Jackson 2001).

The mean values for the exchangeable bases (Ca, Mg, K) at all depth analyzed ranged from 7.29-9.49, 2.95-3.99 and 0.34-0.48 $cmol_{+}$/kg for Ca, Mg and K respectively. The highest values for Ca was at surface layer (0-20 cm) and it tended to decrease with increasing depth. The result showed that Ca and K is significantly different with varying depth but Mg showed no significant different with varying depth down the soil profile (Table 2). The values recorded for the exchangeable bases were classified as moderate to low and this was due to the high content of exchangeable aluminum in the soil solution which impede their availability (Arifin et al. 2008; Abdu et al. 2008), also, it could also be a result of leaching, because peats are susceptible to leaching due to low content of clay and absence of mineral matters (Ahmed et al. 2015). Result obtained for the exchangeable bases revealed that they were strongly influenced by pH, and that Ca occupied most of the exchange site which is similar to study by Lucas (1982), but it was different from the peat soil in Sarawak where Mg occupied most of the exchange site (Tie, 1977).

The cation exchange capacity (CEC) value in the study area ranged from 29.60-68.40 $cmol_{+}$/kg with the highest value at the surface layer (0-20 cm) while the lowest value was at 60-80 cm. The values for CEC in all depth showed that CEC is pH dependent because the H^{+} remain fixed with the functional group in acid materials. Also, the CEC in the study area was influenced strongly by the organic matter content because during decomposition, the organic materials produces a varieties of organic compounds and will exhibit exchange properties, and plays an important role in the sustainable agricultural management of the soils. Available phosphorus (P_{av}) content in all the depths was classified as moderate to very low 8.33-58.36 mg/kg with the highest value at the surface soil (0-20 cm) and the lowest at depth 80-100 cm. The result showed that P was decreasing with increasing depth. There was a significant different with varying depth (Table 2). Reports from previous studies showed that available P is always high at surface soil layers compared to other depths, and this is as a result of high content of organic matter. The low P in the soil of the study suggested immobilization by specific adsorption of the nutrients by Fe and or Al compound (Fageria & Baligar 2008).

Mean value for the selected heavy metals analyzed (Table 1) shows a range of 8.24-20.21, 30.69-53.59, 29.21-52.66, 12.06-16.37 and 3583.40-20487.43 mg/kg for Cu, Zn, Mn, Pb and Fe respectively. The entire elements were significantly different with varying depth in the study site at $p \leq 0.05$ (Table 2). Zn and Mn were high at 40-60 cm, which can be explained as eluviation and illuviation. Though the Fe tends to increase with increasing depth. Previous studies report that when organic soils (Peat) are at pH 3, it will have a high content of Fe and the metals forms a complex with organic matter. But at high pH >5, Fe would be present in available form to the soil thereby increases its availability for plant uptake. High value of Fe also indicate the presence of reddish hermatite and geothite. Arsenic and Cadmium were below the determination limit which implies that the present activities of the farmers (liming and agrochemicals application) in the study area was not able to increase the contents of these two (2) elements (As and Cd) in the soil of the study area. All the values for Cu, Zn, and Pb were all within range for organic soils according to Lukas (1982).

A. DISTRIBUTION OF SOIL FERTILITY INDEX AND SOIL QUALITY INDEX

Lu et al. (2002), reports that the variation in the soil properties makes it difficult to adopt or find a suitable method to assess the soil conditions in any given study area. However, an effective method to assess and quantify the soil quality or the fertility status of a particular site was developed by using multiple soil quality indices. The geostatistics also provides some set of statistical tools that can be used in incorporating the coordinates of spatial observations in data processing (Loganathan et al. 2001). It is also a tool used for optimum sampling design and interpolation of un-sampled locations, considering the spatial correlation of adjacent pixels based on the semivariance. Table 3 shows the spatial analysis of the study area. Soil fertility index (SFI) recorded across the farm area ranged from 141.83 to 20.61 (Table 4) with a decreasing value down the soil profile, while the soil quality index single (SQIa) value also tends to decrease with increasing depth with the values ranging from 0.71 to 0.55 (Table 5). The decreasing values with increasing depth obtained for the soil quality indices (SFI and SQIa) across the study area was a result of the variation in the content of the parameters used and likely due to water table often noted within range of these depth (40-100 cm) across the farm areas. The overall results obtained from this study showed that 75 % of the surface soil (0-20 cm) across the farm area has good fertility rating (S1), 10.71 % has moderate fertility (S2), and 14.29 % has a marginal fertility (S3). While the lowest SFI value was recorded at the last depth (80-100 cm) with zero (0) good fertility rating, 3.75 % of moderate fertility rating (S2), 35.71 % of marginal fertility rating (S3) and 60.71 % of poor fertility rating (N) as shown in table 4. Meanwhile, SQI shows that the soil at 0-60 cm has a Strong Fertility rating (0.61-0.71) as compared to the other depth which have a Moderate fertility rating (0.55) for 60-100 cm (Table 5). The high value of the Soil Quality indices (SFI and SQIa) at the surface soil in the study area was attributed to the greater accumulation of organic matter which is one important soil quality indicator, and less exchangeable Al content than in other depth while the decreasing value was related to low soil pH, decrease in organic matter contents and increasing value of exchangeable Al which are important indicators in assessing the soil quality of an area using soil quality Indices. The spatial distribution (interpolation mapping) of Soil Fertility Index (SFI) and Simple Additive Soil Quality Index (SQIa) for the study area are shown in figure 1 and 2 respectively.

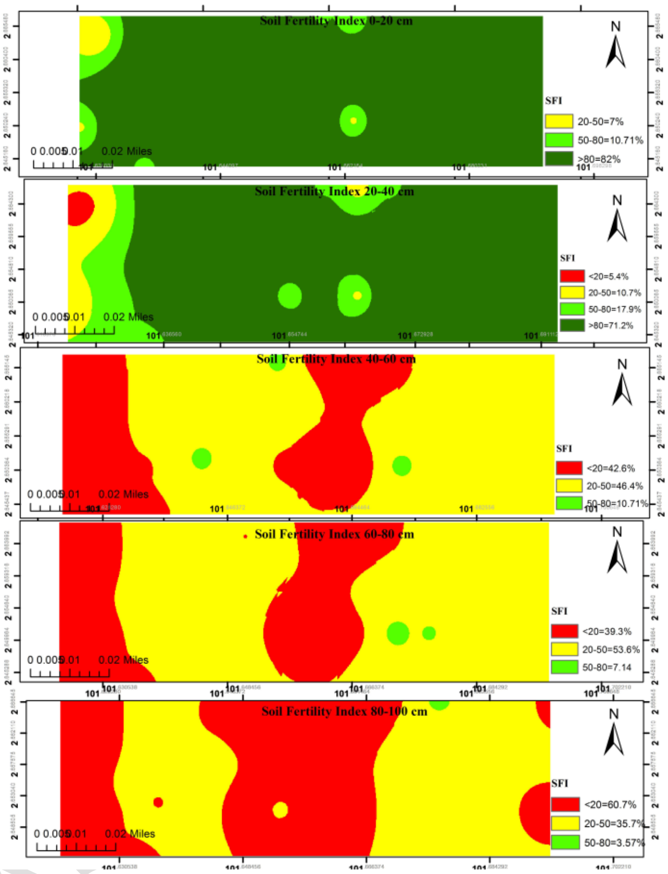

Figure 1: interpolation mapping of Soil Fertility Index in all depth of the study area

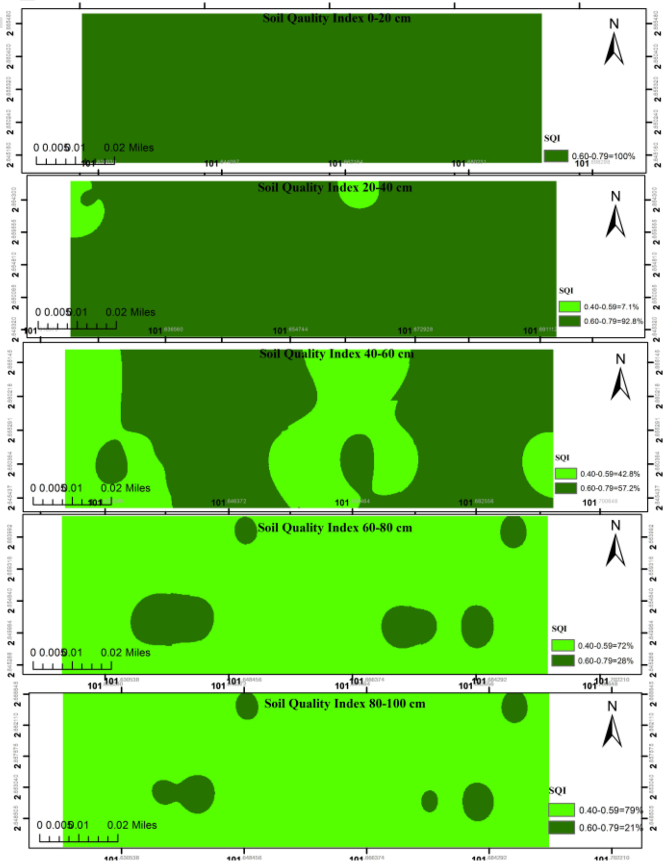

Figure 2: interpolation mapping of Soil Quality Index in all depth of the study area

Depth (cm)	0-20		20-40		40-60		60-80		80-100	
Soil Properties	skew	kurt	skew	kurt	skew	kurt	skew	kurt	skew	kurt
pH	-0.23	-0.2	-0.42	-0.57	0	-1.3	0.21	0.2	0.04	-0.6
SOC %	0.12	1.12	0.66	2.37	-0.23	1.77	-0.23	2.44	1.07	2.29
SOM %	0.12	1.11	1.14	2.93	-0.22	1.77	-0.4	2.88	1.06	2.27
Ca(cmol+/kg)	0.42	-1	1.06	0.29	-0.04	-1.3	0.1	-1.14	0.93	1.33
Mg(cmol+/kg)	1.21	1.15	0.52	-1.15	0.94	0.23	1.18	0.98	1.2	0.79
Avail P (mg/kg)	1.63	2.68	1.21	0.84	0.8	-0.2	1.7	2.87	3.71	15.6
CEC(cmol+/kg)	-0.02	0.32	0.1	-0.68	0.48	0.82	1.02	1.06	0.49	-0.7
Al(cmol+/kg)	0.72	-1.1	0.22	-1.16	-0.68	-0.6	1.4	3.98	1.03	0.88
K(cmol+/kg))	1.76	2.91	1.82	3.69	2.5	8.68	0.9	3.15	0.67	-1
Zn(mg/kg)	1.22	0.53	0.89	-0.43	1.85	4.25	0.72	0.48	2.35	8.52
Cu(mg/kg)	1.18	1	1.18	0.69	1.5	3.82	0.22	-0.03	0.45	-0.5
Mn(mg/kg)	1.21	0.48	1.09	0.27	0.88	1.42	1.46	2.93	2.39	8.84
Fe(mg/kg)	1.02	1.52	1.39	2.46	0.99	0.06	0.02	-0.65	1.93	6.92
SFI	-0.27	-1	0.77	0.71	0.29	-1	0.54	-0.58	1.05	0.34
SQIa	1.07	-1	-1.3	0.95	0.16	-1.9	0.03	0.21	1.57	0.5

S.O.M- Soil Organic Matter, S.O.C- Soil Organic Carbon, Al – Aluminum, Mg- Magnesium, Ca- Calcium, K-Potassium, Avail P- Available Phosphorus, SFI- Soil Fertility Index, SQIa- Simple Additive Soil Quality, N- Number of soil samples analyzed, Cu- Copper, Zn- Zinc, Mn- Manganese, Fe- Iron, Skew- Skewness, Kurt- Kurtosis.

Table 3: *The Spatial Analysis of selected soil properties in the Study Area*

Depth (cm)	Mean	Min	Max	S.D	CV %	Description
0-20	141.83	21	221.82	63.93	45.11	Good Fertility (S1)
20-40	102.35	14.49	221.82	57.79	56.48	Good Fertility (S1)
40-60	24.99	2.09	55.66	17.13	68.55	Marginal Fertility (S3)
60-80	23.09	2.86	55.66	15.61	67.61	Marginal Fertility (S3)
80-100	20.61	2.86	55.66	13.16	63.83	Marginal Fertility (S3)

Table 4: Descriptive statistics of soil fertility index with depth across the study area

Depth (cm)	Mean	Min	Max	S.D	CV %	Description
0-20	0.71	0.69	0.77	0.03	4.87	Strong Fertility
20-40	0.66	0.54	0.69	0.05	7.26	Strong Fertility
40-60	0.61	0.54	0.69	0.07	11.14	Strong Fertility
60-80	0.55	0.46	0.62	0.04	7.73	Moderate Fertility
80-100	0.55	0.54	0.62	0.03	5.69	Moderate Fertility

Table 5: *Descriptive statistics of simple additive soil quality index with depth across the study area*

B. VALIDATING THE SOIL QUALITY INDICES USING PEARSON CORRELATION ANALYSIS

Table 6 shows that aluminum had a high negative correlation with pH (r=-0.78165, p<0.01), Ca (r=-0.5753, p<0.01) and Mg (r=-0.55490, p<0.01) in this study and the relationship is an effect of the electrolyte concentration and the nature of the soil charge. The soil pH of the study had a positive correlation with Mg (r=0.47579, p<0.01) and Ca (r=0.32038, p<0.01) which shows that availability of Mg and Ca was influenced by pH. Also Mg had correlation with Ca (r=0.31299, p<0.01), and K with SOM (0.41579, p<0.05). SFI had a high positive correlation with pH (r=0.6253, p<0.0001), SOC (r=0.5966, p<0.0001), Avail P (r=0.6860, p<0.0001), CEC (r=0.6576, p<0.0001) and SQI (r=0.5661, p<0.0001) but a negative correlation with Al (r=-0.5665, p<0.0001). SQI also had a high positive correlation with pH (r=0.8046, p<0.0001) and SOC (r=0.4474, p=0.0030) with a negative correlation with Al (r=-0.7057, p<0.0001).

	pH	SOC (%)	Al (cmol₊/kg)	Ca (cmol₊/kg)	Mg (cmol₊/kg)	K (cmol₊/kg)	P (mg/kg)	CEC (cmol₊/kg)	SFI	SQI
pH	1									
SOC (%)	0.50371*	1								
Al (cmol₊/kg)	-0.80131	-0.6309	1							
Ca (cmol₊/kg)	0.45906*	0.33179	-0.72196	1						
Mg (cmol₊/kg)	0.34842	0.05063	-0.5782	0.56947*	1					
K (cmol₊/kg)	0.24101	0.22801	-0.25842	0.31753	0.258	1				
P (mg/kg)	0.59219*	0.4648*	-0.59707	0.27819	-0.00745	0.01862	1			
CEC (cmol₊/kg)	0.33578	0.57447*	-0.16486	-0.10868	-0.47117	0.04845	0.49739*	1		
SFI	0.62532*	0.59669*	-0.56651	0.36302	0.048	0.42332	0.68606*	0.65768*	1	
SQI	0.80463*	0.44742*	-0.70571	0.49066*	0.35483	0.26189	0.48948*	0.24493	0.56651*	1

**-Significant at p≤0.05, S.O.C- Soil Organic Carbon, Al – Aluminum, Mg- Magnesium, Ca- Calcium, K- Potassium, Avail P- Available Phosphorus, CEC- cation exchange capacity, SFI- Soil Fertility Index, SQIa- Simple Additive Soil Quality Index.*

Table 6: *Pearson Correlation Coefficient of selected chemical properties with the soil quality indices (SFI, SQI) used in the study*

IV. CONCLUSION

The soil in the study area showed a variation in chemical properties with varying depth. The soil in the study area is however classified as very strong acidic to strong acidic. Therefore, raising the pH to >4 in the sub soil layer would overcome the root injury caused by proton pressure and essential elements would be readily available for plant uptake. High aluminum content in all the depth of the study area contributed to the acidity of the soil. The cycling of plant and carbon inputs from plant roots as well as plant residues depositing on the top soil layer or the frequent application of animal waste product by farmers to ameliorate the soil was the reason for the high content of organic matter in the farm area.

Soil Fertility Index (SFI) values obtained across the farm are indicates that 0-40 cm has good fertility rating (>80) while 40-100 cm has marginal fertility rating (20-50). Soil Quality index (SQIa) values on the other hand showed that depth 0-60 cm has Strong Fertility (0.60-0.79) while other depth has a Moderate Fertility (0.40-0.59). The high significant correlation of these indices (SFI and SQIa) with other soil properties (chemical and selected heavy metals) analyzed satisfies that the indices can serve and also be used as an indicator for soil quality assessment and estimating soil fertility status in any given area. It was concluded from this study, that the surface soil (0-40 cm) has a better soil quality or fertility status than the sub surface layers (40-100), and it shows that the soil could be more suitable for shallow rooted crops (<40 cm) for sustainable Agriculture production. However, it is recommended that more study should be devoted to this topic on peat soils (Histosol) especially on the validation and the usefulness of soil quality indices in making decisions and implementation.

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