UNIVERSITI PUTRA MALAYSIA

SOIL QUALITY AND SPATIAL VARIABILITY ASSESSMENT OF TROPICAL PEAT (Histosol) SOIL CULTIVATED WITH CASSAVA (Manihot esculenta Crantz) IN SEPANG, SELANGOR, MALAYSIA

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By

ADEBAYO KAYODE KABIR

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

February 2022

DEDICATION

This thesis is dedicated to Almighty Allah for making study a reality. Also this thesis is specially dedicated to my **beloved parents, Alhaji Shehu Bayo and Alhaja Sikirat Adebayo,** also to my wife, **Alhaja Rihannat Adebayo.** My Siblings, **Hassanat, Abdulateef, Abubakar, Ibrahim, Abdulkadir.** Also to my Children, **Nabilah, Sophiyah, Najibah, Nafisah, Salaudeen, Saad, Ibrahim and Abdulrahman.** Whom their support encouraged me to do the best.

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

SOIL QUALITY AND SPATIAL VARIABILITY ASSESSMENT OF TROPICAL PEAT (*HISTOSOL*) SOIL CULTIVATED WITH CASSAVA (*Manihot esculenta Crantz*) IN SEPANG, SELANGOR, MALAYSIA.

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Chairman : Roslan bin Ismail, PhD
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Tropical peats are generally acidic (pH 3.0-4.5) and deficient in nutrients such as Ca, Mg, K, P, Mn, Fe, Zn and Cu. Therefore, liming materials (calcium carbonate ($CaCO_3$), magnesium carbonate ($MgCO_3$), dolomite (CaMg (CO_3)), magnesium oxides (MgO)) is commonly practiced besides the use of chemical fertilizers and other cocktail of agrochemicals to improve selected soil characteristics and to produce satisfactory yield.

Furthermore, no standardized method is available on soil quality assessment especially peat. Noteworthy that, various approach and indices have been applied by researchers globally. Therefore, the objective of this present study is to classify and characterize the tropical peat (soil) in the study area, to determine, evaluate and assess the tropical peat (soil) quality (fertility status) using selected quality indices (Soil Fertility Index (SFI), Soil Quality Index (SQI), and Soil Microbial Index (SMI)) and to further produce the peat soil spatial variability by semivariogram of selected crop-nutrients.

This study was conducted at Taman Kekal Pengeluaran Makanan (TKPM) Ulu Chucoh, located in Sepang district in the southern part of the state of Selangor, Malaysia (latitude 02°45^1 N and longitude 101°40^1 E). Soil in the study area were mainly peat (up to 80 cm depth) and underlain by mineral soils. A total of 150 soil samples were collected at five (5) different depths (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm) at each determined grid (total 30 grids) using a hand auger. The soil samples were subjected to morphological, physical and chemical analysis (properties), biological (microbial) and selected heavy metals analyses, based on standard methods well-stated in the literature. Descriptive statistics were analyzed using Analysis of Variance (ANOVA) and the Least Significant Difference (LSD) was used for mean separation at $p \leq 0.05$ using SAS

version 9.4 software. The geostatistical method was used to generate spatial map for SFI, SQI and major soil nutrients of the study site for all the depths using ArcGIS 10.7.1 software.

The soil chemical properties were significantly difference with varying depth at p≤0.05 level of LSD test. Results showed that the peat (soil) in the study area ranged from very strongly acidic to a strong acidic (pH 3.30 to 4.64). Soil organic carbon (SOC) showed a decreasing value with increasing depth (17.64 to 9.31 %). Aluminum content was high across the study site (4.35 to 11.69 $cmol_+/kg$) with increasing values down the depth showing a relationship with the soil pH (hydrolysis). Exchangeable bases (Ca, Mg, K) obtained ranged from low to moderate due to the high content of Al.

The single value obtained for SFI and SQI across the study site ranged from 141.83 to 20.61, and 0.71 to 0.55 respectively. SFI and SQI value decreases down the soil profile. Decreasing trend in SFI and SQI value was attributed to the variation in the content of the indicators, high water table often recorded from depth 40 cm across the farm area. The spatial map showed the classes of fertility for all depth analyzed with variation (low-moderate) across the plots and down the soil profile, revealing the areas that requires amendments for each nutrient for sustainable cultivation based on the values obtained for the nutrient distributed in the study area with depth.

The farmer's management practices are noted to have minimal effect on the soil quality losses. Thus the significant correlation of soil quality indices (p≤0.05) with the soil chemical properties indicates that assessment of soil quality using several indices (SFI, SMI, SQIa) shows conclusive information on the soil fertility status.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENILAIAN KUALITI TANAH DAN VARIABILITI RUANG TANAH GAMBUT TROPIKA (*Histosol*) YANG DITANAM DENGAN UBI KAYU (*Manihot esculenta Crantz*) DI SEPANG, SELANGOR, MALAYSIA.

Oleh

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Tanah gambut tropika umumnya berasid (pH 3.0-4.5) dan kekurangan nutrien seperti Ca, Mg, K, P, Mn, Fe, Zn dan Cu. Oleh itu, bahan pengapuran (kalsium karbonat (CaCO3), magnesium karbonat (MgCO3), dolomit (CaMg (CO3)), magnesium oksida (MgO)) lazimnya diamalkan selain penggunaan baja kimia dan koktel agrokimia lain untuk memperbaiki ciri tanah tertentu dan menghasilkan hasil yang memuaskan.

Tambahan pula, tiada kaedah piawai yang tersedia untuk penilaian kualiti tanah terutamanya gambut. Perlu diperhatikan bahawa, pelbagai pendekatan dan indeks telah digunakan oleh penyelidik di peringkat global. Oleh itu, objektif kajian ini adalah untuk mengklasifikasi dan mencirikan gambut tropika (tanah) di kawasan kajian, untuk menentukan, menaksir dan menilai kualiti gambut (tanah) tropika (status kesuburan) menggunakan indeks kualiti terpilih (Indeks Kesuburan Tanah (Indeks Kesuburan Tanah) SFI), Indeks Kualiti Tanah (SQI), dan Indeks Mikrob Tanah (SMI)) dan seterusnya menghasilkan kebolehubahan spatial tanah gambut dengan semivariogram bagi nutrien tanaman terpilih.

Kajian ini dijalankan di Taman Kekal Pengeluaran Makanan (TKPM) Ulu Chucoh, yang terletak di daerah Sepang di bahagian selatan negeri Selangor, Malaysia (latitud 02°451 N dan longitud 101°401 E). Sebanyak 150 sampel tanah telah dikumpulkan pada lima (5) kedalaman yang berbeza (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm dan 80-100 cm) pada setiap grid yang ditentukan (jumlah 30 grid) menggunakan gerimit tangan. Sampel tanah tertakluk kepada analisis morfologi, fizikal dan kimia (sifat), biologi (mikrob) dan analisis logam berat terpilih, berdasarkan kaedah standard yang dinyatakan dengan baik dalam literatur. Statistik deskriptif dianalisis menggunakan Analisis Varians (ANOVA) dan Perbezaan Ketara Paling Kecil (LSD) digunakan untuk pemisahan min pada

p≤0.05 menggunakan perisian SAS versi 9.4. Kaedah geostatistik digunakan untuk menjana peta spatial untuk SFI, SQI dan nutrien tanah utama tapak kajian untuk semua kedalaman menggunakan perisian ArcGIS 10.7.1.

Sifat kimia tanah adalah berbeza secara signifikan dengan kedalaman yang berbeza-beza pada tahap p≤0.05 ujian LSD. Keputusan menunjukkan bahawa gambut (tanah) di kawasan kajian adalah berjulat dari berasid sangat kuat kepada berasid kuat (pH 3.30 hingga 4.64). Karbon organik tanah (SOC) menunjukkan nilai berkurangan dengan peningkatan kedalaman (17.64 hingga 9.31 %). Kandungan aluminium adalah tinggi di seluruh tapak kajian (4.35 hingga 11.69 cmol+/kg) dengan peningkatan nilai menuruni kedalaman menunjukkan hubungan dengan pH tanah (hidrolisis). Bes boleh tukar (Ca, Mg, K) yang diperoleh berjulat dari rendah hingga sederhana kerana kandungan Al yang tinggi.

Nilai tunggal yang diperolehi untuk SFI dan SQI di seluruh tapak kajian masing-masing berjulat antara 141.83 hingga 20.61, dan 0.71 hingga 0.55. Nilai SFI dan SQI menurun ke bawah profil tanah. Arah aliran menurun dalam nilai SFI dan SQI adalah disebabkan oleh variasi dalam kandungan penunjuk, paras air yang tinggi sering direkodkan dari kedalaman 40 cm merentasi kawasan ladang.

Peta spatial menunjukkan kelas kesuburan untuk semua kedalaman yang dianalisis dengan variasi (rendah-sederhana) merentas plot dan ke bawah profil tanah, mendedahkan kawasan yang memerlukan pindaan bagi setiap nutrien untuk penanaman lestari berdasarkan nilai yang diperoleh untuk nutrien yang diagihkan di kawasan kajian dengan kedalaman.

Amalan pengurusan petani diperhatikan mempunyai kesan minimum terhadap kehilangan kualiti tanah. Oleh itu, korelasi signifikan indeks kualiti tanah (p≤0.05) dengan sifat kimia tanah menunjukkan bahawa penilaian kualiti tanah menggunakan beberapa indeks (SFI, SMI, SQIa) menunjukkan maklumat konklusif tentang status kesuburan tanah.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy in Soil Science. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

AA	Auto analyzer
AAS	Atomic adsorption spectrophotometer
Al	Aluminum
ANOVA	Analysis of variance
As	Arsenic
Ca	Calcium
$CaCO_3$	Calcium carbonate
Cd	Cadmium
CEC	Cation exchange capacity
CP	Concentration of heavy metal in plant
CS	Concentration of heavy metal in soil
Cu	Copper
CV	Coefficient of variation
DHA	Dehydrogenase activity
FAO	Food and agriculture organization
Fe	Iron
FeS_2	Iron sulphide
$FeSO_4(NH_4)_2SO_4$	Ferrous ammonium sulphate
GIS	Geographical information system
GPS	Global positioning system
H	Hydrogen
Ha	Hectare
HCl	Hydrochloric acid
ICP	Inductively coupled plasma

ICP-OES	Inductively couple plasma
IDI	Intelligent devices and implements
IDW	Inversely distant weighted
K	Potassium
$K_2Cr_2O_7$	Potassium dichromate
K_2SO_4	Potassium sulphate
KCl	potassium chloride
LSD	Least significant difference
M	Molarity
MBC	Microbial biomass carbon
MBN	Microbial biomass nitrogen
MDS	Minimum data set
Mg	Magnesium
Mn	Manganese
MST	Malaysian soil taxonomy
N	Nitrogen
N	Normality
Na	Sodium
NaOH	Sodium hydroxide
NH_4	Ammonia
NH_4F	Ammonium fluoride
NH_4OAc	Ammonium acetate
NHO_3	Nitric acid
O	Oxygen
OSM	Organic soil material

P_{av}	Available phosphorus
PCA	Principal component analysis
pH	Soil reaction
PMN	Potentially mineralizable nitrogen
SAS	Statistical analysis software
SFI	Soil fertility index
SMI	Soil microbial index
SOC	Soil organic carbon
SOM	Soil organic matter
SQIa	Simple additive soil quality
TF	Transfer factor
TKPM	Taman kekal pengeluaran makanan
TOC	Total organic carbon
TPF	Triphenylformazan
TTC	Triphenyltetrazolium chloride
USDA	United state department of agriculture
UV	Ultra violent
WHO	World health organization
WRB	World reference base
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Soil is important and a non-renewable natural resources on human time scales, and they are essential to all terrestrial life and cultural heritage (Lal, 2015). The soil plays an active function in determining the suitability of agriculture productivity which depends mainly upon the efficiency or capability of the soil to provide the essential nutrients to the growing plants. The indiscriminate land use and or the poor soil managements are mainly the factors responsible for the diminution in soil quality due to continuous reduction in the soil nutrients and its physical structure (Yu *et al.,* 2014; Hall *et al.,* 2017; Abdalla *et al.,* 2018). However, the thorough management of land use will not only have upheld the health and quality of the soil, rather it will improve the soil quality (Lal 2015; Raiesi 2017).

Further, in Peninsular Malaysia, peat (organic soil) is one type of soil in the region. In Malaysia, it is estimated that there are around 2.5 million ha of peat land. Peninsular Malaysia occupies about 796,782 hectares (Law & Selvadurai, 1968), while Sarawak was reported to have the largest peat land in Malaysia as it occupies about 1,765547 hectares (Melling, 1999). Most of the peat land in Sarawak is located at the Delta of the Rajang River, Baram, and Limbang system (Jarret, 2003).

The peats are formed through the decomposition and mixture of fragmented organic materials (mainly plant) which has accumulated over time and this process occurs mostly in wetlands (Topcuoğlu & Turan, 2018). The peat soil depth is divided into four classes, namely the shallow peat (50-100 cm), moderate peat (100-150 cm), deep peat (150-300 cm) and very deep peat (>300 cm) as proposed by Paramananthan *et al.,*1984. Furthermore, tropical peats are very acidic in nature with the soil pH of less than 4.0 (Lea, 1956; Andriesse, 1988). They are highly buffered with changes to the pH and the buffering capacity of peat is fundamentally due to the carboxyl and phenolic functional groups in the humic substances of organic matter. The acidity and alkalinity of soils are the main environmental problems that threatens sustainable agriculture production for a long time (Farifteh *et al.,* 2006).

The quality or fertility of the soil is an inevitable characteristic that changes via the influence of the natural and human factors (Kavitha, & Sujatha, 2015). A detailed awareness about the fertility of soil is one part of the requirement for assessing long term impact of intensive or continuous mono-cropping techniques on tropical soils (Dobermann & Oberthür, 1997). However, characterization of the soil in relationship to the assessment of the soil quality or fertility in an area is important on the basis of sustainable agriculture (Singh & Mishra, 2012). Therefore, to have a sufficient soil management, the farmer(s) need to understand the fertility status of the soil, and the improvement required for optimum productivity of the soil (Kavitha & Sujatha, 2015).

The concept of soil quality evolved throughout the 90‟s in reaction to increase the global emphasis on land use sustainability and with a systemic way to stress that the management of sustainable soil requires more than controlling soil erosion (Mausel, 1971). However, soil quality had always been used in the background of land evaluation and quality. They are both addressed primarily as the natural soil characteristics that are not easily changed in the entire soil profile (Eswaran et al. 1997). Soil quality is focused mainly on the dynamic (changing) soil attributes which are influenced by soil management, but they are assessed mostly in the surface horizon (Karlen *et al.,* 2003). Assessing the soil quality includes land evaluation and the procedure is used differently for a varying purpose which includes sustainable land management (Hurni *et al.,* 2015), environmental risk assessment, environmental changes (Sonneveld *et al.,* 2010) and land restoration (Schwilch *et al.,* 2012). Soil quality assessment is expressed in other concepts aside from mineral mining. The major interest of soil in this study is its potential for suitable agricultural activities and suitability for crop growth.

Therefore, soil quality is referred to as the ability of the soil to perform some given functions within the ecosystems and the land use boundaries, response to the management of the soil and to withstand soil degradation (Bredja & Moorman, 2001). MacDonald *et al.,* (1998) also defined soil quality as a combined expression of the soil formation and properties, that interlude to determine its suitableness in performing numbers of basic functions, i.e by supporting crop production, (Mohamed, 2013), buffering the environment from nutrients and other chemicals, partitioning water and gases (Belal *et al.,* 2014; Abu-hashim *et al.,* 2016).

Among the components of environmental quality, soil quality is one aside the water and air quality (Andrews *et al*., 2002). In any soil type, the quality of the soil depends mostly on its inherent (parent) composition, but also with the changes related to human activities and management (Pierce & Larson, 1983; Masciandaro 1999). Over time, several methods for assessing the soil quality had been proposed by different researchers among which are, the card design and test kits (Ditzler & Tugel 2002), soil quality index method (Karlen, 1994; Doran & Jones, 1996; Moran *et al.,* 2000; Lu *et al.,* 2002; Qi *et al.,* 2009; Sağlam & Dengiz, 2014) and geostatistical method (Sun *et al.,* 2003). However, the method commonly used by researchers' or the soil scientists cited in literature is the soil quality index method (Andrew *et al.,* 2002), because of its flexibility.

The indicators or parameters for soil quality or fertility includes the physical, chemical and biological characteristics that are used for assessing the quality of any soil type (Dalal & Moloney, 2000). Nevertheless, a lone parameter or indicator is inappropriate to be represented as a consistently reliable and ideal soil quality indicator, but with the integration of these parameters, then the overall soil quality can be assessed by evaluating the changes in these indicators or parameters (Larson & Pierce, 1991; Doran & Parkin, 1994; Dalal & Moloney, 2000; Ditzler & Tugel, 2002; Sahrawat & Narteh, 2002). Therefore, to assess the soil quality, the first step in is by identifying the specific soil parameters or indicators that are desirable for sustainable agriculture production. Thereafter, the measured parameters would be integrated and transformed to a single value known as the soil quality or fertility index (SQI or SFI) (Karlen *et al.,* 2003; Andrew *et al.,* 2004). Soil quality indices were developed from series of soil characteristics combining more parameters or indicators, which will be used to assess and describe the quality of the soil in a given site or area (Pang *et al.,* 2006). Susyan *et al.,* (2011), reported that soil will function well when the soil properties are well integrated and it is essential for maintaining soil quality for crop production.

Soil quality index is an important tool for evaluating the agro-ecosystems, it is used to produce fertility maps, regarding the soil spatial variability in fertility managements of the main restricting factors for agriculture productions (Knoepp *et al.,* 2000; Griffiths *et al.,* 2010). Soil quality index is also employed for preparing a perfect soil management to sustain continuous agriculture production (Moore *et al.,* 2016). Therefore, it is extremely important to assess the changes in the soil characteristics that influences changes in 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).

1.2 Problem statement

In Malaysia, agriculture is one of the main sector contributing to the economy although the industrial sector has contributed much as well to the economic development. But in the course of agricultural activities in Malaysia, the tropical peats (*histosols*) which are noted to be highly acidic in nature with pH value of less than 4.0 (Lea, 1956; Andriesse, 1988) are considered. Also, tropical peat has high water capacity, poor aeration and low bulk density which is not so good for cultivation of crops. However, the tropical peat can extremely be productive for agriculture with the application of fertilizers, liming materials and other of agrochemicals. Such continuous practices will accumulate toxic chemicals and also some heavy metals (Aikpokpodion *et al.,* 2010; Zhou *et al.,* 2011). Crops grown on such contaminated soil may adsorb the heavy metals through the growth medium resulting to be harmful to the health of consumers (human and animal) of such crops. Also, the soil physical, chemical and biological characteristics may be affected. (Zhou et al. 2011; Al-Qahtani et al. 2016).

Further, Cassava (*Manihot esculenta*) is a calorie producing crops in the tropics with a great importance. It efficiently produces carbohydrate, adapt to a range of environmental changes, it is drought and acid soil tolerant (Jones 1959; Rogers

& Appan, 1970; Kawano *et al*., 1978; Cock, 1985). The continuous monocrop cultivation of cassava on peat will undergoes top soil losses (degradation) by erosion and reduction of peat nutrient reserve by the harvesting of cassava roots.

More so, previous researchers basically focused more on the tropical peat surface soil horizon (Andrews *et al.,* 2002a, 2002b; Armenise *et al.,* 2013), while studies that considered the whole horizon in a soil profile are still lacking (Moncada *et al.,* 2014; Vasu *et al.,* 2016; Zhijun *et al.,* 2018). Although, it is much easier to measure and assess the changes in the characteristics of the superficial soil layers, but it will however provide an incomplete information about the given soil, because soil functions are influenced by the pedogenic processes that occurs in the soil. Therefore, measuring and evaluating the soil quality with the surface and subsurface properties will assist in identifying the soil properties with the optimum influence on basic soil functions.

Thus, the purpose of this present study was to provide a fundamental knowledge on the current status of the tropical peat soil in a farm area, by assessing soil quality status using different soil quality indices such as Soil Fertility Index (SFI), Simple Additive Soil Quality Index (SQIa) and Soil Microbial Indices (SMI), and the spatial distribution of some major soil nutrient to provide corrections and proffer recommendations regarding the soil spatial variability in fertility managements of the main restricting factors for agricultural productions. These can be achieved through the following objectives-:

1.3 Objectives of the study

i. To classify and characterize the tropical peat (soil) in the study area based on Soil Taxonomy System (USDA) and World Reference Base (WRB-FAO).

ii. To determine, evaluate and assess tropical peat (soil) quality (fertility status) using the selected soil quality indices (Soil Fertility Index (SFI), Soil Quality Index (SQI), and Soil Microbial Index (SMI)).

iii. To determine, evaluate and assess the tropical peat (soil) spatial variability by semivariogram of selected major crop-nutrients and the selected indices.

iv. To determine the selected heavy metal contents in tropical peat (soil) and plant in the study area.

v. To statistically analyze the relationship between selected fertility parameters with soil quality indices.

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