UNIVERSITI PUTRA MALAYSIA

EVALUATION OF PHYSICAL AND MICROMORPHOLOGICAL PROPERTIES OF SAPROLITES FOR WASTEWATER TREATMENT

CHNG LOI PENG

FP 2002 3

EVALUATION OF PHYSICAL AND MICROMORPHOLOGICAL PROPERTIES OF SAPROLITES FOR WASTEWATER TREATMENT

By

CHNG LOI PENG

Thesis Submitted in Fulfilment of the Requirement for the Degree of Master of Agricultural Science in the Faculty of Agriculture Universiti Putra Malaysia

May 2002

DEDICATION

To:

My mother;
and my family members; and
Ms Low Set Choo

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement of the degree of Master of Agricultural Science

EVALUATION OF PHYSICAL AND MICROMORPHOLOGICAL PROPERTIES OF SAPROLITES FOR WASTEWATER TREATMENT

By

CHNG LOI PENG
May 2002

Chairman : Assoc. Prof. Dr. Hamdan Jol

Faculty : Agriculture

Saprolite is defined as soft, massive, friable, isovolumetrically weathered bedrock that retains the fabric and structure of the parent rock (Pavich, 1986). It is the transitional material between hard rock and the solum and has characteristics of both the parent rock below and the soil above it (Daniels *et al.*, 1984). Saprolite is currently being used for the on-site treatment and disposal of household wastewater (Vepraskas *et al.*, 1996) and storage of some radioactive wastes (Vepraskas and Williams, 1995). Due to extensive housing development, suitable soils for septic systems are being depleted (Schoeneberger *et al.*, 1995). Thus, a greater demand is being placed on the use of saprolite for wastewater disposal purposes.

The objectives of this study are (1) to study the physical and micromorphological characteristics of different saprolites, (2) to study the saturated hydraulic conductivity of different saprolites, and (3) to correlate the saturated hydraulic conductivity with the physical characteristics and develop models to predict K_{sat} for different type of saprolites for wastewater treatment.

The hydraulic conductivity was carried out in the laboratory using metal core rings (7.62 cm internal diameter x 4 cm long) and double-ring infiltrometer were used in situ. To determine the physical properties, standard method is employed for the particle size distribution, bulk density, particle density, total porosity, penetration resistance, and water retention capability. Micromorphology and scanning electron microscopy were used to observe the microfabrics. The pore size distribution was analyzed using an image analyzer and pore shape was also determined.

The result obtained from this study shows that granite saprolite has the highest hydraulic conductivity, while basalt saprolite has the lowest hydraulic conductivity value in both laboratory and in situ methods. There are several factors that govern the K_{sat}, namely the clay and sand content, porosity, pore shape and pore sizes. Both pore size and shape analysis influenced the K_{sat}, especially the mesopores, M_e ($30 \leq 75$ um) and macropores, M_c (> 75 um) and vugh and channel shapes. A linear equation was derived from all the data obtained from the saprolites. The best model to predict the K_{sat} of saprolites is:

$$K_{sat} = 16.859 - 0.182\ \theta_{fc} - 0.183\ \theta_{wp} - 0.128\ S_i + 0.112\ M_{oist}$$

whereby, θ_{fc} and θ_{wp} is the moisture content retained at 9.8 kPa (field capacity) and 1500 kPa (permanent wilting point), S_i is the silt content, and M_{oist} is the air dried moisture content, respectively.

The results obtained from the micromorphology, generally agreed with the results obtained from the physical properties. Granite saprolites has a higher coarse materials than other saprolites. It has spongy to intergrain to intergrain channel microstructure. The presence of weathering "resistant" minerals such as feldspar and quartz are abundant. Basalt saprolites, the reverse micromorphology characterics of granite was observed.

From this study, shale and basalt saprolites can be used for on-site wastewater treatment because of its slow to very slow rate (approximately 0.2 – 0.4 cm hr^{-1}) that provides ample time for bacteria and viruses to be removed from the effluent by filtration or adsorption onto particle surfaces and ample time for organic to stabilize the wastewater. The granite and schist saprolite can also be used for on-site wastewater treatment if modifications are made by adding a low permeability base (a composite liner) and a protective filter layer over the high permeability material (USEPA, 1988).

The use of wastewater instead of distilled water and study of the chemical reactions or chemical characteristics in future studies should be done. It is to determine the true capability of these saprolites for wastewater treatment.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

PENILAIAN CIRI-CIRI FIZIKAL DAN MIKROMORFOLOGI SAPROLIT UNTUK PROSES RAWATAN AIR BUANGAN

Oleh

CHNG LOI PENG
Mei 2002

Pengerusi : Prof. Madya Dr. Hamdan Jol

Fakulti : Pertanian

Saprolit ditakrifkan sebagai lembut, rapuh, isoisipadu batuan terluluhawa yang mengekalkan fabrik dan struktur bahan induknya (Pavich, 1986). Ia merupakan bahan transisi di antara batuan dan solum dan mempunyai ciri kedua-dua bahan induk di bawah dan tanah diatasnya (Daniels *et al*., 1984). Saprolit kini sedang digunakan untuk proses pembuangan air buangan perumahan secara setempat (Vepraskas *et al*., 1996) dan penyimpanan bahan radioaktif (Vepraskas dan Williams, 1995). Disebabkan oleh pembangunan perumahan yang pesat, tanah yang sesuai untuk sistem septik adalah berkurangan (Schoeneberger *et al*., 1995). Maka, bertambahlah permintaan untuk rawatan air buangan pada bahan saprolit.

Objektif kajian ini ialah (1) untuk mengkaji ciri-ciri fizikal dan mineralogikal ke atas jenis-jenis saprolit (2) untuk mengkaji konduksi hidraulik tepu (K_{sat}) ke atas jenis-jenis saprolit, dan (3) untuk menghubung-kait di antara konduksi hidraulik tepu dengan ciri-ciri fizikalnya dan menerbitkan persamaan untuk jenis-jenis saprolit untuk rawatan air buangan.

Hidraulik konduktiviti tepu ditentukan di makmal dengan menggunakan gelang besi (7.62 cm diameter dalaman x 4 cm panjang) dan double-ring infiltrometer digunakan in-situ. Untuk mengkaji ciri-ciri fizikal, cara piawaian digunakan untuk menentukan tekstur, ketumpatan pukal, ketumpatan jisim, jumlah liang-liang, dan tahap pemegangan air. Mikromorfologi dan elektron mikroskop digunakan untuk menghayati mikrofabriknya. Taburan saiz liang-liang dijalankan dengan menggunakan penganalisis imej dan bentuk liang-liang juga ditentukan.

Keputusan diperolehi dalam kajian ini menunjukkan granit saprolit mempunyai tahap K_{sat} yang paling tinggi, manakala basalt saprolit mempunyai K_{sat} yang terendah di dalam ujikaji di makmal dan in situ. Terdapat beberapa faktor yang mempengaruhi K_{sat}, iaitu peratusan lempung dan pasir, jumlah liang-liang, bentuk dan saiz liang-liang. Kedua-dua saiz dan bentuk liang-liang di dapati mempengaruhi K_{sat}, terutamanya meso-liang, M_e ($30 \leq 75$ μm) dan makro-liang, M_c (>75 μm), bentuk vugh dan channel. Satu persamaan linear telah diperolehi daripada kesemua data-data daripada saprolit. Persamaan yang terbaik untuk menjangka K_{sat} saprolit ialah:

$$K_{sat} = 16.859 - 0.182\ \theta_{fc} - 0.183\ \theta_{wp} - 0.128\ S_i + 0.112\ M_{oist}$$

di mana, θ_{fc} dan θ_{fc} ialah kandungan kelembapan pada kapasiti muatan, 9.8 kPa dan 1500 kPa (takat kelayuan maksima), S_i kandungan kelodak, dan M_{oist} kandungan kelembapan kering udara.

Pada amnya, pemerhatian dari segi mikromorfologi adalah selaras dengan keputusan yang diperoleh daripada sifat fizikal saprolit. Granit saprolit mempunyai lebih banyak bahan kasar berbanding dengan saprolit yang lain. Ia mempunyai ciri sponge ke intergrain channel mikrostruktur. Ia juga mempunyai mineral yang “tahan” luluhawa banyak seperti feldspar dan kuartz. Untuk basalt saprolit, pemerhatian mikromorfologi adalah terbalik berbanding dengan granit saprolit.

Daripada kajian ini, saprolit syel dan basalt boleh digunakan untuk proses perawatan air buangan secara on-site kerana mempunyai nilai K_{sat} yang perlahan kepada amat perlahan (lebih kurang 0.2 – 0.4 cm jam^{-1}) yang memberi lebih masa kepada penyingkiran bakteria dan virus daripada efluen secara penapisan atau penyerapan ke atas partikel. Granit dan schist saprolit juga boleh digunakan untuk proses perawatan enapcemar secara on-site jika modifikasi secara penambahan satu bahan asas yang mempunyai permeabiliti yang rendah pada bahagian dasar (a composite liner) dan lapisan filter perlindungan ke atas permeabiliti yang tinggi (USEPA, 1988).

Penggunaan air buangan patut digunakan selain daripada air suling, kajian ke atas kesan kimia atau ciri-ciri kimia patut dijalankan pada kajian pada masa depan. Ini adalah untuk mengetahui kemampuan yang sebenar saprolit ke atas air buangan.

ACKNOWLEDGEMENTS

I wish to acknowledge generous individuals whose valuable support made this study a success and the completion of this thesis possible. I am immensely indebted to them and my only means of repaying them is to express a heartfelt gratitude and a sincere appreciation.

Foremost is to my supervisor, Associate Professor Dr. Hamdan Jol, Chairperson of the Supervisory Committee, who provided me scholarly insights, professional guidance and knowledge, moral support and understanding when I needed them the most. To Associate Professor Dr. Mohd. Mokhtaruddin Manan and Dr. Che Fauziah Ishak, members of the Supervisory Committee, for their guidance, understanding and constructive comments. Sincere appreciation also goes to Associate Professor Dr. Siti Zauyah Darus, for her help, comments and guidance. My sincere thanks.

Special thanks go to all lecturers, and laboratory staffs in the Department of Land Management and especially to Pn. Pauziah in the Micromorphology laboratory, for their invaluable help in the analyses of my samples. They well always be remembered with gratitude.

To my friends, Mr. Neo Sye Peng, Mr. Tai Kin Leong, and other post graduate students in the faculty, for their generosity and countless invaluable help which made my work in the laboratory and field bearable and pleasant. I also wish to thank all my friends especially, Mr. Lee Choon Keat, Mr. Yeoh See Hon, and Pak Fauzi for their help, cooperation, support, and encouragement in my difficult and depressing moment in finishing this work.

I certify that an Examination committee met on 17th May 2002 to conduct the final examination of Chng Loi Peng on his Master of Agricultural Science thesis entitled "Evaluation of Physical and Micromorphological Properties of Saprolites for Wastewater Treatment" in the accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

JAMAL TALIB, Ph.D.
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

HAMDAN JOL, Ph.D.
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

MOHD. MOKHTARUDDIN ABDUL MANAN, Ph.D.
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

CHE FAUZIAH ISHAK, Ph.D.
Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

SHAMSHER MOHAMAD RAMADILI, Ph.D.
Professor/Deputy Dean,
School of Graduate Studies,
Universiti Putra Malaysia.

Date:

I hereby declare that the thesis is based on my original work except for quotations and citations which, have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

CHNG LOI PENG

Date:

TABLE OF CONTENTS

CHAPTER 4

CHAPTER 5

LIST OF TABLES

Tables | Page

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Soil is the weathered and unconsolidated outer layer of the earth's surface and is one of the three natural reservoirs where toxic and refractory pollutants can accumulate. The potential of a soil site for waste treatment may be determined in part by the soil's physical and chemical characteristics. A soil is a complex arrangement of primary minerals and organic particles that differ in composition, size, shape and arrangement. The pores or voids between the particles transmit and retain air and water. The soil is capable of treating organic materials, inorganic substances and pathogens in wastewater by acting as a filter, exchanger, adsorber and a surface on which many chemical and biochemical processes may occur. The combination of these processes acting on the wastewater as it passes through the soil produces water of acceptable quality for discharge into the groundwater under the proper conditions.

Approximately 18 million housing units or 25 % of all housing units in the US dispose their wastewater using on-site wastewater treatment. These systems include a variety of components and configurations. The most common is the septic tank or soil adsorption system. Federal, state and local govemment have refocused their attention on rural wastewater disposal and more particularly on wastewater system affordable by the rural population. On-site systems are gaining recognition as a viable wastewater management alternative that can provide excellent, reliable service at a reasonable cost, while still preserving environment quality (Soil Conservation Service, 1951).

As the soil available for conventional septic systems decreases, onsite wastewater disposal on saprolite is gaining popularity (Vepraskas and Williams, 1995). The evaluation of saprolite for wastewater disposal includes measuring its saturated hydraulic conductivity (K_{sat}) (Amoozegar *et al.*, 1991). The K_{sat} values can be used to estimate the amount of land area needed for the disposal and treatment of sewage. It is also used by hydrologists, water resources engineers and environmental soil scientists to estimate the intemal drainage of soils, for designing subsurface drainage and liquid waste disposal systems and for assessing non-point source pollution (Mbagwu, 1995). Studies of hydrological properties and erodibility of soils have, for long, been objectives of pedological research and are available for soils from most parts of the world. In contrast, similar investigations for saprolites and, particularly, of the whole regolith, referred to as a soil-saprolite complex, are few (Scholten *et al.*, 1997).

Saprolite is defined as soft, massive, friable, isovolumetrically weathered bedrock that retains the fabric and structure of the parent rock (Pavich, 1986). It is the transitional material between hard rock and the solum and has characteristics of both the parent rock below and the soil above it (Daniels *et al.*, 1984). It retains the original rock's structure, foliation and jointing, but its bulk density can be as low as one-half that of the original rock (Pavich *et al.*, 1989). Saprolite is easily crushed to sand, silt and clay sized particles (Schoeneberger and Amoozegar, 1990).

In Peninsular Malaysia, saprolite is exposed near to the surface as a result of water erosion and occasional landslipping (Whitmore and Burnham, 1969; Burnham, 1989) and mechanical land clearing and deep terracing during the early stages of steep land preparation for perennial crops cultivation (Burnham, 1989). Eswaran and Wong (1978) observed that the roots of perennial crops such as rubber and oil palm, planted on bench-terraces, are frequently growing in the saprolite.

Saprolite is currently being evaluated for the on-site treatment and disposal of household wastewater (Vepraskas *et al.*, 1996) and storage of some radioactive wastes (Vepraskas and Williams, 1995). Due to extensive housing development with on-site wastewater disposal systems in the rural areas (Hoover and Amoozegar, 1988), suitable soils for septic systems are being depleted (Schoeneberger *et al.*, 1995). Thus, a greater demand is being placed on the use of saprolite for wastewater disposal purposes.

The objectives of this study are (1) to study the physical and micromorphological characteristics of different saprolites, (2) to study the saturated hydraulic conductivity of different saprolites, and (3) to correlate the saturated hydraulic conductivity with the physical characteristics and develop models to predict K_{sat} for different type of saprolites for wastewater treatment.

CHAPTER 2

LITERATURE REVIEW

2.1 Tropical Geomorphology and Soils

The tropical climate has caused deep weathering due to extensive chemical weathering, leaching, and abundance of organic matter (Pedro, 1968). The tropic is also the place of tectonically stable land areas. It is assumed to have long durations of weathering and low rates of denudation (Isahak, 1993).

The tropical landscape commonly consists of soils of the age from amongst the youngest (e.g. Entisols and Inceptisols) to the oldest (e.g. Ultisols and Oxisols). The tropical soil is normally considered to be deep, red, acidic soil, well drained and lacking distinct horizons. This soil is often associated with the order Oxisols of the Soil Taxonomy system (Soil Survey Staff, 1975; Buol and Eswaran, 1978).

2.2 Peninsular Malaysia

2.2.1 Geomorphology of Peninsular Malaysia

2.2.1.1 Introduction

The summary on the geomorphology of Peninsular Malaysia is extracted mainly from Zauyah (1986) unless otherwise indicated. The topography of the Peninsular Malaysia is dominated by a series of eight prominent mountain ranges alternating with valleys (Figure 1). They are aligned in a general NNW-SSE direction. The most important of these ranges is the Main Range, which has an average width of 45 to 65 km and extends southwards for about 500 km from the Thai border in the

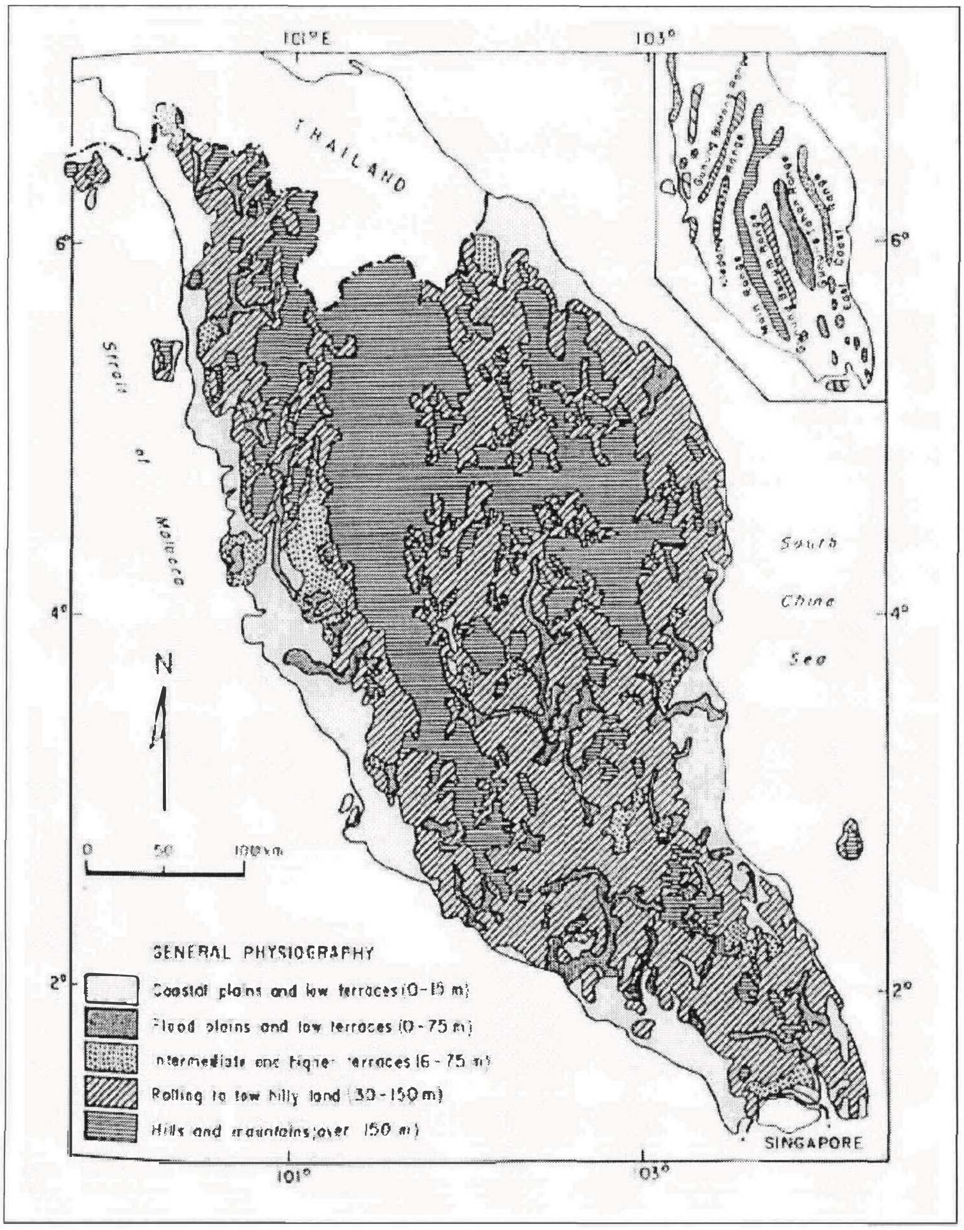

Figure 1: Relief of Peninsular Malaysia (Law, 1970).

north. Most of these ranges are formed of granitic rocks and often, peaks around 2000 m high are present. Occasionally, however, resistant quartzite also forms some peaks e.g. Gunung Tahan (2178 m), the highest peak in the Peninsular. Extensive alluvial plains developed from the widespread alluvial deposition during the Quatemary period, occur along both the east and west coasts of the Peninsular. These alluvial plains consist of fluvial plains, peat swamps, marine, estuarine and brackish water clayey deposits and sandy beach ridge complexes.

Lawrence (1972) divided the topography of Peninsular Malaysia into four distinct zones; e.g. mountains, steep hills, low hills, and coastal plains. However, another important feature of the geomorphology especially in the northwest and west central parts of the Peninsular is the typical karst topography.

In the upland areas, denudation and degradation are the most important geomorphic processes while in the lowlands, aggradation by rivers and the sea dominate. Mass soil movement or soil creep is also a very important process.

2.2.1.2 Mountains

Most of the mountains are developed over granites but occasionally some mountains over sedimentary rocks also occur. The mountains rise to altitudes in excess of 100 m with slopes generally in the $25^0 – 35^0$ but locally they approach 45^0. These mountains are characterized by steep valley walls, numerous waterfalls and rapids and small remnant of upland plateau indicate a youthful stage of erosion.

2.2.1.3 Steep Hills

Like the mountains, they are developed mostly on granite. They occur peripherally to the mountains either as spurs of the main mass or as outlying isolated hills. They may rise to 300 m with slopes of $15^0 - 30^0$. Some of these areas have been planted with rubber.

2.2.1.4 Low Hills

The altitude in these areas may be up to 250 m, but in the south it is often less than 100 m. The low hills are extensive, lying in a continuous belt around the central highlands. Most of these areas have been used for agriculture having been planted with rubber, oil palm, and fruit trees.

2.2.1.5 Coastal Plain

The broad coastal plain of Holocene riverine and marine alluvium has low to almost no relief and lies between the low hills region and the sea. The alluvium has filled the floors of the seaward valleys of the low hills and "fingers" into the low hills of the interior where it forms river plains and terraces. On the average, the coastal plain has widths varying between 20 and 30 km.

2.2.1.6 Limestone Areas

Tower-like limestone hills occur in northwest and west central parts of the Peninsular (Gobbett, 1965; Tjia, 1973). These form a typical tower karst geomorphology. These hills rise abruptly from the alluvial plains and often reach elevations of up to 600 m. These hills are usually honeycombed by caves and old river channels. The origin of these caves is attributed to the work of rivers flowing along joints and/or