UNIVERSITI PUTRA MALAYSIA

PROPERTIES, CLASSIFICATION AND SUITABILITY OF MALAYSIAN SOILS DERIVED FROM GRANITE-GNEISS AND POTENTIAL OF BASALT TO IMPROVE GROWTH OF RUBBER (Hevea brasiliensis Müll. Arg.)

MOHD SHAFAR JEFRI BIN MOKHATAR

FP 2018 37

PROPERTIES, CLASSIFICATION AND SUITABILITY OF MALAYSIAN SOILS DERIVED FROM GRANITE-GNEISS AND POTENTIAL OF BASALT TO IMPROVE GROWTH OF RUBBER (*Hevea brasiliensis* Müll. Arg.)

By

MOHD SHAFAR JEFRI BIN MOKHATAR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

November 2017

DEDICATION

TO MY FAMILY

TO WHOM THEIR TRUE LOVE AND SUPPORT WERE BEHIND MY SUCCESS

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

PROPERTIES, CLASSIFICATION AND SUITABILITY OF MALAYSIAN SOILS DERIVED FROM GRANITE-GNEISS AND POTENTIAL OF BASALT TO IMPROVE GROWTH OF RUBBER (*Hevea brasiliensis* Müll. Arg.)

By

MOHD SHAFAR JEFRI BIN MOKHATAR

November 2017

Chairman : Wan Mohamed Noordin Wan Daud, PhD
Faculty : Agriculture

Soils planted with rubber in Malaysia are usually highly weathered soils and known as acidic soils, characterized by low fertility. Recently, the use of basalt to alleviate soil acidity has attracted soil scientists and agronomists in some parts of the world. This study was conducted to characterize soils developed on granite-gneiss and to evaluate the potential of ground basalt as soil amelioration in relation to growth and nutrition of rubber. The study area was located at Geliar, Jeli, Kelantan (05.70497° N, 101.80118° E). Six soil profiles at different slope position were identified, described and sampled, whereby the areas were already planted with immature rubber. Soils developed on very hilly terrain (20°-25°) and hilly (12°-20°) have better drainage and more weathered compare to soil developed on flat area (0°-2°). In terms of clay mineralogy, it is dominated by kaolinite, as shown in XRD diffractogram at reflections 7.2 Å, 3.58 Å and 3.4 Å, followed by gibbsite at 4.82 Å and 4.32 Å. Goethite (4.18 Å), haematite (2.69 Å and 2.51 Å), and quartz (3.3 Å) also detected in the soil profile. Feldspar (3.25 Å) and mica (10 Å) present in high water table soil profile as shown by weak peak in diffractogram. Pedon I, Pedon II, Pedon III and Pedon VI can be classified as Lanas Series Red Variant deep phase. Pedon V can be classified as Lanas Series deep phase (yellow) and Pedon IV can be classified as Local Alluvium Complex. According to USDA soil taxonomy, Pedon I, Pedon II, Pedon III, Pedon V and Pedon VI can be classified as fine clayey, kaolinitic, isohyperthermic, Typic Kandiudults. All soils on high sloping area can be classified as Haplic Acrisol (Clayic) according to World Reference Base for Soil Resources. Pedon IV situated on flat area can be classified as loamy, mixed, isohyperthermic, Fluvaquentic Endoaquepts and Gleyic Cambisol (Geoabruptic) according to Soil Taxonomy and World Reference Base for Soil Resources, respectively. For soil suitability classification for rubber cultivation, soils on Pedon I, Pedon II, Pedon III and Pedon VI can be categorized into Class III, while soil on Pedon V can be categorized into Class II and Pedon IV can be categorized into Class IV. From growth data collected, steeper area (25°) would be more favorable for rubber growth during immature stage. For nursery trial, two types of soil were selected from six profiles along catena. Both types of soil were subjected to different rates of ground basalt, 0, 40, 80, 160 and 240 g/polybag. The experiment was carried out as randomized complete block design (RCBD) with three blocks. The girth and height were measured for a year. After a year, soil chemical properties and nutrients in leaf tissue were analyzed. The results showed that incorporation of basalt at 240 g/tree had improved soil fertility. Increase of soil pH results in decreasing Al concentration. Basalt applications enhance growth of immature rubber in terms of height and girth. Nutrients content in the tissue also increased with basalt application and increases with increasing rate applied. Effect of ground basalt application on growth was evident after three months and continued to increase over time. This study shows that the logistic growth curve model in the form of $y = A/ (1+be^{-ct})$ [where y and t were the plant parameters and months after transplanting, respectively, while A, b and c were regression constants] was biologically fit in describing the growth in terms of each of the parameters (stem girth and plant height) versus months after transplanting. At each ground basalt rate applied, the model had F value with high approximate probability level at $\alpha = 0.0001$. For confirmation of study in nursery, a field trial was carried out. The experiment was carried out as complete randomized design (CRD), consisting of four rates of basalt (0, 179, 358 and 538 g/plant) and three replications. The field trial and the nursery have similar trend where application of basalt have enhanced fertility of the soil and growth of the rubber. Highest growth showed by plant with highest relative growth rate of height and girth with value of 16.76 cm/month and 0.681 cm/month respectively. Results showed that cation exchange capacity of the soil increased up to 22% and 45% with the application of 538 g/tree of basalt, after six months and a year. Basalt rate at 538 g/tree would be suitable to be used in field planting. From all data gathered in this study, it can be concluded that slope position influenced the soil formation, fertility, suitability and subsequently the growth of immature rubber tree. In order to improve fertility of highly weathered soils and enhancing early growth of rubber tree, ground basalt could be applied as a soil amendment in rubber plantation.

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

SIFAT, KLASIFIKASI DAN KESESUAIAN TANAH MALAYSIA TERBENTUK DARI GRANIT-GNEISS DAN POTENSI BASALT UNTUK MENINGKATKAN PERTUMBUHAN GETAH (*Hevea brasiliensis* Müll. Arg.)

Oleh

MOHD SHAFAR JEFRI BIN MOKHATAR

November 2017

Pengerusi : Wan Mohamed Noordin Wan Daud, PhD
Fakulti : Pertanian

Tanah-tanah yang ditanam dengan getah di Malaysia biasanya tanah yang sangat terluluhawa dan dikenali sebagai tanah berasid, dicirikan oleh kesuburan rendah. Baru-baru ini, penggunaan basalt bagi mengurangkan keasidan tanah telah menarik perhatian saintis dan agronomis di beberapa bahagian dunia. Kajian ini dijalankan bagi mencirikan tanah terbentuk dari granit-gneiss dan menilai potensi basalt sebagai pembaik tanah berkaitan pertumbuhan dan pemakanan getah. Kawasan kajian terletak di Geliar, Jeli, Kelantan (05.70497° N, 101.80118° E). Enam profil tanah di posisi cerun berbeza dikenalpasti, dicirikan dan diambil sampel, di mana kawasan ini telah ditanam dengan getah tidak matang. Tanah yang terbentuk di kawasan yang sangat berbukit (20 ° -25 °) dan berbukit (12 ° -20 °) mempunyai saliran yang lebih baik dan lebih luluhawa berbanding dengan tanah yang terbentuk di kawasan rata (0 ° -2 °). Dari segi mineralogi tanah, ia didominasi oleh kaolinit, seperti yang ditunjukkan dalam difraktogram XRD pada pantulan 7.2 Å, 3.58 Å dan 3.4 Å, diikuti oleh gibbsite pada 4.82 Å dan 4.32 Å. Goethite (4.18 Å), haematit (2.69 Å dan 2.51 Å) dan kuarza (3.3 Å) juga dikesan dalam profil tanah. Feldspar (3.25 Å) dan mika (10 Å) terdapat dalam profil yang mempunyai paras tanah air yang tinggi dikesan dengan puncak lemah di difraktogram. Pedon I, Pedon II, Pedon III dan Pedon VI diklasifikasikan sebagai Fasa Dalam Siri Lanas Varian Merah. Pedon V diklasifikasikan sebagai Fasa Dalam Siri Lanas (kuning) dan Pedon IV diklasifikasikan sebagai Kompleks Alluvium Setempat. Menurut Taksonomi Tanah USDA, Pedon I, Pedon II, Pedon III, Pedon V dan Pedon VI boleh diklasifikasikan sebagai fine clayey, kaolinitic, isohyperthermic, Typic Kandiudults. Semua tanah di kawasan cerun boleh dikelaskan sebagai Haplic Acrisol (Clayic) menurut Pangkalan Rujukan Dunia untuk Sumber Tanah. Pedon IV yang terletak di kawasan rata boleh dikelaskan sebagai loamy, mixed, isohyperthermic, Fluvaquentic Endoaquepts dan Gleyic Cambisol (Geoabruptic), masing-masing mengikut Taksonomi Tanah dan Pangkalan Rujukan Dunia untuk Sumber Tanah. Bagi pengkelasan kesesuaian tanah untuk penanaman getah, tanah di Pedon I, Pedon II, Pedon III dan Pedon VI boleh dikategorikan sebagai Kelas III, manakala tanah di

Pedon V boleh dikategorikan sebagai Kelas II dan Pedon IV boleh dikelaskan sebagai Kelas IV. Dari data pertumbuhan, kawasan curam (25°) lebih baik bagi pertumbuhan getah diperingkat tidak matang. Bagi percubaan nurseri, dua jenis tanah dipilih dari enam profil di sepanjang catena. Kedua jenis tanah tertakluk kepada kadar basalt berlainan, 0, 40, 80, 160 dan 240 g/polibeg. Eksperimen dijalankan sebagai reka bentuk blok lengkap rawak (RCBD) dengan tiga blok. Ukur lilit dan tinggi diukur selama setahun. Selepas setahun, sifat kimia tanah dan nutrien dalam tisu daun dianalisis. Keputusan menunjukkan penambahan basalt pada 240 g/pokok meningkatkan kesuburan tanah. Peningkatan pH tanah mengurangkan kepekatan Al. Aplikasi basalt meningkatkan pertumbuhan getah dari segi ketinggian dan lilitan. Kandungan nutrien dalam tisu meningkat dengan penggunaan basalt dan kadar yang diguna. Kesan aplikasi basalt kisar pada pertumbuhan terbukti selepas tiga bulan dan terus meningkat dari masa ke semasa. Kajian ini menunjukkan bahawa model keluk pertumbuhan logistik dalam bentuk $y = A/ (1+be^{-ct})$ [di mana y dan t masing-masing adalah parameter pokok dan bulan selepas menanam, manakala A, b dan c adalah konstan regressi] sesuai secara biologi dalam menerangkan pertumbuhan dalam konteks setiap parameter (ukur lilit batang dan tinggi pokok) versus bulan selepas menanam. Pada setiap kadar basalt kisar yang diberi, model mempunyai nilai F yang tinggi dengan tahap kebarangkalian pada $\alpha = 0.0001$. Untuk pengesahan kajian di nurseri, percubaan lapangan dijalankan. Eksperimen dijalankan sebagai reka bentuk rawak lengkap (CRD), terdiri dari empat kadar basalt (0, 179, 358 dan 538 g/pokok) dan tiga replikasi. Percubaan lapangan sama seperti di nurseri yang mempunyai trend sama di mana aplikasi basalt meningkatkan kesuburan tanah dan pertumbuhan getah. Pertumbuhan tertinggi dengan kadar pertumbuhan relatif bagi ketinggian dan ukur lilit dengan nilai 16.76 cm/bulan dan 0.681 cm/bulan. Keputusan menunjukkan bahawa kapasiti pertukaran kation tanah meningkat sehingga 22 % dan 45 % dengan penggunaan 538 g/pokok basalt, selepas enam bulan dan setahun. Kadar basalt pada 538 g/pokok sesuai untuk digunakan dalam penanaman. Dari data dikumpulkan, disimpulkan bahawa kedudukan cerun mempengaruhi pembentukan tanah, kesuburan, kesesuaian dan pertumbuhan pokok getah tidak matang. Bagi meningkatkan kesuburan tanah terluluhawa dan meningkatkan pertumbuhan awal pokok getah, basalt boleh digunakan sebagai pindaan tanah di ladang getah.

ACKNOWLEDGEMENTS

The student would like to express his profound gratitude and thanks to the creator, Almighty Allah, who granted me an opportunity to carry out this study. The contributions of many persons and institutions towards the completion of this thesis are gratefully acknowledged.

First and foremost, I wish to express my sincere appreciation and gratitute to my chairman of supervisory committee, Assoc. Prof. Dr Wan Mohamed Noordin Wan Daud for his invaluable guidance, encouragement and consructive discussion throughout the course of this study.

My unreserved gratitude goes to my supervisory committee members, Prof. Dr. Shamshuddin Jusop, Prof. Dr. Mohamed Hanafi Musa and Assoc. Prof. Dr. Zulkefly Sulaiman for their numerous contribution, understanding, compassion and comments throughout period of my study. May God continue to be their guide.

I am very grateful to the following experts:

> Dr Ahmad bin Selamat for his guidance and valuable discussion on the statistical analysis and agronomic aspects of this study;
>
> Dr Paramananthan s/o Selliah for his valuable discussion on soil classification aspects;
>
> Dr Enio Kang bt. Mohd. Sufian Kang for assisting in the analysis and intepretation of soil mineralogy.

My deepest gratitude is extended to distinguished officers from Department of Agriculture (Land Resource Management and Conservation Division), Mr. As'ari bin Hassan, Mr. Noranizam bin Mohd Sahil, Mr. Wan Noor Azhan bin Wan Ab. Rahim, Mr. Mohd Affandi bin Yaacob and state soil survey staffs from Lundang, Kota Bharu, Kelantan for their assistance and valuable discussions on soil survey, mapping and classification aspects of this study.

Heartfelt gratitute is due to Mr. Mahbub Shah bin Gohar Shah, Mr Aizul Azfar bin Zulkeefli, Haji Daud bin Saleh and Mr Mohd Amir Zunnasri Bin Mohd Noor for their continued help and support throughout this study. I gratefully acknowledge the help of Mrs Siti Zarinah binti Che Omar for reading and improving the manuscript.

Special thanks are due to all lab staffs at the Faculty of Agriculture, Faculty of Science (Department of Physic and Department of Chemistry), for their assistance in the analyses.

Many thanks to the Ministry of Education Malaysia for awarding MyPhD fellowship which made this study possible. Sincere thanks to University Consortium for the support in producing this manuscript through the University Consortium Thesis Grant award.

Furthermore, I would like to show my sincere appreciation to my parents, extended family, my in-laws, friends for their understanding, contribution and valuable support. There is nothing to quantify your support for me. I pray Allah in His infinity mercy to continue to reward you manifold.

Last but not least my sincere appreciation and gratitude to those who have assisted me one way or another. Thank you all for your support.

I certify that a Thesis Examination Committee has met on 29 November 2017 to conduct the final examination of Mohd Shafar Jefri bin Mokhatar on his thesis entitled "Properties, Classification and Suitability of Malaysian Soils Derived from Granite-Gneiss and Potential of Basalt to Improve Growth of Rubber (*Hevea brasiliensis* Müll.Arg.)" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Yahya bin Awang, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Mohd Ridzwan bin Abd Halim, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Internal Examiner)

Hamdan bin Jol, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Internal Examiner)

Eric Van Ranst, PhD
Professor Emeritus
Ghent University
Belgium
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 27 February 2018

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

Wan Mohamed Noordin Wan Daud, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Shamshuddin Jusop, PhD
Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Mohamed Hanafi Musa, PhD
Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Zulkefly Sulaiman, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice –Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: ___________________________

Name and Matric No: Mohd Shafar Jefri Bin Mokhatar, GS37083

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

Signature: ______________________

Name of Chairman of Supervisory Committee:
Wan Mohamed Noordin Wan Daud

Signature: ______________________

Name of Member of Supervisory Committee:
Shamshuddin Jusop

Signature: ______________________

Name of Member of Supervisory Committee:
Mohamed Hanafi Musa

Signature: ______________________

Name of Member of Supervisory Committee:
Zulkefly Sulaiman

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AA	Auto Analyzer
AAS	Atom Absorption spectrophotometer
Al	Aluminium
ANOVA	Analysis of variance
C	Carbon
C.E.C	Cation exchange capacity
Ca	Calcium
CGR	Crop growth rate
CIRP	Christmas Island rock phosphate
Cmol	Centi mol
Co	Cobalt
CRD	Complete randomized design
Cu	Copper
FAO	Food Agriculture Organization
Fe	Iron
GML	Ground magnesium limestone
GR	Growth rate
H_2O_2	hydrogen peroxide
H_2SO_4	sulfuric acid
HCl	Hydro chloric acid
IAN	Instituto Agronomico do Norte
IRSG	International Rubber Study Group
IUSS	International Union of Soil Science
K	Potassium
KT	Kota Tinggi
LTC	Latex timber clone
Mg	Magnesium
Mn	Manganese
MRB	Malaysia Rubber Board
N	Nitrogen
Na	Sodium
NH_4OAc	Ammonium acetate
NR	Natural rubber
P	Phosphorus
pH	Potential of Hydrogen
RCBD	Randomized complete block design
RGR	Relative growth rate
RISDA	Rubber Industry Smallholders Development Agency
RRIM	Rubber Research Institute of Malaysia
SAS	Statistical Analysis System
Si	Silicon
UNESCO	United Nation Educational Social Cultural Organization
USDA	United States Department of Agriculture
WRB	World Reference Base
XRF	X-Ray Fluorescence

CHAPTER 1

INTRODUCTION

Brazilian rubber tree or *Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg. is the main source of natural rubber. Although there are many other plants that have been exploited for rubber, such as guayule, *Manihot*, *Funtumia*, *Cryptostegia* and Russian dandelion, especially in times of high prices, in the long run, none could be more economic compared to *Hevea* (Imle, 1978). It has become one of the important commodity crops that have contributed much to the nation's economy as this country is one of the largest producer and consumer of natural rubber in the world (Mooibroek and Cornish, 2000; Shafar et al., 2012). Malaysia has a strong agriculture base *via* being the world leader in the production of several industrial, commercial crops, such as rubber, oil palm, cocoa, pepper, and tropical timber (Shamshuddin et al., 2015; Noordin and Shafar, 2017a).

With the global economic growth, world rubber consumption is expected to increase in tandem. It is forecasted that by the year 2020, 33.9 million tonnes of world rubber will be needed compared with 24.53 million tonnes in the year 2010. It is expected that 45.4% of 33.9 million tonnes will be from natural rubber (NR) (Suarni and Ang, 2011). With the increasing demand due to the expansion of the automobile industry worldwide, it can be concluded that production of natural rubber need to be boosted.

In addition, Noordin (2013) reported that among the factors for Malaysia's declining rubber production are decreasing areas under rubber due to substitution with oil palm plantation, shortage of skilled tappers, poor adoption of modern technologies especially among the smallholders, areas with low tree productivity, and immature areas with high yielding clones not yet in production. As a result of limited suitable planting areas, rubber trees have been planted in low – nutrient soils and dry areas (Noordin, 2013; Shamshuddin et al., 2015; Noordin and Shafar, 2017a).

Agriculture is one of the main land use in Malaysia and has been a significant contributor in economic development of the country as a source of food, employment, export earner and raw materials for agro based industries (Aminuddin et al., 1990; Arshad et al., 2007; Noordin and Shafar, 2017a). Total land area cultivated with rubber is estimated to be 1,078,630 hectares (Malaysian Rubber Board, 2017). The rubber growing areas of Peninsular Malaysia are mainly confined to an elongated north south strip along the west coast. Scattered concentrations are also found on the east coast. Rubber is cultivated on a wide range of terrain ranging from level to steep topography and on a wide variety of soils (Noordin, 1981b; Paramananthan, 1981).

Topography has been one of the criteria used in classifying certain areas into rubber zone. Another factor that influences plant growth is soil suitability. In the tropics, parent material plays the most important role in determining clay mineralogy, soil type and fertility status (Tavernier and Eswaran, 1973). Some detailed information on pedogenesis of shale-derived soil (Noordin, 1975), marine and riverine alluvial (Noordin, 1980a), and igneous and metamorphic rocks (Paramananthan, 1977) has been reported.

High-grade metamorphic complexes could be found in the northern part of Peninsular Malaysia. Regional metamorphism in this regions results in formation of schist and gneiss in various facies (Alexander, 1965; Hutchison, 2009). Soil taxonomy classification system has been widely used in classifying soil according to their similarity in selected properties (Lim and Chan, 1989; Paramananthan, 2000). In Malaysia, soils were classified until the lowest unit, soil series in classification system developed based on parent material. A group of soil derived from the same parent material has identical morphological/profile characteristics (Paramananthan, 2012; Noordin, 2013). From the taxonomic name, clarifications about favourable and adverse characteristics of the soils are easily known and proper crop management recommendation could be made.

Most of the soils in the tropics were classified as Ultisols and Oxisols. These types of soils were highly weathered and known as acid soils and infertile. Most of rubber cultivation was done on these types of soils. Native of forest species, *Hevea* nutrition requirement is quite low compared to other commodity crops such as oil palm and cocoa. However, with the production of the new clones with more vigour properties in terms of growth and high in latex production, more nutrients are needed by the plant (Shafar et al., 2012; Zahidin, 2015).

Mono-cropping system in plantation is common in order to achieve efficiency in terms of management. However, with extensive use of fertilizer, pesticides and herbicides, these practices will result in negative effects to the soil health after a few cycles of rubber cultivation. In India, it was reported that the use of ammonium sulphate fertilizer for a long period in rubber plantations have reduced the soil pH to a level below than 4 (Joseph, 2012). As time passes, the soil pH decreased significantly and this has been investigated and reported by several workers in different countries (Tichy et al., 1997; Kayser et al., 2000; Zhang et al., 2007; Li et al., 2016). Therefore, there is the need to improve soil pH and other properties that have been degraded.

Interdisciplinary approach which is termed as agrogeology or the use of rocks for crops, aims to study geological processes and natural rock and mineral materials that contribute to the maintenance of agro-ecosystems (Van Straaten, 2002, 2006). Liming has been one of agronomic practice in improving soil productivity in rubber plantation. In the absence of lime, silicates, which are rich in Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} but low in Fe^{3+} and Al^{3+} may be used to alleviate soil acidity (Van Ranst, 1995; Noordin, 2013). Furthermore, unlike lime, silicates such as basalt are not easily fixed in the top soil, and consequently, the sub-soil will also be neutralized resulting in deeper less acidic soil (Shamshuddin and Fauziah, 2010a; Noordin, 2013).

Recent findings on alleviating soil acidity revealed that it can be done by application of ground basalt. Apart from increasing the soil pH, it would also supply all macronutrients, except N (Gilman et al., 2002; Shamshudin and Anda, 2012). However, all those findings were made by using basalt from Australia. In Peninsular Malaysia, there are two places where basalt could be found, Kuantan and Segamat. These basalts are available and their potential use in agricultural production is unknown.

Effect of topography on soil pedogenesis and their influence on growth of immature new Latex Timber Clone, RRIM 3001 are not known. Ground basalt could be considered as new soil amendment practice in Malaysia and responses of rubber towards ground basalt application is still unknown. Application of ground basalt could enhance early growth of rubber tree. Furthermore, fertilizer recommendation for new clone grown on soils at different slope could be done precisely. Precision agro-management could save the cost of fertilizer application and time by reducing immaturity period of rubber tree. Thus, this study was conducted with the following objectives:

General Objective: To characterize and evaluate soil developed on granite-gneiss for rubber cultivation and evaluate the potential of ground basalt as soil amelioration in relation to growth and nutrition of new Latex Timber Clone, RRIM 3001.

Specific Objectives:

1. To evaluate the effects of slope on the characteristics of a soil developed on granite-gneiss in Jeli, Kelantan, Malaysia.
2. To investigate the effects of different slope on growth of immature rubber.
3. To study the growth enhancement of immature rubber by ground basalt application under nursery condition.
4. To evaluate the growth and nutrition of immature rubber by ground basalt application under field condition.

REFERENCES

Abu Talib, B. (1988). Management of Soils. In Jalil A. (Ed.), *RRIM Training Manual on Soils, Management of Soils and Nutrition of Hevea* (pp. 76-88). Kuala Lumpur: Rubber Research Institute of Malaysia.

Adriansyah, D. (2017). Systematic Studies of Geoheritage in Jeli District, Kelantan, Malaysia. *Geoheritage*, 9(1): 19-33.

Aide, M.T., Cwick, G.J. and Cummings, M.F. (1999). Clay Mineralogy and Potassium Status of Selected Soils in the Glacial Lake Agassiz Region of Central Manitoba. *Canadian Journal of Soil Science*, 79(1): 141-148.

Akhurst, C.G. and Owen, G. (1950). Manuring Experiments on Young Rubber Trees. I. Effect of Fertilisers on Growth. *Journal of Rubber Research Institute of Malaya*, 12: 167.

Alexander, J.B. (1965). Geological map of Malaya, 6th Edition (Diamond Jubilee), 1: 500,000, Geological Survey Department, West Malaysia.

Alva, A.K., Asher, C.J. and Edwards, D.G. (1986). The Role of Calcium in Alleviating Aluminium Toxicity. *Australian Journal of Agricultural Research*, 37(4): 375-383.

Aminuddin, B. Y., Chow, T.W., and Ng, T.T. (1990). Resources and Problems Associated with Sustainable Development of Upland Areas in Malaysia. In Blair, G. & Lefroy, R. (Eds.), *Technologies for Sustainable Agriculture on Marginal Uplands in South-east Asia.* 55-61. ACIAR Proceedings no. 33.

Anda, M. (2006). *Improvement of Charge Characteristics of Oxisols using Basalt and Rice Husk Compost for Cocoa Growth*. PhD Thesis, Universiti Putra Malaysia.

Anda, M., Shamshuddin, J. and Fauziah, C.I. (2013). Increasing Negative Charge and Nutrient Contents of a Highly Weathered Soil using Basalt and Rice Husk to Promote Cocoa Growth under Field Conditions. *Soil and Tillage Research*, 132: 1-11.

Anda, M., Shamshuddin, J., Fauziah, C.I., and Syed Omar, S.R. (2009). Dissolution of Ground Basalt and Its Effect on Oxisol Chemical Properties and Cocoa Growth. *Soil Science*, 174(5): 264-271.

Arshad, F. M., Abdullah, R.M.N., Kaur, B. and Abdullah, M.A. (2007). *50 Years of Malaysian Agriculture: Transformational Issues, Challenges and Direction*. Serdang: Universiti Putra Malaysia Press.

Auxtero, E.A. (1986). *Influence of Soil Parent Materials and Soil-Related Factors on the Growth and Yield of Rubber under FELCRA Schemce, Sendayan*. MAgrSc Thesis, University Putra Malaysia.

Berner, E.K. and Berner, R.A. (1987). *The Global Water Cycle*. Englwood Cliffs, NJ: Prentice-Hall.

Birkeland, P.W. (1974). *Pedology, Weathering, and Geomorphological Research*. United Kingdom: Oxford University Press.

Bolle-Jones, E.W. (1955). Nutrition of the Rubber Tree. *Nature*, 4461: 753.

Bolle-Jones, E.W. and Ratnasingam,K. (1954). Nutrition of *Hevea brasiliensis* III. The Interrelationships of Magnesium, Potassium and Phosphorus. *Journal of Rubber Research Institute of Malaya*, 14: 231-256.

Boniao, R.D., Shamshuddin, J., Van Ranst, E., Zauyah, S. and Syed Omar, S.R. (2002). Changes in Chemical Properties and Growth of Corn in Volcanic Soils Treated with Basalt Pyroclastics and Calcium Silicate. *Communications in Soil Science and Plant Analysis*, 33(7-8): 1219-1233.

Buol, S.W. (1985). Mineralogy Classes in Soil Families with Low Activity Clays. In Kittrick, J.A. (Ed.), *Mineral Classification of Soils, SSA Special Publication* (no 16, pp. 169-178). Madison, Wisconsin, USA: Soil Science Society of America.

Buol, S.W., Hole, F.D. and McCracken, R.J. (1973). *Soil Genesis and Classification*. Ames, Iowa, USA: The Iowa State University Press.

Carroll, D. (1970). *Clay Minerals: A Guide to Their X-ray Identification*. Colorado: The Geological Society of America Inc..

Casey, W.H. and Bunker, B. (1990). Leaching of mineral and glass surfaces during dissolution. In Hochella MF Jr. & White AF (Eds.), *Mineral-Water Interface Geochemistry* (Rev Min 23: pp. 397–426). Washington: Mineralogical Society of America.

Chan, H.Y. (1975). Macro-pedological Relationships and Classification of Tropical Soils under *Hevea* Cultivation. Proceedings of International Rubber Conference 1975, Kuala Lumpur, 20-25 October, Vol 3, pp.3-22.

Chan, H.Y. (1977). Soil Classification. In Pushparajah, E. and Amin, L.L. (Eds.), *Soils under Hevea and Their Management in Peninsular Malaysia* (pp. 57-74), Kuala Lumpur: RRIM.

Chan, H.Y., Pushparajah, E., Noordin, W.D., Wong, C.B. and Zainol, E. (1977). Parent Material and Soil Formation. In Pushparajah, E. and Amin, L.L. (Eds.), *Soils under Hevea and Their Management in Peninsular Malaysia* (pp. 1-24). Kuala Lumpur: RRIM.

Chan, H.Y., Soong, N.K, Wong, C.B. and Chang, A.K. (1973). Management of Soils under *Hevea* in West Malaysia. *Proc. Rub. Res. Inst. Malaya Planters Conference.* Kuala Lumpur, pp. 243-257.

Chan, H.Y., Wong, C.B., Sivanadyan, K. and Pushparajah, E. (1974). Influence of Soil Morphology and Physiography on Leaf Nutrient Content and Performance of *Hevea*. *Proceedings of Rubber Research Institute of Malaya Planters Conference*, Kuala Lumpur, 1974, pp 115-126.

Chandrasekhar, T.R., Alice, J., Varghese, Y.A., Sarawathyamma, C.K. and Vijayakumar, K.R. (2005). Girth Growth of Rubber (*Hevea brasiliensis*) Trees During the Immature Phase. *Journal of Tropical Forest Science*, 17(3): 399-415.

Coulter, J. K. (1972) Soils of Malaysia- A Review of Investigation on Their Fertility and Management. *Soil and Fertilizers*, 35:475-498.

D' Hotman de Villiers, O. (1961). Soil Rejuvenation with Crushed Basalt in Mauritus. *International Sugar Journal*, 63: 363-364.

Damrongrak, I., Onthong, J. and Nilnond, C. (2015). Effect of Fertilizer and Dolomite Applications on Grwoth and Yield of Tapping Tubber Trees. *Songklanakarin Journal of Science and Technology*, 37(6): 643-650.

Dasha, G. (2011). Remineralize The Earth. Outstanding Results of Dr. Goreau's Rock Dust Trials in Panama at SER2011. Retrieved from https://remineralize.org/2011/08/outstanding-results-of-dr-goreaus-rock-dust-trials-in-panama-at-ser2011-2048/

De Coninck, F. (1978). *Physico-chemical aspects of pedogenesis*. International Training Center for Post-Graduate Soil Scientist, Ghent University.

Debouche, C. (1979). Présentation Coordonnée des Différents Modéles de Croissance. *Revue de Statistsique Appliquée*, 27(4): 5-22.

Department of Agrculture (1978). *Soil Register*. Kuala Lumpur: Department of Agriculture in Peninsular Malaysia.

Department of Agrculture (2003). *Table of Soil Series*. Putrajaya: Department of Agriculture in Peninsular Malaysia.

Department of Agriculture (2008). *Panduan Mengenali Siri-Siri Tanah Di Semenanjung Malaysia*. Putrajaya: Jabatan Pertanian Malaysia.

Department of Minerals and Geoscience Malaysia (2003). Quarry Resource Planning For the State of Kelantan. Osborne & Chappel Sdn Bhd.

Department of Meteorolgy (2017). Malaysia's climate. Retrieved from http://www.met.gov.my/in/web/metmalaysia/climate/generalinformation/malaysia?p_p_id=56_INSTANCE_zMn7KdXJhAGe&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-1&p_p_col_pos=1&p_p_col_count=2&_56_INSTANCE_zMn7KdXJhAGe_page=2

Dharmakeerthi, R.S., Attygalle, T.R., Mapa, R.B., Perera, S.P. and Silva, S.N. (2009). Spatial Dependence of Selected Physico-chemical Properties in a Major Rubber Growing Soil in Sri Lanka. *Journal of Rubber Research*, 12(3): 164-170.

Eggleton, R.A., Foudoulis, C. and Varkevisser, D. (1987). Weathering of basalt: changes in rock chemistry and mineralogy. *Clay and clay minerals*, 35(3): 161-169.

Elisa, A.A., Ninomiya, S., Shamshuddin, J. and Roslan, I. (2016). Alleviating Aluminium Toxicity in an Acid Sulphate Soil from Peninsular Malaysia by Calcium Silicate Application. *Solid Earth*, 7: 367-374.

Eswaran, H., and Wong, C.B. (1978). A Study of a Deep Weathering Profile on Granite in Peninsular Malaysia: III. Alteration of Feldspars. *Soil Science America Journal*, 42: 154-158.

Eswaran, H., and Wong, C.B. (1986). A Study of a Deep Weathering Profile on Granite in Peninsular Malaysia: III. Alteration of Feldspars. In Kittrick, J.A. (Ed.), *Soil Mineral Weathering* (pp. 82-87), New York: Van Nostrand.

Farndon, J. (2012). *The Practical Encyclopedia of Rocks and Minerals*. United Kingdom: Hermes House.

Gardner, F.P., Pearce, R.B. and Mitchell, R.L. (1985). *Physiology of Crop Plants*. USA: Iowa State University Press.

Gillman, G.P. (1980). The Effect of Crushed Basalt Scoria on the Cation Exchange Properties of a High Weathered Soil. *Soil Science Society of America Journal*, 44: 465-468.

Gillman, G.P., Burkett, D.C. and Coventry, R.J. (2001). A Laboratory Study of Application of Basalt Dust to Highly Weathered Soils: Effect on Soil Cation Chemistry. *Australian Journal of Soil Research*, 39(4): 799 – 811.

Gillman, G.P., Burkett, D.C. and Coventry, R.J. (2002). Amending Highly Weathered Soils with Finely Ground Basalt Rock. *Applied Geochemistry*, 17: 987-1001.

Hamdan, J. and Burnham, C.P. (1996). The Contribution of Nutrients from Parent Material in Three Deeply Weathered Soils of Peninsular Malaysia. *Geoderma*, 74: 219-233.

Hamdan, J., Peli, M. and Ruhana, B. (2003). Weathering Behaviour of a Basaltic Regolith from Pahang, Malaysia. *Pertanika Journal of Tropical Agriculture Science*, 26(2): 79-88.

Hanafi, M.M. (2010). *Managing Phosphorus under Acid Soils Environment*. Inaugural lecture series. UPM Press: Serdang.

Hanafi, M.M. and Shamsuddin, Z.H. (1996). Dissolution of Gafsa Phosphate Rock as Affected by Two Species of Bacteria. In: Syers, J.K. and Johnston, J.E. (Eds.) *Nutrient management for sustainable food production in Asia* (pp. 359-361). United Kingdom: CAB International.

Haynes, R.J. (1990). Active Ion Uptake and Maintenance of Cation Anion Balance: A Critical Examination of Their Role in Regulating Rhizosphere pH. *Plant and Soil*, 126: 247–264.

Hodson, M.J., and Evans, D.E. (1995). Aluminium/Silicon Interaction in Higher Plants. *Journal of Experimental Botany*, 46: 161-171.

Holdren, G.R. and Speyer, P.M. (1985). Reaction Rate-Surface Area Relationships During the Early Stages of Weathering: I. Initial Observations. *Geochim Cosmochim Acta*, 49: 675–681.

Hunt, R. (1982). *Plant Growth Curves: The Functional Approach to Plant Growth Analysis*. United Kingdom: Edward Arnold Ltd.

Hutchison, C.S. (2009a). Metamorphism. In Hutchison, C.S. and Tan, D.N.K. (Eds.), *Geology of Peninsular Malaysia* (pp.233-248), Kuala Lumpur: University of Malaya and the Geological Society of Malaysia.

Hutchison, C.S. (2009b). Tectonic Evolution. In Hutchison, C.S. and Tan, D.N.K. (Eds.), *Geology of Peninsular Malaysia* (pp.309-330), Kuala Lumpur: University of Malaya and the Geological Society of Malaysia.

Iddawela, W.M. H. K., and Nugawela, A. (2013). Possible Reasons for Growth Variation among Immature Plants of *Hevea brasiliensis* Clone RRIC 121. *Proceedings of 12th Agricultural Research Symposium* (pp. 251-255).

Imle, E.P. (1978). Hevea Rubber – Past and Future. *Economic Botany*, 32: 264-277.

International Rubber Research and Developmemnt Board (2006). *Potrait of the Global Rubber Industry*. Kuala Lumpur: International Rubber Research and Developmemnt Board.

IUSS Working Group WRB (2014). World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

Joseph, M. (2012). Acid Soils of India under Rubber Cultivation and Response of Rubber to Liming. In Prakash, N.B. et al (Eds), *Proceedings of the 8th International Symposium on Plant-Soil Interaction at Low pH* (pp. 254-255), October 18-22, 2012, Bengaluru, India,.

Juo, A.S.R., and Kamprath, E.J. (1979). Copper Chloride as an Extractant for Estimating the Potetially Reactive Aluminium Pool in Acid Soils. *Soil Science Society of America Journal*, 43: 35-38.

Kayser, A. K., Wenger, A., Keller, W., Attinger, H. R., Felix, S., Gupta, K. and Schulin, R. (2000). Enhancement of Phytoextraction of Zn, Cd, and Cu From Calcareous Soil: The Use of NTA and Sulfur Amendments, *Environment Science Technology*, 34: 1778–1783.

Khaid M., Yang W.-j., Kishwar N., Rajput Z.I. and Garijo A. (2006). Study of Cellulolytic Soil Fungi and Two Nova Species and New Medium. *Journal of Zhejiang University*, 7: 459-466.

Krishan, B. (2015). Growth Assessment of Popular Clones of Natural Rubber (*Hevea brasiliensis*) under Warm, Dry Climatic Conditions of Chattisgarh State, Central India. *Journal of Experimental Biology and Agricultural Sciences*, 3(2): 157-161.

Kungpisadan, N. (2009). *Sustainable Management of Rubber Plantations: Soil, Water, and Plant Nutrients*. Bangkok, Thailand: The Agricultural Co-operatives Federation of Thailand Limited.

Lasaga, A.C., Soler, J.M., Ganor, J., Burch, T.E. and Nagy, K.C. (1994). Chemical Weathering Rate Laws and Global Geochemical Cycles. *Geochim Cosmochim Acta*, 58: 2361–2386.

Li, Y., Xia, Y., Li., H., Deng, X., Sha, L., Li, B., Lin, L. and Cao, M. (2016). Accumulated Impacts of Sulfur Spraying on Soil Nutrient Availability and Microbial Biomass in Rubber Plantations. *Clean – Soil, Air, Water*, 44 (8): 1001–1010.

Lim, J.S. (1991). *Soil-Landscape Relationships in Kedah – A Study in Soil Genesis and Classification*. PhD Thesis, University Putra Malaysia.

Lim, J.S. and Chan, Y.K. (1989). Major Soil Mapping Units in Peninsular Malaysia. In Zauyah et al. (Eds.), *Proceedings of Workshop on Recent Development in Soil Genesis and Classification* (pp. 113-133), Kuala Lumpur, 2-5 October.

Malaysian Rubber Board (2004). *Manual Teknologi Penanaman Getah*. Kuala Lumpur: Malaysian Rubber Board.

Malaysian Rubber Board (2007). *Klon- klon Siri RRIM 2000 Untuk Lateks dan Balak*. Kuala Lumpur: Malaysian Rubber Board.

Malaysian Rubber Board (2009). *Rubber Plantation and Processing Technologies*. Kuala Lumpur: Malaysian Rubber Board.

Malaysian Rubber Board (2016). *Malaysian Rubber Statistics 2015*. Kuala Lumpur: Malaysian Rubber Board.

Malaysian Rubber Board (2017). *Malaysian Rubber Statistics 2016*. Kuala Lumpur: Malaysian Rubber Board.

Malaysian Rubber Export Promotion Council (2017). Industry Overview. Retrieved from http://www.mrepc.com/industry/industry.php#q3

Marschner, H. (1991). Plant-Soil Relationship: Acquisition of Mineral Nutrients by Roots from Soils. In Porter,J.R. and Lawlor, D.W. (Eds), *Plant Growth Interactions with Nutrition and Environment* (pp. 125-156), United Kingdom: Cambridge University Press.

Marschner, H. (1995). *Mineral Nutrition of Higher Plants*, 2nd Edn. Loncod: Academic Press.

Masahuling, B., Mohd Nasaruddin, M.A., Zarawi, A.G. dan Nurmi Rohayu, A.H. (2009). Klon 1 Malaysia. In Tuan Mohamed, T.M. (Ed.), *Sains & Teknologi LGM* (pp. 5-10), Kuala Lumpur: Lembaga Getah Malaysia.

Mathew, N.M. and Sethuraj, M.R. (1992). Nutrition of *Hevea*, *Natural Rubber: Biology, Cultivation and Technology*. 23: 240-243.

McBride, M.B. (1994). *Environmental Chemistry of Soils*. United Kingdom: Oxford University Press.

Mengel, K. and Kirkby, E.A. (1982). *Principles of Plant Nutrition*, 3rd Edn.. Bern: International Potash Institute.

Miranda, S.R. (2012). Calcium and Magnesium Silicate, an Alternative Choice for Liming Acid Soils. In *8th International Symposium on Plant Soil Interactions at Low pH*, 18-22 October 2012, Bengaluru, India, 414-415.

Mitani, N., Jian, F.M. and Iwashita, T. (2005). Identification of the Silicon Form in Xylem Sap of Rice (*Oryza sative L.*). *Plant and Cell Physiology*, 46(2): 279-283.

Mooibroek, H., Cornish K. (2000). Alternative Sources of Natural Rubber. *Applied Microbiology and Biotechnology*, 53: 355-365.

Nair, K. P. P. (2010). Rubber (*Hevea brasiliensis*). In Nair, K. P. P. (Ed.), *The Agronomy and Economy of Important Tree Crops of the Developing World* (pp. 237-273). London: Elsevier.

Ng, S.K. (1965). Potassium Status of Some Malayan Soils. *Malaysia Agriculture Journal*, 45: 143.

Noordin, W.D. (1975). *Pedological Study of Some Shale Derived Soils of Peninsular Malaysia*. MSc Thesis, State University of Ghent, Belgium.

Noordin, W.D. (1977). Soil Genesis on Shales and its Influence on the Suitability for Hevea Cultivation. In Jospeh, K.T. (Ed), *Proceedings of Conference on Classification and Management of Tropical Soils* (pp. 89-41). August, 1977, Kuala Lumpur.

Noordin, W.D. (1980a). *Soil Genesis on Coastal Plain of Perak (Peninsular Malaysia)*. DSc Thesis, State University of Ghent, Belgium. Part I, 293.

Noordin, W.D. (1980b). *The Use of Discriminatory Recommendations of Fertilizers for Hevea Needs to be Reconsidered*. DSc Thesis (Minor), State University of Ghent, Belgium.

Noordin, W.D. (1981a). *Characteristics of Some Marine and Riverine Alluvial Soils, Perak, Malaysia – Correlation Tour Guide, 23-27 Nov 1981*. Serdang: Malaysian Soil Science Society.

Noordin, W.D. (1981b). Distribution and Classification of Soils under Rubber. In Jalil, A. (Ed.) *RRIM Training Manual on Soils, Soil Management and Nutrition of Hevea* (pp. 24-45). Kuala Lumpur: Rubber Research Institute of Malaysia.

Noordin, W.D. (1997). *Rubber Industry Approaching the 21st Century. Science and Technology Malaysia*. Kuala Lumpur: Ministry of Science Technology and Environment and COSTAM.

Noordin, W.D. (2006). Classification of Rubber Zones Using GIS for Sustainable Agricultural Development. Paper presented at ISSSAS Congress. University Putra Malaysia, Serdang, 9-11 December 2006.

Noordin, W.D. (2013). *Rubber Plantation: Soil Management & Nutritional Requirements*. Serdang: Universiti Putra Malaysia Press.

Noordin, W.D. and Shafar, J.M. (2015). Classification of Rubber Zones using Remote Sensing and GIS, The Proceedings of the International Congress on "Soil Science in International Year of Soils, 19-23 October 2015, Sochi, Russia, pp. 150.

Noordin, W.D. and Shafar, J.M. (2017a). Land Use For Agriculture In Malaysia. In Ashraf et. al (Ed), *Soils of Malaysia*, (pp51-68). Boca Raton: CRC Press.

Noordin, W.D. and Shafar, J.M. (2017b). *Getah: Tanah dan Pembangunan Ladang*. Serdang: Universiti Putra Malaysia Press.

Noordin, W.D., Pushparajah, E. and Tavernier, R. (1984). Soil Genesis and Classification on the Coastal Plain of Perak, Malaysia. Paper presented at 5th ASEAN Soil Conference, Bangkok, Thailand. 10-23 June 1984.

Noordin, W.D., Shafar, J.M. and Adam, P. (2014). Nutritional Status of Selected Latex Timber (*Hevea brasiliensis*) Clones Seedling Grown under Contrasting Soil Textures. In Ashikin et al (Ed), *Recent Advances in Crop Science Vol. 2*, (pp 129-139). Serdang: Universiti Putra Malaysia Press.

Noorsuhaila, A.B., Noordin, W.D. and Syawaluddin, I. (2014). Growth Performance and Root Characteristics of Young Immature Rubber Clones (Hevea brasiliensis) in Relation to Size of Nursery Bag. *Journal of Science and Technology in the Tropics*, 10(2): 85-94.

Nur Sabariah, B (2017). *General Geology and Petrography of Igneous and Metamorphic Rock in Kg Baru Sg Rual, Jeli, Kelantan*. BSc Thesis, University Malaysia Kelantan, Malaysia.

Obouayeba, S., Boa, D., Gohet, E., Dian, K., Ouattara, N and Keli, Z.J. (2000). Dynamic of Vegetative Growth of *Hevea brasiliensis* in Determining Tapping Norms. *Journal of Rubber Research*, 3(1): 53-62.

Owen, G. (1953). Determination of Available Nutrients in Malayan Soils. *Journal of Rubber Research Institute of Malaya*, 14: 109.

Paardekooper, E.C. (1989). Exploitation of Rubber Tree. In Webster, C.C. and Baulkwill, W.J. (Eds) *Rubber* (pp. 349-414). Essex, England: Longman Scientific and Technical.

Panhwar, Q.A., Naher, U.A., Shamshuddin, J., Radziah, O., Ismail, M.R. (2016). Applying Limestone or Basalt in Combination with Bio-Fertilizer to Sustain Rice Production on an Acid Sulfate Soil in Malaysia. *Sustainability*, 8(7): 700.

Paramananthan, S. (1977). *Soil Genesis on Igneous and Metamorphic Rocks in Malaysia*. DSc Thesis, State University of Ghent, Belgium.

Paramananthan, S. (1981) *Progress of Soil Surveys in Peninsular Malaysia*. Soil Survey Report No. 13. Kuala Lumpur: Ministry of Agriculture.

Paramananthan, S. (2000). *Soils of Malaysia: Their Characteristics and Identification*. Kuala Lumpur: Academy of Sciences Malaysia and Param Agricultural Soil Surveys.

Paramananthan, S. (2012). *Keys to the Identification of Malaysian Soils Using Parent Materials*. 2nd Ed. Petaling Jaya: Param Agricultural Soil Surveys.

Pavarina E.C., Sette L.D., Anazawa T.A. and Durrant, L.R. (1999). Enzymes Produced by Soil Fungi Following Microaerobic Growth on Lignocellulosic Materials. *Applied Biochemistry and Biotechnology*, 82: 153-163.

Ponnamperuma, F.N. (1972). The Chemistry of Submerged Soils. *Advanced Agronomy*, 24: 29-96.

Pushparajah, E. (1969). Response in Growth and Yield of *Hevea brasiliensis* to Fertiliser Application on Rengam Series Soil. *Journal of Rubber Research Institute of Malaya,* 21(2): 165.

Pushparajah, E. and Tan, K.T. (1972). Factors Influencing Leaf Nutrient Levels in Rubber. In Rajarao, J.C. and Foo, K.Y. (Eds.) *Proceedings of the RRIM Planters Conference* (pp. 140-154), 13-15 July 1972, Kuala Lumpur.

Pushparajah, E. and Yew, F.K. (1977). Management of Soils. In Puhaparajah, E. and Amin, L.L. (Eds.), *Soils Under Hevea in Peninsular Malaysia and Their Management* (pp. 94-113), Kuala Lumpur: Rubber Research Institute of Malaysia.

Pushparajah, E., SIvanadyan, K. and Yew, F.K. (1974). Efficient Use of Fertilisers. *Proceedings of Rubber Research Institute of Malaysia Planters Conference* (pp. 102-114). *Kuala Lumpur, 18-20 July 1974*.

RISDA (2008). *Teknologi dan Pengurusan Getah*. Kuala Lumpur: RISDA

Roslan, I. (2012). *Occurrence, Properties and Suitability of Sandy Beach Ridges (BRIS) Soils in the Kelantan-Terengganu Plains, Peninsular Malaysia*. PhD Thesis, University Putra Malaysia.

Rubber Research Institute of Malaya (RRIM) (1990). *Manual for Diagnosing Nutritional Requirements of Hevea*. Kuala Lumpur: RRIM.

Sahebi, M., Hanafi, M.M., Siti Nor Akmar, A., Rafii, M.Y., Azizi, P., Tengoua, F.F., Nurul Mayzatul Azwa, J. and Shabanimofrad, M. (2015). Importance of Silicon and Mechanisms of Biosilica Formation in Plants, *BioMed Research International*, vol. 2015, Article ID 396010, 16 pages.

Salisu, M., Noordin, D. and Ahmad, I. (2013). Influence of fertilizer rates and soil series on growth performance of natural rubber (*Hevea brasiliensis*) latex timber clones. *Australian Journal of Crop Science*, 7(13): 1998-2004.

Samarappuli, L. (2000). Rubber Growing Soils and Their Characteristics. *Bulletin of the Rubber Research Institute of Sri Lanka*, 41: 10-21.

SAS – Institute (2013). SAS Software, Version 9.4. SAS Institute Inc Cary, NC.

Schuylenborgh, J.V. (1964). The Formation of Sesquioxides in Soils. In Hallsworth, E.G. and Crawford, D.V (Eds.), *Experimental Pedology* (pp. 113-125),.London: Butterwoths.

Selamat, A., Wahab, Z., Awang, Y., Mohamed, M.M.T. and Osman, M. (2008). Use of Absolute Function and its Formation and 'Redevelopment' of Mathematical Models in Some Plant-Related Quantitative Physiology: Salinity Effects on Leaf Development of *Schefflera arboricola* and Harvest Index in Rice. American Institute of Physics, Meville, Proc. 976: 165-170

Sethuraj, M.R. (1985). Physiology of Growth and Yield in *Hevea brasiliensis.* In Rajarao, J.C. and Amin, L.L. (Eds.). *Proceedings of the International Rubber Conference* (pp. 3-20), 21-25 October 1985, Kuala Lumpur.

Sethuraj, M.R. and George, M.J. (1980). Tapping. In: Pillai, P.N.R. (Ed.) *Handbook of Natural Rubber Production in India* (pp.209-229). Kottayam, India: The Rubber Board.

Shafar, J.M., Noordin, W.D. and Fauziah, C.I. (2012). Response of *Hevea brasiliensis* (RRIM 2001) Planted on an Oxisol to Different Rates of Fertilizer Application. *Malaysian Journal of Soil Science,* 16: 57-69.

Shafar, J.M., Noordin, W.D. and Nazera, A. (2011a). Performance of *Hevea brasiliensis* on Haplic Ferralsol as Affected by Different Water Regimes. *American Journal of Applied Sciences*.8 (3): 206-211.

Shafar, J.M., Noordin, W.D. and Noorsuhaila, A.B. (2013). Effect of Contrasting Soil Textures on the Nutritional Status of Three Latex Timber Clones (*Hevea brasiliensis*). *Journal of Science & Technology in the Tropics*, 9(1): 15-23.

Shafar, J.M., Noordin, W.D. and Nursyazwina, M.Z. (2011b). Evaluation of Different Water Regimes on Hevea brasiliensis Grown on Haplic Ferralsol Soil at Nursery Stage. *International Journal of Applied Science and Technology*. 1(3): 28-33.

Shafar, J.M., Noordin, W.D. and Nursyazwina, M.Z. (2011c). Evaluation of *Hevea brasiliensis* (Latex Timber Clone: RRIM 2001 and RRIM 3001) in Relation to Different Water Stress. *American Journal of Agricultural and Biological Sciences*. 6(1): 122-127.

Shamshuddin, J. (1982). *Morphology, physico-chemistry and genesis of T-2 terrace soils of Peninsular Malaysia*. DSc thesis, State University of Ghent, Belgium.

Shamshuddin, J. (2011). *Methods in Soil Mineralogy*. Serdang: University Putra Malaysia Press.

Shamshuddin, J. and Fauziah, C.I. (2010a). *Weathered Tropical Soils: Ultisols and Oxisols*. Serdang: University Putra Malaysia Press.

Shamshuddin, J. and Fauziah, C.I. (2010b). Alleviating acid soil infertility constraints using basalt, ground magnesium limestone and gypsum in a tropical environment. *Malaysian Journal of Soil Science*, 14: 1-13.

Shamshuddin, J. and Ismail, H. (1995). Reactions of Ground Magnesium Limestone and Gypsum in Soils with Variable-Charge Minerals. *Soil Science Society of America Journal*, 59: 106-112.

Shamshuddin, J. and Kapok, J.R. (2010). Effect of Ground Basalt on Chemical Properties of an Ultisol and Oxisol in Malaysia. *Pertanika Journal of Tropical Agricultural Science*, 33(1): 7-14.

Shamshuddin, J. dan Noordin, W.D. (2011). Classification and Management of Highly Weathered Soils in Malaysia for Production of Plantation Crops. In Gungor, B.E.O. (Ed.), *Principles and Assessment in Soil Science* (pp. 75-86). Croatia: InTech.

Shamshuddin, J., Anda, M., Fauziah, C.I., Syed Omar, S.R. (2011a). Growth of cocoa planted on highly weathered soil as affected by application of basalt and/or compost. *Communications in Soil Science and Plant Analysis*, 42(22): 2751-2766.

Shamshuddin, J., Fauziah, C.I. and Sharifuddin, H.A.H. (1991). Effects of Limestone and Gypsum Applications to a Malaysian Ultisol on Soil Solution Composition and Yield of Maize and Groundnut. *Plant and Soil*, 134: 45-52.

Shamshuddin, J., Fauziah, C.I., Anda, M., Kapok, J. and Shazana, M.A.R.S. (2011b). Using ground basalt and/or organic fertilizer to enhance productivity of acid soils in Malaysia for crop production. *Malaysian Journal of Soil Science*, 15: 127-146.

Shamshuddin, J., Panhwar, Q.A., Shazana, M.A.R.S., Elisa, A., Fauziah, C.I. and Naher, U. (2016). Improving the Productivity of Acid Sulfate Soils for Rice Cultivation using Limestone, Basalt, Organic Fertilizer and/or their Combinations. *Sains Malaysiana*, 45(3): 383–392.

Shamshuddin,J. and Anda,M. (2012). Enhancing the Productivity of Ultisols and Oxisols in Malaysia using Basalt and/or Compost. *Pedologist*, 55(3): 382-391.

Shamshuddin. J., Noordin, W.D., Roslan, I., Fauziah, C.I. and Panhwar, Q.A. (2015). *Ultisols & Oxisols: Enhancing Their Productivity for Oil Palm, Rubber and Cocoa Cultivation*. Serdang: Universiti Putra Malaysia Press.

Shazana, M.A.R.S., Shamshuddin, J., Fauziah, C.I. and Syed Omar, S.R. (2013). Alleviating the infertility of an acid sulphate soil by using ground basalt with or without lime and organic fertilizer under submerged conditions. *Land Degradation & Development*, 24(2): 129-140.

Shorrocks, V.M. (1964). *Mineral Deficiencies in Hevea and Associated Cover Plants*. Kuala Lumpur: Rubber Research Institute of Malaysia.

Shorrocks, V.M., Templeton, J.K. and Iyer, G.C. (1965). Mineral Nutrition, Growth and Nutrient Cycle of *Hevea brasiliensis* III. The Relationship between Girth and Shoot Dry Weight. *Journal of the Rubber Research Institute of Malaya*, 19(2): 85-92.

Simmonds, N.W. (1989). Rubber Breeding. In: Webster CC, Baulkwill WJ (Eds) *Rubber* (pp. 85-124), Essex, England: Longman Scientific and Technical.

Sivanadyan, K. (1972). Lysimeter Studies on the Efficiency of Some Potassium and Nitrogenous Fertilizers on Two Common Soils in West Malaysia. Paper presented at 2nd ASEAN Soil Conference Jakarta 18-21 July 1972.

Soil Survey Staff (1999). *A Basic System of Soil Classification for Making and Interpreting Soil Survey*, 2nd Edition, USDA-Natural Resources Conservation Service, Washington, DC.

Soil Survey Staff (2014). *Keys to Soil Taxonomy*. 12th Edition. USDA-Natural Resources Conservation Service, Washington, DC.

Soil Survey Staff (2015). *Glossary of Soil Survey Terms*. USDA-Natural Resources Conservation Service, Washington, DC.

Soong, N.K. (1976). Feeder Root Development of *Hevea brasiliensis* in Relation to Clones and Environment. *Journal Rubber Research Institute of Malaya*, 24(5):283-296.

Soong, N.K. and Lau, C.H. (1977). Physical and Chemical Properties of Soil. In Pushparajah, E. and Amin, L.L. (Eds.), *Soils Under Hevea and Their Management in Peninsular Malaysia* (pp. 25-56). Kuala Lumpur: RRIM.

Suarni, S. and Ang, C.S. (2011). The Malaysian Rubber Industry: Meeting Future Needs. Paper presented at International Rubber Economic Conference 2011, 26-27 July 2011.

Tavernier, R. and Eswaran, H. (1973). Basic Concepts of Weathering and Soil Genesis in the Humid Tropics. Proc. 3rd ASEAN Soil Conf. Bogor, Indonesia, Vol I, 383.

Tavernier, R. and Eswaran, H. (1977). Soil Property Changes as a Function of Soil Genesis in the Humid Tropics. In Jospeh, K.T. (Ed), *Proceedings of Conference on Classification and Management of Tropical Soils* (pp. 92-100), 15-20 August, 1977, Kuala Lumpur.

Teh, C.B.S. and Jamal, T. (2006). *Soil Physic Analyses.* Selangor: Universiti Putra Malaysia Press.

Templeton, J.K. (1968). Growth Studies in *Hevea brasiliensis L* Growth Analysis up to Seven Years after Budgrafting. *Journal of the Rubber Research Institute of Malaya*, 20(3): 135-146.

Tichy, R., Fajtl, J., Kuzel, S. and Kolar, L. (1997). Use of Elemental Sulphur to Enhance a Cadmium Solubilization and Its Vegetative Removal From Contaminated Soil. *Nutrient Cycle Agroecosystem*, 46: 249–255.

Van Ranst, E. (1995). Rational Soil Management in the Humid Tropics. Meded. Zitt. K. Acad. Overzeese Wet. 40 (1994-2); 209-233.

Van Straaten, P. (2002). *Rocks for crops: Agrominerals of Sub-Sharan Africa*. Nairobi, Kenya: ICRAF.

Van Straaten, P. (2006). Farming with rocks and minerals: challenges and opportunities. *Annals of the Brazilian Academy of Sciences*, 78(4): 731-747.

Van Wembeke, A. and Eswaran, H. (1975). *Soil Moisture Regimes and Soil Temperatures Regimes of South East Asia*. Ghent, Belgium: State University of Ghent.

Velde, B. and Barré, P. (2010). *Soils, Plants and Clay Minerals: Mineral and Biologic Interactions*. Berlin: Springer.

Velde, B. and Meunier, A. (2008). *The Origin of Clay Minerals in Soils and Weathered Rocks*. Berlin: Springer.

Verheye, W. (2004). *Land Use, Land Cover and Soil Sciences. Encyclopedia of Life Support Systems (EOLSS)*. Oxford, UK: UNESCO-EOLSS Publishers.

Wahid, P. A. (2001). Radioisotope Studies of Root Activity and Root-Level Interactions in Tree-based Production Systems: A Review. *Applied Radiation and Isotopes*, 54(5): 715-736.

Waterken, L., Bienfait, A. and Peeters, A. (1981). Callose et Silice Epidermiques. Rapports Avec la Transpiration *Cuticulaire, Cellule*, 73(3).

Webster, C.C. and Baulkwill, W.J. (1989). *Rubber*. Essex, England: Longman.

Webster, C.C. and Paardekooper, E.C., 1989. *The Botany of Rubber Tree*. Singapore: Longman Singapura Publisher (Pte) Ltd.

Weerathamrongsak, P. and Wongsurawat, W. (2013). The Rubber Industry of Thailand: A Review of Past Achievements and Future Prospects. *Journal of Agribusiness in Developing and Emerging Economies*, 3: 48-64.

White, R. E. (2006). *Principles and Practice of Soil Science: The Soil as a Natural Resource*.4th Edition. United Kingdom: Blackwell Publishing.

Wong, C.B. (1977). A Toposequence on Granite and its Influence on the Performance of Hevea brasiliensis. In Jospeh, K.T. (Ed.), *Proceedings of Conference on Classification and Management of Tropical Soils* (pp. 74-83), 15-20 August, 1977, Kuala Lumpur.

Wong, C.B. (1978). Discriminatory Fertilizer Use in *Hevea* Cultivation. In Jalil, A. (Ed.), *RRIM Training Manual on Soils, Management of Soils and Nutrition of Hevea* (pp. 233-240). Kuala Lumpur: Rubber Research Institute of Malaysia.

Wong, I. F. T. (1974). *The Present Land Use of Peninsular Malaysia*. Kuala Lumpur: Ministry of Agriculture. 1: 2-6.

Yew, F.K. (1988). Soil Suitability for Rubber. In Jalil A. (Ed.), *RRIM Training Manual on Soils, Management of Soils and Nutrition of Hevea* (pp. 50-75). Kuala Lumpur: Rubber Research Institute of Malaysia.

Yew, F.K. and Pushparajah, E. (1991). Influence of Soil Conditions on Growth of *Hevea*, *Journal of Natural Rubber Research*, 6(1): 62-73.

Zahidin, M.R. (2015). *Determination of Fertilizer Rates and Mulching To Improve the Growth of RRIM 3001 Rubber Clone Grown In Non Traditional Rubber Areas*. MSc Thesis, University Putra Malaysia.

Zainol, E. (1988). Factors Influencing Soil Formation. In Jalil A. (Ed.) *RRIM Training Manual on Soils, Management of Soils and Nutrition of Hevea* (pp. 1-16). Kuala Lumpur: Rubber Research Institute of Malaysia.

Zhang, H., Zhang, G.L., Zhao, Y.G., Zhao, W.J. and Qi, Z.P. (2007). Chemical Degradation of a Ferralsol (Oxisol) under Intensive Rubber (*Hevea brasiliensis*) Farming in Tropical China, *Soil & Tillage Research*, 93: 109–116.