UNIVERSITI PUTRA MALAYSIA

CHARACTERISTICS OF MAGNESIUM RICH SYNTHETIC GYPSUM AND ITS EFFECT AS A SECONDARY NUTRIENT SOURCE FOR RUBBER SEEDLINGS ON ACID SOILS

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By

AROLU FATAI AYANDA

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DEDICATIONS

This thesis is dedicated to my mother who gave up herself to see us succeed

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

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December 2021

Chairperson : Mohd Firdaus bin Mohd Anuar, PhD
Faculty : Agriculture

Ultisols and Oxisols, the common soil in Malaysia, do not usually contain optimal levels of cations such as K, Ca and Mg, required in large amounts for crop growth and productivity. Thus, the management of input plays an important role in crop production in these widely occurring soils of Peninsular Malaysia. Rubber requires large amounts of nutrients to sustain its growth and production so that faster growth and high latex yield can be achieved and maintained. The use of fertilizer to supply nutrients for rubber is essential in rubber cultivation; however, fertilizer costs account for a larger percentage of production costs. As such, it is imperative to seek ~~for~~ a local alternative source that is cost-effective. Recent studies on MRSG, a by-product obtained from industrial refining of rare earth show that the material contains nutrient elements that may be beneficial for rubber growth in addition to its high pH that ameliorate the impact of soil acidity limitation on crop growth. Therefore, this research was conducted to study the physicochemical characteristics of MRSG, its effect on acid soils, rubber growth, and whether MRSG can be a secondary nutrient source for rubber plants at the growing phase. The characterization results indicated that MRSG has valuable properties that can promote its use in amending soil fertility constraints on nutrient-deficient tropical acid soils. Incubation and leaching column studies were conducted to assess the effect of MRSG on the chemical properties of Ultisol and Oxisol in Malaysia and model the nutrient release pattern from the material over a 6-month period. The incubation experiment was as a factorial experiment consisting of 2 soil types, 3 treatments and five rates including control (0, 1, 2, 4 and 8) and laid out as a completely randomized design (CRD). For the leaching experiment, the treatment consists of 1 t ha^{-1} of MRSG, GML and kieserite with three replications arranged in a complete randomized design (CRD). The study comprised two soil orders viz Ultisol and Oxisol belonging to the Bungor and Segamat series based on Malaysian classification for local soils.

The amount of nutrients released into soil solution and present on the soil exchange site due to the application of MRSG at various rates and months were fitted into different functions using python programming script. The pattern of nutrient release from MRSG was similar in the two studied soils and amounts of nutrient released increased with the duration of the experiment. Nutrients release kinetics for all samples are adequately described by the parabolic diffusion, power function and Elovich equations. The intercept constants of the equations are strongly positively related to the ratio of nutrients contained in MRSG. The models showed good performance (R^2 value in range 0.9 to 0.99) in most samples tested except for the kieserite treatment group. The model indicates that MRSG has a disintegration behavior similar to GML and can be used to achieve a similar result in acid soil amelioration and soil nutrient enhancement. The leaching study showed that MRSG is available in the soil system and can move beyond the zone of incorporation into the sub-soil to further ameliorate subsoil acidity. The Ca and Mg ions contained in MRSG are not easily leached out of the soil profile, thus MRSG can be a potential substitute for lime (GML) on acid soils.

For nursery trial to understand the effect of MRSG application on the growth of immature rubber, three-month-old rubber seedlings of the same size and/or height were obtained from RISDA for planting on Ultisol and Oxisol. The experimental units consisted of four rubber seedlings, with a total of 200 seedlings planted in the polybags. Treatments for this study was based on using GML, kieserite and MRSG as fertilizer source to supply the recommended Mg requirement for rubber seedlings in the nursery based on RISDA formulation. Determination of growth parameters of the rubber seedlings was carried out at 3 monthly intervals. The result of the experiment showed that incorporation of MRSG increased the soil pH and decreased the aluminum content. MRSG application also increased the level of available phosphorus and secondary nutrients such as calcium. The growth of rubber seedlings in the glasshouse for the parameters of height, stem diameter, root length and root surface area were significantly enhanced in the two studied soils (Ultisol and Oxisol) by the addition of MRSG which gave a result comparable to other sources of Mg fertilizer. It was observed that plant growth performance was better on the Ultisol compared to the Oxisol. This study showed that the logistic growth curve model in the form of $y = A/ (1+be^{-ct})$, where y and t were the plant growth parameters and months after transplanting, respectively, while A, b and c were regression constants were biologically fitted in describing the growth in terms of each of the parameters (plant height, stem girth and total plant biomass) versus months after transplanting. At each treatment, the model had an F value with a high approximate probability level at a = 0.0001. In terms of the vegetative growth of the rubber seedlings, MRSG treatments gave comparable results to that of GML and kieserite, thus, indicating the possibility of using MRSG as a replacement of kieserite and GML as Mg source (Mg-fertilizer) to sustain rubber seedling growth.

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Oleh

AROLU FATAI AYANDA

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Ultisols dan Oxisols, tanah biasa di Malaysia, biasanya tidak mengandungi kation tahap optimum seperti K, Ca dan Mg, yang diperlukan dalam jumlah besar untuk pertumbuhan dan produktiviti tanaman. Oleh itu, pengurusan input memainkan peranan penting dalam pengeluaran tanaman di tanah Semenanjung Malaysia. Getah memerlukan sejumlah besar nutrien untuk mengekalkan pertumbuhan dan pengeluarannya sehingga pertumbuhan yang lebih cepat dan hasil getah yang tinggi dapat dicapai dan dikekalkan. Penggunaan baja untuk membekalkan nutrien untuk getah sangat penting dalam penanaman getah; namun, kos baja menyumbang peratusan kos pengeluaran yang lebih besar. Oleh itu, sangat mustahak untuk mencari sumber alternatif tempatan yang menjimatkan kos. Kajian terbaru mengenai MRSG, produk sampingan yang diperoleh dari penapisan industri nadir bumi menunjukkan bahawa bahan tersebut mengandungi unsur nutrien yang mungkin bermanfaat untuk pertumbuhan getah di samping pHnya yang tinggi yang dapat meningkatkan kesan pembatasan keasidan tanah terhadap pertumbuhan tanaman. Oleh itu, penyelidikan ini dilakukan untuk mengkaji ciri-ciri fizik-kimia daripada kesan penggunaan MRSG, kesannya terhadap tanah asid, pertumbuhan anak getah dan mengetahui samada MRSG dapat menjadi sumber nutrien sekunder bagi tanaman getah pada fasa pertumbuhan. Komponen fizikal, kimia dan mineralogi MRSG ditentukan melalui analisis unsur kimia, SEM dengan penganalisis EDX, analisis termal, analisis XRF dan XRD. Sifat kristal produk sampingan dikaji menggunakan spektroskopi FTIR. Analisis unsur mengesahkan adanya Ca dan Mg yang merupakan makronutrien penting yang diperlukan oleh tumbuhan. Hasil kajian menunjukkan bahawa produk sampingan yang dikaji adalah bahan kristal heterogen yang terdiri daripada gipsum dan komponen utama yang lain. Agregat ini dapat menyumbang untuk memberi kapasiti peneutralan asid kepada MRSG. Kajian XRD MRSG menunjukkan kandungan gipsum yang tinggi sementara spektrum penyerapan inframerah MRSG menunjukkan persamaan yang dekat dengan gipsum yang di lombong. Hasil eksperimen menunjukkan bahawa MRSG mempunyai sifat yang bernilai yang dapat meningkatkan penggunaannya dalam memperbaiki batasan kesuburan tanah pada tanah asid tropika yang kekurangan nutrien. Kajian kolum inkubasi dan inkubasi

dilakukan untuk menilai kesan MRSG terhadap sifat kimia Ultisol dan Oxisol di Malaysia dan memodelkan pola pelepasan nutrien dari bahan tersebut dalam jangka masa 6 bulan.

Jumlah nutrien yang dilepaskan ke dalam pencemaran tanah dan terdapat di lokasi, pertukaran tanah kerana penggunaan MRSG pada berbagai kadar dan waktu dimasukkan ke dalam fungsi berikut menggunakan skrip pengaturcaraan python. Pola pelepasan nutrien dari MRSG adalah serupa di dua tanah yang dikaji dan jumlah nutrien yang dikeluarkan meningkat sepanjang tempoh eksperimen. Kinetik pelepasan nutrien untuk semua sampel dijelaskan dengan tepat oleh penyebaran parabola, fungsi daya dan persamaan Elovich. Pemalar pemintas persamaan sangat berkaitan positif dengan nisbah nutrien yang terdapat dalam MRSG. Model menunjukkan prestasi yang baik (nilai R2 dalam kisaran 0.9 hingga 0.99) pada kebanyakan sampel yang diuji kecuali untuk kelompok perlakuan kieserite. Model menunjukkan bahawa MRSG mempunyai tingkah laku disintegrasi yang serupa dengan GML dan dapat digunakan untuk mencapai hasil yang serupa dalam peningkatan tanah asam dan peningkatan nutrien tanah. Kajian pencucian menunjukkan bahawa MRSG tersedia dalam sistem tanah dan dapat bergerak melampaui zon penggabungan ke dalam tanah untuk meningkatkan lagi keasidan tanah. Ion Ca dan Mg yang terkandung dalam MRSG tidak mudah keluar dari profil tanah, sehingga MRSG dapat berpotensi menjadi pengganti kapur (GML) pada tanah berasid.

Untuk kajian semaian untuk memahami kesan aplikasi MRSG terhadap pertumbuhan getah belum matang, anak benih getah berusia tiga bulan dengan ukuran dan / atau tinggi yang sama diperoleh dari RISDA untuk penanaman pada Ultisol dan Oxisol. Unit eksperimen terdiri daripada empat anak benih getah, dengan jumlah 200 anak benih ditanam di dalam polibeg. Rawatan untuk kajian ini didasarkan pada penggunaan GML, kieserite dan MRSG sebagai sumber baja untuk membekalkan keperluan Mg yang disarankan untuk anak benih getah di tapak semaian berdasarkan formulasi RISDA. Penentuan parameter pertumbuhan anak pokok getah dilakukan pada selang 3 bulan. Parameter yang ditentukan adalah tinggi tanaman, lilitan, luas daun, kandungan klorofil, berat kering. Persampelan untuk tanah dan tanaman getah dilakukan untuk mengetahui pengaruh perlakuan terhadap sifat kimia tanah dan pertumbuhan vegetatif dari bibit getah. Ini dilakukan pada 3, 6, 9 dan 12 bulan setelah penanaman. Hasil eksperimen menunjukkan bahawa penggabungan MRSG meningkatkan pH tanah dan menurunkan kandungan aluminium Juga, aplikasi MRSG meningkatkan tahap nutrien fosforus dan sekunder seperti kalsium. Pertumbuhan anak benih getah di rumah kaca seperti yang dilihat dari ketinggian, diameter batang, panjang akar dan luas permukaan akar meningkat dengan ketara di kedua tanah yang dikaji (Ultisol dan Oxisol) dengan penambahan MRSG yang memberikan hasil yang setanding dengan sumber lain Baja Mg. Kajian menunjukkan bahawa prestasi pertumbuhan tanaman lebih baik pada tanah Ultisol dibandingkan dengan Oxisol. Kajian ini menunjukkan bahawa mode keluk pertumbuhan logistik dalam bentuk $y = A / (1 + be\text{-}ct)$, di mana y adalah parameter pertumbuhan dan t adalah parameter bulan setelah pemindahan pokok, sementara A, b dan c adalah pemalar regresi bersuaian secara biologi untuk menggambarkan pertumbuhan dari setiap parameter (ketinggian tanaman, ukurlilit batang dan jumlah biojisim tumbuhan) berbanding bulan setelah pemindahan pokok. Pada setiap rawatan, model tersebut mempunyai nilai F dengan tahap kebarangkalian yang tinggi pada $\alpha = 0{,}0001$. dari segi pertumbuhan vegetatif benih getah, rawatan MRSG memberikan hasil yang setanding dengan GML dan kieserite, dengan demikian, menunjukkan

kemungkinan penggunaan MRSG sebagai pengganti kieserite dan GML sebagai sumber Mg (baja Mg) untuk mengekalkan pertumbuhan anak pokok getah

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LIST OF ABBREVIATIONS

%	Percentage
^{O}C	Degree Celsius
ANOVA	Analysis of variance
bi	Regression slope
cm	Centimeter
Diff	Diffusion
Exch	Exchangeable
Func	Function
g	Gram
H_2O_2	Hydrogen peroxide
HCl	Hydrochloric acid
L	Liter
HSD	Honest significant difference
MSD	Minimum significant difference
mg	Milligram
min	Minute
NaCl	Sodium Chloride
PC	Principal Component
SAS	Statistical analysis softwar

CHAPTER 1

INTRODUCTION

1.1 General introduction

In Malaysia, Ultisols and Oxisols are very common especially in the upland areas occupying about 72 % of the country's land area. These soils contain kaolinite, gibbsite, goethite, and hematite in the clay fraction. The soils are very highly weathered due to their existence under tropical environment with high rainfall and temperature throughout the year, resulting in the leaching of plant nutrients and accumulation of sesquioxides (Anda *et al*., 2008). The soils by nature are devoid of basic cations (Ca and Mg) and available P (due to fixation by the oxides) and hence, their productivity is generally considered as low. The soils are mainly utilized for crop cultivation with great success due to excellent soil management practices which ensures that essential macronutrients required for normal plant growth that is deficient are provided. Essential nutrients required for crop growth and yield development include magnesium and calcium.

The vast majority of Malaysian acid soil is low in exchangeable Ca and Mg, with levels that are inadequate for optimum plant performance (Shamshuddin *et al.,* 2011). In Malaysia, Mg-fertilizer (kieserite) is rather expensive, adding cost to rubber production while Ca is not included in the standard fertilizer formulation for immature rubber (RISDA, 2008) despite its low level in Malaysian soils. Magnesium is an essential nutrient whose function in the activation of enzymes for energy metabolism surpasses that of other mineral elements (Azham, 2003). Several hundreds of enzymes require magnesium in other to function. Magnesium is an eessential nutrient element needed in the plant for growth and development. It is an integral constituent of plant chlorophyll, thereby playing important role in photosynthesis. Magnesium also increases water and nutrient uptake, promoting a better nutrient-use-efficiency, transport of phosphate in the plant (Jones, 1979). The importance of magnesium in rubber is such that Mg deficiency leads to the disruption of various metabolic activities in the plant. Interruption of protein synthesis and reduction in starch accumulation are examples of essential metabolic activities disruption that accompany magnesium deficiency (Fairhurst and Hadter, 2003). Calcium is an essential macronutrient that is responsible for cell wall formation, thereby leading to improved tree growth. Ca is also an important activator of cell division in meristematic tissue and vital in root development. Timkhum *et al.* (2013) in an experiment on fertilization of acid soils using NPK and Mg fertilizers reported that calcium was deficient in the plant alongside N and P.

Rubber requires large amounts of nutrients to sustain its growth and production so that faster growth and high latex yield can be achieved and maintained. The use of fertilizer to supply nutrients for rubber is very essential in rubber cultivation. Adequate nutrients are required during the immature phase so that the trees can be brought into tapping in the shortest time possible (Noordin, 2013). Also, during the mature phase, nutrients are essential to sustain the health and wellbeing of the trees and also to maintain yield (Vrignon-Brenas *et al.,* 2019). With the expertise available in the country, rubber is

produced in large amounts for the world market, while problem of low productivity resulting from this nutrient deficiency in acid soils has made fertilizer use indispensable in rubber cultivation (Noordin, 2013). The importance of fertilizers in rubber cultivation on acid soils cannot be over emphasized (Shamshuddin *et al.,* 2018). Rubber seedlings are usually raised in a nursery where they are subjected to optimal growing conditions and given adequate care due to their susceptibility to pest and disease attacks, and also mechanical damage (Noordin, 2013). The cost of seedlings production is high due to fertilizer cost.

As such, it is imperative to look for an alternative means of providing nutrients required for rubber growth, therefore magnesium-rich synthetic gypsum (MRSG) was proposed as a viable material in acid soil fertilization. The material is by-product obtained from an industrial process in the refining of rare earth in Gebeng, Pahang, which can be used to supply magnesium instead of using kieserite and other secondary nutrients required by rubber in the immature phase. MRGS contains about 73% gypsum ($CaSO_4.2H_2O$) and has a high content of magnesium, calcium and sulfur, the macronutrients needed by rubber during its growth. Currently, research on MRSG application in rubber cultivation is still lacking. Although, it is supposed that being an industrial residue, MRSG will be a cheap/low-cost alternative to conventional fertilizers. However, there are lots of questions regarding its use e.g its economic viability, rate/quantity of application, frequency optimization and method of application that are yet to be answered. In this study, the role of MRGS as a potential source of Mg and secondary nutrients for rubber seedlings on nutrient-deficient Ultisols and Oxisols was assessed, and this was compared with seedlings treated with kieserite or GML.

1.2 Problem statement

Adequate nutrients are needed to improve the planting materials of natural rubber to achieve maximum yield (Yaacob *et al.,* 1992). The country (Malaysia) must continue to improve crop yield per area with agronomic practices and soil fertility in the proper way for plantation groups and smallholders (Sabri, 2009). Ultisols and Oxisols; the soils on which rubber is mostly grown do not usually contain sufficient basic cations such as K, Ca and Mg, which are required in high amounts by rubber for its growth and latex production (Shamshuddin *et al.,* 2018). Fertilizer is essential for rubber in the vegetative development stage (first 6 years). Fertilizer is one of the most important inputs in crop cultivation, accounting for about 30% production cost and the cost of fertilizer is usually on a steady increase (Noordin, 2013).

About 90% of fertilizers in Malaysia are imported. The global economic crisis causing the depreciation of the Malaysian Ringgit against the US dollars results in a significant increase in the prices of imported fertilizers. In recent years, the country spends a high amount on the purchase of Mg fertilizer (Shamshuddin *et al.,* 2018). The global pandemic has led to an economic downturn and reduced capital for purchases of fertilizers by most of the plantation owners. This, alongside the increase in price of kieserite and the dependence of Malaysia on a few global players (producers and exporters) who possess sufficient market power in terms of fertilizer price determination,

has made it imperative to evaluate the locally available source to be used as fertilizer against the imported Mg-fertilizer in terms of their performance and cost-effectiveness.

During the past years, some research groups have carried out studies on the new ways of utilizing Mg and gypsum-containing industrial by-products by exploring its use as a low-cost material capable of substituting the relatively costlier kieserite and GML for plant nutrition balance on acid soil. Ayanda *et al.* (2020) conducted a study on the utilization of MRSG as a replacement for kieserite and GML fertilizer in oil palm seedling and the researcher reported a positive influence of the material on plant growth and soil properties. Meanwhile, the environmental assessment impact of MRSG application on acid soil was assessed in the study of Sahibin *et al.* (2019). So far, there are only two notable studies on the application of MRSG on acid soils. Research on the utilization of MRSG in the acid soil system is still in its infancy due to the dearth of concrete scientific evidence to support the claim that MRSG can be a good alternative to conventional Mg fertilizers without a significant detrimental impact on the environment. Thus, it is worthy to conduct further research into this aspect.

In recent years, the application of industrial residue to the soil has been suggested as a management technique for their safe disposal to avoid stacking huge amounts of these materials in landfills and industrial sites. However, there are concerns that these materials may contain a huge proportion of toxic elements which makes them unsafe for land disposal. Several researchers have worked on the application of industrial residue to acid soils. Magnesium-rich synthetic gypsum is a relatively new material and comprehensive report on MRSG application to soil is lacking. The results available so far show the material was applied in one location and on one soil type (Acidic Ultisol in Bera, Pahang, Malaysia). Controversies are surrounding the use of MRSG due to its nature as an industrial residue (Shamshuddin *et al.,* 2021). The lynas plant in Malaysia was established amidst intense opposition from environmentalists, activists and local residents, some of whom tried abortively to get a court order to stop the establishment of the rare earth refining plant producing MRSG (Aljazeera, 2022). Their actions were mostly due to fears of health hazards such as leukaemia and birth deformities alleged to have resulted from a defunct rare earth refinery established in the state of Perak. This rare earth plant was eventually closed after close to 10 years in operation and more than 100 million US dollars spent on cleaning up the site. This comparison with the earlier rare earth plant has been rejected by Lynas who insist its by-products are far less harmful that the one from the plant in Bukit Merah, Perak (Aljazeera, 2022). If the use of the Lynas MRSG is to be certified and acceptable, further research should be conducted on the material in different soil types, using a different test crop. The scope of this study is to identify the mechanism of action, optimum proportions, frequency and application rates of MRSG that can effectively work as a magnesium fertilizer and improve soil acidity condition while having the lowest impact on the environment. The success of this study will go a long way towards reducing the production cost of natural rubber at the immature stage by proposing a potential low-cost alternative to conventional fertilizer. Also, the usage of this industrial by-product will highlight the environmentally sustainable way for the disposal of this by-product rather than large storage in facilities. This will provide an environmentally sustainable way for its disposal via usage in agriculture thereby promoting environmental sustainability.

1.3 Objectives

The general objective of this project was to investigate the use of MRSG as a magnesium fertilizer on the Ultisols and Oxisol order in Malaysia and to evaluate the effect of the MRSG on rubber seedling growth. The specific objectives are:

i. To characterize the physical, chemical and mineralogical properties of MRSG to determine its composition and alternative use

ii. To determine the impact of nutrients release from MRSG on chemical changes in the solid and solution phase of Ultisol and Oxisol via incubation and leaching experiment;

iii. To determine the impact of MRSG on sub-soil acidity via a leaching experiment

iv. To determine the impact of the released nutrients from MRSG on soil chemical properties and rubber growth via a glasshouse experiment.

v. To compare the effect of Ground Magnesium Lime (GML), Kieserite and MRSG on the growth of rubber.

1.4 The hypotheses of this study are as follows:

i. The chemical properties and surface reactivity of MRSG will ensure it release nutrients that can ameliorate acid soil constraints.

ii. The nutrients released from MRSG into the solution phase of the acid soil will increase the level of Ca and Mg in the soil and these can be highly mobile within the soil system thus limiting sub-soil acidity constraint.

iii. MRSG will be a useful source of secondary nutrients for rubber at the immature phase, having a similar or better impact compared to conventional fertilizers.

1.5 Description of thesis chapters

The thesis comprises seven chapters. A brief description of the contents of each chapter is given below:

Chapter 1 contains an introduction to the study, outlining the background, problem statement, significance of the study, study gaps and the research objectives

Chapter 2 reviews the current knowledge of soil acidity, the amelioration of soil acidity and the use of industrial residue for improving soil acidity constraints. The existing

knowledge on the impacts of industrial by-products or residue in agriculture are also discussed and major knowledge gaps are identified.

Chapter 3 describes the general materials and methods used in the process of carrying out the research.

Chapter 4 describes experimental studies to understand the physical, chemical, mineralogical and surface functional groups present in MRSG which is the industrial by-products to be tested on acid soil. The result of this study was used to inform the design of the subsequent studies. In this study, the composition of MRSG determined through elemental chemical analysis, SEM with EDX-analyzer, thermal analysis, XRF and XRD analysis. The crystalline nature of the by-product was studied using FTIR spectroscopy and the result of these studies indicate that the product has valuable content of acid-neutralizing elements and compounds.

Chapter 5 describes the effect of MRSG on the chemical properties of two highly weathered soil series (Ultisol and Oxisol) via incubation and leaching column study. This chapter used a modelling tool (Phyton script) to study the pattern of nutrient release from MRSG into soil solution in the incubation experiment. The leaching study was conducted to assess the movement of MRSG in the soil profile to determine whether MRSG can move the zone of incorporation into the sub-soil or maybe it is highly prone to leaching acidity, thereby becoming inefficient for soil amelioration and fertility improvement. The result established the similarity MRSG and GML in their mode of action in the soil, indicating that MRSG can be a potential substitute for lime (GML) in acid soils.

Chapter 6 describes the effect of MRSG application on the growth of rubber at the immature phase using three-month-old rubber seedlings obtained from RISDA. This study was conducted on the two soil types and soil series used in earlier studies based on the findings obtained in Chapter 5. Treatments for this study was based on using GML, kieserite and MRSG as fertilizer source to supply the recommended Mg requirement for rubber seedlings in the nursery based on RISDA formulation. In this chapter, the logistic growth curve model in the form of $y = A/ (1+be-ct)$ where y and t were the plant growth parameters and months after transplanting, respectively, with A, b and c as regression constants used to determine the plant growth in terms of each of the parameters (plant height, stem girth and total plant biomass) versus months after transplanting. The vegetative growth of the rubber seedlings was compared to GML and kieserite, thus, to determine whether there is a possibility of using MRSG as a replacement of kieserite and GML as Mg source (Mg-fertilizer) to sustain rubber seedling growth.

Chapter 7 summarises the main findings as well as the conclusions of the study. The chapter describes broader implications of the use of industrial residue in the environment. Several recommendations for further studies concerning the use of industrial by-products in Agriculture are also presented.

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