UNIVERSITI PUTRA MALAYSIA

MINERALIZATION OF ORGANIC MATERIALS AND BIOAVAILABILITY OF NUTRIENTS TO PARTIALLY REPLACE THE INORGANIC FERTILIZATION FOR TEA

LIYANA RALLAGE MAHESH CHAMINDA LIYANAGE

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By

LIYANA RALLAGE MAHESH CHAMINDA LIYANAGE

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

July 2022

DEDICATED

My beloved wife son and daughter;
My parents;
All my teachers

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

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Chairman : Professor Mohamed Hanafi bin Musa, PhD
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Soil fertility depletion is one of the main factors for yield stagnation in tea cultivation in Sri Lanka for last few decades. Organic material (OM) incorporation has been identified as the sustainable technique to restore soil fertility in degraded tea fields even though research information is scanty. A series of experiments were carried out to investigate the carbon (C) and nitrogen (N) mineralization dynamics and the effects of OMs, such as *Gliricidia* (GLI), compost (CMP), tea waste (TW), biochar charged with nutrients (CBC) and raw biochar (RBC) without nutrient charging, on bio-availability of nutrients. Experiments were conducted in completely randomized design at the Universiti Putra Malaysia. The potential for partial substitution of inorganic N fertilizers by aforesaid OMs was tested in split plot design under field condition in Sri Lanka using mineralization and bio-availability indicators. The parallel first-order kinetic model fitted well (R^2>0.99) with the C mineralization dynamics demonstrating different C pools in added OMs. All the materials enhanced the soil microbial biomass carbon (MBC) and nitrogen (MBN) over 79 and 70%, respectively. Catalase and dehydrogenase activities were also improved by more than 76%. The carbon mineralization rate was highest in GLI (k=0.7 day^{-1}) and it was lowest in RBC (k=0.01 day^{-1}). *Gliricidia* showed the highest mineralizable C content of 15,350 mg kg^{-1}, which rapidly promoted the soil's biological activities. The CBC behaved similarly to compost in improving soil health. *Gliricidia* had faster released of N amounting to 94% of added N in N, P and S mineralization study. Even though CBC increased urease, protease, dehydrogenase and phosphatase activity by 157, 376, 500 and 75%, respectively, CBC probably immobilized/fixed N in the soil making unavailable for plants. It was confirmed by the bioavailability of mineralized products trial evaluated by implementing the exhaustive cropping technique with *Napier* grass. Approximately, 47% of the mineralized N from GLI was taken up by the plant, and the rest may have been lost or immobilized by microbes. Consequently, GLI showed the highest apparent nutrient recovery (NAR) of 47%. It should be mandatory to fortify biochar with a nutrient solution in order to maximize the utilization of biochar for soil health restoration. The study of different

ratios of OMs to inorganic fertilizers based on N requirements showed that all the tested OMs had the potential to replace the inorganic N fertilizer to an extent of 30%. In conclusion, GLI and CBC can be applied to restore fertility and health status respectively in degraded tea lands. Charged biochar showed the maximum benefits for the restoration of degraded soil with the ability to replace inorganic fertilizer by at least 20% for mature tea cultivation, invariably subsequent to supplementary future investigations.

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

MINERALISASI BAHAN ORGANIK DAN KETERSEDIAAN BIO NUTRIEN BAGI PENGANTIAN SEPARA BAJA BUKAN ORGANIK UNTUK TEH

Oleh

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Kemerosotan kesuburan tanah adalah salah satu faktor utama pengurangan hasil teh di Sri Lanka sejak beberapa dekad yang lalu. Penggunaan bahan organik (OM) telah dikenal pasti sebagai teknik yang paling mampan untuk memulihkan kesuburan tanah di ladang teh yang merosot. Walau bagaimanapun, maklumat mengenai pemulihan kesuburan ladang teh melalui penggunaan OM adalah terhad. Satu siri kajian telah dijalankan untuk menyiasat dinamik permineralan karbon (C) dan nitrogen (N) dan kesan OM, seperti *Gliricidia* (GLI), kompos (CMP), sisa teh (TW), dan biochar dengan pengecasan nutrien (CBC) dan tanpa pengecasan nutrien (RBC), ke atas bioketersediaan nutrien. Potensi OM dalam menggantikan sebahagian penggunaan baja N tak organik juga telah dikaji menggunakan penunjuk permineralan dan bioketersediaan. Model kinetik terbitan pertama selari mempunyai ketepatan padanan yang baik (R^2>0.99) di mana dinamik mineralisasi C membuktikan terdapat kumpulan C yang berbeza dalam OM yang digunakan. Semua jenis bahan meningkatkan karbon biojisim mikrob tanah (MBC) dan nitrogen biojisim mikrob tanah (MBN), masing-masing melebihi 79 dan 70%. Aktiviti katalase dan dehydrogenase juga meningkat sebanyak 76%. Kadar permineralan karbon paling tinggi adalah pada GLI (k=0.7 $hari^{-1}$) dan paling rendah pada RBC (k=0.01 $hari^{-1}$). *Gliricidia* menunjukkan kandungan C yang mampu untuk menjalani permineralan paling tinggi iaitu 15,350 mg kg^{-1}, yang dapat menggalakkan aktiviti biologi tanah untuk berlaku lebih pantas. Bahan CBC bertindak sama seperti kompos dalam meningkatkan kesihatan tanah. *Gliricidia* mempunyai pembebasan N lebih cepat dengan jumlah 94% N tambahan dalam kajian permineralan N, P dan S. Bahan organik menunjukkan kadar dan corak permineralan yang berbeza. Walaupun CBC meningkatkan aktiviti urease, protease, dehidrogenase dan fosfatase masing-masing sebanyak 157, 376, 500 dan 75%, CBC mungkin menyekat gerak/mengikat N dalam tanah lalu mengurangkan ketersediaan N untuk tumbuhan. Ia dibuktikan melalui bioketersediaan bahan termineral yang dinilai melalui kajian menggunakan rumput Napier. Kira-kira, 47% daripada N termineral dari GLI telah diserap oleh tumbuhan, dan selebihnya mungkin telah hilang atau diikat oleh mikrob. Kesannya, GLI menunjukkan

pemulihan nutrien ketara (NAR) tertinggi sebanyak 47%. Biochar perlu diperkuat dengan larutan nutrien untuk memaksimumkan keberkesanannya sebagai pemulih kesihatan tanah. Kajian perbezaan nisbah OM kepada baja tak organik berdasarkan keperluan N menunjukkan bahawa semua OM yang diuji berpotensi untuk menggantikan baja N tak organik sehingga 20%. Kesimpulannya, GLI dan CBC boleh diaplikasikan untuk memulihkan kesuburan dan status kesihatan di tanah ladang teh yang telah merosot. Biochar bercas memberikan faedah maksimum untuk pemulihan tanah yang merosot dengan keupayaan untuk menggantikan sekurang-kurangnya 20% baja bukan organik untuk penanaman teh matang, tertakluk kepada kajian tambahan pada masa hadapan.

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LIST OF ABBREVIATIONS

%	Percent
°C	Degree Celsius
AA	Auto Analyzer
AAS	Atomic absorption spectrophotometer
ANOVA	Analysis of variance
CAT	Catalase
CBC	Charged biochar
CEC	Cation exchange capacity
CMP	Compost
cm	Centimetre
Cmole	Centimole
CRD	Complete randomized design
DH	Dehydrogenase
DTPA	Diethylenetriaminepentaacetic acid
EC	Electrical conductivity
g	Gram
GLI	*Gliricidia*
h	Hour
ha	Hectare
kg	kilogram
L	Litre
mg	Milligram
min	Minutes

mL	Millilitre
mmole	millimole
nm	Nanometre
OC	Organic carbon
OM	Organic matter
ppm	Parts per million
RBC	Row biochar
RCBD	Randomized complete block design
RPM	Rotation per minute
SAS	Statistical analysis system
SD	Standard deviation
SE	Standard error
SOC	Soil organic carbon
SOM	Soil organic matter
TOC	Total organic carbon
TW	Tea waste
µL	Microliter
µg	Microgram
w/w	Weight per weight
Y	Year

CHAPTER 1

INTRODUCTION

1.1 Background

Tea is the most popular, inexpensive, stimulating natural beverage consumed throughout the world because of its characteristic aroma and flavor produced by the shoots of the commercially cultivated tea plants [*Camellia sinensis* (L.) O. Kuntze]. Drinking tea has become increasingly popular owing to the outstanding medicinal and healthcare functions derived from its specifically valuable organic constituents, inorganic mineral elements, and pharmacodynamic composition (Cao et al., 2018). Tea is widely cultivated around the world in more than 50 countries, mostly as plantations covering about 4.88 million ha of arable land (Gebrewold, 2018; International Tea Committee, 2019). Global tea production in the year 2018 was 6.15 million metric tons and the industry has a worth of USD 50 billion sectoral value with the consumption of around 3 billion cups every day across the world (International Tea Committee, 2019; Voora et al., 2019).

Soil degradation is defined as changes in the soil health and quality status resulting in a diminished capacity of the ecosystem to provide goods and services to its' beneficiaries (Lal, 2009; Stocking, 2001). It has become a 21st century global problem, which is especially severe in the tropics and sub-tropics (Lal, 2015). Further, it is more severe and alarming in the Sub-Sahara region and South Asia region, where Sri Lanka is situated as well (Lal, 2009).

Tea is grown as a rain-fed perennial mostly as a hilly or upland crop in tropical and subtropical regions where the growing soil has been continually subjected to degradation. It has become inevitable, even under presently accepted good agronomic management practices (Lal, 2015). This is occurring in all physical, chemical, biological as well as hydrological aspects related to soil properties and conditions.

Tea is the 3rd largest arable land consumer in Sri Lanka next to paddy and coconut. It occupies about 202,000 ha of land ranging from sea level to the central hilly region of the country. All the tea-growing soils belong to *Ultisol*, representing highly weathered soils based on USDA soil taxonomy. The majority of these soils are Red Yellow Podzolic soils (*Tropustults*), whereas Immature Brown Loams (*Rhodudults*) and Reddish-Brown Latosols (*Ustropepts*) are also having an undersized share (Dassanayake & Hettiarachchi, 1999).

As a result of the continuous exploitation of these lands over 150 years, soil degradation has become inevitable in most of the tea cultivating regions of the country. Most of the tea producing countries experience many drawbacks related to this issue and currently suffering from yield stagnation or decline. Stocking (2001) has identified the over-cultivation of croplands as one of the main causes of soil degradation. Current tea-growing soils show a serious degree of soil degradation questioning the sustainability of tea cultivation in Sri Lanka in time to come (Anandacoomaraswamy et al., 2003). Besides, environmental factors, such as high rainfall, elevated temperature, and climate change also have contributed to aggravate the present situation. Despite, the above factors, the effect of agrochemicals on land degradation is also identified as sizeable (Lal, 2015).

In a comparison of tea soils and forest soils, Jayman & Sivasubramaniam (1981) revealed that there is a severity in the level of depletion of soil organic matter and some other mineral nutrients required for tea plant growth. It is obvious that the current situation should be much more alarming by more than forty years since then.

The addition of organic matter has received global attention to overcome numerous shortcomings in such soils. In particular, an appropriate management strategy towards carbon sequestration may improve soil health and thereby overall soil productivity and crop production. It also helps to reduce the atmospheric buildup of carbon dioxide by facilitating the formation of stable soil aggregates and improving the soil structure, aeration, tilth, moisture-holding capacity, cation exchange capacity and biological health of soils. Thus, the addition of organic matter to agricultural soils has become imperative for replenishing the annual carbon losses and for improving most of the chemical, physical and biological properties and conditions (Diacono & Montemurro, 2010; Goyal et al., 1999).

1.2 Problem justification and significance of the study

Even though numerous researchers have been attempting to understand the effects of addition and/or incorporation of organic matter to the soil and for crop production, knowledge on actual contribution to the crop production has not been clearly recognized. Hence, the actual contribution of organic matter for crop productivity should be studied in depth by quantifying nutrient contents, their availability to the plants and contribution to the organo-mineral (Clay-humus) as well as organo-metallic (Chelates) complexes. There is a dearth of specific studies conducted to understand the fertility potentials of the soils coupled to organic resources/pools and transformations leading to enrichment of reserves for sustainable exploitation.

No study has tried to investigate the quality and fertility relationships of organic matter in terms of soil health improvement particularly in tea growing soils, which would invariably provide a better picture of the behavior of organic matter accumulation *vs* decomposition related to microbial behaviors and nutrient availability. The scenario

could obviously be different in relation to dissimilar moisture and temperature regimes. Further, studies on carbon mineralization dynamics will give information on the potential benefits of improving soil health properties which would invariably provide the basis for the restoration of degraded tea cultivating lands.

On one hand, nitrogen is the most demanding nutrient for plant growth. On the other, microorganisms demand more N during the decomposition and mineralization of organic matter added to the soil. Nitrogen mineralization is the process by which organic N is converted to plant-available inorganic forms (Crohn, 2004). Several factors affect mineralization rates, mainly temperature, moisture, aeration and soil reaction so transformation processes may vary throughout the year in a predictable pattern. It is also greatly affected by the chemical composition of the organic matter added (Masunga et al., 2016). An understanding of these patterns is necessary to match crop N demands tagged to the plant-available N in the soil. Two major important aspects of managing N mineralization in agricultural fields are, to avoid excess fertilizer application and reduce N losses to the environment, and to optimize residue management to maximize crop production, especially in low-input agriculture based on nutrient recycling (Bruun et al., 2006).

There are some studies conducted to understand carbon and nitrogen mineralization from organic matter added to soils (Masunga et al., 2016). Most of these studies focused on cumulative N mineralization and CO_2 loss during carbon mineralization. However, periodic changes or the rate of N and C mineralization have been given less attention. Knowing that the information to be collected would provide additional information about the minimum time required to mineralize C from a particular organic matter added. As tropical regions encounter high temperatures, acceleration of all biological processes would also take place in relation to C and N mineralization. Further, the potentials of nutrient supplying ability of each organic matter is another important parameter to be considered when soil fertility is managed. The residue bound-nutrients can be available to the plants in a considerable amount over a given period of time (Rahman et al., 2001).

Well-known parameter, the ‘available nutrients’ for plant uptake is the most common fertility determination method adopted in many studies. However, this fraction of nutrients varies with many parameters, such as soil pH, moisture content, etc. (Mengel, 1982). Quantification of plant nutrients particularly, with organic fertilizers and biofertilizers through conventional methods may not merely demonstrate the actual contribution to plant growth. Hence, the exhaustive cropping technique also known as the Neubauer technique with an indicator plant will provide a better picture of the nutrient availability of a particular organic fertilizer (Materechera, 1999). This exhaustive cropping technique to quantify bio-available potassium in soil paved the way to find a more reliable soil K grading system than the grading based on ‘available potassium’ (Li et al., 2016). A similar mechanism was used to characterize tea-growing soils of Sri Lanka in relation to soil potassium dynamics (Gunaratne et al., 2002). Thus, the exhaustive cropping system could be considered as an appropriate tool for nutrient bioavailability studies.

1.3 Outline of the thesis

This thesis comprises four studies, having two laboratory incubation studies followed by one glasshouse study which were carried out in Universiti Putra Malaysia (UPM) and one field experiment which was conducted in two tea plantation estates in Sri Lanka. The first study is on carbon mineralization from frequently available organic materials in tea-growing regions in Sri Lanka. This incubation study explains how each organic material added to the tea-growing soil gets mineralized and how it improves some soil health properties including microbial biomass and soil dehydrogenase and catalase activities. Further, this study explains the persistence of each organic matter in the soil after addition to the soil. Nitrogen mineralization study describes how nutrients were released through decomposition and mineralization from added organic materials into the soil. Nutrient releasing pattern is explained in this study and soil health quality parameters including microbial biomass nitrogen, urease, phosphatase, protease and catalase activities have also been explained in this study.

The third experiment comprises with glasshouse trial that describes the bioavailability of nutrients released from each organic material added to the soil during decomposition and mineralization. This experiment uses the exhaustive cropping technique with *Napier* grass (*Pennisetum purpureum*) as the indicator plant. The final experiment explicates the potentials of replacement of inorganic fertilizers with freely available organic materials for tea cultivation in different ratios.

Research Hypothesis

1. The addition of organic materials will increase the bioavailability of plant nutrients
2. Organic amendments improve soil health parameters, such as enzyme activities and microbial activities.
3. Organic amendments have a greater potential to restore degraded soils in tea lands.
4. The inorganic fertilizer could be partially substituted by organic manure for tea cultivation in Sri Lanka

Therefore, more specifically, the following research questions are needed to be addressed.

- What is the actual contribution of nutrients from different organic matters to the soil nutrient reserve?
- How will be the variation of mineralization of different organic matter with time?
- What are the changes in soil enzymes and microbial activities with the addition of organic matter?

- What portions of nutrients that are released from organic manure could be bioavailable?
- How much of inorganic nutrients in form of synthetic fertilizers could be replaced by organic manure?

Accordingly, the objectives of this study are as follows.

1.4 Objectives

The primary research objectives of this study were (i) to quantify the amounts of plant nutrients mineralized, the bioavailability of those nutrients and plant dry production from added organic materials and ascertain some soil health parameters improvement to partially replace inorganic fertilizer for mature tea cultivation in acidic soil and (ii) to study the potentials of restoration of degraded tea lands through organic materials amendments.

Specific objectives of the study were;

1. To study the carbon and nitrogen mineralization patterns of available organic matter in tea lands under tropical tea-growing soils,
2. To study the changes in soil enzyme activities as indicators of soil health and quality improvement,
3. To quantify the bioavailable nutrients released from mineralization of available organic matter in tea lands and
4. To study the potentials of partial substitution of inorganic fertilizer with organic manure for tea cultivation.

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