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BORANG PENGESAHAN STATUS TESIS

JUDUL: POTENTIAL OF MYCORRHIZAL FUNGI IN ENHANCING THE SOIL BIOLOGICAL FERTILITY BY IMPROVING THE SOIL BIOLOGICAL HEALTH

IJAZAH: DEGREE OF BACHELOR OF AGRICULTURE SCIENCE WITH HONOURS

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POTENTIAL OF MYCORRHIZAL FUNGI IN ENHANCING THE SOIL BIOLOGICAL FERTILITY BY IMPROVING THE SOIL BIOLOGICAL HEALTH

JOENNA JOEN JULIAN LINDAR

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF AGRICULTURE SCIENCE WITH HONOURS

CROP PRODUCTION PROGRAMME
SCHOOL OF SUSTAINABLE AGRICULTURE
UNIVERSITI MALAYSIA SABAH

2014

DECLARATION

I hereby declare that this dissertation is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that no part of this study has been previously or currently submitted for a degree at this or any other university.

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ACKNOWLEDGEMENT

I would like to express my gratefulness to the Almighty GOD for giving me the strength to finish this dissertation successfully. I would like to express my gratitude to my parents, who they support me by giving me financial and mental support to complete this dissertation.

The most special dedication I would express to Associate Professor Dr. Markus Atong who was my supervisor, respectively for giving me continuous technical information and for leading as well as guiding me in the process of completing this dissertation. I would like to present upon them my utmost gratitude for giving me a chance to gain precious knowledge through his experiences while I'm conducting my final year project. Under his supervisions, I am truly grateful for all that he had done, thus moulding me to become a better man in the near future.

Apart from that, I would like to thank to all lecturers especially to both of my examiners Dr. Mohamadu Boyie Jalloh and Assoc. Prof Hj. Mohd. Dandan @ Ame Hj. Alidin, who have helped, guide and given me valuable teaching to complete dissertation. I also like to thank all the field and laboratory assistants who have provided technical supports to help me prepare my planting site and autoclaving the planting media in smoothening up all my works during the period of this study.

It is also my utmost pleasure to express my gratitude to all my course mates who have cooperated in doing this project together during early preparation until the last step in finishing this dissertation.

Last but not least, I would also like to express my gratitude to my dearest friends, Alvin Lai Ding Han, Raimathy a/p Kanavedee, Emelia Grace Casianus, Kelvin Kalianon and Wee Poh Leong who have assist me a lot to collect and analyses all the samples that I required to finish this study.

My gratitude to all of you can be expressed by the blessings of GOD, Amen. Thank you very much.

ABSTRACT

This study was conducted from July to December 2013 at School of Sustainable Agriculture (SSA), University Malaysia Sabah with a title of the role of mycorrhizae in improving the soil fertility in School of Sustainable Agriculture, UMS Sandakan Campus. This study was carried out to observe the differences of the growth of the trap crops using different types of soils that are taken from different host plants that associated with mycorrhizas and to compare the growth of the maize for mycorrhizae inoculated soil and non-inoculated soil. The treatments involved in this study are control in which there were no addition of fertilizers and mycorrhizal inoculums, followed by fertilizer treatments (NPK Green), and three different application rates of mycorrhizal inoculums. The mycorrhizal inoculums were prepared in the first part of this study. There are two parts in this study which are the first part is the mycorrhizal inoculum preparation and the second part of this study is to study the effect of prepared mycorrhizal inoculum on the growth performance of *Abelmoschus esculantus*. The first part of this study took about 10 weeks and the second part took about 13 weeks. For the first part of this study, the mycorrhizal inoculums were prepared by taking soils from different host plants which are *Paspalum atratum, Mimosa pudica* and *Mucuna bracteata*. GPS positions were taken for each of the host plants by using GPS device. The inoculums were prepared by taking the soils from each of the host plants using spade. The soils from each of the host plants were taken with the depth of 10 cm. Then, the soils were air dried for two days before crushing the soils into smaller pieces. Each of the polybags contains 10kg of soils. There were five replicates for each of the soils taken from different host plants. *Zea mays* were used as trap crop. The experimental design used for the first part was completely randomized Design (CRD). Selection of the best inoculum was conducted by using the parameters of plant height and root length. The analysis conducted is soil phosphorus analysis and mycorrhizal roots colonization percentage. Data for the first part were analyzed using one-way ANOVA and post-hoc analysis using Fisher's Least Significant Difference (LSD) also conducted. Based from the results obtained, inoculum one (soils taken from *Paspalum atratum*) have the highest mean height and root length which is significantly different to inoculum two (soils taken from *Mimosa pudica*) and inoculum three (soils taken from *Mucuna bracteata*). Furthermore, the soil P analysis conducted for the three inoculums showed that the inoculum one (soils taken from *Paspalum atratum*) have the lowest P content in the soils compare to inoculum two (soils taken from *Mimosa pudica*) and inoculum three (soils taken from *Mucuna bracteata*) which indicates that the *Zea mays* for inoculum one (soils taken from *Paspalum atratum*) received the highest P nutrient from the soils. The mycorrhizal colonization percentage were also conducted, which showed that the *Zea mays* from inoculum one (soils taken from *Paspalum atratum*) have the highest mycorrhizal root colonization percentage compare to the *Zea mays* for inoculum two (soils taken from *Mimosa pudica*) and inoculum three (soils taken from *Mucuna bracteata*). This can explained why the phosphorus content in inoculum one (soils taken from *Paspalum atratum*) is the lowest compare to the other two inoculums, this is may be caused by the higher mycorrhiza present in the soil for inoculum one (soils taken from *Paspalum atratum*) compare to the other two treatments which aid the absorption of phosphorus from the soil to the plant effectively. So the best inoculum is the soils taken from the host plants *Paspalum atratum*. The second part of this study is to study the effect of prepared mycorrhizal inoculum on the growth performance of okra (*Abelmoschus esculantus*) and at the same time selecting the best ratio of mycorrhizal inoculums. The treatments involved in this study were control in which there were no addition of fertilizers and mycorrhizal inoculums, followed by fertilizer treatments (NPK Green) and three different application rates of prepared mycorrhizal inoculums which were 0.5kg, 1.0kg and 1.5kg while the amount of fertilizer applied was 7.98g per polybag. The top soil were prepared by drying, crushing and sieving of the top soils were conducted. The top soils were autoclaved before planting; the purpose is to avoid other factors to disturb the association of mycorrhiza with the plant root during the experiment. The experimental unit used for the second part of this study was okra (*Abelmoschus esculantus*). The experimental design applied was completely randomized design (CRD). The parameters measured for the second parts of this study was plant height, leaf length, leaf width, number of leaves, and root length. The analysis conducted was the phosphorus soil analysis and mycorrhizal root colonization percentage. All the collected data were analyzed by using one way ANOVA at 0.05 significant levels and post-hoc analysis using Fisher's Least Significant Difference (LSD) also conducted. From the results, it showed that the parameters measured for plant height, leaf length, number of leaves and root length for okra (*Abelmoschus esculantus*) of treatment two with the application rate of 1.0kg is significantly different to the other treatments. The results obtained shows that the mycorrhiza treatment with the application rate of 1.0kg was more efficient than other treatments. However, the result would be more significant if yield was obtained.

Potensi Mikorhiza dalam Meningkatkan Kesuburan Biologi Tanah Dengan Menigkatkan Kesihatan Biologi Tanah

ABSTRAK

Kajian ini telah dijalankan dari bulan Julai hingga Disember 2013 di Sekolah Pertanian Lestari (SPL), Universiti Malaysia Sabah dengan tajuk potensi mikorhiza dalam menigkatkan kesuburan biologi tanah dengan menigkatkan kesihatan biologi tanah. Kajian ini telah dijalankan untuk melihat perbezaan pertumbuhan tanaman perangkap yang menggunakan pelbagai jenis tanah yang diambil daripada tanaman perumah yang berbeza dan dipercayai mempunyai mikorhiza dan perbandingan antara pertumbuhan jagung untuk tanah diinokulsi dengan mikorhiza dan tanah tanpa inokulasi. Rawatan yang terlibat dalam kajian ini adalah kawalan di mana terdapat tiada penambahan baja dan inokulasi mikorhiza, diikuti dengan rawatan baja (NPK hijau), dan tiga nisbah inokulum mikorhiza yang berbeza. Inokulum mikorhiza telah disediakan dalam bahagian pertama kajian ini. Terdapat dua bahagian dalam kajian ini iaitu bahagian pertama adalah penyediaan inokulum mycorrhiza dan bahagian kedua kajian ini adalah untuk mengkaji kesan inokulum mycorrhizal disediakan kepada prestasi pertumbuhan pokok okra. Bahagian pertama kajian ini mengambil masa kira-kira 10 minggu dan bahagian kedua pula mengambil masa kira-kira 13 minggu. Untuk bahagian pertama kajian ini, inokulum mikorhiza telah disediakan dengan mengambil tanah dari tanaman perumah yang berbeza iaitu Paspalum atratum, Mimosa pudica dan Mucuna bracteata. Kedudukan GPS telah diambil untuk setiap tanaman perumah dengan menggunakan peranti GPS. Inoculums yang telah disediakan dengan mengambil tanah dari setiap satu daripada tanaman perumah yang menggunakan spade. Tanah dari setiap satu daripada tanaman perumah telah diambil dengan kedalaman 10 cm. Kemudian, tanah dibiar kering selama dua hari sebelum menghancurkan tanah kepada serpihan yang kecil. Setiap satu polybeg mengandungi 10kg tanah. Terdapat lima replikasi bagi setiap tanah yang diambil dari tanaman perumah yang berbeza. Zea mays (jagung) telah digunakan sebagai tanaman perangkap. Reka-bentuk eksperimen yang digunakan untuk bahagian pertama adalah Reka bentuk secara Rawak (CRD). Pilihan inokulum terbaik ini dilakukan dengan menggunakan parameter panjang ketinggian dan akar tumbuhan. Analisis yang dijalankan adalah analisis fosforus tanah dan peratusan penjajahan mikorhiza terhadap akar. Data bagi bahagian pertama dianalisis menggunakan ANAVA sehala dan analisis post-hoc menggunakan Fisher's Least Signficant Difference (LSD) turut dijalankan. Berdasarkan dari keputusan yang diperolehi, inokulum satu (tanah diambil daripada Paspalum atratum) mempunyai purata ketinggian yang tertinggi dan panjang akar yang berbeza daripada ketinggian dan panjang akar jagung bagi inokulum dua (tanah diambil dari Mimosa pudica) dan inokulum tiga (tanah diambil dari Mucuna bracteata). Selain itu, analisis tanah P yang dilakukan menunjukkan bahawa inokulum satu (tanah diambil daripada Paspalum atratum) mempunyai kandungan P yang terendah dalam tanah berbanding dengan inokulum dua (tanah diambil dari Mimosa pudica) dan inokulum tiga (tanah diambil dari Mucuna bracteata) yang menunjukkan bahawa jagung bagi inokulum satu (tanah diambil daripada Paspalum atratum) menerima nutrien P tertinggi daripada tanah. Peratusan penjajahan mikorhiza terhadap akar telah juga dijalankan, yang menunjukkan bahawa Zea mays inokulum satu (tanah diambil daripada Paspalum atratum) mempunyai peratusan tertinggi bagi peratusan penjajahan mikorhiza terhadap akar dinbandingkan dengan akar jagung bagi inokulum dua (tanah diambil dari Mimosa pudica) dan inokulum tiga (tanah diambil dari Mucuna bracteata). Ini boleh menjelaskan mengapa kandungan fosforus dalam inokulum satu (tanah diambil daripada Paspalum atratum) adalah rendah jika dibandingkan dengan inokulum yang lain, hal ini mungkin disebabkan oleh kewujudan mikorhiza tertinggi dalam tanah bagi inokulum satu (tanah diambil daripada Paspalum atratum) menyebabkan penyerapan fosforus oleh jagung lebih efektif. Jadi inokulum terbaik adalah tanah yang diambil daripada tanaman perumah yang berbeza adalah Paspalum atratum. Bahagian kedua kajian ini adalah untuk mengkaji kesan inokulum mikorhiza bagi prestasi pertumbuhan pokok bendi (Abelmoschus esculantus) dan pada masa yang sama memilih nisbah terbaik bagi inoculum mikorhiza. Rawatan bagi bahagian kedua dalam kajian ini adalah kawalan di mana terdapat tiada penambahan baja dan mikorhiza inokulum, diikuti dengan rawatan baja (NPK hijau) dan nisbah yang berbeza bagi inoculum mikorhiza iaitu 0.5 kg, 1.0 kg dan 1.5 kg manakala jumlah baja yang diguna pakai adalah 7.98 g satu polibeg. Tanah yang telah disediakan dengan mengeringkan tanah, menghancurkan tanah dan menapis tanah. Tanah telah diautoclave sebelum digunakan untuk penanaman; tujuan adalah untuk mengelakkan faktor-faktor lain mengganggu assosiasi mikorhiza dengan akar tumbuhan semasa eskperimen polibeg. Unit ujikaji yang digunakan bagi bahagian kedua kajian ini adalah pokok bendi (Abelmoschus esculantus). Reka-bentuk eksperimen yang digunakan adalah Reka bentuk secara Rawak (CRD). Parameter yang diukur bagi bahagian kedua kajian ini ialah ketinggian tumbuhan, panjang daun, lebar daun, jumlah daun dan panjang akar. Analisis yang dijalankan adalah analisis fosforus dan Peratusan penjajahan mikorhiza terhadap akar. Semua data yang dikumpul dianalisis dengan menggunakan ANAVA sehala pada tahap signifikan 0.05 dan analisis post-hoc menggunakan Fisher's Least Significance Difference (LSD) turut dijalankan. Dari keputusan, ia menunjukkan bahawa parameter yang diukur bagi ketinggian tumbuhan, daun panjang, bilangan daun-daun dan akar panjang bagi pokok bendi (Abelmoschus esculantus) rawatan dua dengan nisbah 1.0kg adalah berbeza ubagi rawatan lain. Keputusan yang diperolehi menunjukkan bahawa rawatan mycorrhiza dengan nisbah 1.0 kg adalah lebih cekap berbanding rawatan lain. Walau bagaimanapun, keputusannya akan lebih ketara jika hasil tanaman dapat diperolehi.

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LIST OF SYMBOLS, UNITS AND ABBREVIATIONS

FAO	Food and Agricultural Organization
SSA	School of Sustainable Agriculture
UMS	Universiti Malaysia Sabah
SDT	Sunseed Desert Technology
%	Percentage
KOH	Potassium Hydroxide
w/v	weight per volume
ºC	degree Celsius
HCl	Hydrochloric
KCl	Potassium Chloride
cm	Centimeters
INVAM	International Culture Collection of Vascular Arbuscule Mycorrhizal Fungi
ANOVA	Analysis of Variance
SPSS	Statistical Product and Service Solutions
/	or
P	Phosphorus
GPS	Global Positioning System
Kg	Kilogram
CRD	Completely Randomized Design
ml	Milliliter
L	Liter
g	gram
π	pi
LSD	Least Significance Difference
Ppm	Parts per millions
NPK	Nitrogen Phosphorus Potassium

LIST OF FORMULAE

CHAPTER 1

INTRODUCTION

1.1. Introduction

Soil is one of the important resources to human as the soil is the fundamental component in agriculture. However, soils today are facing threats such as reduced fertility and productivity due to soil degradation. According to Panda (2008), one of the factors that affecting the agriculture sustainability is the soil degradation. Soil degradation has become worse throughout the year. In addition, soil degradation occurs more often, especially in tropical countries (FAO, 2000). Cardoso and Kuyper (2006) also stated that the soil in tropic will be easily affected by soil degradation due to the characteristics of the soil itself and the environmental factors affecting the soil.

Soil degradation can be defined as the intensive activities that had been done to the soil either by unsuitable practices or land management practices (FAO, 2000). There are many factors contributing to soil degradation and one of the major factors is human activities (Eswaran *et al.*, 2001). There are several processes that have known to be involved in soil degradation, these include soil erosion caused by water and wind, soil degradation by chemical, and physical (Eswaran *et al.*, 2001). Soil erosion that caused by water and wind is the most common in soil degradation, where the surface of the soil being carried away either by water or wind which leads toward degradation. Soil degradation that caused by chemical is caused by the intense used of herbicides and pesticides that causing the soil to leach. Soil degradation that caused by physical includes the used of machinery that cause the soil to become compact (caused by heavy machinery) and lose (caused by heavy tillage practices) (Eswaran *et al.*, 2001). There are many practices that lead to soil degradation such as deforestation, conventional farming, and construction which exposed the soil to two major factors that contribute to soil erosion which are wind and water (Panda, 2008).

Degradation of land often carries away soil that farmers known as the "good soil" and left only the "poor soil" (Panda, 2008). The upper surface of the soil consists of humus and topsoil which is good for agricultural purpose because it consists of high organic matter. Panda (2008) stated that soil with no organic matter will not serve as suitable mediums for plant growth. "Good soil" often has a high amount of organic matter which provides high amounts of nutrients for the plants to grow (Panda, 2008). "Poor soil" often has high amount of clay and minerals, which is unsuitable to plant growth.

The conditions of soil degradation also happen to School of Sustainable Agriculture (SSA) which located in Sandakan, Sabah. As an agricultural school, SSA should have soils that can give enough nutrients and water to the crops to grow. However, the construction of SSA itself have caused the soil in SSA cannot be the suitable medium for the crops to grow. Planting crops for any school projects have been harder for the students in SSA. Although many alternatives have been conducted such as applying organic fertilizer and mulches, the soils are hard to work with. Furthermore, the soils in SSA can be categorized as low fertility due to its characteristics, so without any applications of fertilizers, the soils are not suitable for any planting or farming purposes. Moreover, the soils in SSA tend to become hard when it is dry and sticky when it is wet, which is the most common characteristics of clay soil. This is a common condition occurring when the topsoil has been removed or degraded. Which left only the subsoil or known as the B horizon. The surface of the soil should have humus and topsoil which consist of organic materials that have enough nutrients, aeration and microorganisms to ensure the growth of plants. As for subsoil or known as the B horizon, it only has clay and mineral, but less in inorganic material which is not suitable for crop cultivation.

Nowadays, many researchers have come out many ways to conserve the soils from further depletion, but the purpose of the practices is to keep up the soils from erosion or degradation only. The affected soils are left uncultivated, which leads to a waste of lands.

Many alternatives have been done by many agencies to restore the affected land, however, agriculture lands drastically decreased throughout the years. Restoring the affected area will took long period of time. One of the alternatives that can be used to restore the soil fertility is by implementing soil microorganisms in the affected land.

Soil contains many microorganisms that have important roles in maintaining the fertility of the soils. One of the soil microorganisms is mycorrhizae. There are many evidences that show mycorrhizae have the ability to improve soil fertility in which the mycorrhizae create a symbiotic relationship with the plant. The mycorrhizae will adhere to or in the plant roots and start to accumulate nutrients in the rhizosphere. The process of accumulation of nutrients in the rhizosphere will improve the soil fertility and can supply enough nutrients for the plants to grow even under extreme and problematic soil conditions. Furthermore, mycorrhizae can degenerate, which lead to the accumulation of organic matter, thus, can increase the organic matter of the soil which can provide aeration for the plant roots to grow. Mycorrhizae have become one of the important soil microorganisms in improving the growth of many crops and at the same time improving the soil fertility.

1.2. Justification

This study is to implement mycorrhizae in improving the soil fertility in the School of Sustainable Agriculture, UMS Sandakan Campus. Mycorrhizae are known as the fungi that can associate with certain plants and create a symbiotic relationship between the plants. This means that the plants and mycorrhizae can give benefits to both sides. Mycorrhizae can help the plants to reach the nutrient from deep into the soil and the plants give sugar for the mycorrhizae to grow. This is because mycorrhizae can associate the plants by adhering to the plant's root surface or inside the roots; the mycorrhizae can provide nutrients directly to the plants. The mycorrhizae can extend several feet from the plants which help the plants to absorb colloid which contain water, minerals and nutrients between the fine particles of the soils. Mycorrhizae also can reduce the insufficient water problem as they can reach to the water table to supply water for the plants. Mycorrhizae also have a short life span, but can grow faster, which can help to add up the organic material in the soil. Therefore, mycorrhizae are important in soil restoration as it has many benefits and roles that can provide another alternative to improve soil fertility in the School of Sustainable Agriculture, UMS Sandakan Campus.

1.3. Objectives

a) To provide other alternatives in improving the soil fertility in the School of Sustainable Agriculture, UMS Sandakan Campus.

b) To compare the growth of the trial crops for control, NPK treatment, treatment one (0.5kg of mycorrhizal inoculums), treatment two (1kg of mycorrhizal inoculums) and treatment three (1.5kg of mycorrhizal inoculums)

1.4. Hypothesis

a) Null hypothesis: There is no significant difference between the growth of the trial crops for control, NPK treatment, treatment one (0.5kg of mycorrhizal inoculums), treatment two (1.0kg of mycorrhizal inoculums) and treatment three (1.5kg of mycorrhizal inoculums)

b) Alternative hypothesis: There is a significant difference between the growth of the trial crops for control, NPK treatment, treatment one (0.5kg of mycorrhizal inoculums), treatment two (1.0kg of mycorrhizal inoculums) and treatment three (1.5kg of mycorrhizal inoculums)

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction to Mycorrhizae

Mycorrhizae have existed since the first plant appeared on earth, but only recently soil scientist and Microbiologist have found the existence of mycorrhizae and start to do research on them. The word "mycorrhizae" are originated from the Greek *mycos* which means fungus and *rhiza* means roots, it is first used by the German researcher in 1885 (Singh *et al.*, 2010).

Nowadays, mycorrhizae become very popular among researchers and scientists because of their potential use in forestry and agriculture. Mycorrhizae are commonly used in any agricultural program, as mycorrhizae can help the crops grow without the intensive used of fertilizers. Other than that, Mycorrhizae can provide benefits to plants such as provide nutrients, provide water, protection from pathogen and increase organic matter in the soil (Smith and Read, 1997; McGee *et al.*, 2013). Furthermore, mycorrhizae can also improve the condition of disturbed soil (Ogle, 1996). Moreover, plants can absorb nutrients efficiently on poor nutrient soil with the present of mycorrhizae (Singh *et al.*, 2010). In exchange, the plants provide carbohydrate and sugar to mycorrhizae (Johnson *et al.*, 1997; Singh *et al.*, 2010). This type of relationship is known as mutualistic beneficial relationship (Smith and Read, 1997; Singh *et al.*, 2010). The word, mutualistic means that both of the organisms obtained benefits from both sides (Singh *et al.*, 2010).

2.2. Economic Importances of Mycorrhizae

The economic importances of mycorrhizae are improving the soil structure, decomposition and nutrient cycling, and protection against pathogen (Johnson and Gehring, 2007; Martin *et al.*, 2007; Tripathi *et al.*, 2008).

2.2.1. Improving Soil Structure

The soil is very significant in agriculture because soil provides a medium for the plant to grow. However, agricultural lands have become limited due to the intensive used of the soil and the wastelands around the world are rapidly increasing (Bagyaraj *et al.*, 2012). The common soil problems are compacted, no soil life, erosion, infiltration, no organic matter residue and low pH (Soil Quality, 2011). Mycorrhizae have a significant function in improving the soil structure (Johnson and Gehring, 2007). However, mycorrhizas react differently on different types of soil, plant and fungal phenotypes (Johnson and Gehring, 2007).

Mycorrhizae can be used to rehabilitate degraded ecosystems (Bagyaraj *et al.*, 2012). Moreover, ectomycorrhizal inoculums can help in the rehabilitation of the degraded soil because the ectomycorrhizal can supply enough nutrients for the plants to survive (Bagyaraj *et al.*, 2012). In addition, mycorrhizae can improve the soil aggregation by the interactions with plant, roots, and the effect of the fungal itself (Rillig and Mummey, 2006). For instance, arbuscular mycorrhizas used the organic materials as binding agent in the soil (Rillig and Mummey, 2006). Mycorrhizae can affect the soil structure by processes that can be grouped into 5 categories; a) root penetration, b) soil, water regime alteration, c) rhizodeposition, d) root decomposition and the e) root entanglement of soil particles.

2.2.2. Decomposition and Nutrients Cycling

Mycorrhizae are known as the fungi that associate in nutrient cycling. The mycorrhizae are important in associating the N, P and C cycling in the ecosystems and decomposing organic material (Martin *et al.*, 2007). Furthermore, mycorrhizae can assist in nutrient cycling by foraging inorganic and organic nutrients which are then provided to the plant directly (Rillig, 2004). For instance, mycorrhizae can help in utilizing organic N, uptake NO_3^- and NH_4^+, utilization of carbon compounds and phosphorus (Martin *et al.*, 2007). Both ECM and AM fungi can utilize phosphorus (Martin *et al.*, 2007).

2.2.3. Protection against Pathogen

Mycorrhizae are used to control the root pathogen populations (Tripathi *et al.*, 2008). When the mycorrhizas associate with the plants, mycorrhizae obtain food sources of the plant (Wheyner *et al.*, 2009). Since mycorrhizae obtain more food sources than pathogen, as a result, the populations of the pathogen are reduced (Wheyner *et al.*, 2009).

2.2.4. Mycorrhizae and nutrient transformation

Mycorrhizal fungi are important component soil microbial activity in arid and semi-arid agro-ecosystem. They influence below ground ecology, nutrient recovery and phytomass production (Rillig, 2004). Mycorrhizal fungal activity in drier soil helps in better absorption of P and certain micronutrients. Although mathematical extrapolations are possible, the net quantity of different soil nutrients translocated via fungal hyphae needs to be ascertained experimentally and perhaps compared with that achieved via roots (Rillig, 2004). Within dryland ecosystems, photosynthetic energy is abundant. Hence Carbon costs of mycorrhizal activity in these agro-environments may not be an important criterion to evaluate mycorrhizal efficiency. In the field, soil moisture uptake is augmented by mycorrhizal hyphae. Extrapolations regarding larger advantages of mycorrhizal symbiosis to nutrient recovery from drylands have also been made (Rillig, 2004). Long term trails analysing the exact effects of mycorrhiza on nutrient recovery, nutrient recycling, phytomass, microbial biomass, particularly that of mycorrhizal fungi should provide better insights about their net role in nutrient cycling (Rillig, 2004).

2.2.5. Mycorrhizae and phosphorus uptake

Mycorrhizae are mutualistic symbiotic associations based on bidirectional nutrient transfer between soil fungi and the roots of vascular plants (Martin *et al.*, 2007; Rillig, 2004). The plant supplies the fungi with sugars produced by photosynthesis, while the hyphae network improves the plant capacity to absorb water and nutrients (Martin *et al.*, 2007). Arbuscular mycorrhizae, also called endomycorrhizae, are the most ancient, common and widespread types of mycorrhizae (Martin *et al.*, 2007; Rillig, 2004). The arbuscular mycorrhizal (AM) fungi are a group of endophytes that constitute the phylum Glomeromycota. AM fungi form symbiosis with the roots of approximately 80% of all vascular plant species, including many important crop species, such as maize, wheat, rice and potato. Demonstrations of the positive effect of mycorrhizal symbiosis on plant productivity are now abundant, stimulation of growth usually following colonization by the AM fungi phosphate solubilizing enzymes. These interactions have positive synergetic effects resulting in enhanced plant nutrition, growth and survival. The nutrients mobilizing processes described above are particularly important in plant nutrition and explain why non-mycorrhizal plants require higher levels of soil fertility to maintain their health (Martin *et al.*, 2007).

2.2.6. Other Benefits of Mycorrhizae

Mycorrhizae can improve the plant growth by accumulating nutrients in the soil and increase the yield of the plants (Singh *et al.*, 2010). Moreover, mycorrhizae can also extend the plant root and provide better soil coverage, which helps to obtain nutrients effectively (Singh *et al.*, 2010). Other than that, the fruiting bodies of ectomycorrhizas can serve as food resources for other organisms and humans (Singh *et al.*, 2010). In addition, mycorrhizas can attract other beneficial microorganism that improves soil ecology, hence improves soil structure (Singh *et al.*, 2010). Furthermore, mycorrhizae populations can be used as the indicator for environmental quality (Singh *et al.*, 2010).

2.3. Type of Mycorrhizae

There are four types of mycorrhizae existing in the soil such as arbuscular mycorrhizae (VAM), ectomycorrhizae, and ericoid and orchid mycorrhizas (Singh *et al.*, 2010). The most common mycorrhizae are arbuscular mycorrhizas (Singh *et al.*, 2010).

2.3.1. Arbuscular Mycorrhizas (VAM)

Arbuscular mycorrhizas (VAM) (Figure 2.1a) are the most common type of mycorrhizas that form symbiosis with any plant types (Smith and Read, 1997; Peterson *et al.* 2004). The fungus species that involved in the association of arbuscular mycorrhizas is the Glomeromycota (Peterson *et al.*, 2004; Brundrett *et al.*, 1996). The main features of arbuscular mycorrhizas are the intraradical hyphae, arbucules, intraradical vesicular, extraradical vesicular, extraradical mycelium and spores (Peterson *et al.*, 2004). The intraradical hyphae of will penetrate into the cell and form the arbuscules (Figure 2.1a) (Peterson *et al.* 2004). The arbuscules can be divided into two types; the Arum-type and Paris-type (Peterson *et al.* 2004). The arbuscular mycorrhiza is responsible in exchanging nutrients inside the root cells. Other features of arbuscular mycorrhizas are the intraradical vesicular and extraradical vesicular (Peterson *et al.* 2004). Both serve as the storage organs for fungal food reserves (Peterson *et al.* 2004). The extraradical mycelium is responsible in extracting and absorbing nutrients from the soils and transports the nutrients to plant roots (Peterson *et al.* 2004). The spores are responsible as the reproductive organs of the arbuscules mycorrhizas (Peterson *et al.* 2004).

2.3.2. Ectomycorrhizas

Ectomycorrhizas (Figure 2.1b) are very important for tree growth, especially conifers (Wiensczyk *et al.*, 2002). However, ectomycorrhizas can also be found on tree species, but some shrub may also associate with this type of mycorrhizas (Peterson *et al.*, 2004). There are several types of fungal species that can form ectomycorrhizas symbiosis with plants such as the Basidiomycotina, Ascomycotina, and Zygomycotina (Peterson *et al.*, 2004; Singh *et al.*, 2010). There are three features that can be used to recognize this mycorrhizas; a) the formation of mantle or fungal sheath that cover half of the plant's roots, b) formation of the Hartig net, and c) the hyphae that grow to the surrounding area (Peterson *et al.* 2004). However, ectomycorrhizas only form the intercellular hyphae; the hyphae will not penetrate into the cells (Singh *et al.*, 2010). The first feature is the mantle; there are two types of mantle which is the inner mantle (root) and the outer mantle (soil) (Singh *et al.*, 2010). The functions of the mantle are to interact with soil microorganisms and to absorb water and nutrients from the soil (Singh *et al.*, 2010). Other than that, the mantle also capable of absorbing sugars such as glucose and fructose from the root cells (Peterson *et al.*, 2004). Moreover, the mantles are responsible in storing and accumulate nutrients (Peterson *et al.*, 2004). The inner mantle will further penetrate between the roots cells and form the Hartig net (Figure 2.1b) (Peterson *et al.*, 2004). The Hartig net will form inside the epidermis and some might develop in cortex for some plants (Peterson *et al.*, 2004; Singh *et al.*, 2010). Hartig net is responsible in nutrient exchanges (Singh *et al.*, 2010). Next is the extraradical mycelium; the extraradical mycelium is the hyphae that grows further into the soil from the outer mantle (Peterson *et al.*, 2004). The extraradical mycelium consists of Rhizomorphs, Sclerotia, and sexual reproductive structures (Peterson *et al.*, 2004).

2.3.3. Ericoid Mycorrhizas

Ericoid mycorrhizas (Figure 2.1c) are known to be the most specific mycorrhizae because this type of mycorrhizas only associates with certain types of plants (Peterson *et al.* 2004). The host plants involved with this association is the Ericales (Straker, 1996). Moreover, this type of mycorrhizae often grows on the soils that are nutrient deficient (Peterson *et al.*, 2004). The main features of ericoid mycorrhizas are intraradical hyphae and extraradical mycelium (Peterson *et al.* 2004). The functions of intraradical hyphae are to penetrate into the root cells and become the site of nutrient exchange (Peterson *et al.*, 2004). As for extraradical mycelium, this feature responsible in enhancing the nutrient uptake, especially on dry land or on nutrient deficient soils (Peterson *et al.*, 2004).

2.3.4. Orchid Mycorrhizas

Orchid mycorrhizas (Figure 2.1d) get its name because this type of mycorrhizas only associates with the family of Orchidaceae, or the orchid family (Cardon and Whitbeck, 2007; Peterson *et al.*, 2004). The general features of orchid mycorrhizas are hyphae and pelatons (Peterson *et al.*, 2004). The pelaton can be defined as coiling hyphal (Peterson *et al.*, 2004).

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