MUSHROOM MEDIUM RESIDUE AS AMENDMENT FOR TURFGRASS PLANTING IN SOIL FROM SELECTED SITE AT UMS SANDAKAN CAMPUS

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ABSTRACT

The use of organic agricultural waste as fertilizer could reduce dependency on chemical fertilizer in turfgrass establishment. In Malaysia, one of the abundant organic wastes that can be used for that purpose is the mushroom medium residue (MMR). Hence, in this study, the effects of different soil: MMR mixtures on *Zoysia matrella* growth was examined in a CRD polybag experiment in an open field. Soil from the Universiti Malaysia Sabah (UMS) Sandakan campus and MMR from a mushroom factory in Mesilau, Kundasang, Sabah were mixed at 1: 0 (control), 1: ¼, 1: ½, 1: ¾, 1: 1, and 0: 1 (weight/weight) soil to MMR with each treatment had five replicates. The turfgrass was cultivated on these planting media mixtures in (37 × 35 × 7.5 cm) polybags and placed in an open area. Within a span of four months, the chemical and physical properties of the mixtures (pH, moisture content, organic matter content (OM), total organic carbon content (TOC) and total nitrogen (N) content) were determined. Several turfgrass growth and quality parameters including shoot density, stolon growth, internodes length, leaf width, leaf colour, rigidity and strength of turfgrass were also recorded. All data were statistically compared across the treatments. The 1: 1 (soil: MMR) resulted in the ideal pH, moisture content, OM and TOC at the beginning and even towards the end of the experiment. The *Z. matrella* in the 1: 1 ratio was found to have a better quality than that in the 1: ½. Hence, the 1: 1 ratio is recommended as the ideal ratio, as it improved chemical and physical properties of the soil and the growth and quality of the *Z. matrella*. Over application of MMR beyond the 1: 1 ratio did improve the quality of the *Z. matrella*, but the benefit is thought to be short-term. Over application of MMR caused high initial mortality rate of the turfgrass, which can be costly in field practice. From the finding of this study, the 1: 1 is recommended as the soil to MMR ratio for *Z. matrella* planting in the selected area in UMS Sandakan campus or at any construction sites in Sabah which has soil characters similar to that of this study. Caution should be taken, however, not to over apply the MMR in turf establishment.

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SISA MEDIA CENDAWAN SEBAGAI RAWATAN UNTUK PENANAMAN RUMPUT TUF DALAM TANAH UMS KAMPUS SANDAKAN

ABSTRAK

Penggunaan sisa organik pertanian boleh menyumbangkan kepada pengurangan penggunaan baja kimia dalam penanaman rumput tuf. Di Malaysia, salah satu sisa organik yang amat banyak yang boleh digunakan dalam penanaman rumput tuf adalah sisa media cendawan (SMC). Maka kajian ini telah dijalankan untuk mengetahui kesan campuran tanah dan SMC yang berbeza terhadap pertumbuhan rumput Zoysia matrella. Tanah dari UMS kampus Sandakan dan SMC dari kilang pusat pengeluaran bibit cendawan, Mesilau, telah dicampurkan pada nisbah 1: 0 (kawalan), 1: ¼, 1: ½, 1: ¾, 1: 1, dan 0: 1 (kg) dengan lima replikasi untuk setiap rawatan. Rumput Zoysia berkenaan ditanam dalam campuran media rawatan tersebut di dalam polibeg berukuran 37 × 35 × 7.5 cm dan diletakkan di tempat terbuka. Dalam tempoh masa empat bulan, sifat kimia dan fizikal (pH, kelembapan, kandungan organik, kandungan karbon dan jumlah nitrogen) media rawatan dianalisa. Kualiti pandangan dan fungsi rumput Zoysia tersebut direkodkan dan dibandingkan antara media rawatan. Keputusan menunjukkan bahawa penambahan SMC memperbaiki pH tanah, mempertingkatkan kandungan kelembapan, kandungan organik dan kandungan karbon media rawatan. Kualiti Z. matrella dengan rawatan 1: 1 didapati lebih baik berbanding kualiti rumput ini dengan rawatan 1: ½. Maka nisbah 1: 1 dicadangkan sebagai rawatan yang lebih ideal sebab ia bukan sahaja memperbaiki kualiti media tetapi juga kualiti rumput tuf berkenaan. Penambahan SMC melebihi nisbah 1: 1 meningkatkan kualiti rumput tuf tetapi kesannya dijangkakan sementara sahaja. Penambahan SMC yang berlebihan membawa kepada kadar kematian awal rumput yang tinggi, yang mana boleh merugikan jika diamalkan dalam keadaan sebenar dilapangan. Berdasarkan kepada keputusan kajian ini, SMC dicadangkan untuk digunakan sebagai rawatan tanah bagi penanaman rumput Zoysia di UMS kampus Sandakan serta kawasan pembinaan di Sabah yang mempunyai persamaan ekologi dengan kawasan kampus ini. Walau bagaimanapun, perhatian harus diambilkira untuk tidak menambah-lebih SMC dalam penanaman rumput tuf.

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LIST OF SYMBOLS, UNITS AND ABBREVIATIONS

®	Registered
ANOVA	Analysis of Variance
CDW	Clippings dry weight
CEC	Cation exchange capacity
CFW	Clippings fresh weight
DDT	Dichlorodiphenyltrichloroethane
DF	Degree of freedom
MMR	Mushroom medium residues
MS	Mean square
OM	Organic matter
rpm	Revolution per minute
SSA	School of Sustainable Agriculture
SSQ	Sums of squares
TOC	Total organic carbon
UMS	Universiti Malaysia Sabah
USDA	United State Department of Agriculture
USGA	United State Golf Association
w/w	Weight per weight

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3.1 Moisture content (%): Turfgrass 20

$$\text{Moisture content}=\frac{\text{Fresh weight–oven dry weight}}{\text{Oven dry weight}}$$

3.2 Moisture content (g): Soil 21

$$\text{Moisture content (\%)} = \frac{\text{Weight of wet soil–weight of oven dry soil}}{\text{Weight of oven dry soil}} \times 100$$

3.3 Organic matter (%) 21

$$\text{Organic matter (\%)}=\frac{\text{Initial weight of sample (g)} - \text{final weight of sample (g)}}{\text{Initial weight of sample (g)}} \times 0.8 \times 100$$

3.4 Total organic content (%) 21

Total Organic Carbon (%)

$$=\frac{\text{Initial weight of sample (g)} - \text{final weight of sample (g)}}{\text{Initial weight of sample (g)}} \times 0.58 \times 100$$

3.5 Total Nitrogen (%) 21

$$\text{Total Nitrogen (\%)}=\frac{(V\text{-}B) \times M \times R \times 14.01}{Wt \times 1000} \times 100$$

Where:
- V = Volume of 0.01 M HCl titrate for the sample (mL)
- B = Digested blank titration volume (mL)
- M = Molarity of HCl solution
- 14.01 = Atomic weight of N
- R = Ratio between total volume of the digest and the digest volume used for distillation
- Wt = Weight of air-dry soil (g)

3.6 Relative water content (g): Turfgrass 23

$$RWC=\frac{\text{Fresh weight (g)} - \text{dry weight (g)}}{\text{Turgid weight (g)} - \text{dry weight (g)}}$$

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CHAPTER 1

INTRODUCTION

1.1 Background

Turfgrasses are grass species, which we domesticate for our own use, and turf is the turfgrass layer inclusive of the upper stratum of earth in which the roots and rhizomes of the plant are growing (Turgeon, 2008). To date, there are 40 species of commercial turfgrasses in the world (Aldous and Chivers, 2002), which we use for various purposes. In fact, turfgrasses are among the oldest species that we are still using today to fashion our lawn and recreational areas (Ingels, 2001). In today's landscape industry, turfgrass planting is one of the most rapidly expanding activities. It is one of the profitable industries in the world. In Malaysia, the sports turf and landscape industry alone had contributed up to RM 1 billion worth of the business within the Eight Malaysian Plan (Saharan, 2001). The economic value of industries associated with turfgrass is substantial, for such industries serve many groups of people, inclusive of million homeowners, athletic field managers, lawn care operators, golf course superintendents, architects, landscape designers and contractors. Its economic value is significant in that the full-service lawn care corporation is currently the leading profit makers among landscape professionals (Saharan, 2001).

As the turfgrass industry grows, a few significant issues arise, which have to be addressed to ensure that the benefits of turf are sustained. One of the current issues is the overuse of chemicals such as inorganic fertilizers in turf management (Landschoot and McNitt, 1994). Nitrate and phosphorus excess from chemical fertilizers could pollute the waterways, and these residues are known to harm human health (Liu *et al.*, 2008). Nitrate N, which dissolves easily in water, is not held by negatively charged soil colloids or will not denitrify to methane gas and will remains in the soil, except that the

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turfgrasses utilize rapidly this form of N (McCarty *et al.,* 2003). Practically, the turfgrass industry itself has to be part of the 'solution' rather than be the 'problem' (Haghighi *et al.*, 2006). Hence, the likely solution for this high excess of nitrate and phosphorus in turf environment is to reduce the usage of chemical fertilizers. For that purpose, the growing current interest is to use organic materials as a soil amendment for turfgrasses planting.

A vast quantity of organic wastes on earth is generated by livestock rearing operations, plant based industries, and municipalities (Eghball and Gilley, 1999; Giusquiani *et al.*, 1995; He *et al.*, 1992). The daily generation of these wastes brings significant pressure on how to dispose them properly. One of the options is to compost these organic wastes and use them as fertilizers, as these wastes are rich in organic matters and contain high level of Nitrogen (N) and Phosphorus (P), which are important for plant growth. Composting of raw organic wastes and using them as fertilizers have already been demonstrated to have a number of benefits: it reduces the mass and water content of the organic materials, suppresses pathogens as well as decreases weed seed viability in the materials, reduces the cost of fertilization, and produces a stable organic material that is easier to handle and spread on the ground (Eghball and Gilley, 1999; Parkinson *et al.*, 2004).

In Malaysia, one of the abundant organic materials is the mushroom medium residue (MMR). To date, this medium is considered as an agricultural waste and has been disposed without being seriously considered for other usage. Therefore, this material is an excellent source of compost to reduce the over dependency on chemical fertilizers in turfgrass planting. The formulation of MMR which consists of wood dust, rice bran and agricultural lime is purely organic and thus is suitable as nutrient source for turfgrass. In United States, MMR has been found to induce good growth of turfgrasses (Landschoot, 2003), but it has never been tested as soil amendment for planting of turfgrasses in tropical climate especially in disturbed soil. Thus, this study was carried out to investigate the growth performance of *Zoysia matrella* grown on a mixture of MMR and soil collected from the construction site at the Sandakan campus (School of Sustainable Agriculture, SSA) of the Universiti Malaysia Sabah (UMS).

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1.2 Justification

MMR is available for free, found abundantly in Sabah and Malaysia, biodegradable and environmentally non-harmful. Hence, a positive result from this study will justify and open up an alternative usage of MMR as soil amendment for turfgrass planting. The results will also provide useful information for the establishment of organic turfgrass lawns and golf course in the UMS Sandakan campus as well as in other areas in Malaysia of which have soil characters similar to the campus environment.

1.3 Objectives

This study was conducted with the following objectives:

I. To investigate the effects of MMR addition on chemical and physical characteristics of the soil from selected site at the UMS Sandakan campus.

II. To compare the effects of different MMR and soil mixtures on the growth of *Zoysia matrella* in polybags planting condition.

1.4 Research Hypothesis

Ho_1: MMR addition has no significant effect on chemical and physical characteristics of the media.

Ha_1: MMR addition has significant effect on chemical and physical characteristics of the media.

Ho_2: Different MMR and soil mixtures have no significant effect on *Z. matrella* growth and quality.

Ha_2: Different MMR and soil mixtures have significant effect on *Z. matrella* growth and quality.

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CHAPTER 2

LITERATURE REVIEW

2.1 Turfgrasses

Grasses belong to the plant family of Poaceae. This plant family is divided into six sub-families, which incorporate 24 tribes, 600 genera, and 7500 species (Wiecko, 2006). About 40 of the species are used as turfgrasses. They are mostly from the subfamilies Festucoideae, Panicoideae, and Eragrostoideae. Turfgrasses in the Festucoideae are usually adapted to cool climates (cool-season grasses), and those in Panicoideae and Eragrostoideae are adapted to warm climates (warm-season grasses).

The warm-season grasses are best adapted to temperatures between 27 °C and 35 °C and the cool-season grasses, are adapted to temperatures between 18 °C and 24 °C (Wiecko, 2006). The unique characteristic of warm-season grasses is they undergo dormancy when soil temperature drops below 10 °C. Even so, tropical grasses are essentially warm-season grasses that never become dormant and often manifest little tolerance to cold stress.

2.1.1 Importances of Turfgrasses

Turfgrasses have been selected as the most suitable surface for historic bowling greens and golf courses since the 13th-century. They have been used to carpet the outdoor rooms of cottages and castles for centuries (Turgeon, 2008). Many types of turfgrass have been developed specifically for golf courses and other recreational uses. A piece of land often covered several acres on which turfgrass are grown and maintained is known as lawn. A beautiful lawn will enhance any landscape by improved the aesthetic and economic value; however, a poor lawn will detract from the overall appearance.

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They provide recreational surfaces for outdoor activities where residents can relax (Normita, 2010). They are comfortable to walk on, suitable and safe for numerous athletic activities, and ideal for picnic blankets and sunning (Trenholm *et al.*, 2001).

Turfgrasses are pleasant to the eyes; they reduce the glare of bright sunlight more than pavement or buildings. Research has shown that looking at a pleasant outdoor view can reduce stress and improve physical health (USGA, 2009). Research has shown that hospital patients recovered faster when they had a view of turf, trees and open spaces (Anonymous, 2007). In another study, employees of businesses with well-designed landscaping and well-maintained turf had a more positive job attitude compared to those of businesses with poorly-designed landscaping and turf areas (Cockerham *et al.*, 2004).

Turfgrasses are also beneficial toward the environment. They hold dust and dirt from along million miles of highways, absorb sound and produce oxygen. As the turf growth, they take carbon dioxide (CO_2) from the air and release oxygen (O_2). Research study has found that a landscape of turf, trees and shrubs about 2,000 square feet generate enough O_2 for one person annually (Anonymous, 2007). Some studies have shown that certain types of turf can even absorb carbon monoxide. This is especially beneficial near roads where carbon monoxide is most concentrated. Moreover, these green grasses eventually reduce temperature and the energy needed for air conditioning. Hence, turfgrasses also act as cooling agent by absorbing the heat of the hot weather especially in tropical climatic conditions.

While turfgrasses are typically thought of for recreation and aesthetic value, they also provide a valuable environmental service by stabilizing and preventing soil erosion from wind and rain. They have very dense root systems that hold the soil and rainwater to reduce erosion (Christians, 2004). They improve soil absorption and infiltration of water as well as remediation of contaminated or polluted water and serve as fire abatement (Beard and Green, 1994). They improve the soil structure by providing a steady supply of compost material and mulch through their clippings, and they inhibit the growth of weeds. As turfgrass grows, it adds organic matter to the soil. This allows it to absorb even more water and hold it. Even during extremely intense rainstorms (three inches per hour), studies show that turf holds up to 20 times more

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soil than traditionally-farmed cropland (Anonymous, 2007). These plants are indeed multipurpose in terms of usage (Cockerham *et al.*, 2004).

2.1.2 *Zoysia matrella*

Zoysia matrella is one of the popular turfgrasses for athletic and golf courses in Malaysia (Normas, 2006). It is also the most commonly used species for home lawns and playground. This species is locally known as Manila grass or Korean grass (Trenholm *et al.*, 2001). Worldwide, zoysiagrasses are occurred naturally along the coastal of Indian Ocean and South China Sea until to the Ryukyu Islands, and in most of South-East Asian countries (Mannetje and Jones, 1992). Now it is extensively cultivated pan-tropically. The leaf-blade of *Zoysia* is 1.5–2.6 mm wide, and more-or-less spreading; its peduncle exerts from the uppermost sheath at anthesis, and the raceme distinctly exerts above the foliage, up to 4.2 cm long. Table 2.1 provides parts of taxonomy description of *Z. matrella*.

Table 2.1 Parts of taxonomy description of *Z. matrella*

Domain	Eukaryote
Kingdom	Plantae
Class	Liliopsida
Order	Poales
Family	Poaceae
Genus	Zoysia
Species	*Zoysia matrella*

Sources: Wiecko, 2006

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This grass is widely use for fine turf in many parts of the world. In East Asia, it is one of the most popularly grasses cultivated for sports and recreational environments. *Z. matrella* has high turf quality, high density and high drought tolerance (it requires moderate moisture). It has an attractive and good colour, and if well maintains, it will produce a good to excellent surface. Its quality may drop if the intensity of management falls and the turf becomes excessively thatch (Aldous and Chivers, 2002). Generally, the low growth rate of *Zoysia* implies lower maintenance requirement.

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2.2 Management of Turfgrass Field

2.2.1 Current Planting Practices of *Zoysia matrella*

Zoysia matrella has a light to dark green colour, grows dense, and is physically harder than other types of fairway grasses. Its leaves are tough and stiff and formed a strong turf of high durability. It has more vertical growth than horizontal so divot recovery is slow. It can grow up to 300 m altitude (Mannetje and Jones, 1992), is primarily adapt to medium textures soil to coarse textures soil such as very sandy soils on coastal areas. It is relatively slow growth habit, because it has both rhizomes and stolons. It may take three to 10 months to establish (Bae *et al.*, 2007). As *Zoysia* grows, it requires full sunlight, even so, it is good shade tolerance. *Z. matrella* is well adapted to wet and saline sites (Wang, 1995). It is able to tolerate high levels of salinity in the range of 36.5 to 49.4 dSm^{-1} (Md. Kamal Uddin *et al.*, 2009). It is able to tolerate pH at 5.5 up to maximum of 8.5. It will not mix well with other grasses. It is quite resistant to weed invasion and disease attack.

Zoysia matrella is a perennial grass, which can only be propagated using sods and sprigs (Turgeon, 2008). It requires frequent mowing as a way to stimulate the growth of young leaves (Wiecko, 2006). The growth rate of *Zoysia* is higher than many other turfgrass; therefore it needs to be cut more often to maintain its aesthetic value. On lawns growing in full sunlight, *Zoysia* can be mowed at a height of 2 to 4 cm on every 5 to 7 days. In shaded sites of lawn, *Zoysia* may be mowed slightly higher than recommended; however, mowing frequency shall not be changed even though the mowing height is slightly increased.

Zoysia matrella requires as much water as humans do; it takes up to 70% water from the soil medium (Normas, 2006). If growing in sandy soils, it requires more frequent irrigations than it requires in heavier clay soils. Irrigation frequency has to be increased when temperature increases. During prolonged droughts, watering *Zoysia* every other day at the rate of 1 cm water are adequate enough to keep the grass alive.

As *Zoysia* is growing, it needs essential nutrients (Wiecko, 2006). The nutrients should be available in the form readily soluble in water so that they can be taken up by the grass roots. The most essential nutrients needed by turfgrasses are Nitrogen (N),

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Phosphorus (P) and Potassium (K). *Zoysia* requires a moderate level of nitrogen fertilizer to maintain a dense turf. Nitrogen requirement for *Zoysia* is ranged from 0.25 to 0.4 kg per 100 m^2 monthly. The proper supply of N is an essential practice to keep the *Zoysia* under optimum condition to meet all characteristic its use (Liu *et al.*, 2008). Phosphorus fertilizer can be supplied to *Zoysia* in the form of inorganic or organic. Inorganic P fertilizers include superphosphates and ammonium phosphates, on the other hands, natural organic fertilizers typically contain phosphorus derived from plant or animal byproducts. These fertilizers can contain as much as 13% P (Landschoot, 2003). Potassium can be supplied to *Zoysia* using inorganic fertilizers, natural organic fertilizers, or both (Landschoot, 2003). However, most fertilizer potassium is derived from inorganic sources, in particular, muriate of potash (potassium chloride) and sulfate of potash (potassium sulfate). Hence, in order to meet the nutritional requirements of a turf, all factors affecting the availability of nutrients such as soil moisture, temperature and light must be considered (Richard, 1983).

2.2.2 Issues Arose from Turfgrass Planting

It is important to select an appropriate turfgrass species for planting in a new site. If unsuitable turfgrass species is selected, changing to another species can be costly, and possibly damaging to the lawn (Normas, 2006). Generally, higher maintenance turf is avoided. However, maintenance cost of turfgrass increases not only because of the turf is naturally requiring intensive care, but because of mismanagement.

One of the mismanagement of turfgrass is, at some locations, it is maintained with large amount of chemical fertilizers (Angle, 1994). Although it appears that N, P and K fertilization can improve the turfgrass growth (Snyder *et al.*, 2007), this practice has largely influenced the environment, in which it will pollute the drinking water if excessively used. Practically, the turfgrass industry itself has to be part of the 'solution' rather than be the 'problem' (Haghighi *et al.*, 2006). Hence, the likely solution for this high excess of nitrate and phosphorus in turf environment is to reduce the usage of chemical fertilizers. The growing current interest is to use organic materials as a soil amendment for turfgrasses planting to reduce the dependency on inorganic fertilizers. Alternately, the usage of organic materials has low management cost and environmentally friendly benefits. They are bulky organic wastes generate from the agricultural industry that exploit as a soil fertilizer with low economic value as compare

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to chemical fertilizers. This is an advantage especially for planting turfgrass at landscape scale (Landschoot, 2003). Thus, it is important to realistically asses the requirement to establish and maintain new lawn in newly constructed area.

2.2.3 Organic Planting of Turfgrass

Compost or commonly known as fermented organic residue or biodegradable waste is available abundantly in the world (He *et al.*, 1992). It can be come from something that is or was alive such as sphagnum peat, wood chips, grass clippings, straw, sawdust and wood ash (Davis and Wilson, 2010). It varies in physical characteristics, chemical constitution and microbiology. If the compost is to be used in turfgrass planting, the general characteristic of compost has to be understood. Basically, compost is an active microbial and on some occasions it plays a role in suppressing fungal diseases in turfgrass. It fasten turf establishment by improves the structure of soil, reduce surface crusting and compaction. Compost allows more air fill pore space for better turf growth and root penetration. Compost medium also improves the soil water holding capacity, as well as has a high fibrous material content which generally improves soil physical properties and biological activity. Compost usually has organic matter content less than 80% but around 50% (Snyder and Wolf, 2003). A minimum acceptable content of 50% might be reasonable but it depends on the nature of the mineral fraction. Good quality peat and compost are unlikely to contain unacceptable proportions, for instances, it can be caused a critical problem with other humified materials.

Besides supplying organic matter, compost also decrease bulk density and particles density whilst improving substrate porosity. Compost normally has a greater nutrient content and supply characteristic than peat but there is wide variation depending on source materials and the nature of additions made to promote microbial activity (Snyder and Wolf, 2003). Organic compost amendment can enhance turfgrass establishment and quality compared with fertilizer sources of nutrient (Angle *et al.*, 1981; Cisar and Snyder, 1992; Garling and Boehm, 2001; Landschoot and McNitt, 1994; Loschinkohl and Boehm, 2001; Norrie and Gosselin, 1996; Schumann *et al.*, 1993).

Recent research has shown that the use of high quality compost can degrade some turf pesticides over time and reduce risks of water contamination (Cooperband,

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2002). Compost has been used successfully to amend soils prior to construction: to increase saturated hydraulic conductivity of compacted soils, to improve water holding capacity and soil fertility of sand better than peat and inorganic amendments and improve turfgrass establishment (Landschoot *et al.*, 1994).

2.3 Mushroom Medium Residue (MMR)

One of the organic agricultural wastes in Sabah is mushroom medium residue. This medium associated with the production of mushroom, a project that introduced by Rural Development Corporation (KPD) in the 80's. KPD introduced the shiitake mushroom (*Lentinus endodes*) cultivation for the rural community with the objective to improve the living standard of rural residents (Jamilah, 2010). Now, the mushroom seed production is progressing well that the state will become Malaysia's main producer of mushrooms in five years (Abdul Rahim Ismail and Lim, 2007). Sabah is currently producing 60 metric tonnes of mushrooms annually, and this is expected to increase to 500 metric tones a year within the next five years.

To grow mushrooms is a waste producing, yet recycling activity (Beyer, 1999). In Malaysia, there are hundred tones of mushroom medium residues produced annually. The Shiitake mushroom generates a co-product of residues in unsightly dumps after undergo an optimized production cycles. These massive amounts of mushroom residues have traditionally been discarded as waste, which can create an environmental nuisance.

In the recent times, the mushroom industry has faced increasing challenges from regulatory agencies demanding an environmentally friendly treatment for MMR. An obvious solution to the disposal problem is to increase the demand for these residues through the exploration and development of new applications for usage. Thus, growers have to find the marketing opportunity of this residue. In this study, its use as soil amendment for turfgrass planting will be one of the solutions.

2.3.1 Physical Characteristics of Mushroom Medium Residue

Worldwide, the most popular basal ingredient used in synthetic substrates composition for the shiitake production is hardwood sawdust. It consists of 80% sawdust and 20%

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