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EFFECTS OF SEWAGE SLUDGE AND LIVESTOCK MANURE VERMICOMPOST ON GROWTH AND YIELD OF MAIZE (Zea mays L.)

MOHD SYAHMI BIN SALLEH

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By

MOHD SYAHMI BIN SALLEH

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

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EFFECTS OF SEWAGE SLUDGE AND LIVESTOCK MANURE VERMICOMPOST ON GROWTH AND YIELD OF MAIZE (*Zea mays* L.)

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Chair: Professor Dato' Nik Muhamad Nik Ab. Majid, PhD

Faculty: Institute of Tropical Forestry and Forest Products

Sewage sludge and livestock manure are being produced in great quantity on a daily basis. Improper disposal of these wastes would cause adverse effects on the environment and human health. Vermitechnology can be used to manage and recycle these wastes to organic fertilizers for crop production. The objectives of this study were to: 1) determine the potential of earthworm to convert sewage sludge into vermicompost, 2) compare the chemical properties of sewage sludge vermicompost with livestock manure vermicompost, 3) determine the effects of sewage sludge and livestock manure vermicompost on yield, biomass and nutrient uptake of maize (*Zea mays*), 4) determine the effects of sewage sludge and livestock manure vermicompost on heavy metal accumulation in the soil and plant, and 5) assess economic potential of substituting mineral fertilizer with vermicompost in maize cultivation.

Sewage sludge (SS), cattle manure (CM) and goat manure (GM) were subjected to pre-composting for 15 days prior to vermicomposting for another 30 days. Earthworm number and biomass were recorded before and after vermicomposting. Vermicompost produced was evaluated as a fertilizer for maize (*Zea mays*) cultivation. The experimental design was a randomized complete block design (RCBD) with three replications (blocks). Treatments involved mixture of vermicompost (VC) and mineral fertilizer (MF) in the following ratios of VC and MF: 100% VC (T1 for SS VC, T5 for CM VC and T9 for GM VC), 75:25 (T2 for SS VC, T6 for CM VC and T10 for GM VC), 50:50 (T3 for SS VC, T7 for CM VC and T11 for

GM VC), 25:75 (T4 for SS VC, T8 for CM VC and T12 for GM VC), and 100% MF (T13) along with T14 (without fertilizer) as control. Standard laboratory procedures were used to determine chemical properties of vermicompost and soil. Nutrient uptake (N, P, and K) and heavy metals (Pb, Cd, Cu and Zn) content in the plant tissues were also measured. Data collected were statistically analysed using analysis of variance (ANOVA) followed by Duncan's new multiple range test (DNMRT) for mean comparison.

Earthworm growth performance was significantly low in the sewage sludge compared to the livestock manure due to the high amounts of NH_4 (1736.07 ppm), low pH (5.22) and low C/N ratio (6.64) at the beginning of vermicomposting process. Sewage sludge vermicompost contained significantly higher amount of total N, exchangeable NH_4, total and available P and exchangeable Ca compared to livestock manure vermicompost. Vermicompost produced in this study was considered safe to be used in maize cultivation due to the lower heavy metal content than the maximum permissible limits.

The fresh yield of maize from sewage sludge vermicompost based treatments was not significantly different compared to the livestock manure vermicompost based treatments. Combined application of 25% and 50% vermicompost with mineral fertilizer (T3, T4, T7, T8 and T12) produced no significant difference in fresh yield and plant biomass as compared to 100% mineral fertilizer (T13). Nitrogen uptake in these treatments was also not significantly different. Significant increase of Pb (28.57 mg kg^{-1}) and Cd (1.03 mg kg^{-1}) in the soil at harvest were recorded in T13. However, heavy metal content in the soil and plant tissues for all treatments did not exceed the standard permissible limits. Substitution of 50% mineral fertilizer with vermicompost was economically viable due to the increase in total net benefit at 4.87% (RM162.52) and the benefit-cost ratio from 2.70 to 2.83 as compared to the 100% mineral fertilizer application.

This study has highlighted the potential of sewage sludge and livestock manure vermicompost to substitute mineral fertilizers in maize cultivation through vermitechnology and biological agriculture concept. However, study on the pathogenic aspect of sewage sludge and livestock manure vermicompost is necessary to evaluate the possibility of disease incidence.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KESAN VERMIKOMPOS ENAPCEMAR KUMBAHAN DAN TINJA HAIWAN TERNAKAN TERHADAP PERTUMBUHAN DAN HASIL JAGUNG (*Zea mays* L.)

Oleh

MOHD SYAHMI BIN SALLEH

Februari 2015

Pengerusi: Professor Dato' Nik Muhamad Nik Ab. Majid, PhD

Fakulti: Institut Perhutanan Tropika dan Produk Hutan

Sisa enap cemar kumbahan dan tinja haiwan ternakan dihasilkan dalam kuantiti yang banyak setiap hari. Pelupusan sisa dengan kaedah yang tidak terurus akan menyebabkan kesan buruk terhadap alam sekitar dan kesihatan manusia. Vermiteknologi boleh digunakan untuk mengurus dan mengitar semula sisa-sisa ini menjadi baja organik untuk pengeluaran tanaman. Objektif kajian ini ialah untuk: 1) menentukan potensi cacing untuk menukarkan enap cemar kumbahan menjadi vermikompos, 2) membandingkan sifat kimia vermikompos enap cemar kumbahan dengan vermikompos tinja haiwan ternakan, 3) menentukan kesan penggunaan vermikompos enap cemar kumbahan dan tinja haiwan ternakan terhadap hasil, jisim bio dan pengambilan nutrien oleh jagung (*Zea mays*), 4) menentukan kesan penggunaan vermikompos enap cemar kumbahan dan tinja haiwan ternakan terhadap pengumpulan logam berat di dalam tanah dan tumbuhan, dan 5) menilai potensi ekonomi penggantian baja mineral dengan vermikompos di dalam penanaman jagung.

Enap cemar kumbahan (SS), tinja lembu (CM) dan tinja kambing (GM) telah di pra-kompos selama 15 hari sebelum proses vermikompos selama 30 hari berikutnya. Bilangan dan jisim bio cacing telah direkodkan sebelum dan selepas proses vermikompos. Semua vermikompos yang dihasilkan turut diuji untuk menggantikan penggunaan baja mineral bagi penanaman jagung (*Zea mays*). Reka bentuk eksperimen adalah reka bentuk blok rawak lengkap (RCBD) dengan tiga replikasi (blok). Rawatan

yang terlibat adalah campuran vermikompos (VC) dan baja mineral (MF) mengikut nisbah campuran VC dan MF seperti berikut: 100% VC (T1 untuk SS VC, T5 untuk CM VC dan T9 untuk GM VC), 75:25 (T2 untuk SS VC, T6 untuk CM VC dan T10 untuk GM VC), 50:50 (T3 untuk SS VC, T7 untuk CM VC dan T11 untuk GM VC), 25:75 (T4 untuk SS VC, T8 untuk CM VC dan T12 untuk GM VC), dan 100 % MF (T13) dan juga T14 (tanpa baja) sebagai kawalan. Prosedur makmal yang piawai telah digunakan untuk menentukan kandungan sifat kimia vermikompos dan tanah. Pengambilan nutrien (N, P, dan K) dan kandungan logam berat (Pb, Cd, Cu dan Zn) di dalam tisu pokok juga turut dianalisa. Semua data yang dikumpul telah dianalisa menggunakan analisa varians (ANOVA) diikuti dengan ujian DNMRT untuk perbandingan min.

Prestasi pertumbuhan cacing di dalam enapcemar kumbahan adalah lebih rendah berbanding tinja haiwan ternakan kerana kandungan NH_4 (1736.07 ppm) yang tinggi, pH yang rendah (pH 5.22) dan nisbah C/N (6.64) yang rendah ketika proses vermikompos bermula. Vermikompos enap cemar kumbahan mengandungi kepekatan nutrien tumbuhan yang lebih tinggi terutamanya jumlah N, NH_4, P, dan Ca berbanding dengan vermikompos tinja haiwan ternakan. Vermikompos yang dihasilkan di dalam kajian ini dianggap selamat untuk digunakan bagi penanaman jagung kerana kandungan logam berat yang lebih rendah berbanding had maksima yang dibenarkan.

Hasil segar jagung bagi plot rawatan vermikompos enapcemar kumbahan tidak menunjukkan perbezaan yang ketara berbanding dengan plot rawatan vermikompos tinja haiwan ternakan. Gabungan aplikasi vermikompos sebanyak 25% dan 50% dengan baja mineral (T3, T4, T7, T8 dan T12) menghasilkan hasil jagung dan biomas pokok yang sama berbanding 100% baja mineral (T13). Pengambilan nitrogen di dalam rawatan-rawatan ini juga tidak menunjukkan perbezaan yang ketara. Peningkatan ketara Pb (28.57 mg kg^{-1}) and Cd (1.03 mg kg^{-1}) di dalam tanah semasa tuai telah direkodkan bagi T13. Walaubagaimanapun, kandungan logam berat dalam tanah dan tisu tumbuhan untuk kesemua rawatan tidak melebihi had standard yang telah ditetapkan. Penggantian baja mineral sebanyak 50% dengan vermikompos adalah berdaya maju ekoran peningkatan jumlah keuntungan sebanyak 4.87% (RM162.52) dan nisbah faedah-kos bagi penanaman jagung dari 2.70 kepada 2.83 berbanding dengan 100% penggunaan baja mineral.

Kajian ini telah menunjukkan potensi vermikompos enap cemar kumbahan dan tinja haiwan ternakan untuk menggantikan baja mineral di dalam penanaman jagung menggunakan vermiteknologi dan konsep pertanian biologi. Walaubagaimanapun, kajian ke atas aspek patogen vermikompos enap cemar kumbahan dan tinja haiwan ternakan adalah penting bagi mengukur kemungkinan berlakunya penyebaran penyakit.

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I certify that a Thesis Examination Committee has met on (date of viva voce) to conduct the final examination of (student's name) on his (her) thesis entitled ("Title of Thesis") in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the (insert the name of relevant degree).

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Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
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Shamshuddin Jusop, PhD
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Faculty of Agriculture
Universiti Putra Malaysia
(Internal Examiner)

Ahmed Osumanu Haruna, PhD
Associate Professor
Faculty of Agriculture and Food Sciences
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(Internal Examiner)

Hasnah Md. Jais, PhD
Associate Professor
School of Biological Sciences
Universiti Sains Malaysia
Malaysia
(External Examiner)

_____
ZULKARNAIN ZAINAL, PhD)
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 13 May 2015

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

Dato' Nik Muhamad Nik Ab. Majid, PhD
Principal Research Fellow, Professor
Institute of Tropical Forestry and Forest Product
Universiti Putra Malaysia
(Chairman)

Nor Azwady Abd Aziz, PhD
Senior lecturer
Faculty of Science
Universiti Putra Malaysia
(Member)

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Signature: _____
Prof. Dato' Nik Muhamad Nik Ab. Majid, PhD

Signature: _____
Nor Azwady Abd Aziz, PhD

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1.	AAS	Atomic Absorption Spectrophotometry
2.	ANOVA	Analysis of Variance
3.	Ca	Calcium
4.	Cd	Cadmium
5.	CEC	Cation exchange capacity
6.	CM	Cattle manure
7.	Cu	Copper
8.	DNMRT	Duncan's New Multiple Range Test
9.	FAO	Food and Agriculture Organization of the United Nations
10.	GM	Goat manure
11.	HCl	Hydrochloric acid
12.	HNO_3	Nitric acid
13.	IWK	Indah Water Konsortium Sdn. Bhd.
14.	N	Nitrogen
15.	N_2O	Nitrous oxide
16.	NH_3	Ammonia
17.	NH_4	Ammonuim
18.	NO_3	Nitrate
19.	K	Potassium
20.	MF	Mineral fertilizer
21.	Mg	Magnesium
22.	N	Nitrogen
23.	P	Phosphorus
24.	Pb	Lead
25.	SS	Sewage sludge
26.	T	Treatment
27.	VC	Vermicompost
28.	WHO	World Health Organization
29.	Zn	Zinc

CHAPTER 1

INTRODUCTION

The daily production of sewage sludge is increasing as population increases. According to the national sewerage treatment provider, Indah Water Konsortium Sdn. Bhd. (IWK), the national sewage sludge production per year is about five million m^3 and estimated to increase to about seven millions m^3 by 2022 (IWK, 2011). IWK is currently facing problems in disposing this waste due to the stringent national environmental policy on sewage sludge disposal and also the scarcity of land for new disposal sites. The common disposal method of landfilling or spreading on open lands may cause environmental contamination such as heavy metal toxicity and public health hazard (Azizi *et al.*, 2011). Heavy metals may enter human food chain and get accumulated in the human body that later may cause health problems (Islam *et al.*, 2007). In addition, the problem of limited landfill space warrants a practical solution of sewage sludge disposal. One of the alternatives is by converting it into a value added material for agricultural purposes. In addition, sewage sludge is generally known to contain high amounts of essential nutrients for plant growth.

The National Meat Policy (ruminant sector) stated that Malaysia is aiming to achieve self-sufficiency in meat products from 18% in 2006 to 40% in 2015 (Department of Veterinary Services, 2006), thus necessitating an increase of national livestock production. However, increasing livestock production will proportionately increase the amount of livestock waste produced. Mokhtar and Chia (2000) reported that in 1999, about 1.4 million metric tons of wastes were produced from cattle farms. Nurul-Aini (2012) estimated that total amount of livestock waste produced on daily basis is about 2.3 million metric tons. Livestock waste generally includes a mixture of manure and urine of the animals**.** The Malaysian Third National Agricultural Policy has recommended the practice of organic waste recycling for sustainable agriculture purposes (Ministry of Agriculture, 1999). Livestock manure is a common recycled material used as organic fertilizer for crop production. However, livestock manure may contain high amounts of heavy metals that originated from their food sources such as enriched Cu or Zn feed materials (Nicholson *et al.*, 1999). Therefore, proper guidelines are required for sustainable use of livestock manure in crop production to control the hazards of heavy metals to soil, plants and human.

Malaysia plans to achieve food sufficiency and security as stated in the national agricultural policy namely National Agrofood Policy 2011-2020 (Ministry of Agriculture, 2011). In order to attain this goal, agriculture production needs to be expanded and intensified which require greater use of agricultural inputs such as mineral fertilizers. Unfortunately, most of the mineral fertilizers are imported. According to the Department of Statistics Malaysia, about 1.32 million tons of mineral fertilizers were imported into Malaysia in 2001 with incurred cost of about RM1.14 billion (US$ 0.3 billion) and increased to US$ 2.96 billion in 2008 (Sabri, 2009). The Food and Fertilizer Technology Center in Taiwan also reported that the amount of mineral fertilizer consumption in Malaysia has increased from 1188 million tons in 2000 to 2101 million tons in 2010 (Lee, 2012). As a result of increasing cost of production in crop cultivation due to the increase in fertilizer cost, the consumer price index (CPI) for food has also increased. Latest consumer price index for food in April 2014 released by the Department of Statistics Malaysia shows an increase of 3.6% as compared to April 2013. If this continues, the food prices will increase and subsequently lead to additional burden especially the needy and poorer citizens. In addition, continuous and excessive use of mineral fertilizers in crop production will cause degradation of agricultural soils and environmental pollution such as heavy metal contamination, eutrophication, greenhouse gas emission and nitrate contamination which may affect human health.

The concept of biological agriculture has been recently introduced as an alternative solution. According to the International Federation of Organic Agriculture Movement (IFOAM), “biological agriculture is an ecologically, socially and economically sustainable agricultural production system which combines tradition, innovation and science to sustain and enhance soil health and fertility, maximizing yield and production at the same time minimizing the negative effects on the environment and human health thus promoting a sustainable relationship and a good quality of life for the entire ecosystem” (IFOAM, 2014). In this context, the integrated use of organic fertilizers produced from organic wastes such as sewage sludge and livestock manure with mineral fertilizers for agricultural production is recommended.

Although developed countries such as the United States of America and the European community have successfully used sewage sludge to substitute mineral fertilizer for crop production, similar approach has yet to be practiced in Malaysia. In fact, the developed countries have been conducting research for the past 30 years on the use of sewage sludge in agriculture including the use of earthworms to convert sewage sludge into organic fertilizer for crop production. This approach is known as vermitechnology. According to Sinha *et al.* (2009), vermitechnology includes two components mainly vermicomposting and vermi-agro-production. Vermicomposting is a non-thermophilic accelerated biological

degradation process of organic wastes through a joint action of earthworms and microorganisms (Arancon *et al.*, 2005). The end product of the process called vermicompost is a combination of earthworm cast and naturally decomposed organic materials. Vermi-agro-production involves the utilization of vermicompost for crop production. Vermicompost could function as an organic fertilizer and also as soil amendment to improve soil fertility.

In the context of promoting biological agriculture practice and sustainable management of sewage sludge and livestock manure through the application of vermitechnology in Malaysia, this research was conducted to evaluate the potential of sewage sludge and livestock manure vermicompost to substitute mineral fertilizer in crop production.

The specific objectives of this study were to:

(i) determine the potential of earthworm to convert sewage sludge into vermicompost,

(ii) compare the chemical properties of sewage sludge vermicompost with livestock manure vermicompost,

(iii) determine the effects of sewage sludge and livestock manure vermicompost on yield, biomass and nutrient uptake of maize (*Zea mays* L.),

(iv) determine the effects of sewage sludge and livestock manure vermicompost on heavy metal accumulation in the soil and maize,

(v) assess the economic potential of substituting mineral fertilizer with vermicompost in maize cultivation.

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