UNIVERSITI PUTRA MALAYSIA

EFFECTS OF SOIL AUGMENTATION BY Pontoscolex corethrurus ON BANANA PLANT RESPONSE TO FUSARIUM WILT

SITI ROHANI SULAIMAN

FS 2017 92

EFFECTS OF SOIL AUGMENTATION BY *Pontoscolex corethrurus* ON BANANA PLANT RESPONSE TO FUSARIUM WILT

By

SITI ROHANI SULAIMAN

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

November 2016

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

EFFECTS OF SOIL AUGMENTATION BY *Pontoscolex corethrurus* ON BANANA PLANT RESPONSE TO FUSARIUM WILT

By

SITI ROHANI SULAIMAN

November 2016

Chair: Assoc. Prof. Nor Azwady Abd Aziz, PhD
Faculty: Science

Fusarium wilt is a major problem to banana cultivation worldwide and thus, effective environmental-friendly control measures for the disease is in great demand. One of the method is using endogeic earthworms of which the activities of the worm influence nutrient cycle and composition of microbes in soil. This study was conducted to assess the impact of soil augmentation by *Pontoscolex corethrurus,* a tropical endogeic earthworm on banana plant response to Fusarium wilt. Photographic record and scaling of external and internal wilt symptom, plant wet weight, chlorophyll content and disease severity index (DSI) were performed. Additionally, Salicyclic acid (SA) and Jasmonic acid (JA) levels of the plants were also analysed due to their significant role in plant defense mechanism against pathogen. The results showed that the presence of earthworms contributed to higher plant wet weight, chlorophyll content and lower DSI compared to treatment without earthworm in non-infected and infected banana plants. The plants with earthworm inoculation also showed one week delayed appearances of external and internal wilt symptoms. The concentration of SA in non-infected plants with earthworm treatment showed higher value (0.72±0.09 µg/g, $p<0.05$) compared to without earthworm. For JA, the concentration in week 1 was doubled for infected plant with earthworm (0.96±0.01 µg/g) compared to without earthworm (0.47±0.03 µg/g). Thus, earthworms were proposed to improve plant basal defense *via* intensifying the plant defense hormones. The present study suggested that soil augmentation by *P. corethrurus* could improve plant growth, delayed appearance of wilt symptom and improve phytohormone production for plant defense system.

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

KESAN PENAMBAHBAIK TANAH OLEH *Pontoscolex corethrurus* KE ATAS TINDAK BALAS POKOK PISANG TERHADAP LAYU FUSARIUM

Oleh

SITI ROHANI SULAIMAN

November 2016

Pengerusi: Prof. Madya Nor Azwady Abd Aziz, PhD
Fakulti: Sains

Penyakit layu Fusarium merupakan masalah utama penanaman pisang di seluruh dunia dan langkah yang berkesan dan mesra alam untuk mengawal penyakit ini sangat diperlukan. Salah satu cara adalah dengan menggunakan cacing tanah yang mana aktiviti cacing tersebut mempengaruhi kitaran nutrien dan komposisi mikrob dalam tanah. Kajian ini dijalankan untuk menilai kesan penambahbaik tanah oleh *Pontoscolex corethrurus,* sejenis cacing tanah endogik di tropika terhadap tindak balas pokok pisang kepada layu Fusarium. Rekod fotografi dan penskalaan gejala layu luaran dan dalaman, berat basah tumbuhan, kandungan klorofil dan indeks keterukan penyakit (DSI) telah dilakukan. Disamping itu, kepekatan asid salisilik (SA) dan asid jasmonik (JA) daripada tumbuhan juga telah dianalisa kerana kedua-duanya memainkan peranan penting dalam mekanisma pertahanan tumbuhan terhadap patogen. Hasil kajian menunjukkan kehadiran cacing tanah menyumbang kepada peningkatan berat basah tumbuhan, kandungan klorofil yang tinggi dan DSI lebih rendah berbanding dengan pokok pisang tanpa cacing tanah yang tidak dijangkiti dan dijangkiti. Pokok dengan inokulasi cacing tanah juga menunjukkan kelewatan seminggu munculnya gejala layu luaran dan dalaman. Kepekatan SA dalam pokok dengan rawatan cacing yang tidak dijangkiti menunjukkan nilai yang lebih tinggi (0.72 ± 0.09 µg/g, $p<0.05$) berbanding tanpa cacing tanah. Untuk JA, kepekatan pada minggu pertama adalah dua kali ganda untuk pokok dengan cacing tanah yang dijangkiti (0.96 ± 0.01 µg/g) berbanding tanpa cacing tanah (0.47 ± 0.03 µg/g). Oleh itu, cacing tanah dicadangkan boleh meningkatkan pertahanan asas pokok dengan meningkatkan hormon pertahanan tumbuhan. Hasil kajian ini menunjukkan bahawa penambahbaikkan tanah oleh *P. corethrurus* boleh meningkatkan pertumbuhan tumbuhan, melambatkan kemunculan gejala layu dan meningkatkan penghasilan hormone tumbuhan bagi system pertahanan pokok.

ACKNOWLEDGEMENTS

In The Name of ALLAH, the Most Gracious and Most Merciful

First and foremost, I offer my greatest gratitude upon The Almighty Allah S.W.T for the opportunity and strength given in completing this study. Million appreciations to my helpful supervisor, Assoc. Prof. Dr. Nor Azwady Abd Aziz for all his guidances, knowledge and support given throughout the journey of completing my study. My appreciation also goes to both of my co-supervisor, Dr. Nur Ain Izzati Mohd Zainudin and Dr. Noor Baity Saidi for sparing their time for discussions, encouragement and supports in every aspect needed for completing my master study. A special thanks to the staffs of Biology Department, especially Mr. Johari Sepet and Mrs Farah for lending their helps during the research work. I would like to offer my gratitude towards my senior colleague, Vicky Teng Suk Kuan for her shared knowledges and experiences throughout the research journey. Thank you also to Nur Syahirah Abdullah and Asyurah Azman for their help in this research.

My endless gratitude to my family especially my parents, Mr. Sulaiman b Hamdan and Mrs. Parina bt Basri for their love and support for me at every time with patience. Thank you also to all my friends either far or near for the helps and moral supports given. I would like to acknowledge Universiti Putra Malaysia and Ministry of Higher Education for the financial support via GRF scholarship, SGRA scholarship given under Fundamental Research Grant Scheme (FRGS) and MyMaster under My Brain15 program respectively. This scientific research study could not be achieved without the cooperation of all the aforementioned people as well as numerous individuals who have directly or indirectly contributed to my research experiences at UPM.

I certify that a Thesis Examination Committee has met on 7 November 2016 to conduct the final examination of Siti Rohani Binti Sulaiman on her thesis entitled "Effects of soil augmentation by *Pontoscolex corethrurus* on banana plant response to Fusarium wilt" 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 Master of Science.

Members of the Thesis Examination Committee were as follows:

Muskhazli bin Mustafa, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Hishamuddin bin Omar, PhD
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Latiffah binti Zakaria, PhD
Professor
Universiti Sains Malaysia
Malaysia
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 28 February 2017

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:

Nor Azwady Abd Aziz, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Nur Ain Izzati Mohd Zainudin, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Member)

Noor Baity Saidi, PhD
Senior Lecturer
Faculty of Biotechnology and Biomolecular Science
Universiti Putra Malaysia
(Member)

_____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of Chairman of Supervisory Committee: Assoc. Prof. Dr. Nor Azwady Abd Aziz

Signature: _____
Name of Member of Supervisory Committee: Dr. Nur Ain Izzati Mohd Zainudin

Signature: _____
Name of Member of Supervisory Committee: Dr. Noor Baity Saidi

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

%	Percentage
°C	Degree celcius
µg/g	Microgram/gram
µL	Microliter
ABA	Abscisic acid
ANOVA	Analysis of variance
Avr	Avirulence
BDB	Blood disease bacteria
C	Carbon
CH_3CN	Acetonitrile
CHOOH	Formic acid
Cm	Centimeter
CMV	Cucumber mosaic virus
CRD	Completely randomized design
DNA	Deoxyribonucleic acid
DSI	Disease severity index
Foc	*Fusarium oxysporum* f. sp. *cubense*
G	gram
GAP	Good agricultural practice
H_2O	Water
HL	Human lysozyme
HR	Hypersensitive response
ICS	Isochorismate synthase
INA	Isonicotinic acid
ISR	Induced systemic resistance
JA	Jasmonic acid
Jas	Jasmonates
Kg	Kilogram
LAR	Locally acquired resistance
M	Meter
MBC	Methyl benzimidazole carbamate
mg/cm^2	Milligram/centimeter square
mgL^{-1}	Milligram per liter
mL	Milliliter
N	Nitrogen
Nm	nanometer
NPR	Nonexpresser pathogenesis-related protein
O_2	Oxygen
PAL	Phenylalanine ammonia-lyase
PDA	Potato dextrose agar
PGPR	Plant growth-promoting bacteria
PR	Pathogenesis-related
R	Resistance
RuBisCO	Ribulose biphosphate carboxylase/oxygenase
SA	Salicylic acid
SAMT	Salicylic acid methyl transferase
SAR	Systemic acquired resistance

SE	Standard error
SR	Systemic resistance
TCV	Turnip crinkle virus
TR4	Tropical Race 4
UFLC	Ultra-fast liquid chromatography
US$	United of State Dollar

CHAPTER 1

INTRODUCTION

Banana is one of the most important fruit crops grown commercially in Malaysia. It is also one of the world most valuable agricultural commodities (Ploetz, 2015). In Malaysia, 294,000 metric tonnes of banana was produced annually, valued at US$24 million (Tengku Ab. Malik *et al*., 2011). Most of the production is for domestic consumption but it is also exported to Singapore, Indonesia, Brunei, Saudi Arabia, and Hong Kong (Husain and William, 2011). The potential of banana plantation growth is however hampered due to a myriad of diseases that greatly affects the fruit yield. One of the extremely destructive banana diseases is Fusarium wilt.

Fusarium wilt is a major disease that causes serious problem to the global banana cultivation. It is caused by *Fusarium oxysporum* f. sp. *cubense* (*Foc*), a soil-borne fungus (Ploetz, 2006). In Southeast Asia especially Indonesia and Malaysia, Fusarium wilt was discovered in many banana commercial plantations in the early 1990s (Molina *et al*., 2009). This disease affects not only the large plantation but also involves small cultivated area. A serious epidemic of Fusarium wilt has caused big losses in banana production involving millions of dollars (Molina *et al.*, 2009). Fusarium wilt affects a wide variety of bananas consisting of cooking and dessert cultivars. The high variability of this fungus which include its ability to remain for decades in soil, wide host range, easily spreadable and along with its lethal impact to the host plant makes it difficult to control. The pathogen can be transferred easily through water, soil, farming tools, machinery or through insect vector which enables this disease to spread rapidly in the plantation (Tengku Ab. Malik *et al*., 2011). Thus, disease management approaches or srategies that can control this disease is highly demanded.

Control strategies that have been implemented to overcome this disease includes chemical control, genetic improvement, use of disease-free planting materials and application of biological control (Moore *et al.,* 1999; Nel *et al*., 2007; Ploetz, 2015). However, there are various constraint in the application of the strategies such as the negatives effects on the environment, public concern on food safety, and practical limitation. Biological control approach has become an increasingly popular consideration for disease management because it is environmental friendly and highly practical. For instance, the use of cyanobacteria and *Trichoderma* based formulation to control root rot disease in cotton (Babu *et al*., 2015). However, it is only effective for short-cycle plant such as tomato or radish, but it is not suitable for banana which is a perennial plant (Ploetz, 2007). In addition, the effectiveness depends largely on the concentration of the microbes in the soil that need to be replenished frequently. With many constraints in disease control application, focus was given more on approaches of promoting plant health to increase its defense.

Promoting plant health is of global interest at present as potential strategies for disease control against the pathogen in sustainable agriculture. Most of the existing practices have failed to tackle the importance of soil ecology that might contribute to the emergence of disease. Earthworms is a significant organism that can contribute to soil ecological improvement (Edwards and Fletcher, 1988; Doube *et al.*, 1994; Elmer, 2009; Amossé *et al*., 2015; Pelosi *et al*., 2015). The nutrient cycle and decomposition in soil are enhanced by their burrowing, feeding and casting activities (Brown *et al*., 2004; Capowiez *et al.*, 2014). Thus, they give positive impacts on the overall soil function and ecosystem. *Pontoscolex corethrurus,* an endogeic earthworm is one of the most important fauna which is dominant in the tropical soil has significant effects on soil properties (Sabrina *et al*., 2009). This earthworm gives significant changes in soil composition especially in the first 10 cm stratum. *P. corethrurus* actively consume soil and humified organic matter on the upper soil layer and form burrows within the soil (Bottinelli *et al*., 2010). Their presence in soil help to lay out a conducive condition for plant growth. Earthworms also have the ability to regulate soil microbes which are proven to enhance the plant growth (Edward and Bohlen, 1996; Zhang *et al*., 2014). In this perspective, earthworms may direct or indirectly affect soil-borne pathogen that causes plant diseases. Teng *et al.* (2016) reported on antimicrobial properties of earthworm excretion that could inhibit blood disease bacteria (BDB). This shows that earthworm presence can cause direct effect on plant pathogen. Besides that, plant growth and health improvement via earthworm activities in soil may indirectly improve plant defense towards pathogen.

Plant health may influence the plant defense which is linked to their metabolic system (Van Loon, 2007). Phytohormones that play a major role in plant system, have great contribution in mediating the plant responses towards biotic and abiotic stresses including pathogen infection. Salicylic acid (SA) and jasmonic acid (JA) are the phytohormones that actively involved in building resistance towards biotrophic and necrotrophic pathogens (Glazebrook, 2005). SA and JA production in plants may also induced by external factors such as abiotic and biotic factors (Puga-Freitas and Blouin, 2014). As one of the major contributors to healthy soil ecosystem, earthworms may enhance plant defense system by improving plant health. If the plant is healthy, it can produce more of this compound where the chances for successful pathogen infection and invasion can be reduced and thus decrease disease prevalence in the plant (Elmer and Ferrandino, 2009). The earthworm-pathogen relationship was earlier thought to only involve direct interaction like predation, habitat destruction, competition for organic matter, and production of antibacterial or antifungal properties that decrease the pathogen population (Brown *et al*., 2004). However, it is found that earthworm interaction with plants actually induces some of the genes in plants which contribute to better plant growth and defense mechanisms (Puga-Freitas and Blouin, 2014). Though, it is still unclear whether earthworms can have significant effects on the level of plant defense hormone.

Currently, there is a lack of study on the earthworm role as soil engineer in inducing ecological improvement which may affect banana plant and its

response to Fusarium wilt. Furthermore, there is also no report on earthworm effect on phytohormones responsible for the plant defense specifically SA and JA. Therefore, the present study was designed to look into the possibility of soil augmentation caused by *P. corethrurus* to affect the banana plant with Fusarium wilt infection and investigate the earthworm effects on SA and JA levels that reflects the plant defense. Therefore, objectives of the present study are:

- To assess the impact of soil augmentation by *Pontoscolex corethrurus* on banana plant growth and its response to fusarium wilt disease infection

- To conduct bioassay study on salicylic acid and jasmonic acid content of healthy banana plant and those infected with fusarium wilt disease grown in soil augmented by *Pontoscolex corethrurus*

REFERENCES

Alabouvette, C. and Couteaudier, Y. (1992). Biological control of fusarium wilts with non-pathogenic *Fusaria*. In: *Biological control of Plant Diseases,* Tjamos, E.C., Cook, R.J. and Papavizas, G.C. (eds). Plenum, New York. Pp. 415- 426.

Alabouvette, C. and Lemanceau, P. (2000). Joint action of microbials for disease control. In: *Methods in Biotechnology, Volume 5. Biopesticides: Use and delivery*. Humana Press Inc., Hall, F.R. and Menn, J.J. (eds). Totowa, N.J. Pp. 117-135.

Alabouvette, C., Hoeper, H., Lemanceau, P. and Steinberg, C. (1996). Soil suppressiveness to diseases induced by soilborne plant pathogens. In: *Soil Biochemistry*, Stotzky, G. and Bollag, J.M. (eds). Volume 9. Marcel Dekker, Inc. New York. Pp. 371-413.

Alabouvette, C., Lemanceau, P. and Steinberg, C. (1993). Recent advances in the biological control of Fusarium wilts. *Pesticide Science, 37*, 363-373.

Amossé, J., Turberg, P., Kohler-milleret, R., Gobat, J., Bayon, R. Le, and Le Bayon, R.C. (2015). Effects of endogeic earthworms on the soil organic matter dynamics and the soil structure in urban and alluvial soil materials. *Geoderma*, *243-244*, 50–57.

An, C., and Mou, Z. (2011). Salicylic Acid and its Function in Plant Immunity. *Journal of Integrative Plant Biology*, *53*, 412–428.

Babu, S., Bidyarani, N., Chopra, P., Monga, D., Kumar, R., Prasanna, R., Kranthi, S., Saxena, A. K. (2015). Evaluating microbe-plant interactions and varietal differences for enhancing biocontrol efficacy in root rot disease challenged cotton crop. *European Journal of Plant Pathology*, *142*, 345–362.

Bakker, P.A.H.M., Bakker, A.W., Marugg, J.D., Weisbeek, P.J. and Schippers, B. (1987). Bioassay for studying the role of siderophores in potato growth stimulation by *Pseudomonas* spp. in short potato rotations. *Siol Biology and Biochemistry*, *19*, 451-457.

Baldwin, B.C. and Rathmell, W.G. (1988). Evolution of concepts for chemical control of plant diseases. *Annual Review of Phytopathology, 26,* 265-283.

Bardgett, R. D., Mommer, L., and De Vries, F. T. (2014). Going underground: Root traits as drivers of ecosystem processes. *Trends in Ecology and Evolution*. *29*, 692-699

Bari, R., and Jones, J. D. G. (2009). Role of plant hormones in plant defense responses. *Plant Molecular Biology, 69*, 473–488.

Barois, I., Villemin, G., Lavelle, P., Toutain, F. (1993). Transformation of the soil structure through *Pontoscolex corethrurus* (Oligochaeta) intestinal tract. *Geoderma, 56*, 57-66

Becker, D.K., Dugdale, B., Smith, M.K., Harding, R.M. and Dale, J.L. (2000). Genetic transformation of Cavendish banana (*Musa* sp. AAA group) cv. Grand Nain via micro projectile bombardment. *Plant Cell Reports, 19,* 229-234.

Bhagwat, B. and Duncan, E.J. (1998). Mutation breeding of banana cv. Highgate (*Musa* spp. AAA group) for tolerance to *Fusarium oxysporum* f. sp. *cubense* using chemical mutagens. *Scientia Horticulturae, 73*, 11-22.

Bityutskii, N.P., Solov'eva, A.N., Lukina, E.I., Oleynik, A.S., Zavgorodnyaya, Yu.A., Demin, V.V., and Byzov, B.A., (2007) Stimulating Effect of Earthworm Excreta on the Mineralization of Nitrogen Compounds in Soil, Pochvovedenie, , *European Journal of Soil Science, 40*, 426–431

Blomme, G., Ploetz, R., Jones, D., De Langhe, E., Price, N., *et al*. (2013) .A historical overview of the appearance and spread of *Musa* pests and diseases on the African continent: highlighting the importance of clean *Musa* planting materials and quarantine measures. *Annals of Applied Biology, 162*, 4–26

Blouin, M., Hodson, M. E., Delgado, E. A., Baker, G., Brussaard, L., Butt, K. R., Dai, J., Dendooven, L., Peres, G., Tondoh, J.E., Cluzeau, D., Brun, J.J. (2013). A review of earthworm impact on soil function and ecosystem services. *European Journal of Soil Science, 64*, 161-182

Blouin, M., Zuily-Fodil, Y., Pham-Thi, A. T., Laffray, D., Reversat, G., Pando, A., Tondoh, J., Lavelle, P. (2005). Belowground organism activities affect plant aboveground phenotype, inducing plant tolerance to parasites. *Ecology Letters*, *8*, 202–208.

Bolwerk, A., Lagopodi, A.L., Wijfjes, A.H.M., Lamers, G.E.M., Chin-A-Woeng, T.F.C., Lugtenberg, B.J.J. and Bloemberg, G.V. (2003). Interactions in the tomato rhizosphere of two *Pseudomonas* biocontrol strains with the phytopathogenic fungus *Fusarium oxysporum* f. sp. *radicis-lycopersici*. *Molecular Plant-Microbe Interactions, 16*, 983-993.

Borrero, C., Ordovás, J., Trillas, M.I. and Avilés, M. (2006). Tomato Fusarium wilt suppressiveness. The relationship between the organic plant growth media and their microbial communities as characterised by Biolog®. *Soil biology and Biochemistry, 30*, 1631-1637.

Bossuyt, H., Six, J., Hendrix, P.F. (2006). Interactive effects of functionally different earthworm species on aggregation and incorporation and decomposition of newly added residue carbon. *Geoderma, 130*, 14–25.

Bottinelli, N., Henry-des-Tureaux, T., Hallaire, V., Mathieu, J., Benard, Y., Duc Tran, T., Jouquet, P. (2010). Earthworms accelerate soil porosity turnover under watering conditions. *Geoderma, 156,* 43-47.

Bouché, M. B. (1977) Stratégies lombriciennes. In: *Soil Organisms as Components of Ecosystems* (eds. Lohm, U. and Persson, T.). *Ecological Bulletin* (Stockholm), *25,* 122-132.

Bresson, L. M., Koch, C., Le Bissonnais, Y., Barriuso, E., and Lecomte, V. (2001) Soil surface structure stabilization by municipal waste compost application. *Soil Science Society of America Journal, 65,* 1804–1811.

Brown, G. G., Edwards, C. A., Brussaard, L. (2004). How earthworms affect plant growth: burrowing into the mechanisms. In: *Earthworm ecology*, Edwards C. A. (2nd Ed.). CRC. USA. pp. 13–49

Buddenhagen, I.W. (1994). Moko disease. In: *Compendium of Tropical Fruit Diseases*, Ploetz, R. C. (ed.) St. Paul, MN: APS Press. Pp. 15–16.

Buddenhagen, I.W. (2009). Blood bacterial wilt of banana: history, field biology and solution. *Acta Horticulturae, 828*, 57–68.

Cabrera-Ponce, J.L., López, L., Assad-Garcia, N. Medina-Arevalo, C., Bailey, A.M. and Herrera-Estrella, L. (1997). An efficient particle bombardment system for the genetic transformation of asparagus (*Asparagus oficinialis* L.). *Plant Cell Reports, 16*, 255-260.

Cao, L., Giu, Z., Dai, X., Tan, K., Lin, Y. and Zhou, S. (2004). Isolation of endophytic actnomycetes from roots and leaves of banana (*Musa acuminata*) plants and their activities against *Fusarium oxysporum* f. sp. *cubense*. *World Journal of Microbiology and Biotechnology, 20*, 501-504.

Cao, L., Qiu, Z., You, J., Tan, H. and Zhou, S. (2005). Isolation and characterization of endophytic streptomycete antagonists of fusarium wilt pathogen from surface- sterilized banana roots. *Microbiology, 247*, 147-152.

Capowiez, Y., Sammartino, S., and Michel, E. (2014). Burrow systems of endogeic earthworms: Effects of earthworm abundance and consequences for soil water infiltration. *Pedobiologia, 57*, 303–309.

Carrera, L.M., Buyer, J.S., Vinyard, B., Abdul-Baki, A.A., Sikora, L.J., Teasdale, J.R. (2007). Effects of cover crops, compost, and manure amendments on soil microbial community structure in tomato production systems. *Applied Soil Ecology, 37,* 247–255.

Carter, M.R. (2007). Long-term influence of compost on available water capacity of a fine sandy loam in a potato rotation. *Canadian Journal of Soil Science, 87,* 535–539.

Chan KY, Van Zwieten L, Meszaros IA, Downie A, Joseph S (2008) Using poultry litter biochars as soil amendments. *Australian Journal of Soil Research, 46*, 437–444.

Chaoui, H. I., Zibilske, L. M., and Ohno, T. (2003). Effects of earthworm casts and compost on soil microbial activity and plant nutrient availability. *Soil Biology and Biochemistry, 35*, 295–302.

Chuang, T.Y. (1991). Soil suppressiveness of banana Fusarium wilt in Taiwan. *Plant Protection Bulletin (Taiwan Roc), 33,* 133-141.

Churchill, A.L.C. (2011). *Mycosphaerella fijiensis*, the black leaf streak pathogen of banana: progress towards understanding pathogen biology and detection, disease development, and the challenges of control. *Molecular Plant Pathology, 12,* 307–28

Ciotola, M., DiTommaso, A. and Watson, A.K. (2000). Chlamydospore production, inoculation methods and pathogenicity *Fusarium*

oxysporum M12-4A, a biocontrol for *Striga hermonthica*. *Biocontrol Science and Technology, 10,* 129- 145.

Conrath, U., Beckers, G. J., Flors, V., García-Agustín, P., Jakab, G., Mauch, F., *et al.* (2006). Priming: getting ready for battle. *Molecular Plant Microbe Interaction. 19*, 1062–1071.

Côte, F.X., Legavre, T., Grapin, A., Valentin, B., Frigout, O., Babeau, J., Meynard, D., Bakry, F. and Teisson, C. (1997). Genetic transformation of embryogenic cell suspension in plantain (*Musa* AAB) using particle bombardment. In: *Proceedings of the international symposium on biotechnology of tropical and subtropical species. Part 1*. Drew, R.A. and Sasson, A. (eds). *Acta Horticulturae, p 460*.

Creelman, R.A., Mullet, J.E. (1997) Biosynthesis and action of jasmonates in plants, *Annual Review of Plant Physiology and Plant Molecular Biology, 48,* 355–381.

Crouch, J.H., Vuylsteke, D. and Ortiz, R. (1998). Perspectives on the application of biotechnology to assist the genetic enhancement of plantain and banana (*Musa* spp.). *Journal of Biotechnology, 1*, 11-22.

Davey, M.R., Anthony, P., Power, J.B. and Lowe, K.C. (2005). Plant protoplast technology: Current status. *Acta Physiologiae Plantarum, 27,* 117-129.

Davis, A.J., Say, M., Snow, A.J., Grant, B.R., (1994). Sensitivity of *Fusarium oxysporum* f. sp *cubense* to phosphonate. *Plant Pathology. 43*, 200-205.

Davis, J.G. and Wilson, C.R. (2005) Choosing a soil amendment. Fort Collins: Colorado State University. http://www.ext.colostate.edu/pubs/garden/07235.pdf

Deacon, J.W. (1991). Significance of ecology in the development of biocontrol agents against soil-borne pathogens. *Biocontrol Science and Technology, 1,* 5-20.Devliegher, W. and Verstraete, W. (1997). The effect of *Lumbricus terrestris* on soil in relation to plant growth: Effects of nutrient- enrichment processes (NEP) and gut-associated processes (GAP). *Soil Biology and Biochemistry, 29,* 341-346.

Dhingra, O.D., Coelho-Netto, R.A., Rodrigues, F.Á., Silva, G.J. and Maia, C.B. (2006). Selection of endemic non-pathogenic endophytic *Fusarium oxysporum* from bean roots and rhizosphere competent fluorescent

Pseudomonas species to suppress Fusarium-yellow of beans. *Biological control, 39,* 75-86.

Dita, M.A., Waalwijk, C., Buddenhaguen, I.W., Souza, M.T., Kema, G.H.J. (2010). A molecular diagnosis for tropical race 4 of the banana Fusarium wilt pathogen. *Plant Pathology*, *59*, 348–357

Djerbi, M., Aouad, L., Filali, H., Saaidi, M., Chtioui, A., Sedra, M.H., Allaoui, M ., Hamdaoui, T. and Oubrich, M. (1986). Preliminary results of selection of high quality bayoudh-resistant clones among natural date palm population in Morocco. *In: Proceedings of the Second Symposium on the Date Palm. Saudi Arabia*. Pp. 383-399.

Domínguez, J., Negrín, M.A., and Rodríguez, C.M. (2001). Aggregate water-stability, particle size and soil solution properties in conducive and suppressive soils to Fusarium wilt of banana from Canary Islands. *Soil Biology and Biochemistry, 33,* 449-455.

Doube, B.M., Brown, G.G., (1998). Life in a complex community: functional interactions between earthworms, organic matter, microorganisms and plant growth. In: Edwards, C.A. (Ed.), *Earthworm Ecology*. St. Lucie Press, Boca Raton, pp. 179–211.

Doube, B. M., Stephens, P. M., Davoren, C. W., and Ryder, M. H. (1994). Interactions between earthworms, beneficial soil microorganisms and root pathogens. *Applied Soil Ecology, 1,* 3–10.

Duijff, B.J., Pouhair, D., Olivain, C., Alabouvette, C. and Lemanceau, P. (1998). Implication of systemic induced resistance in the suppression of fusarium wilt of tomato by *Pseudomonas fluorescens* WCS 417r and by nonpathogenic *Fusarium oxysporum* Fo47. *European Journal of Plant Pathology, 104,* 903-910.

Durner, J., Shah, J., Klessig, D.F. (1997) Salicylic acid and disease resistance in plants, *Trends in Plant Science., 2*, 266–274.

Durrant, W.E., Dong, X., (2004). Systemic acquired resistance. *Annual Review of Phytopathology, 42,* 185–209.

Edwards, C.A. and Bohlen, P.J. (1996). Biology and ecology of earthworm. (3rd ed.), Chapman and Hall, London. pp. 426.

Edwards, C.A., and Fletcher, K.E. (1988). Interactions between earthworms and microorganisms in organic-matter breakdown. *Agriculture, Ecosystems and Environment, 24*, 235–247.

Eisenhauer, N., Milcu, A., Nitschke, N., Sabais, A. C. W., Scherber, C., and Scheu, S. (2009). Earthworm and belowground competition effects on plant productivity in a plant diversity gradient. *Oecologia*, *161*, 291–301.

Ellis, J., Dodds, P., and Pryor, T. (2000). Structure, function and evolution of plant disease resistance genes. *Current Opinion in Plant Biology*, *3*, 278–284.

Elmer, W.H. (2009). Influence of Earthworm Activity on Soil Microbes and Soilborne Diseases of Vegetables. *Plant Disease, 93*, 175–179.

Elmer, W.H., and Ferrandino, F.J. (2009). Suppression of Verticillium Wilt of Eggplant by Earthworms. *Plant Disease, 93*, 485–489.

Engelberth, J., Alborn, H.T., Schmelz, E.A. and Tumlinson, J.H. (2004) Airborne signals prime plants against insect herbivore attack. *Proceedings of the National Academy of Sciences. U.S.A., 101*, 1781–1785.

Ezawa, T., Yamamoto, K., and Yoshida, S. (2002). Enhancement of the effectiveness of indigenous arbuscular mycorrhizal fungi by inorganic soil amendments. *Soil Science and Plant Nutrition*, *48*, 897-900.

Fan, J. W., Hu, C. L., Zhang, L. N., Li, Z. L., Zhao, F. K., and Wang, S. H. (2014). Jasmonic Acid Mediates Tomato's Response to Root Knot Nematodes. *Journal of Plant Growth Regulation*, 34, 196-205.

FAOSTAT. (2014). http://faostat.fao.org/

Feys, B. J., and Parker, J. E. (2000). Interplay of signaling pathways in plant disease resistance. *Trends in Genetics*, *16*, 449–455.

Flors, V., Ton, J., Van Doorn, R., Jakab, G., García-Agustín, P., & Mauch-Mani, B. (2008). Interplay between JA, SA and ABA signalling during basal and induced resistance against *Pseudomonas syringae* and *Alternaria brassicicola*. *Plant Journal*, *54*, 81–92.

Forcat, S., Bennett, M. H., Mansfield, J. W., and Grant, M. R. (2008). A rapid and robust method for simultaneously measuring changes in the

phytohormones ABA, JA and SA in plants following biotic and abiotic stress. *Plant Methods*, *4*, 16.

Fourie, G., Steenkamp, E. T., Ploetz, R. C., Gordon, T. R., & Viljoen, A. (2011). Current status of the taxonomic position of *Fusarium oxysporum* formae specialis *cubense* within the *Fusarium oxysporum* complex. *Infection, Genetics and Evolution*, *11*, 533–542.

Fravel, D., Olivain, C. and Alabouvette, C. (2003). *Fusarium oxysporum* and its biocontrol. *New Phytologist, 157*, 493-502.

Friedrich, L., Lawton, K., Ruess, W., Masner, P., Specker, N., Gut Rella, M, Meier, B., Dincher, S., Staub, T., Uknes, S., Métraux, J.P., Kessmann, H. and Ryals, J. (1996). A benzothiadiazole derivative induces systemic acquired resistance in tobacco. *The Plant Journal, 10*, 61-70.

Fuchs, J.G., Moënne-Loccoz, Y. and Défago, G. (1997). Non-pathogenic *Fusarium oxysporum* strain Fo47 induces resistance to Fusarium wilt in tomato. *Plant Disease, 81,* 492-496.

Gaffney, T., Friedrich, L., Vernooij, B., Negrotto, D., Nye, G., Uknes, S., Ward, E., Kessmann, H., Ryals, J. (1993) Requirement of salicylic acid for the induction of systemic acquired resistance. *Science, 261,* 754–756

Ganapathi, T.R., Higgs, N.S., Balint-Kurti, P.J., Arntzen, C.J., May, G.D. and Van Eck, J.M. (2001). Agrobacterium-mediated transformation of the embryogenic cell suspensions of the banana cultivars Rasthali (AAB). *Plant Cell Reports, 20,* 157-162.

Garbeva, P., Postma, J., Van Veen, J. A., and Van Elsas, J. D. (2006). Effect of above-ground plant species on soil microbial community structure and its impact on suppression of *Rhizoctonia solani* AG3. *Environmental Microbiology, 8*, 233–246.

Garcia, J.A and Fragoso, C. (2002). Growth, reproduction and activity of earthworm in degraded and amended tropical open mined soils: laboratory assays. *Applied soil ecology, 20*, 43-56

Geering, A.D.W. (2009).Viral pathogens of banana: outstanding questions and options for control. *Acta Horticulturae, 828*, 39–50

Genoud, T., Buchala, A. J., Chua, N. H., and Métraux, J. P. (2002). Phytochrome

signalling modulates the SA-perceptive pathway in Arabidopsis. *Plant Journal*, *31*, 87–95.

Gerlach, W. and Nirenberg, H. (1982). The Genus *Fusarium* – A Pictorial Atlas. Paul Parey. Berlin. Germany. 406pp.

Getha, K. and Vikineswary, S. (2002) Antagonistic effects of *Streptomyces violaceusniger* strain G10 on *Fusarium oxysporum* f. sp. *cubense* race 4: Indirect evidence for the role of antibiosis in the antagonistic process. *Journal of Industrial Microbiology and Biotechnology, 28*, 303–310.

Glazebrook, J. (2005) Contrasting mechanisms of defense against biotrophic and necrotrophic pathogens. *Annual Review of Phytopathology, 43*, 205-227.

Görres, J. H., Savin, M. C., Neher, D. A., Weicht, T. R., Amador, J. A., (1999) Grazing in a porous environment: 1. The effect of pore structure on C and N mineralization. *Plant and Soil, 212*, pp. 75–83

Green, R. J. (1981). An overview. In: *Fungal wilt diseases of plants,* Mace, M.E., Bell, A. A. and Beckman, C. H. (eds.). Academic Press, New York. Pp. 1-21.

Gullino, M. L., Minuto, A., Gilardi, G. and Garibaldi, A. (2002). Efficacy of azoxystrobin and other strobilurins against Fusarium wilts of carnation, cyclamen and Paris daisy. *Crop Protection, 21,* 57-61.

Haas, D. and Défago, G. (2005). Biological control of soil-borne pathogens by *Fluorescent pseudomonads*. *Nature Reviews Microbiology, 3*, 307-319.

Handreck, K. A. and Black, N. D. (2002). Growing media for ornamental plants and turf. New South Wales University Press, Kensington, Australia. pp. 550

Harman, G.E., Howell, C.R., Viterbo, A., Chet, I. and Lorito, M. (2004). *Trichoderma* species: opportunistic, avirulent plant symbionts. *Nature reviews Microbiology, 2,* 43-56.

Haware, M.P., Narayana, R.J. and Pundir, R.P.S. (1992). Evaluation of wild *Cicer* species for resistance to four chickpea diseases. *International Chickpea Letter, 27,* 16-18.

Heil, M., and Bostock, R.M. (2002). Induced systemic resistance (ISR) against pathogens in the context of induced plant defences. *Annals of Botany, 89*, 503–512.

Henrot, J. and Brussaard, L. (1997). Abundance, casting activity, and cast quality of earthworms in an acid Ultisol under alley-cropping in the humid tropics. *Applied Soil Ecology, 6*, 169-179.

Herbert, J.A. and Marx, D. (1990). Short-term control of Panama disease of bananas in South Africa. *Phytophylactica, 22,* 339-340.

Höfte, M. (1993). Classes of microbial siderophores. In: *Iron chelation in plants and soil microorganisms*, Barton, L.L. and Hemming, B.C. (eds). Academic Press, San Diego, California. Pp. 3-26.

Hoitink, H.A.J., Boehm, M.J. and Hadar, Y. (1993). Mechanisms of suppression of soilborne plant pathogens in compost-amended substrates. In: *Science and Engineering of Composting: Design, Environmental, Microbiological and Utilization Aspects*, Hoitink, H.A.J. and Keener, H.M. (eds). Renaissance Publications. Worthington. OH. Pp. 601–621.

Hoogerkamp, M., Rogaa, H., Eijsackers, H. J. P. (1983) Effect of earthworms on grassland on recently reclaimed polder soils in the Netherlands. In: *Satchell JE (ed) Earthworm Ecology*. Chapman & Hall, London, pp 85–105

Huber, D.M. and Watson, R.D. (1974). Nitrogen form and plant disease. *Annual Review of Phytopathology, 12,* 139-165.

Husain, M., and William, R. (2011) Status of Banana Cultivation and Diseases Incidences in Malaysia. *Paper presented at the Workshop on 'Integrated Approaches in Banana Disease Management'*, in MAEPS, Serdang, Malaysia on 22nd March 2011

Hwang, S.C. (1999). Recent development on Fusarium R&D of banana in Taiwan. In: *Banana Fusarium wilt management: Towards sustainable cultivation*. *Proceedings of the International Workshop on banana Fusarium wilt disease,* Molina, A.B., Masdek, N.H.N., and Liew, K.W. (eds). Genting Highlands Resort, Malaysia. Pp. 39-49.

Hwang, S.C. and Ko, W.H. (2004). Cavendish banana cultivars resistant to

Fusarium wilt acquired through somaclonal variation in Taiwan. Plant Disease *88*, 580- 588.

Jain, S.M. (2001). Tissue culture derived variation in crop improvement. *Euphytica, 118,* 153-166.

Jana, U., Barot, S., Blouin, M., Lavelle, P., Laffray, D., and Repellin, A. (2010). Earthworms influence the production of above- and belowground biomass and the expression of genes involved in cell proliferation and stress responses in *Arabidopsis thaliana*. *Soil Biology and Biochemistry, 42*(2), 244–252.

Jones, J.B., Jones, J.P., Stall, R.E. and Zitter, T.A. (1991). Compendium of Tomato Diseases. *American Phytopathological Society, 28*(3), 370

Jones, J.P., Engelhard, A.W. and Woltz, S.S. (1989). Management of fusarium wilt of vegetables and ornamentals by macro- and microelement nutrition. In: *Soilborne Plant Pathogens: Management of Diseases with Macro- and Microelements,* A.W. Engelhard (ed). *American Phytopathological Society*. Pp. 18–32.

Jones, D.R. (2000). Diseases of Banana, Abaca and Enset. (ed.) Oxfordshire, UK: CABI

Jongmans, A.G., Pulleman, M.M., Marinissen, J.C.Y., (2001). Soil structure and earthworm activity in a marine silt loam under pasture versus arable land. *Biology and Fertility of Soils, 33*, 279–285.

Jouquet, P., Bottinelli, N., Podwojewski, P., Hallaire, V., Tran Duc, T. (2008). Chemical and physical properties of earthworm casts as compared to bulk soil under a range of different land-use systems in Vietnam. *Geoderma, 146*, 231-238.

Khan, M.R. and Khan, S.M. (2002). Effects of root-dip treatment with certain phosphate solubilizing microorganisms on the fusarial wilt of tomato. *Bioresource Technology, 85,* 213-215.

Khodary, S. E. (2004). Effect of Salicylic Acid on the Growth, Photosynthesis and Carbohydrate Metabolism in Salt Stressed Maize Plants. *International Journal of Agriculture & Biology*, *6*, 5–8.

Kistler, H.C. and Miao, V. (1992). New modes of genetic change in

filamentous fungi. *Annual Review of Phytopathology, 30*, 131-152.

Kjemtrup, S., Nimchuk, Z., and Dangl, J. L. (2000). Effector proteins of phytopathogenic bacteria: Bifunctional signals in virulence and host recognition. *Current Opinion in Microbiology. 3*, 73-78

Koornneef A and Pieterse C. M. J. (2008) Cross-talk in defense signaling. *Plant Physiology, 146,* 839–844

Kumar, D. (2014). Salicylic acid signaling in disease resistance. *Plant Science, 228*, 127–134.

Laffan, M. D., and Kingson, T. J. (1997). Earthworms in some Tasmanian forest soils in relation to bioturbation and soil texture profile. *Australian Journal of Soil Research*, *35*, 1231–1243.

Laossi, K.R., Ginot, A., Noguera, D.C., Blouin, M., and Barot, S. (2010). Earthworm effects on plant growth do not necessarily decrease with soil fertility. *Plant and Soil, 328*, 109–118.

Larkin, R.P. and Fravel, D.R. (2002). Effects of varying environmental conditions on biological control of Fusarium wilt of tomato by nonpathogenic *Fusarium* spp. *Phytopathology, 92*, 1160 – 1166.

Lavelle, P., Melendez, G., Pashanasi, B., Schaefer, R., (1992). Nitrogen mineralization and reorganization in casts of the geophagous tropical earthworm *Pontoscolex corethrurus* (Glossoscolecidae). *Biology and Fertility of Soils, 14*, 49–53.

Le Bayon, R.C. and Binet, F. (2001). Earthworm surface casts affect soil erosion by runoff water and phosphorus transfer in a temperate maize crop. *Pedobiologia*, *45*, 430–442.

Lee, K.E. (1985). Earthworms, Their Ecology and Relationships with Soils and Land Use. Academic Press, Sydney, Australia.

Lee, J.S. (1998). The mechanism of stomatal closing by salicylic acid in *Commelina communis L. J. Plant Biology. 41*, 97–102.

Leeman, M., Den Ouden, F.M., van Pelt, J.A., Dirks, F.P.M., Steijl, H., Bakker, P.A.H.M. and Schippers, B. (1996). Iron availability affects

induction of systemic resistance to Fusarium wilt of radish by *Pseuomonas fluorescens*. *Disease Control and Pest Management, 86,* 149-155.

Leong, J. (1986). Siderophores: their biochemistry and possible role in biocontrol of plant pathogens. *Annual Review of Phytopathology, 25*, 187-209.

Leon-Reyes, A., Van der Does, D., De Lange, E. S., Delker, C., Wasternack, C., Van Wees, S. C. M., Ritsema, T., Pieterse, C. M. J. (2010). Salicylate-mediated suppression of jasmonate-responsive gene expression in arabidopsis is targeted downstream of the jasmonate biosynthesis pathway. *Planta*, *232*, 1423–1432.

Leslie, J.F. and Summerell, B.A. (2006). The Fusarium Laboratory Manual. Blackwell Publishing Ltd, Iowa. Pp. 212-218

Lugtenberg, B.J.J. and Dekkers, L.C. (1999). What make *Pseudomonas* bacteria rhizosphere competent? *Environmental Microbiology*, *1,* 9-13.

Lugtenberg, B. J. J., Kravchenko, L. V. and Simons, M. (1999). Tomato seed and root exudate sugars: composition, utilization by *Pseudomonas* biocontrol strains, and role in rhizosphere colonization. *Environmental Microbiology, 1,* 439-446.

Maeda, T., and Ishiwari, H. (2012). Tiadinil, a plant activator of systemic acquired resistance, boosts the production of herbivore-induced plant volatiles that attract the predatory mite *Neoseiulus womersleyi* in the tea plant *Camellia sinensis*. *Experimental and Applied Acarology*, *58*, 247–258.

Mak, C., Mohamed, A.A., Liew, K.H., Ho, Y.W., *et al*. (2004) Early screening technique for Fusarium wilt resistance in banana micropropagated plants. *Banana improvement, 18,* 219-227

Malarkey, T. (2003). Human health concerns with GM crops. *Mutation Research, 544*, 217-221.

Marhan S, Scheu S (2005). The influence of mineral and organic fertilisers on the growth of the endogeic earthworm, *Octolasion tyrtaeum* (Savigny). *Pedobiologia, 49,* 239-249.

Marshall, G. (1993). Recent developments in flax breeding relevant to

production technologies. *Industrial Crops and Products, 1,* 273-281.

Martin, G.B. (1999) Functional analysis of plant disease resistance genes and their downstream effectors. *Current Opinion in Plant Biology. 2*, 273–279

Miguel, A., Maroto, J.V., San Bautista, A., Baixauli, C., Cebolla, V., Pascual, B., López, S. and Guardiolo, J.L. (2004). The grafting of triploid watermelon is an advantageous alternative to soil fumigation by methylbromide for control of *Fusarium* wilt. *Scientia Horticulturae, 103,* 9-17.

Molina, A. B., Fabregar, E., Sinohin, V. G., Yi, G., and Viljoen, A. (2009). Recent occurrence of *Fusarium oxysporum* f. sp*. cubense* tropical race 4 in Asia. *Acta Horticulturae, 828*, 109–116.

Moore, N.Y., Pegg, K.G., Smith, L.J., Langdon, P.W., Bentley, S. and Smith, M.K. (1999). Fusarium wilt of banana in Australia. In: *Banana Fusarium wilt management: Towards sustainable cultivation*. *Proceedings of the International Workshop on banana Fusarium wilt disease,* Molina, A.B., Masdek, N.H.N. and Liew, K.W. (eds). Genting Highlands Resort, Malaysia. Pp. 64-75.

Morris, K., MacKerness, S.A., Page, T., John, C.F., Murphy, A.M., Carr, J.P., Buchanan-Wollaston, V. (2000). Salicylic acid has a role in regulating gene expression during leaf senescence. *Plant Journal, 23*, 677–685.

Nel, B., Steinberg, C., Labuschagne, N. and Viljoen, A. (2006). The potential of nonpathogenic *Fusarium oxysporum* and other biological control organisms for suppressing fusarium wilt of banana. *Plant Pathology, 55,* 217-223.

Nel, B., Steinberg, C., Labuschagne, N. and Viljoen, A. (2007). Evaluation of fungicides and sterilants for potential application in the management of Fusarium wilt of banana. *Crop Protection, 26*, 697-705.

Nelson, P.E., Toussoun, T.A. and Marasas W.O. (1983). Fusarium species. An Illustrated Guide for Identification. Pennsylvania State University Press. University Park. USA. Pp. 193.

Niemann, G.J., Baayen, R.P. and Boon, J.J. (1990). Localization of phytoalexin accumulation and determination of changes in lignin and carbohydrate composition in carnation (*Dianthus caryophyllus* L.) xylem

as a consequence of infection with *Fusarium oxysporum* f. sp. *dianthi* by pyrolysis-mass spectrometry. *European Journal of Plant Pathology, 96*, 133-153.

Niki, T., Mitsuhara, I., Seo, S., Ohtsubo, N. and Ohashi, Y. (1998) Antagonistic effect of salicylic acid and jasmonic acid on the expression of pathogenesis- related (PR) protein genes in wounded mature tobacco leaves. *Plant and Cell Physiology, 39,* 500–507.

Okubara, P.A. and Paulitz, T.C. (2005) Root defense responses to fungal pathogens: a molecular perspective. *Plant Soil, 274*, 215–226

Oleĭnik, A.S., and Byzov, B.A. (2008). Response of bacteria to earthworm surface excreta. *Mikrobiologiia, 77*, 854–862.

Olivain, C., Humbert, C., Nahalkova, J., Fatehi, J., L'Haridon, F. and Alabouvette, C. (2006). Colonization of tomato root by pathogenic and non-pathogenic *Fusarium oxysporum* strains inoculated together and separately into the soil. *Applied and Environmental Microbiology, 72,* 1523-1531.

Olivain, C., Steinberg, C. and Alabouvette, C. (1995). Evidence of induced resistance in tomato inoculated by non-pathogenic strains of *Fusarium oxysporum*. In: *Environmental Biotic Factors in Integrated Plant Disease Control*, Manka, M. (ed). The Polish Phytopathological Society, Poznan, Poland. Pp. 427-430.

Oostendorp, M., Kunz, W., Dietrich, B. and Staub, T. (2001). Induced disease resistance in plants by chemicals. *European Journal of Plant Pathology, 107,* 19- 28.

Palm, J., van Schaik, N. L. M. B., and Schröder, B. (2013). Modelling distribution patterns of anecic, epigeic and endogeic earthworms at catchment-scale in agro-ecosystems. *Pedobiologia*, *56*, 23–31.

Papavizas, G.C. (1969). Survival of root-infecting fungi in soil. XI: Survival of *Rhozoctonia solani* as affected by inoculum concentration and various soil amendments. *Phytopathology, 64,* 101-111.

Pattison, T., Lindsay, S., (2006). Banana Root and Soil Health User's Manual: FR02023. Soil and Root Health for Sustainable Banana Production. The State of Queensland, Department of Primary Industries and Fisheries, Australia.

Pei, X.W., Chen, S.K., Wen, R.M., Ye, S., Huang, J.Q., Zhang, Y.Q., Wang, B.S., Wang, Z.X. and Jia, S.R. (2005). Creation of transgenic banana expressing human lysozyme gene for Panana wilt resistance. *Journal of Integrative Plant Biology, 4,* 971-977.

Pelosi, C., Bertrand, M., Thénard, J., and Mougin, C. (2015). Earthworms in a 15 years agricultural trial. *Applied Soil Ecology, 88,* 1–8.

Pelosi, C., Toutous, L., Chiron, F., Dubs, F., Hedde, M., Muratet, A., Ponge, J. F., Salmon, S., Makowski, D. (2013). Reduction of pesticide use can increase earthworm populations in wheat crops in a European temperate region. *Agriculture, Ecosystems and Environment*, *181*, 223–230.

Peña JE, Sharp JL, Wysoki, M. (2002). Tropical Fruit Pests and Pollinators: *Biology, Economic Importance, Natural Enemies, and Control.* (eds.) Wallingford, UK: CABI

Peng, H.X., Sivasithamparam, K. and Turner, D.W. (1999). Chlamydospore germination and Fusarium wilt of banana plantlets in suppressive and conducive soils are affected by physical and chemical factors. *Soil Biology and Biochemistry, 31,* 1363-1374.

Pérez-vicente, L., and Dita, M. A. (2014). Technical Manual Prevention and diagnostic of Fusarium Wilt (Panama disease) of banana caused by Technical Manual Prevention and diagnostic of Fusarium Wilt (Panama disease) of banana caused by *Fusarium oxysporum* f . sp . *cubense. Tropical, 4* (May), 1–74

Pieterse, C. M. J., Leon-Reyes, A., Van der Ent, S., and Van Wees, S. C. M. (2009). Networking by small-molecule hormones in plant immunity. *Nature Chemical Biology, 5,* 308–316.

Pieterse, C.M.J., Van Pelt, J.A., Van Wees, S.C.M., Ton, J., Léon-Kloosterziel, K.M., Keurentjies, J.J.B., Verhagen, B.W.M., Knoester, M., Van der Sluis, I., Bakker, P.A.H.M. and Van Loon, L.C. (2001). Rhizobacteria-mediated induced systemic resistance: triggering, signaling and expression. *European Journal of Plant Pathology, 105,* 51-61.

Pieterse, C.M.J., Van Wees, S.C.M., Hoffland, E., Van Pelt, J.A. and Van Loon, L.C. (1996). Systemic resistance in *Arabidopsis* induced by biocontrol bacteria is independent of salicylic acid accumulation and pathogenesis-related gene expression. *Plant Cell, 8,* 1225-1237.

Pieterse, C.M.J., Van Wees, S.C.M., Van Pelt, J.A., Knoester, M., Laan, R., Gerrits, H., Weisbeck, P.J., Van Loon, L.C. (1998). A novel signaling pathway controlling induced systemic resistance in *Arabidopsis*. *Plant Cell, 10*, 1571–1580.

Pieterse, C.M.J., Van Wees, S.C.M., Ton, J., Van Pelt, J.A. and Van Loon, L.C. (2002). Signaling in rhizobacteria induced systemic resistance in *Arabidopsis thaliana*. *Plant Biology, 4*, 535–544

Ploetz, R. C. (1990). Fusarium Wilt of Banana. Minnesota, US. APS. p. 139

Ploetz, R. C. (2006). Fusarium Wilt of Banana Is Caused by Several Pathogens Referred to as *Fusarium oxysporum* f. sp. *cubense*. *Phytopathology, 96*(6), 653–656.

Ploetz, R. C. (2007). Diseases of tropical perennial crops: challenging problems in diverse environments. *Plant Disease. 91*, 644-663

Ploetz, R. C. (2015). Management of Fusarium wilt of banana: A review with special reference to tropical race 4. *Crop Protection, 73*, 7–15.

Ploetz, R. C, and Bentley, S. (2001). Workshop reports. Pathogen diversity. In: *Banana Fusarium Wilt Management: Towards Sustainable Cultivation*. Molina, A. B., Masdek, N. H. N., and Liew, K. W. (eds.) International Network for the Improvement of Banana and Plantain. Los Baños, Philippines. Pp. 293-294

Ploetz, R.C. and Pegg, K.G. (2000). Fungal diseases of the root, corm and Pseudostem. In: Disease of banana, abaca and enset, Jones, D. (ed). CABI Publications, London.

Ploetz, R. C., Thomas, J. E., and Slabaugh, W. R. (2003). Diseases of banana and plantain. *America*, 73–134.

Poonam, S., Kaur, H., and Geetika, S. (2013). Effect of Jasmonic acid on photosynthetic pigments and stress markers in *Cajanus cajan* (L.) Mill sp. seedlings under copper stress. *American Journal of Plant Sciences, 4*, 817-823.

Puga-Freitas, R., and Blouin, M. (2014). A review of the effects of soil organisms on plant hormone signalling pathways. *Environmental and Experimental Botany. 114,* 104-116

Rajou, L., Belghazi, M., Huguet, R., Robin, C., Moreau, A., Job, C., Job, D. (2006) Proteomic investigation of the effect of salicylic acid on *Arabidopsis* seed germination and establishment of early defense mechanisms. *Plant Physiology, 141*, 910–923.

Ram, R., Manuja, S., Dhyani, D. and Mukherjee, D. (2004). Evaluations of fortified fungicide solutions in managing corm rot disease of gladiolus caused by *Fusarium oxysporum*. *Crop Protection, 23,* 783-788.

Rao, M.V., Lee, H.I., Davis, K.R. (2002). Ozone-induced ethylene production is dependent on salicylic acid, and both salicylic acid and ethylene act in concert to regulate ozone-induced cell death. *Plant Journal, 32*, 447–456.

Reuveni, R., Raviv, M., Krasnovsky, A., Freiman, L., Medina, S., Bar, A. and Orion, D. (2002). Compost induces protection against *Fusarium oxysporum* in sweet basil. *Crop Protection, 21,* 583-587.

Rigert, K.S. and Foster, K.W. (1987). Inheritance of resistance to two races of Fusarium wilt in three cowpea cultivars. *Crop Science, 27,* 220-224.

Rivas-San Vicente, M., and Plasencia, J. (2011). Salicylic acid beyond defence: Its role in plant growth and development. *Journal of Experimental Botany, 62*, 3321–3338.

Römbke, J., Jänsch, S., Didden, W. (2005). The use of earthworms in ecological soil classification and assessment concepts, *Ecotoxicology and Environmental Safety, 62,* 249-265.

Sabrina, D. T., Hanafi, M. M., Azwady Nor, A. A., and Mahmud, T. M. M. (2009). Earthworm Populations and Cast Properties in the Soils of Oil Palm Plantations. *Malaysian Journal of Soil Science, 13,* 29–42.

Sági, L., Panis, B., Remy, S., Schoofs, H., De Smet, K., Swennen, R. and Cammue, (1995). Genetic transformation of banana (*Musa* spp.) *via* particle bombardment. *Biological Technology, 13,* 481-485.

Santner, A., and Estelle, M. (2009). Recent advances and emerging trends in plant hormone signalling. *Nature, 459*, 1071–1078.

Santner, A., Calderon-Villalobos, L. I. A., and Estelle, M. (2009). Plant hormones are versatile chemical regulators of plant growth. *Nature Chemical Biology, 5*, 301–307.

Sawyer, M., and Kumar, V. (2003). A rapid high-performance liquid chromatographic method for the simultaneous quantitation of aspirin, salicylic acid, and caffeine in effervescent tablets. *Journal of Chromatographic Science*, *41*(8), 393–397.

Schenk, P.M., Kazan, K., Wilson, I., Anderson, J.P., Richmond, T., Somerville, S.C. and Manners, J.M. (2000) Coordinated plant defense responses in *Arabidopsis* revealed by microarray analysis. *Proceedings of the National Academy of Science USA*, *97,* 11655–11660.

Scher, F.M. and Baker, K.F. (1982). Effect of *Pseudomonas putida* and a synthetic iron chelator on induction of soil suppressiveness to Fusarium wilt pathogens. *Phytopathology, 72,* 1567-1573.

Scheu, S. (1987). Microbial activity and nutrient dynamics in earthworm casts (Lumbricidae). *Biology and Fertility of Soils*, *5*, 230–234.

Schouten, A., Van den Berg, G. Edel-Hermann, V., Steinberg, C., Gautheron, N., Alabouvette, C., de Vos, C.H., Lemanceau, P. and Raaijmakers, J. (2004). Defense responses of *Fusarium oxysporum* to 2,4-diacetylphlorolucinol, a broad-spectrum antibiotic produced by *Pseudomonas fluorescens*. *Molecular Plant-Microbe Interactions, 17,* 1201-1211.

Shah, J., Kachroo, P., and Klessig, D.F. (1999). The Arabidopsis ssi1 mutation restores pathogenesis-related gene expression in npr1 plants and renders defensin gene expression salicylic acid dependent. *Plant Cell, 11*, 191–206.

Shahin, E.A. and Spivey, R. (1986). A single dominant gene for Fusarium wilt resistance in protoplasts-derived tomato plants. *Theoretical and Applied Genetics, 73,* 164-169.

Shen, C.Y. (1985). Integrated management of *Fusarium* and *Verticillium* wilts of cotton in China. *Crop Protection, 4,* 337-345.

Shobha, S.V. and Kale, R. (2006). Antimicrobial potency of *Eudrilus*

eugeniae extracts on certain plant pathogens, *Abstract from 8th International Symposium on Earthworm Ecology*, Kracow, p. 245.

Siegrist, J., Orober, M. and Buchenauer, H. (2000). ß-Aminobutyric acid-mediated enhancement of resistance in tobacco to tobacco mosaic virus depends on the accumulation of salicylic acid. *Physiological Molecular Plant Pathology, 56,* 95-106.

Simons, M., Permentier, H.P., de Weger, L.A., Wijffelman, C.A. and Lugtenberg, B.J.J. (1997). Amino acid synthesis is necessary for tomato root colonization by *Pseudomonas fluorescens* strain WCS365. *Molecular Plant-Microbe Interactions, 10,* 102-106.

Sivan, A. and Chet, I. (1986). Biological control of *Fusarium* spp. in cotton, wheat and muskmelon by *Tricoderma harzianum*. *Journal of Phytopathology, 116,* 39-47.

Sivan, A. and Chet, I. (1989). The possible role of competition between *Trichoderma harzianum* and *Fusarium oxysporum* on rhizosphere colonization. *Phytopathology, 79,* 198-203.

Sivan, A. and Chet, I. (1993). Integrated control of fusarium crown and root rot of tomato with *Trichoderma harzianum*n in combination with methyl bromide. *Crop Protection, 12,* 380-386.

Smith, C.J. (1996) Accumulation of phytoalexins: defense mechanism and stimulus response system. *New Phytologist, 132,* 1–45

Smith, J.J., Jones, D.R., Karamura, E., Blomme, G., Turyagyenda, F.L. (2008). An analysis of the risk from *Xanthomonas campestris* pv. *musacearum* to banana cultivation in Eastern, Central and Southern Africa. *Bioversity International*. Rome.

Smith, J. L., De Moraes, C. M., and Mescher, M. C. (2009). Jasmonate- and salicylate-mediated plant defense responses to insect herbivores, pathogens and parasitic plants. *Pest Management Science*, *65*, 497–503.

Snyder, W.C. and Hansen, H.N. (1940). The species concept in Fusarium. *American Journal of Botany, 27,* 64-67

Snyder, W.C. and Smith, S.N. (1981). Current status. In: *Fungal Wilt Diseases of Plants,* Mace, M.E., Bell, A.A. and Beckman, C.H. (eds.). Academic Press. New York.

Stacey, G., Mc Alvin, C.B., Kim, S.Y., Olivares, J., Soto, M.J. (2006) Effects of endogenous salicylic acid on nodulation in the model legumes *Lotus japonica*s and *Medicago truncatula. Plant Physiology, 141*, 1473–1481.

Sticher, L., Mauch-Mani, B. and Métraux, J.P. (1997). Systemic acquired resistance. *Annual Review of Phytopathology, 35,* 235-270.

Stinner, B. R., Mccartney, D. A., Blair, J. M., Parmelee, R. W., and Allen, M. F. (1997). Earthworm effects on crop and weed biomass, and N content in organic and inorganic fertilized agroecosystems. *Soil Biology and Biochemistry*, *29*(3-4), 423–426.

Stover, R.H. (1962). Fusarial wilt (Panama Disease) of bananas and other Musa. Commonwealth Mycological Institute, Kew, UK.

Stover, R.H. (1986). Disease management strategies and the survival of the banana industry. *Annual Review of Phytopathology, 24,* 83–91

Stover, R.H. and Simmonds, N.W. (1987). Bananas (3rd ed.). Longman. London, UK.

Stover, R.H. (1972) Banana plantain and abaca diseases. Commonwealth Mycological Institute: Kew, G.B.

Stratmann, J. W. (2003). Long distance run in the wound response - Jasmonic acid is pulling ahead. *Trends in Plant Science*, *8*(6), 247-250

Su, H., Hwang, S. and Ko, W. (1986). Fusarial wilt of Cavendish bananas in Taiwan. *Plant Disease, 70,* 814-818.

Takahashi, H., Kanayama, Y., Zheng, M. S., Kusano, T., Hase, S., Ikegami, M., and Shah, J. (2004). Antagonistic interactions between the SA and JA signaling pathways in Arabidopsis modulate expression of defense genes and gene-for-gene resistance to cucumber mosaic virus. *Plant and Cell Physiology*, *45*, 803–809.

Tamietti, G. and Valentino, D. (2006). Soil solarization as an ecological method for the control of Fusarium wilt of melon in Italy. *Crop Protection, 25,* 389-397.

Teng, S.K., Aziz, N. A. A., Mustafa, M., Laboh, R., Ismail, I. S., and Devi, S. (2016). Potential role of endogeic earthworm *Pontoscolex corethrurus* in remediating banana blood disease: a preliminary observation. *European Journal of Plant Pathology, 145,* 321-330

Tengku Ab. Malik, T.M., Rozeita, L., Maimun, T., and Umikalsum, M.B. (2011). Status of banana disease research in Malaysia. *Paper presented at the Workshop on 'Integrated Approaches in Banana Disease Management'*, in MAEPS, Serdang, Malaysia on 22nd March 2011.

Thangavelu, R., Mustaffa, M.M., (2012). Current advances in the Fusarium wilt disease management in banana with emphasis on biological control. In: Cumagun, C.J. (Ed.), *Plant Pathology*. *InTech,* pp. 273-298.

Thomma, B.P.H.J., Eggermont, K., Penninckx, I.A.M.A., Mauch-Mani, B., Vogelsang, R., Cammue, B.P.A. and Broekaert, W.F. (1998) Separate jasmonate-dependent and salicylate-dependent defense-response pathways in Arabidopsis are essential for resistance to distinct microbial pathogens. *Proceedings of the National Academy of Science USA, 95,* 15107–15111.

Tomati, U., Grappelli, A., and Galli, E. (1988). The hormone-like effect of earthworm casts on plant growth. *Biology and Fertility of Soils, 5*(4), 288–294.

Ton, J., D'Alessandro, M., Jourdie, V., Jakab, G., Karlen, D., Held, M., Mauch-Mani, B. and Turlings, T.C.J. (2006) Priming by airborne signals boosts direct and indirect resistance in maize. *Plant Journal, 49*, 16–26.

Topoliantz, S., and Ponge, J. F. (2003). Burrowing activity of the geophagous earthworm *Pontoscolex corethrurus* (Oligochaeta: Glossoscolecidae) in the presence of charcoal. *Applied Soil Ecology, 23*, 267–271.

Tripathi, L., Mwangi, M.M., Abele, S., Aritua, V., Tushemereirwe, W.K., Bandyopadhyay, R. (2009). Xanthomonas wilt. A threat to banana production in East and Central Africa. *Plant Disease, 93,* 440–51

Turner, J. G., Ellis, C., and Devoto, A. (2002). The Jasmonate Signal Pathway. *Signal Transduction*, 153–165.

Uesugi, Y. (1998). Fungicide classes: Chemistry, uses and mode of action. In: *Fungicide activity, chemical and biological approaches to plant protection*, Hutson, D. and Miyamoto, J. (eds.). Wiley, Chichester, England. Pp. 23-56.

Ulloa, M., Hutmacher, R.B., Davis, R.M., Wright, S.D., Percy, R. and Marsh, B. (2006). Breeding for Fusarium wilt race 4 resistance in cotton under field and greenhouse conditions. *The Journal of Cotton Science, 10,* 114-127.

Vallad, G.E. and Goodman, R.M. (2004). Systemic acquired resistance and induced systemic resistance in conventional agriculture. *Crop Science, 44,* 1920-1934.

Vanacker, H., Lu, H., Rate, D.N., Greenberg, J.T. (2001) A role for salicylic acid and NPR1 in regulating cell growth in Arabidopsis*. Plant Journal, 28*, 209–216.

Van Bel, A.J.E., Hibberd, J., Prüfer, D. and Knoblauch, M. (2001). Novel approach in plastid transformation. *Current Opinion in Biotechnology, 12,* 144-149.

Van den Bulk, R.W., Löffer, H.J.M., Lindhout, W.H. and Koornneef, M. (1990). Somoclonal variation in tomato: effect of explant source and a comparison with chemical mutagenesis. *Theoretical and Applied Genetics, 80,* 817-825.

Van Hulten, M., Pelser, M., van Loon, L.C., Pieterse, C.M.J. and Ton, J. (2006) Costs and benefits of priming for defense in Arabidopsis. *Proceedings of the National Academy of Sciences U.S.A., 103*, 5602–5607.

Van Loon, L.C., Pierpoint, W.S., Boller, T. and Conejero, V. (1994) Recommendations for naming plant pathogenesis-related proteins. *Plant Molecular Biology Reporter, 12*, 245–264.

Van Loon, L.C. (1997). Induced resistance in plants and the role of pathogenesis- related protein. *European Journal of Plant Pathology, 103,* 753-765.

Van Loon, L.C., Bakker, P.A.H.M. and Pieterse, C.M.J. (1998). Systemic resistance induced by rhizosphere bacteria. *Annual Review of Phytopathology, 36,* 453- 483.

Van Loon, L. C. (2007). Plant responses to plant growth-promoting rhizobacteria. *European Journal of Plant Pathology, 119*, 243–254.

Van Wees, S. C., de Swart, E. a, van Pelt, J. a, van Loon, L. C., and Pieterse, C. M. (2000). Enhancement of induced disease resistance by simultaneous activation of salicylate- and jasmonate-dependent defense pathways in *Arabidopsis thaliana*. *Proceedings of the National Academy of Sciences of the United States of America*, *97*, 8711–8716.

Welbaum, G., Sturz, A.V., Dong, Z. and Nowak, J. (2004). Fertilizing soil microorganisms to improve productivity of agro-ecosystems. *Critical Review of Plant Science, 23*, 175-193.

Weststeijn, G. (1973). Soil sterilization and glasshouse disinfection to control *Fusarium oxysporum* f. sp. *lycopersici* in tomatoes in the Netherlands. *European Journal of Plant Pathology, 79,* 36-40.

Whipps, J.M. (2001). Microbial interactions and biocontrol in the rhizosphere. *Journal of Experimental Botany, 52,* 487-511.

Wildermuth, M.C., Dewdney, J., Wu, G., Ausubel, F.M. (2001) Isochorismate synthase is required to synthesize salicylic acid for plant defense. *Nature, 414*, 562–565.

Woltz, S.S. and Jones, J.P. (1981). Nutritional requirements of *Fusarium oxysporum*: basis for a disease control system. In: *Fusarium: diseases, biology and taxonomy,* Nelson, P.E., Toussoun, T.A. and Cook, R.J. (eds.). University Park, PA, USA: State University Press. Pp. 340-349.

Wong, M.H., Crous, P.W., Henderson, J., Groenewald, J.Z., Drenth, A. (2012). *Phyllosticta* species associated with freckle disease of banana. *Fungal Diversity, 56,* 173–87

Wu, J.L., Wu, C., Lei, C., Baraoidan, M., Bordeos, A., Madamba, M.R.S., Ramos- Pamplona, M., Mauleon, R., Portugal, A., Ulat, V.J., Bruskiewich, R., Wang, G., Leach, J., Khush, G. and Leung, H. (2005). Chemical and irradiation induced mutants of Indica rice IR64 for forward and reverse genetics. *Plant Molecular Biology, 59,* 85-97.

Wurst, S., Dugassa-Gobena, D., Langel, R., Bonkowski, M., Scheu, S. (2004) Combined effects of earthworms and vesicular-arbuscular mycorrhizas on plant and aphid performance. *New Phytology, 163*,169–173

Xu, Y., Chang, P.L.C., Liu, D., Narasimhan, M.L., Kashchandra, G.R., Hasegawa, P.M. and Bressan, R.A. (1994) Plant defense genes are synergistically induced by ethylene and methyl jasmonate. *Plant Cell, 6,* 1077–1085.

Zhang, B.H., Liu, F., Yao, C.B. and Wang, K.B. (2000). Recent progress in cotton biotechnology and genetic engineering in China. *Current Science, 79,* 37-44.

Zhang, N., He, X., Zhang, J., Raza, W., Yang, X.M., Ruan, Y.Z., Shen, Q.R., and Huang, Q.W. (2014). Suppression of Fusarium Wilt of Banana with Application of Bio-Organic Fertilizers. *Pedosphere, 24*, 613–624.