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INTEGRATED NUTRIENT MANAGEMENT FOR MAIZE-SOYBEAN CROPPING SYSTEM

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By

ALMAZ MESERET GEZAHEGN

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

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Specially dedicated to

My beloved parents (Mr. Meseret Gezahegn and Mrs. Etenesh Tamene), my husband (Dawit Yilma) and my daughter (Christina Dawit), who inspired, support and encourage me to be a better person.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Doctor of Philosophy

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Novmber 2016

Chairman: Associate Professor Mohd Ridzwan B Abd Halim, Phd
Faculty: Agriculture

Low soil fertility due to monocropping, inadequate fertilizer application, and biomass removal are recognized as the major causes for declining maize and soybean yield. In this regard, two field experiments, one laboratory experiment and economic study of the alternative treatments were conducted at Universiti Putra Malaysia. The first experiment was carried out to evaluate the effect of combined application of poultry manure and inorganic fertilizer on yield, nutrient uptake and quality of maize and soybean intercrops and fertility status of soil. Treatments comprised of combinations of three cropping systems (sole maize, sole soybean, and maize + soybean) and four nutrient management (control, 100% NPK, 100% poultry manure (PM) and 50% NPK + 50% PM). The experiment was laid out in a randomized complete block design (RCBD) with three replications. The number of plants per plot in sole maize, sole soybean and maize + soybean intercropping treatments were 144, 240 and 192, respectively. Results showed that maize + soybean intercropping had greater yield and monetary return than monocropping based on land equivalent ratio (LER) and monetary advantage index (MAI). The combination of 50% NPK+50% PM fertilizer increased maize (28,264 kg/ha) and soybean (3,637 kg/ha) yield to the same level as 100% NPK (28,340 kg/ha and 3,475 kg/ha, respectively) but using 100% PM alone cannot increase the yield to the same level as 100% NPK. Combined application of 50% NPK + 50% PM increased nutritive quality over sole application of either fertilizer. Soil fertility was improved in sole soybean and intercropping of maize with soybean with application of PM alone or combined with NPK fertilizer. The second experiment was conducted by using the plots of the first experiment for each treatment to determine the residual effect of organic manures with supplemental inorganic fertilizers on the performance of the succeeding maize crop and on fertility status of soil. The experiment comprised of 14 treatments, 12 based on the first experiment and two additional treatments for comparison (control and 100% NPK). The treatment was laid out in RCBD with three replications. Results revealed that incorporation of soybean residue + 100% PK (36,500 kg/ha) and soybean residue + 50% residual PM + 50% PK (37,010 kg/ha) can increase maize yield to the same level as 100% NPK (37,290 kg/ha) without

addition of N fertilizer. Combined application of crop residue with a residual PM and PK fertilizer increased nutritive quality over sole application of either fertilizer. The combination of crop residue with residual PM enhanced soil pH, organic matter and nutrient availability in the soil. The third experiment was carried out to determine C and N mineralization patterns during decomposition of individual and mixed maize and soybean residue under laboratory conditions. The experiment was carried out in randomized complete design (CBD) with three replications. The treatments consisted of maize, soybean and maize + soybean residue and control (without residue). The mixture of soil and crop residue was incubated aerobically in the dark at 25^{o}C for 90 days. The result showed the rate of decomposition of crop residue was highly influenced by the C:N ratio and the composition of the cell wall particularly the lignin content. Hence, residues containing soybean had a faster rate of decomposition and released a high amount of N (98.4 mg/kg soil and 67.9 mg/kg soil from soybean and maize + soybean residue, respectively) compared to maize residues (15.05 mg/kg soil). An economic analysis, such as partial budget, dominance, marginal and sensitivity analysis were done for different treatments. According to the economic analysis maize + soybean intercropping with the application of 50% NPK + 50% PM gave the highest net benefit (RM 68,897 ha^{-1}) and rate of return (2169). Incorporation of soybean residue with a residual of 50% PM + 50% PK treatment also gave the highest net benefit (RM 62,507 ha^{-1}) for maize production. Therefore, 50% substitution of inorganic fertilizer with PM for maize and soybean intercrops and substitution of N fertilizer with soybean residue and use of residual PM for the subsequent maize crop is recommended to produce economic and high-quality crop without deteriorating soil fertility.

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

PENGURUSAN NUTRIEN BERSEPADU UNTUK SISTEM PENANAMAN SELINGAN JAGUNG DENGAN-SOYA

Oleh

ALMAZ MESERET GEZAHEGN

November 2016

Pengerusi: Prof. Madya Mohd Ridzwan B Abd Halim, PhD
Fakulti: Pertanian

Kesuburan tanah yang rendah disebabkan oleh kaedah penanaman secara tunggal, pembajaan yang tidak mencukupi dan penyingkiran biomas dikenalpasti sebagai fakor-faktor utama pengurangan hasil tanaman jagung dan soya. Justeru, dua eksperimen lapangan, satu eksperimen di dalam makmal dan ekonomi kajian rawatan alternatif telah dijalankan. Eksperimen pertama dilaksanakan bagi menilai kesan menggabungkan aplikasi baja tahi ayam dan baja kimia terhadap hasil, pengambilan nutrien, dan kualiti tanaman selingan jagung-soya dan sifat-sifat kimia tanah. Rawatan bagi eksperimen ini terdiri daripada tiga kombinasi tanaman (tanaman jagung tunggal, tanaman soya tunggal, dan tanaman selingan jagung dengan soya) dan empat pengurusan nutrient bersepadu (kawalan, 100% NPK, 100% tahi ayam (PM), dan 50% NPK + 50% PM). Percubaan telah dibentangkan dalam rekabentuk blok lengkap (RCBD) dengan tiga replications. Bilangan tumbuhan setiap plot tunggal jagung, kacang soya yang tunggal dan soya jagung intercropping rawatan adalah 144, 240 dan 192, masing-masing. Keputusan kajian mendapati tanaman selingan jagung dengan soya memperoleh hasil paling tinggi dan pulangan kewangan lebih tinggi berbanding tanaman tunggal berdasarkan nisbah setara tanah (LER) dan Indeks kelebihan kewangan (MAI). Kombinasi baja 50% NPK + 50% PM (28,264 kg/ha jagung dan 3,637 kg/ha kacang soya) meningkatkan hasil sama seperti 100% NPK (28,340 kg/ha dan 3,475 kg/ha, masing-masing) tetapi penggunaan 100% PM tidak mampu mencapai pengeluaran hasil seperti 100% NPK. Eksperimen kedua dilaksanakan di plot eksperimen pertama untuk menentukan kesan sisa baja organik yang ditambah dengan baja kimia terhadap prestasi tanaman jagung dan pada sifat-sifat kimia tanah. Eksperimen ini terdiri daripada 14 rawatan, 12 daripadanya adalah daripada plot eksperimen pertama dan tambahan 2 plot lagi untuk tujuan perbandingan (plot kawalan dan 100% NPK). Rawatan yang telah dibentangkan di RCBD dengan tiga replications. Keputusan mendapati bahawa menggunakan sisa tanaman soya sahaja tanpa penambahan baja N (36,500 kg/ha) mampu meningkatkan hasil jagung setara dengan pengeluaran hasil oleh 100% NPK (37,290 kg/ha). Gabungan aplikasi sisa tanaman dan sisa baja PM dan NPK meningkatkan kualiti nutrisi melebihi aplikasi yang hanya menggunakan baja PM

atau PK. Kombinasi sisa tanaman dan sisa baja PM pula telah meningkatkan pH tanah, bahan organik, dan kedapatan nutrien dalam tanah. Eksperimen ketiga dijalankan di dalam makmal bagi menentukan kadar penguraian N oleh jagung, soya dan campuran sisa tanaman. Eksperimen telah dijalankan di Keratan rekabentuk lengkap (CBD) dengan tiga replications. Campuran tanah dan sisa tanaman diinkubasi dengan kehadiran oksigen dan dalam berkeadaan gelap pada suhu 25^0C selama 90 hari. Keputusan menunjukkan kadar penguraian sisa tanaman sangat dipengaruhi oleh nisbah C:N dan penguraian oleh dinding sel pada kandungan lignin. Justeru, sisa tanaman yang mengandungi soya lebih tinggi kadar penguraian dan membebaskan kandungan N (tanah 98.4 mg/kg dan 67.9 mg/kg tanah dari kacang soya dan saki-baki kacang soya dan jagung, masing-masing) yang lebih tinggi berbanding sisa tanaman jagung (tanah 15.05 mg/kg). Berdasarkan analisis ekonomi penanaman selingan jagung dengan soya, aplikasi baja 50% NPK + 50% PM (RM 68,897 ha^{-1}) menghasilkan keuntungan bersih dan kadar pulangan paling tinggi (2169). Gabungan sisa tanaman soya dan sisa baja 50% PM + 50% PK (RM 62,507 ha^{-1}) turut menghasilkan keuntungan bersih tertinggi bagi pengeluaran jagung. Oleh itu, penggantian 50% baja kimia dengan tahi ayam untuk tanaman selingan jagung-soya dan menggantikan baja N dengan sisa tanaman soya dan sisa baja PM untuk tanaman jagung di musim berikutnya adalah sangat disarankan supaya penghasilan tanaman yang lebih ekonomi dan berkualiti tinggi dapat dihasilkan tanpa merosakkan kesuburan tanah.

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I certify that a Thesis Examination Committee has met on 2 November 2016 to conduct the final examination of Almaz Meseret Gezahegn on her thesis entitled ‘’Integrated Nutrient Management for Maize-Soybean Cropping System’’ 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 beawarded the degree of Doctor of Philosophy.

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

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LIST OF ABBREVIATIONS

ADF	Acid digestion fiber
ANOVA	Analysis of Variances
ATER	Area Times Equivalent Ratio
C:N	Carbon:Nitrogen ratio
CEC	Cation Exchange Capacity
CGR	Crop Growth Rate
CIMMYT	International Maize and Wheat Improvement Center
CRD	Complet Random Design
D	Dominate
DMRT	Duncan's Multiple Range Test
FC	Field Capacity
FYM	Farm Yard Manure
GB	Gross Benefits
HI	Harvest Index
INM	Integrated Nutrient Management
LAI	Leaf area index
LER	Land Equivalent Ratio
LSD	Least significant difference
MAI	Monetary Advantage Index
MOP	Muriate of Potash
MRR	Marginal Rate of Return
NaOAC	Sodium acetate
NB	Net Benefit
NDF	Neutral detergent fiber
NH_4OAC	Ammonium acetate
NPK	Nitrogen, Phosphorus and Potassium
PM	Poultry Manure
RCBD	Randomized Complete Block Design
RM	Malaysian Ringgit
TSP	Triple Super Phosphate
TVC	Total Variable Cost

CHAPTER ONE

INTRODUCTION

Maize (*Zea mays L*) or corn is one of the important cereal crops next to wheat and rice in the world. Maize serves as a staple food for over 900 million people in the developing countries, and it is the most dependable crop to bring about food self-reliance and independence (Zerihun et al., 2013). Maize has high production potential compared to any other cereal crops. Although the crop plays a significant role for the farmers as a source of food, feed and cash crop, the yield of maize in Sub-Saharan African countries and several Asian countries are extremely low, averaging approximately 1.5 t/ha and 3 t/ha, respectively (CIMMYT, 2013). Soybean *(Glycine max L. Merril)* is the most essential known oil seed and protein crop in the world. It is a great source of unsaturated fats, minerals like P and Ca and vitamins like A, B and D that meet the diverse nutritional needs (Alam et al., 2009). Soybean crop has a capability of supplying nitrogen for its growth and component cereals through symbiotic nitrogen fixation, thus reducing the requirement for costly and environmentally polluting nitrogen fertilizer (Zerihun et al., 2013). Despite having the above advantages, soybean production in most of the developing countries is very low (Knight, 2012). Hence, both maize and soybean have a big gap between the yield obtained in the developing countries and potential yield. The potential of the crops is not being exploited satisfactorily due to several constraints.

Low soil fertility due to monoculture cereal production systems, inadequate fertilizer application, biomass removal, soil erosion, nutrient losses through leaching and runoff are recognized as the major causes for decreasing per capita food production in developing countries (Negassa et al., 2007). Application of inorganic fertilizers is considered the most efficient way to reverse soil nutrient depletion and improve crop production (Bationo et al., 2007). However, the use of inorganic fertilizer in developing countries is insignificant as most of the smallholder farmers who are resource poor cannot afford to buy one bag to apply for their crops (Odhiambo & Magandini, 2008). Long-term use of chemical fertilizers in intensive cropping system leads to increased soil acidity and nutrient imbalance which adversely affects the soil health and crop production (Odhiambo & Magandini, 2008). These effects can be alleviated through the use of organic fertilizers which can improve biological, physical and chemical properties of the soil. Organic fertilizers like poultry manure and incorporation of crop residues have been used for crop production in additional to chemical fertilizers (Ayoola & Makinde, 2007a). Several studies have reported positive effects of organic fertilizers on the soil (Edmeades, 2003; Ibrahim & Fadni, 2013). However, application of organic manure alone to sustain crop productivity is inadequate due to their relatively low nutrient content and slow release of nutrients (Negassa et al., 2007). Incorporation of organic sources at higher amount is beneficial, but may not be affordable by smallholder farmers.

Therefore, neither the chemical fertilizers alone, nor the organic sources exclusively can achieve the sustainable productivity of soil as well as crops under intensive cropping system. To achieve

the sustainability of soil and crop productivity, combined use of organic and inorganic fertilizer together with other nutrient management practices like intercropping with legumes are very important. The basic concepts of integrated nutrient management practices are to reduce the use of chemical fertilizer, to maintain soil organic matter, to increase nutrient use efficiency and to improve soil quality in terms of physical, chemical and biological properties (Wu & Ma, 2015) and hence increase the yield potential of crops and sustain high crop yields in different cropping systems ensuring long-term sustainability of the system (Aulakh, 2010).

Currently, the emphasis has been shifted from individual crop to cropping system as a whole since the responses of the component crop in the cropping system are influenced by the previous crops and the applied inputs (Silva et al., 2006). The available nutrients in organic manure are not fully accessible to the crops in the current season (Rosen & Bierman, 2005). Organic manure, besides providing nutrients to the existing crop, usually leaves a considerable residual nutrient on the subsequent crops in the cropping system. The residual effect of organic manure applied to the soil refers to the carry-over effect of the application on the subsequent crop (Silva et al., 2006). Decomposition of organic manure, such as crop residue is an important process regulating energy flows and nutrient cycles in cropping system (Schmidt et al., 2015). Therefore, understanding the decomposition and nutrient release pattern can help to predict the potential benefits of residue on soil fertility. Since cropping system is considered as a component of integrated nutrient management through its efficient nutrient cycling, balanced fertilization to sustain the productivity of a system should be based on the concept of the cropping system as a whole rather than an individual crop (Mugwe et al., 2007). Combined use of different fertilizer sources with appropriate cropping system can result in improved soil fertility, crop productivity and a better environment for future generations. However, several reports indicated that the technology has not been well practiced in the developing countries (Getachew & Chilit, 2009; Guteta & Abegaz, 2015; Negassa et al., 2007). Considering these facts, this study was conducted with the following objectives:

General Objective

To evaluate agronomic implications and economic feasibility of combined application of organic and inorganic fertilizer on maize-soybean cropping systems and their residual effects on subsequent maize crop and fertility status of the soil.

Specific Objective

- To evaluate the effect of integrated application of organic and inorganic fertilizers on yield, quality and nutrient uptake of maize and soybean in maize-soybean intercropping system
- To evaluate the residual effect of poultry manure and cropping system with supplemental inorganic fertilizer on the performance of the succeeding maize crop
- To determine the effect of integrated nutrient management and cropping system on chemical properties of soil
- To determine the decomposition rate and nitrogen release from crop residues
- To determine the economic benefits of integrated nutrient management and maize-soybean intercropping system

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LIST OF PUBLICATIONS

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Almaz, M. G., R. A. Halim, M. Y. Martini & S. A. Wahid. Effect of Incorporation of Crop Residue and Inorganic Fertilizer on Yield and Grain Quality of Maize. (under revision).

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