



UNIVERSITI PUTRA MALAYSIA

**SUSTAINABLE GRAIN MAIZE PRODUCTION IN A GLIRICIDIA
ALLEY CROPPING SYSTEM**

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ALLEY CROPPING SYSTEM**

By

NORZIANA ZIN ZAWAWI

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

October 2007



DEDICATION

This thesis is dedicated to those who have given me their unfailing support



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Master of Science

SUSTAINABLE GRAIN MAIZE PRODUCTION IN A *GLIRICIDIA* ALLEY CROPPING SYSTEM

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October 2007

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Crop production under Ultisols in the humid tropics is usually limited by N deficiency and acid soil infertility problems. Effectiveness of legume residues as a nitrogen source is generally known to improve crop productivity by enhancing the availability of soil N where chemical fertilizer use often leads to deterioration in environmental quality. The aim of the study was to evaluate *Gliricidia sepium* residues (leaves and roots) as a potential source of N for a sustainable grain maize production in an alley cropping system in the tropics. In order to identify the determinants of the N dynamics of the *Gliricidia sepium* residues (leaves and roots), a laboratory incubation experiment was carried out with an Ultisols amended with *Gliricidia sepium* leaves, roots and their mixtures for 50 days. Quality of *Gliricidia sepium* residues was in order of leaves > mixtures > roots. The nitrogen and carbon mineralization also followed the same sequence ($P < 0.05$) and this observation suggests that the potential of *Gliricidia sepium* residues to increase soil inorganic N depends on their quality. Results obtained



showed that the *Gliricidia sepium* residues treatment was able to mitigate the soil acidity. The addition of *Gliricidia sepium* residues also increased major soil nutrient availability such as N, P, K, Ca and Mg. An experiment was carried out in semi-field conditions to compare the ^{15}N labeling technique for estimating maize crop N uptake from *Gliricidia sepium* leaves and roots using direct ^{15}N labeling and ^{15}N dilution method. Results indicate that N contributed by *Gliricidia sepium* leaves to maize measured by direct ^{15}N labeled and ^{15}N dilution method were not significantly different ($P>0.05$). The percentage of nitrogen derived (%Ndfr) from the *Gliricidia sepium* ^{15}N labeled leaves (direct labeling) was 26.9% and 41.9% from unlabeled leaves (^{15}N dilution) in maize stover. Meanwhile, in maize cob, the %Ndfr from *Gliricidia sepium* leaves was 24.3% using ^{15}N direct labeling and 46.4% using ^{15}N dilution method. A field study was conducted using the ^{15}N dilution method on N contribution from *Gliricidia sepium* leaves either integrated with or without additional urea fertilizer, or, with or without the presence of hedgerows. There was no significant difference ($P>0.05$) in maize yield upon application of *Gliricidia sepium* leaf mulch with urea fertilizer (LM+FERT) compared to *Gliricidia sepium* leaf mulch only (LM), suggesting that without additional amount of urea, *in situ* *Gliricidia sepium* leaf pruning is equally effective in maize production.



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**PENGELUARAN JAGUNG SECARA MAMPAN DENGAN
MENGUNAKAN SISTEM TANAMAN SELANG DENGAN POKOK
*GLIRICIDIA***

Oleh

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Pengeluaran hasil tanaman pada tanah Ultisol di kawasan humid dan semi arid tropika biasanya terhad disebabkan oleh kekurangan nitrogen dan masalah ketidaksuburan tanah berasid. Keberkesanan sisa legum kekacang diketahui sebagai sumber nitrogen dan dapat meningkatkan hasil pengeluaran tanaman dengan menggalakkan kehadiran N di dalam tanah dimana kegunaan baja kimia biasanya menjurus kepada pencemaran alam sekitar. Sasaran kajian ini adalah untuk menilai keupayaan sisa *Gliricidia sepium* (daun dan akar) sebagai sumber nitrogen kepada pengeluaran tanaman jagung secara mampan di kawasan tropika. Dalam mengenalpasti ketentuan dinamik N, sisa *Gliricidia sepium*, eksperimen penderaman di dalam makmal dilakukan dengan menggunakan satu tanah Ultisol yang ditambah dengan daun, akar dan campurannya selama 50 hari. Hasil yang diperolehi menunjukkan turutan kualiti bagi sisa *Gliricidia sepium* iaitu daun > campuran>akar. Melalui ujian mineralisasi nitrogen dan karbon, ia juga menunjukkan turutan yang sama ($P < 0.05$) dan melalui pemerhatian ini adalah

dicadangkan bahawa sisa *Gliricidia sepium* berpotensi untuk meningkatkan N tak organik tanah berdasarkan kualitinya. Keputusan yang diperolehi menunjukkan bahawa rawatan sisa *Gliricidia sepium* dapat mengurangkan keasidan tanah. Pertambahan sisa *Gliricidia sepium* juga meningkatkan ketersediaan nutrien utama dalam tanah seperti N, P, K, Ca dan Mg. Satu kajian yang telah dijalankan dalam keadaan separa ladang untuk membandingkan teknik penglabelan ^{15}N untuk menganggar pengambilan N oleh jagung dari daun dan akar *Gliricidia sepium* menggunakan kaedah penglabelan ^{15}N secara langsung dan kaedah pencairan ^{15}N . Keputusan menunjukkan tiada perbezaan bererti ($P>0.05$) diantara N yang disumbangkan oleh daun *Gliricidia sepium* kepada jagung menggunakan kaedah penglabelan ^{15}N secara langsung dan kaedah pencairan ^{15}N ($P>0.05$). Peratus nitrogen yang diperolehi daripada sisa *Gliricidia sepium* (%Ndf) daun berlabel ^{15}N adalah 26.9% dan 41.9% daripada daun yang tidak dilabel ^{15}N (kaedah pencairan ^{15}N) dalam batang jagung. Sementara itu dalam buah jagung, %Ndf yang diperolehi daripada *Gliricidia sepium* adalah 24.3% menggunakan penglabelan ^{15}N secara langsung dan 46.4% dengan menggunakan kaedah pencairan ^{15}N . Kajian ladang dijalankan menggunakan kaedah pencairan ^{15}N keatas sumbangan N dari daun *Gliricidia sepium* sama ada digunakan bersama dengan atau tanpa baja urea, atau melalui kehadiran rimbunan pokok *Gliricidia sepium* atau tanpa rimbunan pokok. Tiada perbezaan signifikan ($P>0.05$) antara aplikasi daun *Gliricidia sepium* dengan tambahan baja urea (LM+FERT) dengan daun *Gliricidia sepium* sahaja tanpa tambahan baja urea (LM) ke atas hasil jagung. Dengan itu disarankan bahawa aplikasi daun *Gliricidia sepium* secara *in situ* dapat memberi kesan yang efektif walaupun tanpa pertambahan baja urea ke atas hasil tanaman jagung.

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I certify that an Examination Committee met on 4th October 2007 to conduct the final examination of Norziana binti Zin Zawawi on her Master of Science thesis entitle “Sustainable Grain Maize Production in a *Gliricidia* Alley Cropping System” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

NORZIANA ZIN ZAWAWI

Date: 4th February 2008



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LIST OF ABBREVIATIONS/NOTATIONS/GLOSSARY OF TERMS

ANOVA	Analysis of Variance
BNF	Biological Nitrogen Fixation
CEC	Cation Exchange Capacity
CRD	Completely Randomized Design
DMRT	Duncan's New Multiple Range Test
Fert	Fertilizer
H	Hedgerow
HCl	Hydrochloric Acid
IAEA	International Atomic Energy Agency
KCl	Potassium Chloride
KOH	Potassium Hydroxide
L	Lignin
LM	Leaf as Mulch
M	molar
mL	mililitre
mM	milimolar
NaOH	Sodium Hydroxide
Ndfr	Nitrogen Derived From Residues
rNE	recovery of N From Residue
SAS	Statistical Analysis System
USDA	United State Department of Agriculture



CHAPTER 1

INTRODUCTION

Malaysia is one of the largest user of fertilizers in the world with most of them imported. In 2004, nitrogenous fertilizers and potash are the major imports with 1.41 and 1.40 million tones, respectively, followed by phosphate (0.7 million tonnes) (Malaysian Agricultural Directory Index, 2006). The unbalanced use of chemical fertilizers usually leads to a loss in soil productivity as well as deterioration in environmental quality. This has resulted in concerted efforts to review the use of such fertilizers and to place more emphasis on organic matter inputs (Szott et al., 1991; Szott and Kass, 1993).

In Malaysia, agroforestry (forestry together with agriculture for multiple benefits) has been receiving long overdue attention as an environmental and sustainable way of production. It has been considered for integrating forest plants (timber trees, rattan, bamboo, medicinal plants and others. Even tree crops like rubber and oil palm are considered forest plants for this purpose) with food production (maize, padi, livestock, aquaculture) to maximize the returns from the land. In recent years, integrated farming has been promoted actively among Malaysian farmers (Faridah, 2001). The integration, if properly designed, can improve the soil fertility and increase crop



productivity, in recycling and maximizing the use of plant nutrients. However, for the maximum benefits to accrue, it is important that the integration be designed right, for which the cropping and nutrient management systems need to be studied.

Alley cropping has been identified as an efficient system in agroforestry (Kang et al., 1990; Szott et al., 1991). In it, leguminous shrubs are grown in rows wide apart, and in-between is grown the food crops or livestock reared. Thus, litter from the tree (especially if they are legumes which fix atmospheric nitrogen) can be used as mulch, reducing the need for extraneous fertilizers to be applied. The leguminous trees may have to be pruned from time to time to prevent excessive shading, and the biomass can also be used as mulch. The research on alley cropping has focused on the ability of the system to maintain its productivity without extraneous fertilization, in particular, on the ability of leguminous trees to supply the nitrogen requirement (Fernandes, 1990; Szott and Kass, 1993). Leguminous trees normally have higher nitrogen content than non-N fixing species although the content is variable (Palm, 1995). Tree prunings normally have higher concentrations of mobile nutrients such as nitrogen, phosphorus, potassium and zinc than naturally fallen litter from which elements are translocated by the tree prior to abscission (Marschner, 1995). Similarly, the young, leaf rich biomass of frequently pruned trees has higher nutrient concentrations than the more woody biomass of infrequently pruned trees, although the quantity of biomass produced decreases with pruning frequency (Duguma et al., 1988).



A major consideration in the selection of leguminous trees for agroforestry is the rate and amount of N available from the litter and prunings to benefit the undercrop. *Leucaena leucocephala* and *Gliricidia sepium* in hedgerows have been found to yield large quantities of nitrogen (Kang et al., 1981; Kang and Duguma, 1985). On an Entisol, Kang and Duguma (1985) estimated that *Leucaena Leucocephala* contributed about 40 kg N ha⁻¹ to its companion maize crop. High yields of maize and cassava were obtained in alley cropping with *Leucaena* and *Gliricidia* on high base status soils in the humid and sub-humid lowland tropics of Africa (Kang et al., 1984; Atta Krah et al., 1985). *Gliricidia sepium* was found to be one of the more leguminous woody species used in hedgerows in the humid tropics (Fernandes et al., 1993). It is highly suitable for the purpose because of its easy establishment by direct seeding and stem cuttings. It is also a long-lived tree, sufficiently hardy to withstand frequent pruning and produces large amounts of biomass and nutrients (Kang, 1993).

Despite of these amusing discoveries, there is actually little data on *Gliricidia sepium* as a nitrogen source in alley cropping in the humid tropics such as Malaysia. With current interest in maize production for animal feed, there is interest in integrating *Gliricidia sepium* with maize in a sustainable production system. By adopting the potential benefits of *Gliricidia sepium* grown in alley cropping and its role as nitrogen contributor in plant nutrient management, this study was undertaken to evaluate

Gliricidia sepium residues as a potential source of nitrogen for grain maize production in the tropics with the following aims to:

1. Determine chemical composition of *Gliricidia sepium* residues (leaves and roots) which affect the pattern of N mineralization on Bungor series soil.
2. Quantify the relative contribution of *Gliricidia sepium* roots and leaves to N uptake by grain maize using two different ^{15}N isotope labeling techniques.
3. Evaluate the effects of different *Gliricidia sepium* land-use systems on soil chemical properties and N uptake by grain maize in an alley cropping system.



CHAPTER 2

LITERATURE REVIEW

2.1 Sustainable Agriculture

Sustainable agriculture involves the management of agricultural resources to satisfy changing human needs while maintaining or enhancing the environmental quality and conserving natural resources (Kang et al., 1985; Salinas-Garcia, 1997; Borch, 2007). Sustainable land management should maintain the soil productivity, minimize risks, preserve the soil and water quality and be economically feasible and socially acceptable (Bouma, 2002). The increasing demand for agricultural land has led to more intensive land use, resulting in rapid land degradation. The application of hazardous compounds and excessive fertilizers has worsened the land degradation and its fertility. The use of chemical fertilizers such as urea and ammonium sulphate is believed to result in some N losses. This may lead to environmental degradation, such as groundwater pollution if the leaching losses are high. Further, applying urea and ammonium sulphate acidifies the soil, making it less fertile. Despite the ills, the practice has continued because it is financially more cost-effective than sustainable agriculture in the short term.

The development of alternative, sustainable and more productive food crop systems has only had limited success in the humid and subhumid tropics (Kang et al., 1991).



There is considerable interest in reducing the use of chemical fertilizers while maintaining crop yields, not only to lower the cost of production but also to minimize pollution. Organic fertilizers, for example, can be used, especially to supply N (Huntington et al., 1985; Stute and Posner, 1995; Ranells and Waggar, 1996). It is known that external chemical inputs are needed to achieve sustained high crop yields, their availability and cost (without subsidies) may be prohibitive for their use in food crop production in many developing countries. In addition, continuous use of only high external chemical inputs can result in increased land degradation on poorly buffered upland soils (Kang and Balasubramanian, 1990). Combining decreased levels of inorganic N inputs with organic N inputs may be an avenue for sustaining N availability to a crop in the transition to alternative management as well (Liebhart et al., 1989; Hussain et al., 1995; Cavero et al., 1997). It is, therefore, imperative that alternative integrated soil and nutrient management systems are developed that can maximize incorporation of biological nutrient sources and organic material.

2.2 Alley Cropping System

In the tropics, alley cropping can be used for sustainable food production as it allows well for soil fertility replenishment. The system is basically planting tree crops in hedgerows, and food crops in between. The hedgerow trees are pruned regularly to minimize shading and competition with the companion crops (Kang and Wilson, 1987). The prunings are used to mulch the food crops, contributing both organic

matter and nutrients. Ideally, the nutrients in the mulch should be released at the same rates as taken up by the crop. Kang (1997) stated that alley cropping, sometimes also called the 'improved bush fallow system', is based on the following:

1. Trees are grown in managed hedgerows to perform the same functions as the bush in the traditional bush fallow system for nutrient recycling and soil fertility regeneration;
2. Hedgerow prunings supply *in situ* as mulch and green manure;
3. Partial shading by the hedgerows during the off-season helps in weed suppression;
4. Inclusion of N-fixing legumes to add N to the system;
5. Presence of woody species aids in soil and water conservation;
6. Hedgerows also serve as a source of browse and other auxiliary products, such as staking materials and firewood.

Radersma et al (2004) reported that alley cropping mimics natural ecosystems in a simplified way. The initial expectations for alley cropping were high based on the assumption that trees grown within crop fields could function as a 'fallow component' in the combined system. Alley cropping was meant to provide a sustainable alternative to traditional cropping systems with long fallows, which had given way to continuous production due to population pressure (Kang et al., 1985). Pioneering work of this technology was initiated at the International Institute of Tropical Agriculture (IITA),



Ibadan, Nigeria by B.T Kang and his co-workers in the early 1980s (Vanlauwe, 2005). It was found suitable for the uplands (Kang and Mulongoy, 1992; Kang et al., 1990) with food crops grown between hedges of preferably N₂ fixing trees (Kang et al., 1985).

Alley cropping can be very important in agroforestry with nitrogen-fixing trees (to produce fertilizer) and non nitrogen-fixing trees (for timber) grown in alternate rows.

The mulch produced should:

1. Improve the crop performance due to addition of nutrients and organic matter to the soil/plant system.
2. Reduce the use of chemical fertilizers.
3. Improve the physical soil environment - lower the soil temperature, reduce evaporation, improve the soil microbial activity and structure resulting in better infiltration, reduced runoff and improved water use efficiency.
4. Provide additional products such as forage, firewood or stakes when a multipurpose tree legume is used as the hedgerow (Kang and Gutteridge, 1994).
5. Improve weed control. The mulch may inhibit germination and establishment of weeds (Ssekabembe, 1985).

Alley cropping has shown considerable promise on land such as slopes where it was an effective erosion control measure, where rainfall was adequate throughout the