INTERCROPPING OF CORN (Zea mays L.) WITH GROUNDNUT (Arachis hypogea L.) AND BAMBARA NUT (Vigna subterranea L.) TO INCREASE PROTEIN CONTENT OF COMBINED FORAGE

DAUDA MUSTAPHA BELEL

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By

DAUDA MUSTAPHA BELEL

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

September 2016
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DEDICATION

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

INTERCROPPING OF CORN (*Zea mays* L.) WITH GROUNDNUT (*Arachis hypogea* L.) AND BAMBARA NUT (*Vigna subterranea* L.) TO INCREASE PROTEIN CONTENT OF COMBINED FORAGE

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September 2016

Chairman : Associate Professor Mohd Ridzwan Abd. Halim, PhD
Faculty : Agriculture

Forage corn has been used as a feed resource for ruminant but it is low in crude protein content such that animals have to be supplemented with protein sources. In order to increase the protein in corn forages, three corn intercropping experiments were conducted with two grain legumes: bambara nut (*Vigna subterranea* L. Verdc) and groundnut (*Arachis hypogea* L.) to evaluate their potential to increase forage quality.

In the first experiment, six introduced bambara nut landraces from Nigeria (Bambwus, Kurvu, KwadaZwalang, Tanyanyi, IndaraAyaghayagha and Karamagdanda) and one from Thailand (Songkla 1) were evaluated. The Songkla 1 variety has been grown in Malaysia over the last 15 years while the Nigerian landraces are newly introduced. The objective was to evaluate whether the Nigerian landraces could perform as well or better than the Songkla 1 variety in the Malaysian environment. There were significant differences (p<0.05) among the introduced African landraces and the adapted Songkla 1 variety. Kurvu recorded a higher forage dry matter (2,343 kg ha\(^{-1}\)) and pod yield (1,349 kg ha\(^{-1}\)). Harvest index was higher at 46.8% for Bambwus. In general, the introduced African landraces showed a better performance than the adapted Songkla1 variety and hence some of these landraces could be selected for planting in the tropical humid climate of Malaysia. Bambwus was superior to other varieties and was ranked first and was selected for inclusion in the subsequent corn/legume intercropping experiments.

In the second experiment, corn was intercropped with bambara nut and groundnut at a 1:1 ratio to determine the contribution of each legume towards the yield and quality of the combined forage. The experiment involved six treatments (sole corn with nitrogen, sole corn without nitrogen, sole groundnut, sole bambara nut, corn/bambara nut intercrop and corn/groundnut intercrop) replicated three times in a randomized complete block design. Nitrogen fertilizer was not applied to all treatments except for the first treatment. Intercropping significantly (p≤ 0.05) increased the growth of corn crop and suppressed both bambara nut and groundnut.
A higher yield was obtained from nitrogen-fertilized corn. However, intercropping showed its advantage through 36% and 59% better land equivalent ratio (LER) in intercrop than in monocrop for corn/bambara nut and corn/groundnut respectively. The relationship between corn and the legumes was synergistic in nature as shown by relative yield total which was 1.36 for corn-bambara nut and 1.59 for corn-groundnut. Digestibility was higher in the corn/legume forage (57.5%) compared to sole corn (51.8%). Similarly, corn intercropped with bambara nut and groundnut had higher protein content (10.8 and 12.9%) compared to sole corn (8.21%). Groundnut was a better legume for intercropping with corn than bambara nut in terms of yield but bambara nut was selected for the next study in order to further understand its performance in humid tropical environment.

In the third experiment, corn was intercropped with bambara nut landrace Bambwus in a randomized complete block design using different planting patterns based on the ratio of corn/bambara nut as follows (C=Corn, B=Bambara, N=Nitrogen): C4:B0, C4:B0+N, C3:B1, C2:B2, C1:B3, C0:B4. The crop growth rate, leaf chlorophyll and total leaf area were significantly higher among the intercrops compared to monocrops. Total dry matter yield was similar in all combinations. Sole corn had 73% neutral detergent fiber (NDF) which was higher than in the intercrops except C1:B3. Corn/bambara nut combinations ratios also differed significantly in NDF and acid detergent fiber (ADF). Protein in sole bambara nut was 14.8%. Among the combinations, crude protein was highest in C1:B3 (17.3%). Crude protein in sole corn was 8.52%. Lignin was highest in combinations with more bambara nut with sole bambara nut having 4.92% lignin. The planting patterns all gave a land equivalent ratio (LER) higher than 1.00 which indicated the benefit of intercropping. Aggressivity index indicates that corn was more aggressive than bambara nut in their competition. For improvement of overall forage quality it is recommended that bambara nut be planted as an intercrop with corn at the ratio of 1 corn to 3 bambara nut. The Nigerian landrace Bambwus should be used in place of Songkla 1 because of its relatively superior performance.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

**PENANAMAN SELINGAN ANTARA JAGUNG DENGAN KACANG TANAH DAN KACANG BAMBARA UNTUK MENINGGIKAN KANDUNGAN PROTEIN BAGI FORAJ CAMPURAN**

Oleh

**DAUDA MUSTAPHA BELEL**

*September 2016*

Pengerusi : Profesor Madya Mohd Ridzwan Abd. Halim, PhD  
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Eksperimen pertama membuat penilaian terhadap enam jenis kacang bambara dari Nigeria (Bambwus, Kurvu, KwadaZwalang, Tanyanyi, IndaraAyaghayagha, and Karamagdanda) dan satu varieti dari Thailand (Songkla 1). Varieti Songkla 1 telah ditanam di Malaysia semenjak 15 tahun dahulu manakala varieti Nigeria baru diperkenalkan. Keputusan menunjukkan perbezaan yang signifikan (p<0.05) antara enam jenis kacang bambara (varieti dari Afrika) berbanding varieti Songkla 1. Kurvu mencatatkan hasil berat kering (2,343 kg ha\(^{-1}\)) dan hasil kantung kacang (1,349 kg ha\(^{-1}\)) yang paling tinggi. Indeks hasil tertinggi dicatatkan oleh Bambwus iaitu sebanyak 46.80%. Secara keseluruhannya, varieti-varieti dari Afrika menunjukkan hasil yang lebih memberansangkan daripada varieti Songkla1 dan sebahagian daripada varieti tersebut boleh dipilih untuk penanaman di iklim tropika lembab yang terdapat di Malaysia. Bambwus dinilai menduduki tempat pertama dan telah dipilih untuk tujuan penanaman selingan dengan tanaman jagung.

Eksperiman kedua, merupakan penanaman selingan antara jagung dengan kacang bambara dan kacang tanah dengan nisbah 1:1 bagi menentukan sumbangan tanaman kekacang terhadap hasil dan kualiti foraj campuran. Eksperiman ini melibatkan enam rawatan (jagung tunggal dengan baja nitrogen, jagung tunggal tanpa baja nitrogen, kacang tanah tunggal, kacang bambara, penanamam selingan jagung/bambara dan penanamam selingan jagung/kacang tanah) dalam tiga replikasi. Baja nitrogen hanya digunakan untuk rawatan yang pertama, rawatan yang lain tidak diletakkan baja nitrogen. Keputusan menunjukkan penanamam selingan telah
meningkatkan pertumbuhan tanaman utama iaitu jagung dan melebihi pertumbuhan tanaman selingan tanaman kekacang sama ada bagi kacang bambara mahupun kacang tanah. Hasil tertinggi diperolehi oleh jagung dengan rawatan baja nitrogen. Walau bagaimanapun, penanaman selingan jagung/bambara dan penanamam selingan jagung/kacang tanah menunjukkan peningkatan nisbah setara tanah (LER) lebih baik daripada penanamam jagung tunggal dengan masing-masing sebanyak 36% dan 59%. Pola persaingan antara tanaman utama dan tanaman gandingan yang diukur oleh jumlah hasil relatif (LER) menunjukkan bahawa perhubungan sinergi berlaku antara jagung dan tanaman kekacang iaitu kacang bambara menunjukkan LER 1.36 dan kacang tanah 1.59. Berlaku juga peningkatan terhadap nilai pencernaan oleh campuran jagung/kekacang berbanding jagung tunggal (57.5% bagi campuran berbanding 51.8% bagi jagung tunggal. Peningkatan kandungan protein dapat dilihat juga dengan penanaman selingan jagung dengan kacang bambara dan kacang tanah kerana kandungan protein lebih tinggi daripada penanaman jagung tunggal (10.8% dan 12.9% dalam penanaman campuran berbanding 8.21% dalam penanaman jagung tunggal). Kacang tanah adalah legum yang lebih baik untuk intercropping dengan jagung dari bambara nut dari segi hasil tetapi bambara nut telah dipilih untuk kajian akan dating untuk memahami lagi prestasinya dalam persekitaran tropika lembap.

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I certify that a Thesis Examination Committee has met on 5 September 2016 to conduct the final examination of Dauda Mustapha Belel on his thesis entitled "Intercropping of Corn (Zea mays L.) with Groundnut (Arachis hypogea L.) and Bambara Nut (Vigna subterranea L.) to Increase Protein Content of Combined Forage" 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 Doctor of Philosophy.

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<tr>
<td>ADF</td>
<td>Acid Detergent Fiber</td>
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<tr>
<td>ADL</td>
<td>Acid Detergent Lignin</td>
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<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
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<tr>
<td>AYL</td>
<td>Actual Yield Loss</td>
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<tr>
<td>CB</td>
<td>Corn/ Bambara nut</td>
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<tr>
<td>CFFRC</td>
<td>Crops for the Future Research Centre</td>
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<tr>
<td>CG</td>
<td>Corn/Groundnut</td>
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<tr>
<td>CGR</td>
<td>Crop Growth Rate</td>
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<td>CP</td>
<td>Crude Protein</td>
</tr>
<tr>
<td>CR</td>
<td>Competitive Ratio</td>
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<tr>
<td>CTAB</td>
<td>Cetyl trimethylammonium bromide</td>
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<tr>
<td>CV</td>
<td>Coefficient of Variation</td>
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<tr>
<td>C0:B4</td>
<td>Pure stands of Bambara nut</td>
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<tr>
<td>C1:B3</td>
<td>Two Row Corn: Six Rows Bambara nut</td>
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<td>C2:B2</td>
<td>Four rows Corn: Four Rows Bambara nut</td>
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<td>C3:B1</td>
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<td>C4:B0</td>
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<td>C4:B0+N</td>
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<tr>
<td>DF</td>
<td>Degree of Freedom</td>
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<tr>
<td>DMD</td>
<td>Dry Matter Digestibility</td>
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<td>DMY</td>
<td>Dry Matter Yield</td>
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<tr>
<td>EDTA</td>
<td>Disodium ethylene diamine tetra acetate</td>
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<tr>
<td>FAOSTAT</td>
<td>Food and Agriculture Organization Statistics</td>
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<td>HI</td>
<td>Harvest Index</td>
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<td>Acronym</td>
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<tr>
<td>ICRISAT</td>
<td>International Cereal Research Institute for Semi-Arid Tropics</td>
</tr>
<tr>
<td>LAI</td>
<td>Leaf Area Index</td>
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<tr>
<td>LC</td>
<td>Leaf Chlorophyll</td>
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<tr>
<td>LER</td>
<td>Land Equivalent Ratio</td>
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<tr>
<td>LSD</td>
<td>Least Significant Difference</td>
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<td>MOP</td>
<td>Muriate of Potash</td>
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<tr>
<td>NDF</td>
<td>Neutral Detergent Fiber</td>
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<tr>
<td>ns</td>
<td>Not Significant</td>
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<tr>
<td>RCBD</td>
<td>Randomized Complete Block Design</td>
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<tr>
<td>RSR</td>
<td>Root to Shoot Ratio</td>
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<tr>
<td>RYT</td>
<td>Relative Yield Totals</td>
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<tr>
<td>SB</td>
<td>Sole bambara nut</td>
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<tr>
<td>SG</td>
<td>Sole groundnut</td>
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<tr>
<td>TLA</td>
<td>Total Leaf Area</td>
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<td>TSP</td>
<td>Triple Super Phosphate</td>
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CHAPTER 1

INTRODUCTION

The cultivation of cereal and legumes in a compatible combination is popular among subsistence farmers in the tropics. This is with the ultimate aim of producing food grains for immediate family consumption, leaving out the remaining vegetative leaf litter and straw as residue for livestock grazing on the farm. Intercropping of legumes and cereals at a given proportion is aimed at improving the quality and yield of forage (legumes and cereals) in order to provide better livestock feed.

The expected increase in demand for animal products makes it critical to develop forage with higher protein content. Legumes fix nitrogen in the soil which help to improve fertility of such soil and thus increase the nitrogen and protein levels in crops. Nowadays, attention is focused on providing a quality grazing pasture of high protein content for livestock in order to boost both quality meat and milk production. Protein is a major constituent in cell multiplication and bodybuilding in animals and the quality forage required for the growing nutritional needs of the livestock has to be sourced through corn-legume intercropping. Intercropping of cereal and legume gives a balanced and high forage protein due to substrate transfer during this interaction.

Many countries of the world have now achieved productivity in crops through intercropping (Francis, 1986). The system has shown to be more effective than monocropping as it helps to produce surplus food from a less expanse of land with minimal impact on the environment.

Most studies on intercropping have concentrated on the useful and sustainable system, i.e. on the legume-cereal intercropping (Fusuo and Li, 2003). Intercropping plays a dynamic role in subsistence food production in both advanced and emerging countries (Adeoye et al., 2005). Several researches have been reported on intercropping (Mandal et al., 1990; Brintha and Seran, 2009; Ijoyah, 2012), mostly focusing on cereal-legume intercrops (Ofori and Stern, 1987; Hugar and Palled, 2008) and all proved successful.

Intercropping of cereal and legume is a good combination which gives high energy and protein which could provide good source of feed for livestock. Certain legumes such as bambara nut has not been grown in the humid tropics under different intercropping patterns with corn. Bambara nut is a legume that was recently introduced to Asia (and Malaysia) and it presents a great potential for improved food production on tropical marginal soils (CFFRC, 2012). In Malaysia, the Crops for the Future Research Center (CFFRC) located in the University of Nottingham adopted it as its mandate crop in the underutilized crops program. The crop has several natural agronomic advantages including: high nutritional value, drought resistance, resilience to high temperatures and is fit for marginal soils where other leguminous crops cannot grow. Hence, there is a need to evaluate the performance of different landraces to
identify a suitable choice for intercropping with corn for the improvement of forage production in the humid tropics. The world’s need for an improved supply of quality food and feed demands that crops be grown outside their usual growing environment, especially hardy crops that can adapt to a wide range of ecological conditions.

The majority of ruminant livestock in tropical countries are raised on natural pastures which decline rapidly in quality due to ageing in the dry seasons. In order to reduce the nitrogen fertilizer requirement as well as to improve quality through the increase of protein in the feed, planting corn with grain legumes may be a solution. The understanding of these critical needs, especially from different grain legume crops in a suitable combination with corn for high protein forage should be explored. Under-utilized grain legume forages are potential sources of supplement in ruminant livestock diet.

Different planting patterns for cereal-legume intercropping have been practiced by many researchers and farmers and the yield advantage of intercropping has not been so marked in several situations possibly due to the use of supra-optimal plant population proportions and in some cases, to the use of sub-optimal population proportions for component crops. The use of different combination ratio between corn and the legume to ascertain the optimal yield and forage value of the mixture becomes eminent. Different planting patterns and crop composition need to be optimized to obtain the best yield and forage quality in a corn-legume intercrop. The cropping system of the humid tropical environment could be enriched by including the bambara nut legume in intercropping through different planting patterns.

The main objective of this research is to intercrop corn with groundnut and bambara nut to increase the protein content of combined forage. The following are the specific objectives of the study:

i) To evaluate the performance of different landraces of bambara nut and to select the best landrace for incorporation into a corn-legume intercropping.

ii) To evaluate the performance of two different legumes (bambara nut and groundnut) in intercropping and select the better legume for incorporation into the corn-legume intercropping system.

iii) To assess the yield and forage quality of corn and legume in different intercrop ratios.
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