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NITROGEN CONTRIBUTION BY GROUNDNUT (ARACHIS HYPOGAEA L.) IN A ROTATIONAL CROPPING SYSTEM ON AN ULTISOL

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By

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In Malaysia, about 120,000 ha of highly weathered Oxisols and Ultisols come off either from rubber or oil palm annually under the replanting programme. Annual crops such as groundnut and maize are often used as cover crops, which can replace non-food legume cover crops, during the first four years under the replanting programme. The acidic nature associated with high aluminum concentration and low native nitrogen status often pose severe constraints to the growth and productivity of annual food crops on these Ultisols.

An approach which involved the adoption of advanced legume technology and liming was hypothesized to reduce these two soil-related constraints affecting annual food crop production on Ultisols. Using this approach the following aspects were investigated :

i) the amount of lime needed to reduce the high Al saturation level (82%) in an Ultisol required for satisfactory growth and yield of uninoculated groundnut and maize,

ii) the selection of compatible groundnut cultivar-*Bradyrhizobium* strain combination on limed-Ultisol for maximum yield and legume-N return to the soil,

iii) the amount of legume-N contributed by groundnut inoculated with selected *Bradyrhizobium*,

iv) the amount of legume-N contributed by groundnut inoculated with compatible *Bradyrhizobium* in three groundnut (L)-maize (M) sequence - LMLM, MLLM and LLLM in rotational crop system as estimated in the yield of maize,

v) the correction of soil acidity by chemicals other than lime.

To investigate aspect (i), a short-term experiment and for aspect (iv) a long term experiment (4 years), were carried out in the field. All other experiments (ii, iii, and v) were carried out under glasshouse conditions.

Liming an Ultisol with 4 mt GML (ground magnesium limestone) ha^{-1}, reduced Al saturation in the Bungor sandy clay loam (Typic Paleudult) from 82 to <20% and increased the yield of groundnut (cv. V13) by 26% and maize (cv. Sg. Buluh) fertilized with 90 kg ha^{-1} of fertilizer N by 71% compared to control where no lime was applied. Liming also increased the amount of residual or legume N by 44 kg N ha^{-1} which could be returned to the soil (i).

The appropriate *Bradyrhizobium* selected for groundnut V13 on limed Ultisol was *Bradyrhizobium* CB756 (ii). This groundnut-*Bradyrhizobium* strain combination further increased the yield and N accumulation in the haulm under unlimed and limed conditions. The amount of legume N which could be returned to the soil in plant residue was about 77 under unlimed and 105 kg N ha^{-1} under limed conditions (iii), an increase of more than double that estimated from unimproved *Bradyrhizobium* in the open field situation (i). As this was under closed system, the estimate was higher (ii).

In the open field system, however, apart from the first crop in the first year (1981), this groundnut-*Bradyrhizobium* combination returned as legume-N an average of 51 kg ha^{-1} of fertilizer N equivalent in the LMLM sequence, during the four year period (1981-1984). In the MLLM sequence, the accumulative legume N returned after two crops of groundnut was 106 kg ha^{-1} in the first and 102 kg ha^{-1} in the second crop cycles. During the same period, three successive groundnut crops prior to maize (LLLM), the accumulative legume-N accounted 142 kg ha^{-1} for the first cycle (1981-1982) and 165 kg ha^{-1} of fertilizer N equivalent for the second (1983-1984) crop cycles.

The recovery of legume-N in maize from the LMLM sequence was 31%, and from the MLLM sequence, it was 21% for the first crop cycle and 25% for the second crop cycle. In plots receiving three successive groundnut crop (LLLM), the recovery was 31 and 37% for the first and second crop cycles, respectively. This gave fertilizer N equivalent between 13-16, 22-26 and 44-61 kg N ha^{-1}. Fertilizer N equivalent to 56 kg N ha^{-1} which was estimated from N-uptake response curve from the N-fertilized monocropping experiment, represent ca. 35% of the maize N requirement (159 kg N ha^{-1}) on limed Ultisol (iv).

Amending Ultisols with Ca, Mg, and K fertilizer materials other than the liming materials did not alleviate soil acidity or increase pod yield. However, $CaSO_4$ and K_2SO_4 temporarily reduced Al saturation and increased the top dry weight of groundnut at 30 days after planting (v).

Throughout the field study the soil pH was maintained at pH 5.5 by liming with GML. This reduced the Al saturation to ca. 15% and increased both yield and legume-N contribution to maize. The field study showed that only the three successive groundnut crops in the LLLM sequence managed to contributed about a third of the N requirements of maize to achieve maximum grain yield of 6.4 mt ha^{-1}.

Abstrak tesis yang dikemukakan kepada Senat Universiti Pertanian Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah.

SUMBANGAN NITROGEN OLEH KACANG TANAH (*Arachis hypogaea* L.) DI DALAM SISTEM TANAMAN GILIRAN PADA TANAH ULTISOL

Oleh

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Setiap tahun lebih kurang 120,000 ha tanah terluluhawa Oksisol dan Ultisol di Malaysia yang ditanam sama ada dengan getah atau kelapa sawit adalah di bawah rancangan tanaman semula. Tanaman kontan seperti kacang tanah dan jagung biasanya ditanam sebagai tanaman menggantikan tanaman penutup bumi yang biasa ditanam di peringkat awal di bawah rancangan tanaman semula ini. Sifat keasidan berkaitan dengan kandungan Al yang tinggi dan kandungan N yang rendah biasanya menghadkan tumbesaran dan daya produktiviti kedua-dua tanaman tersebut di kawasan tanah Ultisol.

Penggunaan teknologi tanaman kekacang dan kadar pengapuran adalah satu cara mengatasi masalah dua faktor tersebut yang menghadkan pengeluaran tanaman makanan di kawasan tanah Ultisol. Dengan menggunakan kaedah ini, aspek-aspek berikut telah dikaji:

i) kadar pengapuran yang diperlukan untuk menurunkan tahap ketepuan Al yang tinggi ke paras yang menggalakkan tumbesaran dan hasil kacang tanah dan jagung yang memuaskan di kawasan Ultisol,

ii) kombinasi kacang tanah-*Bradyrhizobium* yang berkesan dipilih dari segi kaitan dan sumbangan N di kawasan tanah Ultisol yang dikapur,

iii) sumbangan N daripada kombinasi kacang tanah-*Bradyrhizobium* yang terpilih,

iv) sumbangan N daripada kacang tanah untuk tanaman jagung dalam tiga sistem tanam bergiliran kacang tanah (L) - jagung (M) : LMLM, MLLM dan LLLM yang dianggarkan melalui hasil tanaman jagung berbaja N,

v) mengatasi keasidan tanah dengan bahan kimia selain daripada kapur.

Untuk mengkaji aspek (i), kajian jangkamasa pendek dan untuk (iv), kajian jangkamasa panjang (4 tahun), telah dijalankan di ladang. Kajian-kajian lain (ii, iii, dan v) telah dijalankan di rumahkaca.

Empat tan metrik kapur GML sehektar telah mengurangkan ketepuan Al daripada 82% ke paras < 20%. Keadaan ini meningkatkan hasil berat kering kacang tanah cv. V13 26% dan jagung 71% dibandingkan dengan hasil daripada petak kawalan tanpa kapur. Pengapuran juga meningkatkan sumbangan N daripada kacang tanah sebanyak 44 kg N ha^{-1} yang boleh digunakan sebagai baja organik (i).

Kacang tanah kultivar cv. V13 dan *Bradyrhizobium* CB756 adalah kombinasi terbaik yang dipilih (ii) dan didapati sesuai untuk meningkatkan lagi hasil dan timbunan N dalam sisa kacang tanah pada keadaan tanah tanpa kapur dan yang berkapur. Sumbangan N daripada sisa kacang tanah adalah lebih kurang 77 kg N ha^{-1} di bawah keadaan tanpa kapur dan 105 kg N ha^{-1} berkapur, iaitu peningkatan lebih dua kali ganda daripada anggaran yang didapati daripada keadaan semulajadi dalam kajian di ladang (i). Anggaran yang dikaji adalah tinggi kerana ianya di bawah keadaan sistem tertutup (ii).

Di kawasan ladang, selain pada keadaan di musim pertama tahun 1981, kombinasi ini (kacang tanah cv. V13-*Bradyrhizobium* CB756) menyumbangkan purata sebanyak 51 kg N ha^{-1} daripada sistem tanaman giliran LMLM, manakala sistem MLLM menyumbangkan timbunan N sebanyak 106 kg ha^{-1} untuk edaran tanaman pertama dan 102 kg ha^{-1} untuk edaran kedua dalam jangkamasa empat tahun (1981-1984). Dalam jangkamasa yang sama, sumbangan daripada kacang tanah yang ditanam tiga kali berturut-turut sebelum jagung (LLLM), timbunan N daripada sisa kacang tanah ialah 142 kg N ha^{-1}

untuk edaran pertama (1981-1982) dan 165 kg N ha^{-1} untuk edaran tanaman kedua (1983-1984).

Tanaman jagung mengambil 31% daripada N berasal daripada sisa kacang tanah dalam sistem LMLM, manakala 21% di peringkat edaran tanaman pertama dan 25% di peringkat edaran tanaman kedua. Pengambilan sebanyak 31% terdapat di peringkat edaran tanaman pertama dan 37% daripada edaran kedua di bawah sistem LLLM. Persamaan baja N sebanyak 56 kg N ha^{-1} yang dianggarkan daripada keluk gerakbalas pengambilan N dari percubaan kadar pembajaan N, adalah mencukupi 35% daripada keperluan N untuk jagung (159 kg N ha^{-1}) di kawasan tanah Ultisol yang dikapurkan.

Bahan kimia selain daripada kapur tidak mempengaruhi/memperbaiki keasidan tanah atau meningkat hasil kacang tanah. Tetapi $CaSO_4$ dan K_2SO_4 menurunkan paras ketepuan Al dan meningkatkan hasil berat kering bahagian atas kacang tanah 30 hari selepas ditanam (v).

Sementara itu, kapur GML mengekalkan pH tanah di paras 5.5. Keadaan ini menurunkan ketepuan Al ke tahap 15% dan meningkatkan hasil dan sumbangan N kepada tanaman jagung. Di bawah keadaan di ladang, cuma kacang tanah ditanam tiga kali berturut-turut, menyumbangkan lebih kurang satu per tiga daripada keperluan N untuk mendapatkan hasil maksimum jagung sebanyak 6.4 mt ha^{-1}.

CHAPTER ONE

INTRODUCTION

The acidic nature of Oxisols and Ultisols is an important consideration in a rubber and oil palm replanting programme in Malaysia although it does not limit the productivity of these main crops. These two perennial species are extremely well adapted to high extractable soil aluminium (Al) levels. The plantation system, however, relies on a low input soil management technology which includes the chemical fertilizers and symbiotically-fixed N from legume interrows (cover crops). These legume interrows are replaced by relatively less acid tolerant legume and non-legume annual food crops during the early phase of a replanting programme. An extensive area, about 120,000 ha of the highly weathered Oxisols and Ultisols are utilized for replanting each year.

In the annual cropping system for food legume production Al toxicity is one of the major soil-related constraints (Foster *et al*., 1980). This toxicity along with the low supply of native soil-N limit the productivity of Oxisols and Ultisols when these soils are cropped to cereals such as maize. The N_2 fixing capacity and yield potential of grain legumes, such as groundnut, on such soils during the early phase of a replanting programme, however, have not been exploited although some related studies using soybean and siratro under simulated tropical environment have shown their potential to enrich the soil (Yaacob and Blair, 1979, 1980). Among the grain legumes groundnut has the capacity to fix large quantities of atmospheric N and leave residual N equivalent to 20-60 kg N ha^{-1} per season (Jones, 1974; Giri and De, 1980; MacColl, 1989b). Some groundnut cultivars are tolerant of soil acidity but they require relatively high Ca supply (Munns, 1977). An increase in groundnut yield on soils where this crop has not been previously grown can be achieved through inoculation with effective *Bradyrhizobium* strains (Burton, 1976; Nambiar and Dart, 1983). Consequently, research on *Bradyrhizobium* selection for groundnut to maximize N_2 fixation and increase yield under acid soil conditions in Malaysia is necessary. Acidity factors also significantly influence symbiotic growth of legumes (Andrew, 1978; Carvalho *et al.*, 1981; Shamsuddin, 1987); these effects on groundnut warrant further research. Although lime enhanced symbiotic growth of legume through the neutralization of Al, the optimum rate required by groundnut for maximum growth and N_2 fixation under field conditions is not fully known. Solution culture studies have shown that Al toxicity in soybean at 20-22 μM $\Sigma_{a\ Almono}$ can be reduced by the inclusion of 15,000 μM Ca (Alva *et al.*, 1986). However, Shamsuddin and Kasran (1989) indicated that excess Ca supply (5000 μM Ca) was antagonistic to uptake of Mg and reduced nodulation in groundnut. It has been suggested that the protective action of Ca can also be extended to other cations, such as K, Mg and NH_4, which may have similar effects reducing Al toxicity.

A series of field and pot studies were undertaken to test the hypothesis that intensive cropping of a selected groundnut cultivar inoculated with a compatible and highly effective *Bradyrhizobium* strain could substantially contribute N to the succeeding cereal crop, after being cropped several times in various crop sequence on a limed-amended Ultisol.

In testing this hypothesis, a part of the earlier study by Yaacob and Blair (1979) was extended to the field situation where the following aspects were investigated :

i) the amount of lime required to reduce the high toxic Al level (82%) in an Ultisol for satisfactory growth and yield of uninoculated local groundnut cultivar and maize (Experiment 1),

ii) selection of appropriate *Bradyrhizobium*-groundnut combination on unlimed and limed Ultisol for maximum yield and legume-N return to the soil (Experiment 2 and 3),

iii) the amount of legume-N returned to soil by selected *Bradyrhizobium*-groundnut combination on limed Ultisol receiving varying amounts of legume-N (Experiment 4),

iv) the increase in the yield of maize (M) grown on limed soil from inclusion of groundnut (L) inoculated with selected *Bradyrhizobium* planted before or after maize in three sequence (LMLM, MLLM and LLLM) in the rotational crop system (Experiment 4), and

v) the alleviation of soil acidity by chemicals other than lime (Experiment 5).

For investigating (i) a short preliminary experiment and for (iv) a long term (4 years) experiment were carried out under actual field conditions, at Puchong Farm, UPM, Malaysia. All other experiments were carried out in the glasshouse.

CHAPTER TWO

REVIEW OF LITERATURE

Ultisols

Ultisols are soils with an argillic or kandic horizon and less than 35% base saturation (at pH 8.2) in the subsoil (Soil Survey Staff, 1975). They are usually deep, well-drained red or yellow soils with less desirable physical properties and relatively low inherent fertility. These soils are most extensive in warm humid climates (749 million ha) that have a seasonal deficit of precipitation and can be formed from a wide variety of parent materials. Kaolin, gibbsite and aluminium-interlayered clays are common minerals in the clay fraction. In Ultisols of tropical America (320 million ha), deficiencies of N and P are the most limiting soil chemical characteristics. Other soil limiting factors include deficiencies of K, S, Ca, Mg, Zn and Cu, Al toxicity, P fixation, and low CEC (Sanchez and Cochrane, 1980; Sanchez and Salinas, 1981). Similar soil fertility problems also occur in Ultisols of Southeast Asia (Dent, 1980). In Malaysia most of the upland soils with good drainage are Ultisols which belong to two common great groups: Tropudults and Paleudults. The common series of Ultisols in Malaysia are the Rengam and Bungor (Paramananthan, 1978).

The Bungor series is a member of the clayey, kaolinitic, isohyperthermic family of the Typic Paleudults. They have a thick argillic horizon which has a low base status and the clay content does not decrease significantly within 1.5 m of the surface. According to the FAO/UNESCO Legend for the Soil Map of the World, Bungor series will be classified as Dystric Nitosols (FAO, 1976). They are characterized by dark grayish brown A horizon with fine sandy loam texture and deep B horizon having brownish yellow to yellowish brown colours and fine sandy clay texture. Soil consistency is friable and becomes firmer with depth. Weak to moderate medium and fine subangular blocky structures are found in such soils. Few medium to coarse distinct red mottles usually appear at depths below 100 cm. At depths below 150 cm the colours become paler. This soil is developed over interbedded sandstones and shales or sandy shales. They have been mapped over a wide range of terrain ranging from gently undulating to steep, the commonest being undulating to hilly.

The Bungor series is fairly well distributed in Peninsular Malaysia. It has been mapped in Perak, Selangor, Negeri Sembilan, Johore, Malacca, Pahang, Terengganu and Kelantan. Their extent is, however, not known since the semi-detailed soil survey of Malaysia is yet to be completed. The soils are usually well-drained, have a good permeability, and are planted with a variety of crops including rubber, oil palm, fruit trees, and cocoa although such soils poses limitations of Al toxicity to annual crops such as maize and groundnut. Some of these areas are still under primary forest vegetation.

Soil Factors Limiting Plant Growth

Soil reaction (pH) may affect plant growth and development by its influence on the availability of certain essential elements. The sorption and precipitation of phosphates is increased in acid soils with high concentrations of Fe and Al, such as the Bungor series. A decrease in soil pH results in Mo being reduced in the soils. Acid mineral soils are usually high in soluble Al and Mn and excessive amounts of these elements are toxic to plants. Although the solubility of Fe^{3+} is low in well-aerated acid soils, iron oxides can still have a major role in the reversion of fertilizer phosphorus.

Aluminium toxicity is the most important growth-limiting factor in many acid soils, particularly those having pH levels below 5.0 which are commonly found in many Malaysian soils (Law and Tan, 1975). Poor growth of plants in acid soils has been associated with the high concentration of Al in the soil solution (Evan and Kamprath, 1970; Friesen *et al.,* 1980). The exchangeable and solution Al are closely correlated with pH (Adams and Lund, 1966; Kamprath, 1970; 1978). Al toxicity affects the yield of sensitive species as the pH is lowered to 5.0 (Al solution concentration, 20 μM) and 4.5 for the tolerant species (Al solution concentration, 60 μM) (Adam, 1978; Helyar, 1978; Munns, 1978). The epipedons of Oxisols and Ultisols are generally dominated by exchangeable Al (IBSRAM, 1984). According to Kamprath (1980), crop production is drastically reduced when Al saturation of the active cation exchange sites is greater than 60%, which is associated with the toxic level of Al in solution ($>$ 0.1 mmol(+)L^{-1}), and it tends to be optimum when this