UNIVERSITI PUTRA MALAYSIA

EFFECTS OF ALUMINIUM TOXICITY ON EARLY GROWTH AND NODULATION OF GROUNDNUT IN SOLUTION CULTURE

ROSMIN KASRAN

FP 1989 6

EFFECTS OF ALUMINIUM TOXICITY ON EARLY GROWTH AND NODULATION OF GROUNDNUT IN SOLUTION CULTURE

ROSMIN KASRAN

Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Agricultural Science in the Faculty of Agriculture, Universiti Pertanian Malaysia.

September 1989

Dedicated to my family

ACKNOWLEDGEMENTS

I wish to expresss my special thanks and appreciation to my supervisor, Assoc. Prof. Haji Zulkifli Haji Shamsuddin for his invaluable suggestions and critical comments in the preparation of the thesis. I would also like to express my deepest gratitude for his professional guidance in my academic and research programme.

I would like to thank ACIAR (The Australian Centre for International Agricultural Research) for funding my research assistantship under Project 8375 entitled 'The Management of Soil Acidity for Sustained Crop Production'.

My appreciation is recorded to ACIAR Project Collaborators from the University of Queensland, especially to Assoc. Prof. D.G. Edwards, Assoc. Prof. L.C. Bell, Prof. C.J. Asher, Dr. N. J. Grundon and others in sharing their knowledge and expertise. To Dr. N. J. Grundon, I would like to extend my sincere thanks for his training and assistance in using the Nutrient Addition Method and Almono Computer Programmes.

My gratitude is also conveyed to Assoc. Prof. Shamshuddin Jusop and Mr. Anuar Abdul Rahim for sharing their research experiences and providing assistance in the various computer programmes.

My glasshouse and laboratory experiments would not have been successful without the efficient and dedicated help of Mr. Kamarudin Yusof, Mr. Dzulkifli Duaji and all the Research Assistants in the Soil Microbiology Laboratory. I would like to thank them all. To Mr. Ibrahim Shamsuddin, Mr. Ramli Yusof and all staff of Soil Science Department, I would like to thank them for their kind cooperation.

I am greatly indebted to the Malaysian Agricultural Research and Development Institute (MARDI) for allowing me to complete this thesis after my initial appointment as a Research Officer towards the end of the postgraduate programme.

Last but not least I would like to express my deepest gratitude to my family for their constant support and inspiration throughout my study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of thesis submitted to the Senate of Universiti Pertanian Malaysia in partial fulfilment of the requirements for the degree of Master of Agricultural Science.

EFFECTS OF ALUMINIUM TOXICITY ON EARLY GROWTH AND NODULATION OF GROUNDNUT IN SOLUTION CULTURE

By

ROSMIN BIN KASRAN

September, 1989

Supervisor : Assoc. Prof. Haji Zulkifli Haji Shamsuddin

Faculty : Agriculture

Five glasshouse experiments were undertaken using groundnut (Arachis hypogaea L. cv. Matjam) plants grown in nutrient solution under acid conditions. The minimum total external solution concentrations of phosphorus, calcium and magnesium required for optimum non-symbiotic growth of groundnut by the depleting nutrient method in 5 L pots at pH 4.75 ± 0.1 for 40 days were 200, 400 and 100 µM, respectively. This corresponds to their nutrient concentrations in youngest fully expanded leaves (YFEL) of 0.33, 1.47 and 0.32%.

The H^+ ion concentration at pH 3.5 did not affect plant top dry weight but markedly decreased root growth and length. The pH level recommended for growth of groundnut was ≥ 4.4. The non-toxic concentration of aluminium for growth of tops and root elongation in groundnut supplied with 400 µM Ca was ≤ 12.2

uM Σa_{Almono}.

The non-symbiotic growth of groundnut at pH 4.3 $\pm$ 0.1 for 21 days, by Nutrient Addition Method (Nutradd) in 30 L pots required an external solution Ca concentration of 2500 µM to alleviate aluminium toxicity at 24 µM Σa_{Almono}. No calcium level can alleviate aluminium toxicity at 30 and 60 µM Σa_{Almono}. A calcium concentration of $\geq$ 5000 µM reduced top dry weight and the magnesium concentration in YFEL.

In the selection of bradyrhizobia, Bradyrhizobium strain NC92 was more effective than strain UPM29 in forming nodules on groundnut under aluminium stress.

In the inoculation experiment, 7-day old groundnut seedlings with the shortest duration in sand culture (4 days) and the earliest to be inoculated (3 days) after being transferred to solution culture at pH 4.3 $\pm$ 0.1 produced maximum nodulation and the highest nitrogen concentration in YFEL.

The nodulation experiment showed that 2500 µM external solution Ca alleviated aluminium toxicity (15 µM Σa_{Almono}) on growth of groundnut inoculated with Bradyrhizobium strain NC92. The combined effect of aluminium stress and high concentration of solution Ca (5000 µM) reduced nodulation and the magnesium concentration in YFEL.

Abstrak tesis yang dikemukakan kepada Senat Universiti Pertanian Malaysia sebagai memenuhi sebahagian daripada syarat keperluan untuk Ijazah Master Sains Pertanian

KESAN KERACUNAN ALUMINIUM KE ATAS TUMBESARAN AWAL DAN PEMBINTILAN AKAR KACANG TANAH DI DALAM KULTURA LARUTAN

Oleh

ROSMIN BIN KASRAN

September, 1989

Penyelia : Prof. Madya Haji Zulkifli Haji Shamsuddin

Fakulti : Pertanian

Sebanyak lima eksperimen rumah kaca telah dijalankan menggunakan pokok kacang tanah (Arachis hypogaea L. cv. Matjam) yang ditanam di dalam kultura larutan pada keadaan berasid. Jumlah minimum kepekatan-kepekatan larutan luar bagi phosphorus, kalsium dan magnesium yang diperlukan untuk pertumbuhan bukan-simbiotik kacang tanah yang optimum secara kaedah 'depleting nutrien' menggunakan bekas 5 L pada pH 4.75 ± 0.1 adalah 200, 400 dan 100 µM, masing-masing berturutan. Ini bersamaan dengan kepekatan-kepekatan nutriennya di dalam daun termuda yang berkembang sepenuhnya (YFEL) sebanyak 0.33, 1.47 dan 0.32%.

Kepekatan ion H^+ pada pH 3.5 tidak menjejaskan berat kering bahagian atas pokok tetapi menjejaskan pertumbuhan akar

dan pemanjangannya. Paras pH yang disyorkan untuk tumbesaran kacang tanah adalah $\geq$ 4.4. Kepekatan aluminium yang tidak toksik untuk pertumbuhan bahagian atas dan pemanjangan akar kacang tanah yang dibekalkan dengan 400 µM Ca adalah $\leq$ 12.2 µM Σa_{Almono}.

Pertumbuhan bukan-simbiotik kacang tanah pada pH 4.3 $\pm$ 0.1, secara kaedah penambahan nutrien (Nutradd), menggunakan bekas 30 L memerlukan kepekatan larutan luar Ca sebanyak 2500 µM untuk mengatasi keracunan aluminium pada 24 µM Σa_{Almono}. Tiada kepekatan kalsium yang dapat mengatasi keracunan aluminium pada 30 dan 60 µM Σa_{Almono}. Kepekatan kalsium $\geq$ 5000 µM Ca merendahkan berat kering bahagian atas dan kepekatan magnesium di dalam YFEL.

Dalam pemilihan bradyrhizobia, *Bradyrhizobium* strain NC92 adalah lebih efektif berbanding dengan strain UPM29 dalam pembentukan nodul kacang tanah pada keadaan ketegasan aluminium.

Dalam eksperimen inokulasi, anak benih kacang tanah yang berumur 7 hari dengan jangkamasa terpendik di dalam kultura pasir (4 hari) dan yang terawal diinokulasi (3 hari) selepas dipindahkan ke dalam kultura larutan pada pH 4.3 $\pm$ 0.1 memberikan pembintilan maksimum dan kandungan nitrogen di dalam YFEL yang tertinggi.

Kajian pembintilan akar menunjukkan 2500 µM larutan luar Ca dapat mengatasi keracunan aluminium pada 15 µM $£a_{Almono}$ ke atas pertumbuhan kacang tanah yang diinokulasi dengan Bradyrhizobium strain NC92. Kesan kombinasi diantara ketegasan aluminium dan kepekatan kalsium yang tinggi (5,000 µM) merendahkan pembintilan akar dan kepekatan magnesium di dalam YFEL.

CHAPTER 1

INTRODUCTION

The lack of response by groundnut (Arachis hypogaea L.) and other legumes to normal fertilization and cultural practices, under acid soil conditions, has been ascribed to deficiency or unavailability of calcium, magnesium, phosphorus and molybdenum; low pH per se; toxicity of aluminium or manganese (Coleman and Thomas, 1967; Foy et al., 1978; Kamprath and Foy, 1985) or a combination of these factors (Alva et al., 1987). These complex of acid soil infertility factors can limit host plant growth, nutrient uptake, nodulation, or nodule function (Munns and Franco, 1982; Alva et al., 1987).

Aluminium toxicity becomes a major problem for the growth of many plant species in acid soils if the pH (1:5 soil : water) falls below 5.0 but can occur as high as pH 5.5 in kaolinitic soils (Foy, 1984; Kamprath and Foy, 1985). Injury due to aluminium is usually first expressed in reduced root growth (Jackson, 1967; Foy, 1974), and to failure in the survival and growth of Rhizobium, nodule initiation, or nodule development (Munns and Franco, 1982). Investigations on pasture legumes (Stylosanthes species, Macroptilium lathyroides cv. Murray and Centrosema pubescens cv. Belalto) have shown that the effects of aluminium toxicity are more severe on nodulation than on the non-symbiotic growth of the host plants or of freeliving Bradyrhizobium (Carvalho et al., 1981, 1982 a,b; Murphy et al., 1984). Similarly, it has been shown that in winged bean (Psophocarpus tetragonolubus (L) D.C.) low pH and aluminium toxicity limited nodulation more severely than the growth of host plant (Shamsuddin, 1987).

Calcium performs an essential role in maintaining selective ion absorption by roots (Viets, 1944; Epstein, 1961), hence a suitable calcium concentration would reduce aluminium transport to the stele of plant roots. However, in groundnut the suitable solution calcium concentration required to alleviate aluminium toxicity on growth and nodulation has not been established.

Objectives of Study

The objectives of this study were:

i . to determine the toxic effects of summation activity of monomeric aluminium (Σa_{Almono}) on growth and nodulation of groundnut cv. Matjam and,

ii . to determine the external solution calcium concentration required to alleviate aluminium toxicity on growth and nodulation of groundnut cv. Matjam.

CHAPTER 2

REVIEW OF LITERATURE

Aluminium in Soils

The high concentrations (181-325 µM) of monomeric aluminium which occur in soil solutions and leachates from untreated and lime-amended soils (3-6 t ha^{-1} $CaCO_3$) would, if present in an uncomplexed state, reduce plant growth (Jarvis, 1987). A solution pH of 4.5 was found to reduce growth of four genotypes of white clover and decrease nitrogen metabolism at an Al^{3+} concentration as low as 12.5 µM (Jarvis and Hatch, 1987). The form of monomeric aluminium in the soil solutions studied by Jarvis (1987) is not known, but a major proportion of the monomeric inorganic aluminium in solutions from a Spodosol (pH 4.5) (1:2.5, soil:0.01 M $CaCl_2$) were calculated to be complexed with fluoride, F^-, or hydroxyl, OH^-, ion (Driscoll et al.,1985); only in a very acidic (pH 3.6) horizon was Al^{3+} in the dominant inorganic form. Furthermore, a high proportion of the total soluble monomeric aluminium were also complexed by the organic matter present in the Spodosol (Jarvis, 1987). Much of the extractable aluminium in the Pelostagnoley soil of the Hallsworth series, is associated with organic matter (Jarvis, 1986) and consequently the proportion of organically complexed aluminium in solution may be high. Complexed aluminium species of this nature will be able to exist in solution at a higher pH (6.6), as indicated by the relatively high aluminium concentration in the 40-90 mm of a limed (3-6 t ha^{-1} $CaCO_3$) soil (Jarvis, 1987).

The increase in apparent $Al(OH)_3$ solubility with increased pH has been attributed to the greater solubility of amorphous $Al(OH)_3$ precipitated by liming (Frink and Peech, 1962). Based on the solubility calculations, $Al(OH)^{2+}$ was assumed to be the only significant hydrolyzed ion. Other investigators have applied different hydrolysis schemes in an attempt to obtain more constant $(Al^{3+})(OH^{-})^3$ values. Marion et al. (1976) assumed that the predominant hydrolyzed ion was $Al(OH)_2^{+}$ while Richburg and Adams (1970) assumed that the predominant hydrolyzed ion was $Al_6(OH)_{15}^{3+}$. The hydrolysis constants used in both investigations, however, were not consistent with the constant given by Baes and Mesmer (1976).

The variation in apparent $Al(OH)_3$ solubility in soils can be due to the difference in solubility of the crystalline minerals (Marion et al., 1976). However, organic matter has been shown to influence the relationship between pH and the quantity of aluminium in soil solutions (Pierre et al., 1932; Clark and Nichol, 1966; Evans and Kamprath, 1970). The addition of 2% partially rotted leaf humus to an Inceptisol subsoil resulted in a 40% reduction of Al^{3+} in solution at a pH range of 3.9 to 4.9 compared to suspensions with no added humus