COMPETITION FOR NODULE SITES BY COWPEA-*BRADYRH1ZOBIUM* AND PARASITIC FLOWERING PLANTS AS AFFECTED BY INOCULATION, N, P AND Mo.

BY

NKECHI MARYELEEN CHINKE
(B. Agric.)

A THESIS SUBMITTED TO THE POSGRADUATE SCHOOL
AHMADU BELLO UNIVERSITY, ZARIA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE
IN SOIL SCIENCE

DEPARTMENT OF SOIL SCIENCE
FACULTY OF AGRICULTURE
AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA

JUNE, 1999

DECLARATION

I hereby declare that this thesis has been written by me and that it is a record of my own research work except where reference is made to published literature and where assistance is acknowledged. It has not been presented before in any previous application for higher degree.

Nkechi 26-10-99

NKECHI MARYELEEN CHINKE
(M.Sc Candidate)

DATE

The above declaration is confirmed.

E.N.O. Iwuafor 03 NOV. 1999

DR. E.N.O. IWUAFOR
(Major Supervisor)

DATE

DEDICATION

This thesis is dedicated to God the Father Almighty for his guidance and mercies throughout the course of this study.

ACKNOWLEDGEMENT

This study was funded by PEDUNE IAR/IITA, PROJECT, Nigeria, through an M.Sc. scholarship award to me. The research was conducted at the Soil Science Department, Faculty of Agriculture, Ahmadu Bello University, Zaria, Nigeria. I am most grateful to my supervisors Dr. E.N.O. Iwuafor, Dr. N. Sanginga, and Prof. V.O. Chude for their patience, tolerance and contributions. Also grateful to Dr. A. Okogun; Mr. V. Adedokun, Mr. Isaac Ajigbe, Mr. J. Oyedipe, and other members of staff of the Soil Microbiology Laboratory IITA, Ibadan, Nigeria, for their technical assistances. Also to Prof. A.M. Emechebe, Crop Protection Department, Faculty of Agriculture, ABU, Zaria, Nigeria, for his useful comments on this thesis and to my Uncle, Air Commodore S.E. Omeruah (Rtd.) for his financial contribution and encouragement towards the completion of this project.

My appreciation also goes to my parents, Chief and Lolo M.O. Chinke and my sisters, Barrister N.G. Chinke and, Mrs. I.N. Okochi for their love and understanding.

To my colleagues in the Soil Science Department, A.B.U., Zaria, I thank them for their moral support and understanding throughout the course.

I sincerely appreciate the cooperation and assistance given to me by Dr. T. Oluwasimire and the entire staff of the IAR Data Processing Unit for helping me to analyse the data. My special thanks go to my niece, Ms Chikerenma Mary Babah who worked with me throughout the growing seasons till the completion of the entire work. I also wish to acknowledge the contribution of Mr. Mathias Asuquo Udoh, for typing this thesis.

Finally, I offer my praises and heartfelt gratitude to God, the Almighty for His guidance and mercies.

ABSTRACT

Studies in the greenhouse and field were initiated to evaluate the effects of *Striga* and *Alectra* on cowpea nodulation and N-fixation, to determine the influence of cowpea - *Bradyrhizobium* strains on *Striga* and *Alectra* and the influence of phosphorus, molybdenum and nitrogen on *Striga* and *Alectra* infection of cowpea.

The effect of inoculant strains of cowpea - *Brady rhizobium* on *Striga* and *Alectra* infection of cowpea was studied in the greenhouse. The results showed that inoculation with *Brady rhizobium* strain IRc 506c resulted in the lowest incidence of infection by these parasitic flowering plants and thus, produced higher total dry matter, nodule number, nodule dry weight and percentage nitrogen fixed than strain IRc 291 or IRc 461a, suggesting that strain IRc 506c is more efficient in competing for nodule sites or in fixing atmospheric nitrogen with the cowpea varieties used.

Two field experiments were carried out during the 1995 and 1996 cropping seasons. The first experiment investigated the influence of urea nitrogen fertilizer applied seven days after planting on the incidence of *Striga* and *Alectra* infection of cowpea. The second field experiment studied the effect of phosphorus and Mo on *Striga* and *Alectra* infection in cowpea. Phosphorus and Mo were applied also at seven DAP.

Results of the first field experiment showed that application of 15kgNha-' urea nitrogen fertilizer reduced the incidence of *Striga* and *Alectra* infection in susceptible varieties (SAMPEA-7, SAMPEA-1 and IT82D-849) but not in the resistant variety (B301) by 16 and 14% (in terms of the number of attached *Striga* and *Alectra* per cowpea

plant, respectively); and 21 and 19% (in respect of the number of emerged *Striga* and *Alectra* per cowpea plant respectively). Among the susceptible varieties, IT82D-849 performed better than SAMPEA-1 and SAMPEA-7. Total cowpea dry matter (TDM) yield was increased by 12% in the fertilized, uninfested plots compared to the control. In the fertilized *Striga* - or *Alectra* - infested plots, TDM was increased by 19 or 17%, compared to the unfertilized, infested plots respectively. Grain yield increased with the application of l5kgNha^{1} by 19% in the fertilized, uninfested plots compared to the control. The *Striga* or *Alectra* infested but fertilized plots produced more grain yield than the unfertilized but infested plots by 21 or 10% respectively. Cowpea variety B 301 produced the highest grain yield. Nodulation (nodule number and nodule dry weight) was increased by 8 and 4% in the fertilized uninfested plots compared to the control. On the other hand, plants in the *Striga* - infested but fertilized plots had 28% higher nodule number and 5% higher nodule dry weight compared to the unfertilized but infested plots. Similarly, plants in *Alectra* infested but fertilized plots had 19 and *5%* higher nodule number and nodule dry weight, than unfertilized plots respectively.

Results of the second field experiment indicated that application of 40kgPha-^{1} in all treatments reduced the incidence of *Striga* or *Alectra* infection compared to 80 and 20kgPha^{-1}*K* Molybdenum application also reduced the incidence of *Striga* or *Alectra* infection compared to the control while combined application of 0.25kgMoh^{-1} and 40kgPha-^{1} resulted in the lowest incidence of infection by *Striga* or *Alectra* compared to the control. Application of 80kgPha'" either alone or in combination with various levels of Mo produced the highest TDM. Compared to *Alectra* infested but unfertilized plots,

application of 80kgPha^{-1} to *Alectra* infested plots increased TDM by 77%, the corresponding figure for *Striga* infested plot being 109%. In respect of Mo fertilization, application of 0.25kgMoha^{-1} and O.SOkgMoha^{-1} to *Alectra* infested plots increased TDM by 33 and 44%, respectively, the corresponding figures for *Striga* being 30 and 33%. Cowpea grain yield was also increased compared to the control. Phosphorus at 40kg Pha^{-1} produced the highest grain yield among the P levels. However, among all fertilizer treatments application of Mo at 0.50kgha^{-1} and 40kgPha^{-1} produced the highest grain yield;compared to grain yields of the control, application of these levels of Mo and P resulted in 221% increase in grain yield in *Alectra* infested plots and 144% increase in *Striga* infested plots. Application of P enhanced nodulation and nitrogen fixation compared to the control. Application of 40kgPha^{-1} resulted in higher nodule number, nodule dry weight and percentage N-fixed either alone or in combination with various levels of Mo in the *Striga* or *Alectra* infested plots.

TABLE OF CONTENTS

Page

DECLARATION ii

CERTIFICATION iii

DEDICATION iv

ACKNOWLEDGEMENTS v

ABSTRACT vi

TABLE OF CONTENTS x

LIST OF TABLES xv

LIST OF FIGURES xvii

LIST OF APPENDICES xx

CHAPTER ONE 1

INTRODUCTION 1

CHAPTER TWO 4

2.0. REVIEW OF LITERATURE 4

2.1. Parasitism of *Striga* and *Alectra* *4*

2.2. Symptoms of Infection of *Striga* and *Alectra* in Cowpea 5

2.3. Effect of Parasitic Flowering Plants on Cowpea Yield 6

2.4. Factors Influencing Infection and Damage by Parasitic Flowering Plants . . . 7

2.5. Possible control methods for *Striga* and *Alectra* 8

2.6. Legume - *Rhizobium* symbiosis 11

2.7. Association between *Bradyrhizobium* and the Parasitic Flowering Plants on Cowpea 12

2.8. Soils of the Nigerian Savanna 13

2.9. The role of Nitrogen, Phosphorus and Molybdenum in plants 15

2.9.1. Nitrogen (N) 15

2.9.2. Phosphorus (P) 16

2.9.3. Molybdenum (Mo) 16

2.10. Effect of Nitrogen application on Growth, Nodulation and Symbiotic N_2 Fixation of Cowpea 17

2.11. Effect of Phosphorus application on Growth, Nodulation and Symbiotic N_2 fixation of Cowpea 18

2.12. Effect of Molybdenum application on Growth, Nodulation and Symbiotic N_2 fixation of Cowpea 19

2.13. Effect of Nitrogen Fertilizer on Parasitic Flowering Plants of Cowpea . . . 20

2.14. Effect of Phosphate Fertilizer on Parasitic Flowering Plants of Cowpea . . 21

2.15. Effect of Molybdenum Fertilizer on Parasitic Flowering Plants of Cowpea 22

CHAPTER THREE 23

3.0. MATERIALS AND METHODS 23

3.1. Greenhouse Study: Effect of *Bradyrhizobium* strains on *Striga* and *Alectra* infection of Cowpea 23

3.1.1. Location 23

3.1.2. Collection and preparation of soil and sand samples 23

3.1.3. Preparation of sterile sand and soil cultures 24

3.1.4. Collection and preparation of *Striga* or *Alectra* seeds 24

3.1.5. Preparation of soil inoculated with *Striga* or *Alectra* 24

3.1.6. Seed sterilization 26

3.1.7. *Bradyrhizobium* inoculation of cowpea seeds 26

3.1.8. Treatment and experimental design 27

3.1.9. Cultural practices 27

3.1.9(a) Planting 27

3.1.9(b) Watering and management of plants 28

3.1.10. Observations and measurement 28

3.1.11. Sampling procedure for estimating nitrogen fixation (Ureide Method) . . 29

3.1.12. Calculations 30

3.1.13. Root sampling 31

3.2. Field Study 32

3.2.1. Site description 32

3.2.2. Treatment and experimental design 33

3.2.2(a) Effect of urea nitrogen fertilizer 33

3.2.2(b) Effect of phosphorus and molybdenum 33

3.2.3. Cultural practices 34

3.2.4. Observations and measurements 34

3.2.5. Soil sampling 35

3.2.6. Plant sampling 35

3.3. Soil Analyses 35

3.4. Plant Analyses . . . . .

3.5. Statistical Analyses 36

CHAPTER FOUR 37

4.0. RESULTS AND DISCUSSIONS 37

4.1. Greenhouse Experiment 37

4.1.1. Characterization of the soil used 37

4.1.2. Morphological observations on the effect of *Striga gesnerioides* and *Alectra vogelii* infection on cowpea 39

4.1.3. Effect of *Bradyrhizobium* strains on the incidence of cowpea- *Striga* and- *Alectra* infection 40

4.1.4. Effect of *Bradyrhizobium* strains and parasitic flowering plants on cowpea total dry matter yield 46

4.1.5. Effect of *Bradyrhizobium* strains and parasitic flowering plants on cowpea nodulation and nitrogen fixation 50

4.2. Field Experiments 57

4.2.1. Morphological observations on the effect of *Striga gesnerioides* and *Alectra vogelii* infection on cowpea 57

4.2.2. Effect of urea nitrogen fertilizer on the incidence of cowpea-*Striga* and- *Alectra* infection 58

4.2.3. Effect of urea nitrogen fertilizer on cowpea total dry matter yield 63

4.2.4. Effect of urea nitrogen fertilizer on cowpea grain yield 66

4.2.5. Effect of urea nitrogen fertilizer on cowpea nodulation 70

4.2.6. Effect of urea nitrogen fertilizer on cowpea nitrogen fixation 73

4.2.7. Effect of phosphorus and molybdenum on the incidence of cowpea-*Striga* and-*Alectra* infection 78

4.2.8. Effect of phosphorus and molybdenum on total cowpea dry matter yield. . 83

4.2.9. Effect of phosphorus and molybdenum on cowpea grain yield 87

4.2.10 Effect of phosphorus and molybdenum on cowpea nodulation and nitrogen fixation 91

CHAPTER FIVE 100

SUMMARY AND CONCLUSION 100

RECOMMENDATION 101

REFERENCES 102

APPENDIX 118

BIOGRAPHY 150

LIST OF TABLES

Table 1. Physiochemical properties of the soil used 38

Table 2a. Effect of *Bradyrhizobium* strains on the number of *Alectra* attached/emerged on four cowpea varieties in the greenhouse 41

Table 2b. Effect of *Bradyrhizobium* strains on the number of *Striga* attached/emerged on four cowpea varieties in the greenhouse 42

Table 3. Effect of *Bradyrhizobium* strains on the number of parasitic flowering plants on cowpea total dry matter yield in the greenhouse 47

Table 4. Effect of *Bradyrhizobium* strains and parasitic flowering plants on cowpea nodulation in the greenhouse 52

Table 5. Effect of *Bradyrhizobium* strains and parasitic flowering plants on cowpea nitrogen fixation in the greenhouse 53

Table 6a. Effect of nitrogen fertilizer on the attachment of *Striga* or *Alectra* infection of cowpea at Samaru in 1995 and 1996 61

Table 6b. Effect of nitrogen fertilizer on the emergence of *Striga or Alectra* infection of cowpea at Samaru in 1995 and 1996 62

Table 7. Effect of nitrogen fertilizer and parasitic flowering plants on total cowpea dry matter yield at Samaru in 1995 and 1996 64

Table 8. Effect of nitrogen fertilizer and parasitic flowering plants on cowpea grain yield at Samaru in 1995 and 1996 68

Table 9a. Effect of nitrogen fertilizer and parasitic flowering plants on cowpea nodule number at Samaru in 1995 and 1996 71

Table 9b. Effect of nitrogen fertilizer and parasitic flowering plants on cowpea nodule dry weight at Samaru in 1995 and 1996 71

Table 10. Effect of nitrogen fertilizer and parasitic flowering plants on cowpea nitrogen fixation at Samaru in 1995 and 1996 75

Table 11a. Effect of phosphorus and molybdenum on the attachment and emergence of *Alectra vogelii* infection of cowpea at Samaru in 1995 and 1996 80

Table 11b. Effect of phosphorus and molybdenum on the attachment and emergence of *Alectra vogelii* infection of cowpea at Samaru in 1995 and 1996 81

Table 12. Effect of phosphorus and molybdenum on total dry matter yield of cowpea planted on *Striga* or *Alectra* infested plots at Samaru in 1995 and 1996 85

Table 13. Effect of phosphorus and molybdenum on grain yield of cowpea planted on *Striga* or *Alectra* infested plots at Samaru in 1995 and 1996 89

Table 14a. Effect of phosphorus and molybdenum on nodulation of cowpea planted on *Striga* infested plots at Samaru in 1995 and 1996 . . . 93

Table 14b. Effect of phosphorus and molybdenum on nodulation of cowpea planted on *Alectra* infested plots at Samaru in 1995 and 1996 . . . 94

Table 15. Effect of phosphorus and molybdenum on nitrogen fixation of cowpea at 50% podding stage planted on *Striga* or *Alectra* infested plots using the root bleeding sap method at Samaru in 1995 and 1996. 95

LIST OF FIGURES

		Page
Figure 1a.	Effect of cowpea varieties on the attachment of *Striga* and *Alectra* in the greenhouse	43
Figure 1b.	Effect of cowpea varieties on the emergence of *Striga* and *Alectra* greenhouse	43
Figure 1c.	Effect of *Bradyrhizobium* strains on *Striga* and *Alectra* attachment on cowpea irrespective of varieties in the greenhouse	44
Figure 1d.	Effect of *Bradyrhizobium* strains on *Striga* and *Alectra* emergence on cowpea irrespective of varieties in the greenhouse	44
Figure 2a.	*Striga* and *Alectra* effects on total dry matter yield of cowpea varieties in the greenhouse	48
Figure 2b.	Effect of *Bradyrhizobium* strains on total dry matter yield of cowpea varieties planted in *Striga* or *Alectra* infested pots in the greenhouse	48
Figure 3a.	*Striga* and *Alectra* effects on nodule number of cowpea varieties in the greenhouse	54
Figure 3b.	*Striga* and *Alectra* effects on nodule dry weight of cowpea varieties in the greenhouse	54
Figure 3c.	Effect of *Bradyrhizobium* strains on nodule number of cowpea planted in *Striga* or *Alectra* infested pots in the greenhouse	55
Figure 3d.	Effect of *Bradyrhizobium* strains on nodule dry weight of cowpea planted in *Striga* or *Alectra* infested pots in the greenhouse	55
Figure 4a.	*Striga* and *Alectra* effects on % nitrogen fixed by cowpea varieties in the greenhouse	56
Figure 4b.	Effect of *Bradyrhizobium* strains on the percentage of nitrogen fixed by cowpea varieties planted in *Striga* or *Alectra* infested pots in the greenhouse	56
Figure 5.	Effect of cowpea variety on the attachment and emergence of *Striga* and *Alectra* in Samaru (averaged over two years)	62

Figure 6. Effect of nitrogen fertilizer on the attachment or emergence of *Striga* and *Alectra* at Samaru (averaged over two years) 62

Figure 7. Dry matter yield of different cowpea varieties at Samaru (averaged over two years) 65

Figure 8. Nitrogen fertilizer effect on total cowpea dry matter yield at Samaru (averaged over two years) 65

Figure 9. Grain yields of different cowpea varieties at Samaru (averaged over two years) 69

Figure 10. Nitrogen fertilizer effect on cowpea grain yield at Samaru (averaged over two years) 69

Figure 11. Nodulation of different cowpea varieties at Samaru (averaged over two years) 72

Figure 12. Nitrogen fertilizer effect on cowpea nodulation at Samaru (averaged over two years) 72

Figure 13. Percentage nitrogen fixed by cowpea varieties at 50% podding at Samaru (averaged over two years) 77

Figure 14. Nitrogen fertilizer effect on percent nitrogen fixed by cowpea at 50% podding at Samaru (averaged over two years) 77

Figure 15a. Phosphorus and molybdenum effects on cowpea-*Striga* and *Alectra* attachment at Samaru (averaged over two years) 82

Figure 15b. Phosphorus and molybdenum effects on cowpea-*Striga* and -*Alectra* emergence at Samaru (averaged over two years) 82

Figure 16. Phosphorus and molybdenum effects on total cowpea dry matter yields at Samaru (averaged over two years) 86

Figure 17. Phosphorus and molybdenum effects on cowpea grain yields at Samaru (averaged over two years) 90

Figure 18a. Phosphorus and molybdenum effects on cowpea nodule numbers at Samaru (averaged over two years) 98

Figure 18b. Phosphorus and molybdenum effects on cowpea nodule dry weight at Samaru (averaged over two years) 98

Figure 19. Phosphorus and molybdenum effects on nitrogen fixation of cowpea at 50% podding using root bleeding sap method at Samaru (averaged over two years) 99

LIST OF APPENDICES

Page

Appendix 1. Analysis of variance table showing the effect of *Alectra vogelii* and *Striga gesnerioides* attachment on cowpea varieties inoculated with *Bradyrhizobium* strains in the greenhouse in 1996. 123

Appendix 2. Analysis of variance table showing the effect of *Alectra vogelii* and *Striga gesnerioides* emergence on cowpea varieties inoculated with *Bradyrhizobium* strains in the greenhouse in 1996. 124

Appendix 3. Analysis of variance table showing the effect of *Alectra vogelii* and *Striga gesnerioides* on total dry matter yields of cowpea inoculated with *Bradyrhizobium* strains in the greenhouse in 1996. 125

Appendix 4. Analysis of variance table showing the effect of *Alectra vogelii* and *Striga gesnerioides* on nodule number of cowpea inoculated with *Bradyrhizobium* strains in the greenhouse in 1996. 126

Appendix 5. Analysis of variance table showing the effect of *Alectra vogelii* and *Striga gesnerioides* on nodule dry weights of cowpea inoculated with *Bradyrhizobium* strains in the greenhouse in 1996. 127

Appendix 6. Analysis of variance table showing the effect of *Alectra vogelii* and *Striga gesnerioides* on nitrogen fixation of cowpea inoculated with *Bradyrhizobium* strains in the greenhouse in 1996. 128

Appendix 7. Analysis of variance table showing the effect of nitrogen fertilizer on *Striga* and *Alectra* attachment on cowpea at Samaru in 1995 and 1996 . 129

Appendix 8. Analysis of variance table showing the effect of nitrogen fertilizer on *Striga* and *Alectra* emergence on cowpea at Samaru in 1995 and 1996 130

Appendix 9. Analysis of variance table showing the effect of nitrogen fertilizer on cowpea total dry matter yield at Samaru in 1995 and 1996 131

Appendix 10. Analysis of variance table showing the effect of nitrogen fertilizer on cowpea grain yield at Samaru in 1995 and 1996 132

Appendix 11. Analysis of variance table showing the effect of nitrogen fertilizer on cowpea nodule number at Samaru in 1995 and 1996 133

Appendix 12. Analysis of variance table showing the effect of nitrogen fertilizer on cowpea nodule dry weights at Samaru in 1995 and 1996 134

Appendix 13. Analysis of variance table showing the effect of nitrogen fertilizer on cowpea nitrogen fixation using the root bleeding sap method at 50% podding at Samaru in 1995 and 1996 135

Appendix 14. Analysis of variance table showing the effects of phosphorus and molybdenum on cowpea *Alectra* attachment at Samaru in 1995 and 1996. 136

Appendix 15. Analysis of variance table showing the effects of phosphorus and molybdenum on cowpea *Alectra* emergence at Samaru in 1995 and 1996. 137

Appendix 16. Analysis of variance table showing the effects of phosphorus and molybdenum on cowpea *Striga* attachment at Samaru in 1995 and 1996. 138

Appendix 17. Analysis of variance table showing the effects of phosphorus and molybdenum on cowpea *Striga* emergence at Samaru in 1995 and 1996. 139

Appendix 18. Analysis of variance table showing the effects of phosphorus and molybdenum on total dry matter yield of cowpea planted on *Alectra* infested plots at Samaru in 1995 and 1996. 140

Appendix 19. Analysis of variance table showing the effects of phosphorus and molybdenum on total dry matter yield of cowpea planted on *Alectra* infested plots at Samaru in 1995 and 1996. 141

Appendix 20. Analysis of variance table showing the effects of phosphorus and molybdenum on grain yield of cowpea planted on *Alectra* infested plots at Samaru in 1995 and 1996. 142

Appendix 21. Analysis of variance table showing the effects of phosphorus and molybdenum on grain yield of cowpea planted on *Striga* infested plots at Samaru in 1995 and 1996. 143

Appendix 22. Analysis of variance table showing the effects of phosphorus and molybdenum on nodule number of cowpea planted on *Alectra* infested plots at Samaru in 1995 and 1996. 144

Appendix 23. Analysis of variance table showing the effects of phosphorus and molybdenum on nodule number of cowpea planted on *Striga* infested plots at Samaru in 1995 and 1996. 145

Appendix 24. Analysis of variance table showing the effects of phosphorus and molybdenum on nodule dry weight of cowpea planted on *Alectra* infested plots at Samaru in 1995 and 1996. 146

Appendix 25. Analysis of variance table showing the effects of phosphorus and molybdenum on nodule dry weight of cowpea planted on *Striga* infested plots at Samaru in 1995 and 1996. 147

Appendix 26. Analysis of variance table showing the effects of phosphorus and molybdenum on cowpea nitrogen fixation at 50% podding stage on *Alectra* infested plots using the root bleeding sap method at Samaru in 1995 and 1996. 148

Appendix 27. Analysis of variance table showing the effects of phosphorus and molybdenum on cowpea nitrogen fixation at 50% podding stage on *Striga* infested plots using the root bleeding sap method at Samaru in 1995 and 1996. 149

CHAPTER ONE

INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) is the most important grain legume in the semi-arid regions of West Africa. This grain legume provides more than half the plant protein in human diets of the region (Rachie, 1985) and contains a protein supplement of about 23-25% to staple diets in Africa where animal protein is limited and expensive (Rachie, 1985 and Quin, 1997). As a food it is eaten in the form of dry seeds, green pods, green seeds and tender green leaves. It is also used as fodder (dried shoot and leaves) which provides a valuable feed during the dry season and also serves as a quick-growing cover crop under a wide range of conditions (Quin, 1997). In addition, it fixes atmospheric nitrogen through symbiosis with nodule bacteria (*Bradyrhizobium* sp.) and contributes about 40-80 kg N/ha of soil N levels while the total amount of nitrogen fixation is 70 - 350 kg/ha (Quin, 1997).

World production figures of cowpea show that over 75% of the grain production occur in West Africa with most of this (60% of the world production) in Nigeria (Singh and Singh, 1982). Annual world grain production is estimated at 3 million tons (Singh *et al.*, 1997). About 80% of Nigeria's annual total cowpea grain production is obtained from the northern Guinea and Sudan savanna zones of the country (Emechebe *et al.*, 1988) and the average grain yield is given as 0.47t/ha for Nigeria (Quin, 1997).

Among the factors contributing to low yields are low soil fertility, acidity and Al-toxicity, moisture stress, as well as inadequate management practices and insect pests and diseases. The attack by parasitic flowering plants, namely *Striga gesnerioides* (Willd.)

Vatke and *Alectra vogelii* Benth. also constitutes very serious but peculiar constraints to cowpea production (Emechebe *et al.*, 1991). According to Aggarwal (1985), Lane *et al.*, (1996) and Emechebe *et al.* (1991), *Striga* is more wide spread in the Sahel and Sudan savannas of the sub-Saharan Africa ecological zones that are subject to a long, dry intercrop period (Wien and Summerfield, 1980), while *Alectra* appears to be more destructive in the northern Guinea savanna. Though *Striga* is much more important and widely distributed than *A. vogelii*, total yield loss is not uncommon in fields heavily infested by any of these parasitic flowering plants when susceptible varieties of cowpea are planted (Emechebe *et al.*, 1983, Emechebe *et al.*, 1988).

As parasitic flowering plants, *Striga* and *Alectra* depend mostly on their host for nutrients which they obtain through haustoria attachment to the roots. The attachment of these parasitic flowering plants to the roots of the crop may tend to reduce root site attachment by the cowpea-*Bradyrhizobium* and consequently negatively affect nodulation and atmospheric N-fixation by cowpea, thus resulting in low yields. Such a competition between *Bradyrhizobium* and the parasitic flowering plants for root attachment is therefore a potentially important factor in cowpea production and yet it has not received much research attention. In order for the crop to maintain its vigor and yield potential, the cowpea-*Bradyrhizobium* association should be well sustained by appropriate production practices which includes those that enhance the cowpea-*Bradyrhizobium* association and minimize the competition by the parasitic flowering plants for nodule sites on the roots.

Several methods of control of these parasitic flowering plants have been reported such as deep cultivation, intercropping, crop rotation, early planting, use of trap crops, resistant varieties, nitrogenous fertilizers and chemical seed treatement. Among these, control by improving the nutrition of the crop has received very little attention. However, Adu *et al*. (1989) reported that application of about 60kg N ha^{-1} nitrogen fertilizer reduced the incidence of *Striga gesnerioides* attack on cowpea without affecting grain yield.

Phosphorus (P) and Molybdenum (Mo) are important nutrient elements required by cowpea for maximum yield. Phosphorus is very essential for effective nodulation and N-fixation while molybdenum is important for both nitrate reduction before protein synthesis and nitrogen fixation (Mengel and Kirkby, 1979).

In view of the importance of cowpea as a crop and the potential competition between *Bradyrhizobium* and parasitic flowering plants for nodule sites, this research report was conducted with the following objectives:

(1) To evaluate the effects of *Alectra* and *Striga* on nodulation and nitrogen fixation in cowpea.

(2) To evaluate the performance of four cowpea varieties inoculated with *Bradyrhizobium* strains in soils infested with *Striga* or *Alectra*.

(3) To determine the influence of nutrient elements (especially P, Mo and N) on *Striga* and *Alectra* infection of cowpea.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Parasitism and Botany of *Striga* and *Alectra*

The biology of the cowpea parasites, *Striga gesnerioides* and *Alectra vogelii* have been studied by several scientists (Kuijt 1969; Visser 1975, 1978; Dorr *et al.*, 1977, 1979; Okonkwo and Nwoke 1978; Reid and Parker 1979; Ba 1984; Riches 1989; Lane *et al.*, 1991, Okonkwo, 1991, Dorr, 1995). Their seeds germinate when in contact with root exudates from cowpea or other host exudates that stimulate germination. Their radicles elongate in response to the concentration gradient of root exudate (Singh and Emechebe, 1997). When in contact with host roots, radicle apex developes numerous hairs and gets attached to host roots. *Striga* radicle penetrates and stimulates cell division in host root, and forms a large haustorium with it. This unites the parasite with the host's tissue stele enabling transfer of nutrients and water from host to parasite. In the case of *Alectra*, a profused root formation is developed by the host, forming a larger haustorium than *Striga*. Shoots of both *Striga* and *Alectra* emerge from the haustorium about 2 weeks after infection and grow into plants (Singh and Emechebe 1997). *Striga* has been reported to emerge faster than *Alectra* when cowpea was planted on field infected with both parasites (Emechebe, unpublished). Their plants normally branch below ground and grow as one bunch above ground level.

The leaves of *Striga* are small, scale-like, succulent and somehow fused to the stem, while those of *Alectra* are larger and more open. Flowers develop above ground level and are purple, white, pink or occasionally yellow for *Striga* and consistently yellow for *Alectra*. Seeds are produced in capsules and each may have up to 400 - 500 seeds depending on the extent of branching and growth (Singh and Emechebe, 1997). Seeds are very small or tiny and dispersed over long distances by agents of dispersion such as water, wind, animals (Parker and Riches, 1993) and by crop seeds (Berner *et al.*, 1994b).

2.2. Symptoms of Infection of *Striga* and *Alectra* in Cowpea

The removal of nutrients, water and carbohydrates from the host's tissue stalk through the haustorium of the parasites which consists of phloem and other transport cells have led to various symptoms exhibited by the host plant. These symptoms can be noticed on cowpea, at about 2 - 3 weeks before the emergence of these parasites above ground level (Singh and Emechebe, 1997). The frequent symptoms shown by cowpea infected by *Striga* both in the greenhouse and the field are interveinal chlorosis, general stunting and smaller leaves. In severe infection, there is complete foliar desiccation, rusty brown-purplish spots, which dry to give straw-coloured necrotic spots with water soaked margins and blighting of the lamina due to coalescence of several spots (Emechebe *et al.*, 1983; Emechebe *et al.*, 1991; Singh and Emechebe, 1997). Similar symptoms (sometimes less severe) are observed on *Alectra*-infected cowpea (Emechebe *et al.*, 1983). Cowpea plants show general stunting, chlorosis, foliar and stem necrosis,

and wilting resulting in reduced number of flowers, and pods. Complete wilting can result due to serious moisture deficit (Chukwezi, 1986; Aliyu, 1988; Mugabe, 1983).

2.3. Effect of Parasitic Flowering Plants on Cowpea Yield

These parasitic flowering plants may cause a lot of damage on food grains and fodder plants, prior to their emergence above soil level. Some workers consider that *Striga* causes the greatest damage to food production in sub-Saharan Africa (Sauerborn, 1991). Emechebe (1981) and Emechebe *et al.*, (1991) reported up to 100% yield loss when susceptible cowpea variety was planted in heavily infested fields, while Aggarwal and Ouedraogo (1989) reported mean yield loss of about 30 - 50% in local variety in Burkina Faso. Cowpea seed yield has been estimated to be decreased by 20 - 60% with an average of 30% in susceptible varieties, irrespective of plant type and maturity or complete crop loss can occur (Singh and Emechebe, 1990; Reiss *et al.*, 1995). Atokple *et al.*, (1991) observed up to 100% yield loss using susceptible variety and up to 90% in moderately resistant or susceptible variety when *Striga* infection was over 10 per cowpea.

The effect of *Alectra* can be equally devastating as that of *Striga*. Total destruction of cowpea has been reported from Kano, Sokoto, Bauchi, Katsina, Borno due to *Alectra/Striga* complex (Emechebe *et al.*, 1991). Yield losses due to *Alectra* have been observed in some parts of Botswana (Parker and Riches, 1993), Kenya (Bagnall-Oakeley *et al.*, 1991) and Nigeria (Singh and Emechebe, 1991; Emechebe, 1986; Magani *et al.*, 1991). It has been observed that in fields heavily infested with both *Striga* and

Alectra, the crop is mostly infected by *Striga* if the variety is susceptible to both parasites (Singh and Emechebe, 1997). If the cowpea is resistant or moderately resistant to *Striga* and susceptible to *Alectra* (as in IT82D-849 and Suvita-2) *Alectra* infection is severe, causing a high yield loss (Singh and Emechebe, 1997). Mugabe (1983) working on the effect of *Alectra* infection on cowpea in Zimbabwe reported that *A. vogelii* parasitism resulted in delayed onset of flowering, reduced number of flowers and pods, and reduced weight of pods and grain.

2.4. Factors Influencing Infection and Damage by Parasitic Flowering Plant

Striga and *Alectra* show wide environmental tolerance, with *Striga* being more widespread in the Sahel and Sudan savanna Zones of sub-Saharan Africa while *Alectra* is more damaging and widespread in the Guinea savanna zone (Musselman *et al.*, 1991; Parker and Riches, 1993). These parasitic flowering plants cause serious damage to cowpea resulting in decrease in yield, nodulation and N_2 fixation (Emechebe *et al.*, 1991; Lagoke *et al.*, 1994).

Some scientists have reported the occurrence of these parasites beyond the above agroecological zones. Thus *Striga* has been found in derived coastal savanna of Benin Republic (Lane *et al.*, 1994) and Togo (Agbobli, 1991) and also in southern Guinea savanna of Nigeria, (Emechebe *et al.*, 1991), while *Alectra* has been found in some parts of East and Southern Africa (Riches, 1989; Singh *et al.*, 1993). The cultivation of susceptible hosts in monocrop or in mixtures, especially in areas with sandy soils, poor soil fertility, and low rainfall result in severe attack by parasitic flowering plants (Singh

and Emechebe, 1997). The control of these parasites are difficult due to their production of large number of seeds (up to 50,000 seeds per plant) and the capacity of the seeds to remain dormant in the soil for up to 10 or more years (Emechebe *et al.*, 1991; Singh and Emechebe, 1997).

2.5. Possible Control Methods for *Striga* and *Alectra*

Considering the damage done to grain crops by these parasitic plants, especially in Africa and Asia, efforts have been made to formulate control measures. Deep cultivation, intercropping, crop rotation, early planting, use of nitrogenous fertilizers, and chemical seed treatment have been observed to reduce infection of cereals by parasitic flowering plants (Singh and Emechebe, 1997). However, only limited studies have been done in respect of control of cowpea parasites (Adu and Emechebe, 1991; Adu *et al.*, 1991).

There has been gradual reduction in *Striga* infection with increasing nitrogen concentration in sandy soil in pot experiments (Emechebe *et al.*, 1991). They observed 88%, 25%, and 12% *Striga* infection using 0, 60 and 120 ppm of nitrogen respectively in watering solution. Above 120ppm, *Striga* infection was not found at all. Field trials did not confirm these results, showing that fertilizer N may not be a sustainable control option, especially as many local farmers use nitrogen fertilizers on cowpea in the form of NPK fertilizers. Emechebe *et al.*, (1988) showed that 140ppm N applied as $NaNO_3$ solution completely prevented the incidence of *S. gesnerioides* with rapid decrease in nodule numbers. About 37 and 76% reduction in *Striga* incidence or attack using 30 and

120kgN/ha in the Sudan savanna zone of Nigeria has been reported (Adu *et al.*, 1989). Some level of benefit from nitrogen application to cowpea in soil heavily infested by *Striga* has been observed but without commensurate increase in grain yield (Adu and Emechebe, 1991).

Planting resistant cowpea varieties or growing cowpea in rotation or as intercrop with certain millet and sorghum varieties stimulate suicidal germination of *S. generioides* seed, thus reducing its seed concentration in the soil (Singh and Emechebe, 1997). Early planting has also been found to produce better grain yield than late planting (Lagoke *et al.*, 1994).

The use of seed treatment chemicals has been reported to be effective to some extent (Yadharjrut and Hosmani, 1979; Lagoke *et al.*, 1991; Eplee and Norris, 1987, Eplee, 1981; Carson, 1988). Although these chemicals have proved effective to some extent as control measures, they have limitations. For instance, Berner *et al.*, (1994a) reported that soaking cowpea seeds in imazaquin solution of 3.6mg a.i./ml for 5 minutes before planting in a pot experiment reduced *Striga* and *Alectra* infection. This chemical was somehow toxic to the cowpea plants. Also, phenoxy materials, ametryne and linurion damage the cowpea plant (Eplee and Norris, 1987; Emechebe *et al.*, 1991) but stop *Striga* seed production with minimum crop yield benefits in the very season of application. With respect to the use of post-emergence herbicides, some workers consider that the nature and growth of *Alectra* and time of seed set make their use in *Striga* control difficult (Emechebe *et al.*, 1983).

The use of biological control method has been reported to reduce *Striga* incidence. Singh and Emechebe (1997), observed moderate to high incidence stem galling by *Smicronyx* spp. (and consequently no *Striga* seed production by galled stem) on *S. gesnerioides* at Kano in Nigeria, indicating a possibility of reducing *Striga* by this biological control.

The use of resistant varieties has also shown that the *Striga*-resistant cowpea varieties not only protect the crop from *Striga* infection, but also reduce the *Striga* seed bank in the soil, hence minimizing level of infection in the next crop (Singh and Emechebe, 1997). This has proved the safest and most economical method of control. A lot of work has been done in controlling *Striga* and *Alectra* on cowpea by host plant resistance (IITA 1982, 1983). In Burkina Faso, high level of resistance to *Striga* was shown by 'Gorom Local' and '58-57' but their susceptibility in other countries showed the presence of different strains (Aggarwal, 1985).

Two new resistance sources, B301 (a landrace from Botswana) and IT82D-849 (an improved breeding line from IITA) showed stable resistance to *Striga* across Burkina Faso, Mali, Niger, and Nigeria (Parker and Polniaszek, 1990; Aggarwal, 1991; Emechebe *et al.*, 1991; Singh and Emechebe, 1997). Some lines were found to be less susceptible to *Striga*, shown by a lower number of *Striga* plants as well as delayed emergence of *Striga* (Singh and Emechebe, 1991). These lines show various levels of resistance to *Striga* strain found in Kano, Nigeria. IT82D-849 is moderately resistant to *Striga* but highly susceptible to *Alectra*, while IT86D-534, IT86D-371 and IT84D-666

NIGERIA
Ahmadu Bello University

are moderately resistant to *Striga* and highly resistant to *Alectra*. By contrast, variety B301 is completely resistant to both parasites. Cowpea variety B 301 roots have been shown to stimulate germination of *Striga* seeds and permit attachment, but haustorial formation and/or further growth are inhibited (Lane *et al.*, 1991).

Hence a combination of several control measures such as host-plant resistance, crop rotation, seed treatment, improving the nutrient status of the soil, chemical and biological methods are required to obtain a good and sustainable control.

472106

2.6. Legume/Rhizobium Symbiosis

The plants in the Leguminosae family are found in temperate and tropical environments (Elkan, 1992). They represent a very large and diverse group, ranging from plants like cowpeas to large trees such as *Acacia* species and the family is estimated to contain between 16,000 - 17,000 species in about 750 genera (Elkan, 1992). Most of the species fix nitrogen in symbiosis with rhizobia (Allen and Allen, 1981).

Legumes commonly form symbiosis with the species of the bacterial family Rhizobiaceae which can result in an efficient biological nitrogen fixation systems (Elkan, 1992). *Bradyrhizobium* (nodule bacteria) is one of the recognised genera (Jordan, 1982). They are gram-negative, non-spore forming, aerobic, motile, short-medium rods and mesophilic (Alexander 1977). The ability of the nodule bacteria to reduce atmospheric nitrogen to usuable forms has been known for over 100 years. It is generally estimated that biological nitrogen fixation accounts for about 175 million of fixed nitrogen (Kg N/year), 75% of which is available for fertilizer (Elkan, 1992). Effective cowpea-Bradyrhizobium symbiosis fix more than 150kgN/ha and supply 80 - 90% of the host plant nitrogen requirement (Eaglesham *et al.*, 1977; Summerfield *et al.*, 1977) allowing

KASHIM I[illegible]RARY

adequate yields of N-deficient soils where non-nodulated crops such as cereals fail.

2.7. Association Between *Bradyrhizobium* and the Parasitic Flowering Plants on Cowpea

The amount of nitrogen obtained by legumes through *Bradyrhizobium* symbiosis has been of great interest due to its agricultural importance in enhancing soil productivity. *Bradyrhizobium* possesses nitrogenase complex, an enzyme which is capable of reducing atmospheric nitrogen into compounds assimilable by the host plant. They are host specific and several carbohydrates are utilized, sometimes with the accumulation of acid but never of gas (Alexander, 1977). The cowpea-*Bradyrhizobium* symbiotic process begins in the rhizosphere and culminates in the establishment of an effective N_2 fixing nodule. This process is a multistage sequence of interdependent steps divided into four major phases. These stages are rhizobial colonisation of the rhizosphere, attachment to the root surface, root hair branching, and root hair curling. Following infection, nodule formation involves the establishment of one or several centres of disomatic meristem (nodule initiation), bacterial release into cortical cells, intracellular multiplication of the rhizobia and development of bacteriods (Vincent, 1980). The root of parasitic flowering plants may limit nodule initiation and development by affecting the function of either the host plant or the *Bradyrhizobium* sp. The root of parasitic flowering plants, apart from their wide ecological distribution, are soil-borne with highly specialized parasitic relationship with their host plants, and have wide genetic variability (Emechebe *et al.*, 1991). They germinate when in contact with the root exudate from host plants (such as cowpea) and get attached to the host roots through

haustorium. This unites the parasite with the host's tissue stele enabling transfer of nutrients, carbohydrates especially sucrose and water from host to parasite leading to physiological disorder on cowpea (Ba, 1984). These carbohydrates, especially sucrose are being utilized by the *Bradyrhizobium* during nitrogen fixation in the root nodule of the host plant (cowpea).

Therefore, since the area immediately adjacent to the cowpea root system is the site of origin of the infecting *Bradyrhizobium*, it is possible that the associated parasitic flowering plants in the rhizosphere has an effect upon the development of the symbiosis. Indeed, occasional *Bradyrhizobium* inoculation failures may result from a microbiological competition that suppresses the desired microsymbiont and prevent initiation of the infection (Alexander, 1977).

2.8. Soils of the Nigerian Savanna

Four major types of soil occur in the Nigerian savanna region. They are Entisols/Inceptisols, Alfisols, Ultisols and Vertisols (USDA Soil Survey Staff, 1976). There is considerable micro- and macro variability within these soil types (Tomlinson, 1965; Klinkenberg and Higgins, 1968).

The dominant soil types are well-drained but shallow, immature Entisols and Inceptisols (Harpstead, 1973) with little profile differentiation and derived primarily from recent aeolian deposits. Generally, they are course-textured, yellowish gray or yellowish brown in the first 0 - 20 cm layer and have red or reddish brown B horizons with higher clay content. The Vertisols occur mainly in the north-eastern part of the country

(latitudes 8°N and 13°N and longitudes 10°N and 14°N). They are generally deep, dark coloured, heavy clayey soils with very low water infiltration capacity and poor internal drainage. Hence, these soils are porrly structured and a few years of continuous cultivation leads to rapid decline in soil productivity arising partly from declining soil fertility and partly from deterioration of soil physical condition (Lombin *et al.*, 1991).

Jones and Wild (1975) reported that organic matter content of the savanna soils range from 5.0g kg^{-1} in Entisols and Inceptisols to about 20g kg^{-1} in Vertisols and hydromorphic soils. The Alfisols generally are shallow, course textured, yellowish grey or brown in the surface layer and have red or reddish brown sub-surface and lower horizons with higher clay content. The organic matter content is low, rarely reaching 2g kg^{-1} and total nitrogen content rarely exceeds 1.0g kg^{-1}. Due to low organic matter and low clay content which is mainly Kaolinitic, CEC, buffering capacity, total N, S, P and exchangeable K are also low. Cation Exchange Capacity values as low as less than 5cmol kg^{-1} have been reported for most savanna soils (Jones and Wild, 1975). Native soil N is so low that all cereal crops respond to N fertilizer. Jones (1973) reported values ranging from 0.08 to 2.90g kg^{-1} with mean of 0.5g kg^{-1}. This is closely linked to the generally very low organic C of these soils. Average value of 4.70 ppm has been reported for phosphorus (Jones, 1973). Total K content of the savanna soils varies from 0.60 to 39.90g kg^{-1}. Iwuafor (1986) reported exchangeable K values averaging 0.13 cmol kg^{-1} soil for Mokwa, while Ca and Mg deficiences are not common (Jones and Wild, 1975). Micronutrient levels in these soils are still fairly high (Heathcote and Smithson, 1974; Heathcote, 1972). The soil pH is slightly acidic with

the range of between 6.0 to 6.8 been reported (Jones and Wild, 1975).

2.9. The Role of Nitrogen, Phosphorus and Molybdenum in Plants

2.9.1 Nitrogen

Nitrogen is a key element required for plant growth. Nitrogen deficiency results in general chlorosis, starting with the older leaves; branching is reduced while growth is retarded (Humphreys, 1987); this eventually lead to poor yields and crop failures. Nitrogen is used by the plant in the formation of protein, nucleoprotein, aminoacids, amines, amino sugars, the nucleic acids which play a vital part in cell metabolism, and of coenzymes which control the rate of chemical reactions in the plant (Humphreys, 1987). It is called the "growth element" and is present in largest amounts in the buds, tips of shoots and developing leaflets. As a constituent of all proteins, a high content of non-protein N in plants is usually an indication of some mineral imbalance, (example, sulphur deficiency), which affects protein synthesis. However, for nitrogen to function effectively in plant life, a sufficient quantity of other essential elements such as phosphorus, potassium, sulphur, calcium, magnesium and micronutrients must be present (Humphreys, 1987). In a plant's early growth phase, N is particularly active and hence a steady supply of N must be available; such a supply is provided by the action of soil micro-organisms on soil organic matter or by applied fertilizers. N supply is essential during seed formation and with the approaching maturity of the plant, stored N in the vegetative parts is transported to the developing seed.

2.9.2. **Phosphorus**

Phosphorus plays a key role in the energy transfer of all living cells, and regulates many enzyme processes (Humphreys, 1987). Phosphorus deficient plants often exhibit purple or red discolourations of the older leaves, especially on the veins, and this may extend to the stems. At first leaves are dark green or more blue-green than normal. Growth is stunted, and the deficiency is more easily seen in seedlings than in old plants (Humphreys, 1987).

2.9.3. **Molybdenum**

Molybdenum is essential for nitrate reduction before protein synthesis and also required for nitrogen fixation by *Rhizobium* (Mengel and Kirkby, 1979; Humphreys, 1987). Molybdenum is an essential component of two major enzymes in plants, nitrogenase and nitrate reductase, both of whose effective mechanisms depend on the valency change (Mengel and Kirkby, 1979), as shown by the equation:

$$Mo^{5+} \rightleftarrows Mo^{6+} + e^{-}.$$

Molybdenum is absorbed as molybdate by plants. The basic mechanism of nitrogen fixation by nitrogenase, and the Mo function too, is the same for free living nitrogen fixing bacteria as for nitrogen fixing microorganisms living in symbiosis with higher plants (Bergersen, 1971).

Molybdenum deficiency symptoms are similar to those of nitrogen. Molybdenum deficient legumes bear many small ineffective nodules. The chlorosis is sometimes

interveinal and leaf margins tend to curl and roll (Humphreys, 1987). Molybdenum deficiency results also in the decrease in the activty of nitrate reductase, decrease in photosynthetic rate (because of low chlorophyll levels), and increased respiration (Loneragan and Arnon, 1954). Growth and flower formation are restricted and leaves become pale and eventually wither (Hagstrom and Berger, 1965; Hewitt *et al.*, 1954). Nitrogen nutrition is restricted by affecting both nitrate reduction and N_2 fixation. Also the middle lamella of the cell wall is not completely formed at very early stage in leaf development (Bussler, 1970). In extreme deficiency, leaf lamina is not formed only leafrib is present and appears like a whip, hence the name 'whip tail.

2.10. Effect of Nitrogen application on Growth, Nodulation and Symbiotic N_2 Fixation of Cowpea

Depending on the effectiveness of the cowpea-*Bradyrhizobium* symbiosis, variable responses to nitrogen fertilizers are likely. Effective cowpea-*Bradyrhizobium* symbiosis have been found to fix more than 150kgN/ha and supply 80 - 90% of the host plant nitrogen requirement (Eaglesham *et al.*, 1977; Summerfield *et al.*, 1977), allowing adequate yields of N-deficient soils where non-nodulated crops such as cereals fail. With effective nodulation and symbiosis, nitrogen application did not increase cowpea seed yields in Sierra Leone (Summerfield *et al.*, 1977). It was observed also that about 30kgN ha^{-1} applied at sowing can benefit symbiotic fixation but higher levels were detrimental (Sanginga *et al.*, 1988a; Becker *et al.*, 1991; Dart and Mercer, 1975; Eaglesham *et al.*, 1977; Kang, 1975). The soil may contain available N equivalent to these values so that further nitrogen fertilizer application would be detrimental to

symbiosis. Legume nodulation and nitrogen fixation have been found to decrease in the presence of high levels of soil inorganic N (Allison and Ludwig, 1935; Sanginga, 1985; Sanginga *et al.*, 1988a; Kang, 1975; Minchin *et al.*, 1981; Dart, 1974; Becker *et al.*, 1991; Lie, 1974). This inhibitory effect of non-nodulation is probably plant-mediated. Large amounts of applied nitrogen, especially nitrate, reduces root hair infection and available infection sites on the roots (Munns, 1977), and lectin binding (Dazzo *et al.*, 1985; Dazzo and Drill, 1978), subsequently nodulation and nitrogen fixation are affected.

2.11. Effect of Phosphorus application on Growth, Nodulation and Symbiotic N_2 Fixation of Cowpea

Phosphorus is the most limiting nutrient in legume production. This is as a result of its physiological role in nodule formation. Most studies show that phosphorus fertilization improves nodulation and nitrogen fixation (Wan Othman *et al.*, 1991; Sanginga *et al.*, 1988, 1989; Sanginga, 1992; Benge, 1982). In Nigeria, Tiwan (1965) reported increase in nodulation in cowpea due to Phosphorus fertilization.

Wan Othman *et al.*, (1991) reported increased growth and nodulation which resulted in corresponding increase in symbiotic N_2 fixation, when an application of 20 or 40kgP ha^{-1} was made on a glasshouse-grown nodulated cowpea in sand culture. Enhanced nodulation and plant growth after adequate levels of P application have been reported for other legume species (Dhingra *et al.*, 1988; Sanginga *et al.*, 1988, 1989, 1995; Sanginga, 1992, Mohammad *et al.*, 1989; Becker *et al.*, 1991; Hart, 1989). However, a few authors such as Adu - Gyamfi *et al.*, (1989) reported that positive plant

responses to applied P in P-deficient soils was associated with increased N_2 fixation. Some scientists reported suppression of growth rate and of acetylene reduction activity of mineral N-dependent and nodulated soyabean and other legumes, when P supply was low (Fist *et al.*, 1987; Israel, 1987).

2.12. Effect of Molybdenum application on Growth, Nodulation and Symbiotic Nitrogen Fixation of Cowpea

Molybdenum occurs in the soil as an oxycomplex (MoO_4^{2-}) and resembles phosphate or sulphate in its behaviour in the soil. It is absorbed as molydate by plants. In acid soils, its likely to exist in association with sesquioxides, thus firmly binded and largely unavailable to plants. Molybdenum deficiency symptoms resemble those of nitrogen (Hagstrom and Berger, 1965); Sillanpaa, 1982). Molybdenum is a constituent of one of the two proteins which together form Mo-nitrogenase, and therefore a sufficient supply of Mo is essential for nitrogen fixation in cowpea and other legumes. This marked dependence of symbiotic legumes on Mo is shown by the evident symptoms on nitrogen deficiency shown by Mo deficient symbiotically dependent legumes (O'Hara *et al.*, 1988; Robson, 1978).

It is reported that adequate levels of Mo had no effect on shoot dry weight, nodulation, growth or total nitrogen (Sanginga *et al.*, 1988a; Andrew, 1978). However, increase in shoot dry weight due to Mo has been reported by other workers such as Rao *et al.*, (1978) and Gupta and Potalia (1987), while increases in growth, nodulation and yield have been observed by others, (Nayak *et al.*, (1989), Park *et al.*, (1987), Huceng,

(1979), Rao *et al.*, (1978), Demory (1970), and Pal *et al.* (1989). On the other hand, the chlorophyll content of leaves has been observed to increase due to Mo application (Smith, 1970). This beneficial effect of Mo was attributed to nitrogen fixation (Weerartha, 1988).

2.13. Effect of Nitrogen Fertilizer on Parasitic Flowering Plants of Cowpea

Though there has been no reported work on effect of nitrogen fertilizer on the incidence of infection of cowpea by *Alectra*, there are reports on the effect of N fertilizer on the infection of cowpea by *S. gesnerioides.* These reports tended to indicate that nitrogen fertilizer would be a potential method of controlling *Striga* and possibly *Alectra* (Adu *et al.*, 1989; Singh and Emechebe, 1997). Pot culture studies by Emechebe *et al.*, (1991) have revealed a gradual reduction in *Striga* infection with increasing nitrogen concentration in sandy soil. They observed 88, 25 and 12% *Striga* infection using 0, 60 and 120ppm of nitrogen in watering solution respectively. Above 120ppm, *Striga* infection was not found at all. Field trials did not confirm these results, showing that fertilizer N may not be a sustainable control option since many local farmers use nitrogen fertilizers on cowpea in the form of NPK fertilizers. Emechebe *et al.* (1988) showed that 140ppm N applied as $NaNo_3$ solution in sand culture completely prevented the incidence of *S. gesnerioides* with rapid decrease in nodule formation and number.

Field studies at Samaru, northern Nigeria have shown that application of nitrogen fertilizer (in the form of urea and CAN) up to 60kgN ha^{-1} reduced the incdence of cowpea attack by *S. gesnerioides* (Adu *et al.*, 1989). In this respect, this study showed

that the use of urea had only negligible advantage over CAN. However, grain yield was significantly increased with 60kg N ha^{-1} of urea or 30kg N ha^{-1} of CAN, when compared to the control. Reduction in incidence of *Striga* infection due to nitrogen application to heavily infested field has been observed, though this was not associated with grain yield increase (Adu and Emechebe, 1991). Despite the adverse effects of high nitrogen levels on nodulation, there seems to be a need for a concerted effort in research on the use of fertilizers in general for control of *Striga* in cowpea. Field studies at Ibadan, Nigeria have shown also that application of urea and ammonia nitrogen compounds reduced the incidence of *Striga* hermonthica on maize (Igbinnosa 1993; Igbinnosa *et al.*, 1996).

2.14. Effect of Phosphate Fertilizer on Parasitic Flowering Plants of Cowpea

Although there are reports on the effect of N on the infection of cowpea by *S. generioides*, not much has been done using phosphate fertilizers. Work done by Mugabe (1983) in Zimbabwe studied effect of *Alectra* infection in the presence of phosphorus fertilizer. He showed that *A. vogelii* parasitism resulted in delayed onset of flowering, reduced number of flowers and pods, and reduced weight of pods and grain (Mugabe, 1983). He showed that in the presence of phosphate fertilizer, however most of these negative effects of *Alectra* parasitism in cowpea, except delayed onset of flowering, were reduced. He attributed these ameliorating effects of P fertilizer on the suppressive effect of P on the early growth of *A. vogelii*. In Nigeria, Magani *et al.*, (1991) reported increased cowpea grain yield and also increased number of *Alectra* shoot emergence, when P was applied as single super phosphate.

2.15. Effect of Molybdenum Fertilizer on Parasitic Flowering Plants of Cowpea

Unlike in N and P, no work has been done on the effect of molybdenum fertilizer on cowpea planted on *Striga* or *Alectra* infested or inoculated fields or pots. However, work done on the effect of Mo on plants have been observed (Bergersen, 1971; Humphreys, 1987, Loneragan and Arnon, 1954, Bussler, 1970). Nodulation, nitrogen nutrition, growth and yield of cowpea were found to increase when Mo fertilizer was applied (Nayak *et al.*, 1989; Weerartha, 1988). These beneficial effects of Mo are attributed to its influence on nitrogen fixation. It is possible that the effect of Mo on the parasitic flowering plants would be similar to that of P; i.e. Mo could have a suppressive effect on the early growth of *Striga* and *Alectra*, and consequently, result in reducing the negative effects of the parasites on cowpea. This should receive research attention.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Greenhouse Study: Effect of *Bradyrhizobium* Strains on *Striga* and *Alectra* Infection of Cowpea

3.1.1. Location

The experiment was carried out in the PEDUNE greenhouse, Department of Crop Protection, Faculty of Agriculture/Institute for Agricultural Research (IAR), Ahmadu Bello University (ABU), Zaria from February - April, 1996.

3.1.2. Collection and preparation of soil and sand samples

The soil samples for the study were collected from a field at the research farm of the IAR, Samaru in Nigeria's northern Guinea savanna zone (longitude 11° 11^{N} and latitude 07° 38^{E}, 686m above sea level). It has a mean annual rainfall of about 1100mm. The field had been used for millet and sorghum production during the 1993 and 1994 cropping seasons. The soil is derived from aeolian deposits underlain by basement complex parent material. It is classified as Alfisol, loam (Moberg and Esu, 1989). Soil samples were collected from 16 equally spaced points at 0 - 20cm depth, bulked and mixed thoroughly and allowed to air dry. The samples were sieved through 2mm stainless steel sieve and subsamples taken for characterization of the soils.

The sand used was collected from a dried river in the Bie village behind Area BZ, University Staff quarters. The sand was also sieved using the 2mm stainless steel sieve.

3.1.3. Preparation of sterile sand and soil cultures

The sieved sand and soil samples were autoclaved separately for 20 minutes using 1.20kg/cm^2 pressure. The heated samples were air-dried for four days to allow the escape of gaseous materials or substances that may be harmful to the crop. Heating was carried out to kill off any bacteria or microorganism in the samples.

3.1.4. Collection and preparation of *Striga* or *Alectra* seeds

At the end of harvesting in 1994 cropping season, matured *Striga* and *Alectra* plants were uprooted from sick field, in IAR research farm. The branches, flower buds and leaves were carefully removed from the stem; dried and ground carefully in a small motar. These were then sieved using a column of sieves of several mesh sizes (710 and 500 microns - mesh No. 22 and 30 respectively). The *Striga* or *Alectra* seeds were then collected on the last container of the column which has the smallest mesh size of 500 microns (mesh No. 30).

To estimate the number of *Striga* or *Alectra* seeds, 1ml of the threshed and sieved *Striga* or *Alectra* seeds was taken and then 9ml of fine sand added and thoroughly mixed. One ml of the *Striga* or *Alectra*/sand mixture was then taken and mounted on a microscope and with the aid of a tally counter, the number of *Striga* or *Alectra* seeds present in the 1ml mixture was then determined.

3.1.5. **Preparation of soil inoculated with *Striga* or *Alectra***

About 10ml of *Alectra* seeds were measured into a polyethylene bag to which 10ml of sieved, dry sand was added. The mixture was shaken thoroughly for 5 minutes to ensure a uniform distribution of *Alectra* seeds. To the 20ml of *Alectra* seed/sand mixture, 20ml of sieved sand was added and again thoroughly shaken for 5 minutes. Another 40ml of sieved sand was added to the *Alectra* seed/sand mixture and the shaking process repeated. Subsequently, 20, 100 and 200ml of the sand were serially added to the *Alectra* seed/sand mixture and the shaking process repeated after every addition. The final volume of *Alectra* seeds/sand mixture was therefore 400ml. The mixture of the 400ml was shaken for 3 minutes and then poured out on a sheet of polyethylene. The mixture was then quartered and coned 5 times with a hand trowel. It was then poured back again into the polyethylene bag and shaken for 2 minutes. The mixing process was continued with the addition of 400ml of the sieved sand to the 400ml *Alectra* seed/sand mixture.

The 800ml *Alectra* seed/sand mixture obtained was then made up to a final volume of 1000ml by addition of 200ml of sand. This final mixture contained about 10ml of *Alectra* seeds. Based on enumeration procedure of Emechebe (1986) the density of *Alectra* seeds was determined; in this case it was 160,000 seeds/10 ml of original *Alectra* seed stock.

From the 1000ml, which is the stock, 100ml (containing 16000 seeds) was taken and used to prepare inoculated soil for each of 10 pots; thus each pot contained 1600

Alectra seeds. To accomplish this the 100ml (containing 16000 seeds) was first made up to 1000ml by gradual dilution with soil-sand mixture and subsequent shaking to mix. The final potting mixture was obtained by taking 100ml of the mixture (containing 1600 seeds) and making it up to 900ml, which was added to each pot.

The pots have holes which were covered with sheets of paper and then 100ml of sterile sand added to the bottom of each pot, before the above 900ml of inoculated soil was added. The pots were then placed on flat plastic plates before planting. The same procedure was repeated for *Striga*.

For the field study, the same procedure of preparation was followed but the quantity of *Striga* and *Alectra* seeds measured out were increased from 10ml to 100ml. This was to ensure good inoculation of the field.

3.1.6. **Seed sterilization**

The cowpea seeds used were sterilized by soaking in 95 percent ethanol for 10 seconds in a conical flask to kill off any bacterial or microorganism and then followed by another soaking in 3 percent solution of Hydrogen peroxide (H_2O_2) for 3 minutes to enhance germination. The seeds were then rinsed 6 times with distilled water.

3.1.7. ***Bradyrhizobium*** **inoculation of cowpea seeds**

10g of sugar was weighed out into a beaker and dissolved in 100ml of distilled water. This sugar solution was used to act as an adhesive to ensure good seed inoculation with the peat inoculum and also as a source of energy for the *Bradyrhizobium*.

Then 15ml of solution was pipetted and poured into the polyethylene bag containing about 1kg seeds of each of the varieites and shaken. 5g of each of the peat inoculum (IRc 291, IRc 461a and IRc 506c) was then added and the shaking process repeated until the seeds were thoroughly coated with the inoculum, ready for planting.

3.1.8. **Treatments and experimental design**

The treatments involved:

(a) pure sterile sand/soil mixture with *Bradyrhizobium* (R_0)

(b) Sterile sand/soil mixture with *Striga* or *Alectra* (S/A)

(c) sand/soil mixture with *Bradyrhizobium* sp plus *Striga* or *Alectra* (RS/RA)

Four cowpea varieites (B 301, SAMPEA-7, SAMPEA-1 and IT82D-849) three of *Bradyrhizobium* sp (IRc 291, IRc 461a and IRc 560c) were used in the study . These *Bradyrhizobium* strains originated from Nigeria. Strains IRc 291 and IRc 506c were isolated at Ibadan in 1979 ~~which~~ while IRc 461a was isolated at Onne in the same year. This gave 36 treatment combinations (3S/A X 3Rh X 4 var) arranged in a randomised complete block design with three replications giving a total of 108 experimental units.

3.1.9. **Cultural Practices**

3.1.9(a) **Planting**

Three seeds of each cowpea variety were planted per pot. At 5 - 7 days after planting, the seedlings were thinned down to two plants per pot. After thinning, the pots

were then placed in flat plastic plates. Using a syringe, 1ml of broth inoculum of the same strain was taken and dispensed around the root of each seedling. Proper inoculation was ensured by making a ring around the plant on the soil surface before dispensing the inoculum into the ring depression created around the root. After the inoculation, distilled water was then used to water the plants thereby flushing the inoculum down the root system. Finally, small quantity of pure sterile sand was poured into the pots to cover the soil/sand mixture surface to reduce contamination.

3.1.9(b) **Watering and management of plants**

The pots were watered once a day. Each watering was done by pouring water into the flat plastic plates to avoid the flushing of *Bradyrhizobium* from around the root system to ensure good nodulation and nitrogen fixation.

Weeds were controlled by hand pulling but left in the pots to decay and return to the soil the nutrients absorbed by them. Chemical control methods were avoided to prevent toxic effect of any kind on the introduced bacteria strains.

3.1.10. Observations and measurement

Daily observations were made on the plants for morphological symptoms of *Striga* and *Alectra* and also to keep pests in check.

Data on the following parameters were collected:

(i) days to emergence of *Striga*

(ii) days to emergence of *Alectra*

The data collection commenced immediately the parameters mentioned began to manifest, and collection was done daily till the termination of the experiment.

3.1.11. **Plant Sampling procedure for estimating nitrogen fixation (Ureide Method) in the greenhouse.**

In this study, the experiment was terminated at 50% podding when nitrogen fixation, nodulation and root growth are at their maximum. The number of *Striga* or *Alectra* emerged were counted. The shoot was harvested by cutting the stem below the first node close to soil level with a pair of secateurs or shape blade and then washed under running water from a tap. The shoot samples were placed in large envelopes and dried in an oven at 65°C-70°C to constant weight. The root exudate (xylem sap) were collected using rubber tubings with internal diameter slightly smaller than their stems. The rubber tubings were placed over the exposed root stumps. The sap exuding under root pressure into each rubber tubing reserviour was recovered with a syringe and no exudate was allowed to stay for more than 20 - 30 minutes before collection. The accumulated exudates were collected every few minutes and placed in vacutainers kept in a cooler with some iced blocks to minimize potential decomposition or metabolism of xylem-N components. Sap samples were kept chilled in a deep freezer at -15°C until analysed. The syringe was washed with water and then with distilled water after sampling for each pot.

Each of the sap samples collected was analysed for ureide, nitrate and alpha amino-N in the soil microbiology laboratory of International Institute of Tropical Agriculture (IITA), Ibadan, using procedures described in Australian Centre for International Agricultural Research, ACIAR Project 9210, Workshop Handbook, 1994.

3.1.12 Calculations

In most investigations, the technique provided an index of fixation activity, rather than a quantitative estimate of N fixed. The absolute solute concentration in the xylem and in the extracts of the stem are determined by plant water status and are related to transpiration rate. As a result, the concentration of individual N compounds vary from plant to plant. Hence, the ureide content of a sample is more accurately expressed in terms of relative proportional value or ratio, rather than single component molarity.

$$\text{Relative Ureide Index (\%)} = \frac{\text{Ureide N} \times 100}{\text{Total Sap N}}$$

Since one ureide molecule contains 4N atoms, ureide N is calculated as 4 x Ureide molar concentration. Total Sap N is estimated as (4 x ureide + amino acid + nitrate) molar concentration determined by colorimetric analysis (Peoples *et al.*, 1989).

$$\text{Relative Ureide Index (\%)} = \frac{4 \times \text{ureide} \times 100}{(4 \times \text{ureide} + \text{amino acid} + \text{nitrate})}$$

The functions that describe the relationship between the proportion of plant N derived from N_2 fixation (P) and the relative abundance of ureides in root bleeding

exudate (X) are:

P = 1.2 (X - 4.8) for plants in the vegetative and flowering stages.

P = 1.5 (X - 21.3) for plants during pod fill.

The proportion of plant N derived from N_2 fixation (P) could be read directly from the table provided in the laboratory manual once the relative ureide index is known.

This method is a new technique called xylem-solute technique using root bleeding method to estimate the percentage of nitrogen fixed. This method is based on measurement and comparisons of nitrogen containing compounds, which are transported from the roots to the shoots in the xylem sap. These compounds are assimilated products of N_2 fixing nodules or mineral N taken up from the soil. This technique is applicable mainly for legumes that transport most of their fixed nitrogen in the form of ureides, allantoin and allantoic acid e.g. soyabean, cowpea, common bean (Peoples *et. al.*, 1989).

3.1.13. **Root sampling**

The roots were freed of soil by immersing each pot in a large bucket of water for about 5 minutes; the pot was then inverted to release the ball of soil and the roots were then carefully freed of adhering soil in such a way that there was no loss of *Striga* or *Alectra* plants attached, emerged and subterrenean.

The following parameters were then determined:

(i) The number of *Striga* or *Alectra* emerged.

(ii) Number of *Striga* or *Alectra* plants attached to the cowpea roots.

(iii) Nodule dry weight and number:

The nodules of individual plants were removed, counted and oven dried at the same temperature an the shoot and weighed.

(iv) Root dry weight:

The individual plant roots were carefully washed, under tap water on a mesh, placed in large envelopes and dried also in an oven at 65°C - 70°C to constant weight.

(v) Shoot dry weight:

Shoots of individual plants at the time of harvesting were removed and oven dried at 65°C - 70°C to constant weight. The leaves were removed and the stem and petioles were ground and stored in small labelled plastic bags for analysis.

3.2. **Field Study:**

The following trials were carried out in the field in 1995 and 1996.

(a) Effect of urea nitrogen fertilizer on *Striga* or *Alectra* infection of cowpea.

(b) Effect of phosphorus and molybdenum on *Striga* or *Alectra* infection of cowpea.

3.2.1. **Site description**

The two field experiments were conducted during the wet season in the 1995 and

1996 periods at the Institute for Agricultural Research (IAR) Samaru in Nigeria's northern Guinea savanna zone. The field is fairly flat but for some areas that are slopy and have been used for the production of millet and sorghum. The soil derived from aeolian deposits underlain by basement complex parent material is an Alfisol loam (Moberg and Esu, 1989). Samaru has mean annual rainfall of about 1100mm.

3.2.2. **Treatment and experimental design**

3.2.2(a) **Effect of nitrogen fertilizer**

Treatments consisted of two levels of nitrogen fertilizer (0 and 15kgNha^{-1}) applied as urea, four cowpea varieties (B301, SAMPEA-7, SAMPEA-1 and IT82D-849) and three levels of parasitic flowering plants (No weed, *Striga* and *Alectra*). The 24 treatments were arranged in a randomised complete block design with three replications. The nitrogen fertilizer was applied 7 days after planting.

3.2.2(b) **Effect of phosphorus and molybdenum**

Treatments consisted of field infestation with two parasitic flowering plants *(Striga* and *Alectra*), four levels of P (0, 20, 40 and 80kgP ha^{-1}) applied as single superphosphate, three levels of molybdenum (0, 0.25 and 0.5kg Mo ha^{-1}) applied as ammonium molybdate and two cowpea varieties (B301 and SAMPEA-7) giving 24 treatment combinations arranged in a randomised complete block design and replicated two times, giving a total of 48 experimental plots. Phosphorus and Mo were applied 7 days after planting (DAP) by hill placement.

3.2.3. Cultural practices

The cultural practices were the same for the field experiments. The field was ploughed mechanically, harrowed twice and then ridged at 75cm apart. The plots were marked out at $16m^2$ (4m x 4m). Each experimental plot consisted of 4 ridges with the two inner ones used as net plots while the two outer ones as sampling plots. The ridges were split open with handhoes or handtrowels and the prepared *Striga* or *Alectra* seeds manually were sprinkled into the hole and then covered up before planting. Two seeds of cowpea were planted per hole at 30cm between plants.

Weeding was carried out manually using hoes. Benomyl as Benlate and Mancozeb as Dithane M45 were applied at 30g/20litres of water and 125g/20 litres respectively to control fungal and bacterial diseases. Cypermethrin as Karate and Perfekthion at 1 lha^{-1} of water each was applied to control insect pests.

3.2.4. Observations and measurements

At 10 WAP five plants were sampled from the two outer rows for nodulation assessment, dry matter production and nitrogen fixation. Root bleeding sap (RBS) was collected at 50% podding stage and analysed as described for the greenhouse experiment. Nodules were collected, counted, oven-dried and weighed. Roots and shoots were also dried and weighed as described for the greenhouse study. Pods were picked as they dried from the two inner rows, further dried and threshed. Grains were further dried, weighed and grain yield calculated.

Morphological symptoms caused by *Striga* or *Alectra* on cowpea were observed on the two out rows, date of emergence noted and number of *Striga* or *Alectra* emerged were counted.

3.2.5. Soil sampling on the field.

Soil samples were taken at 0 - 20cm depth initially before land preparation and from each plot after harvest. The samples were air-dried and sieved through a 2mm stainless steel sieve. Then subsamples were taken for characterisation in the laboratory.

3.2.6. Plant sampling on the field

Plant samples (Root Bleeding Sap (RBS)) were collected by cutting plants to ground level with a sharp blade or a pair of secateurs and placed sleeves of silicon rubber tubing over the root stumps. The sap, exuding under root pressure into each tubing reservior was recovered with a syringe after 20-30 minutes. Root bleeding sap from all plants in each replicate, were immediately placed in a cooler with some iced blocks, and later frozen until analysed.

3.3. Soil Analyses

The soil samples were then analysed for the various parameters. Soil pH was determined in 1:2.5 soil: water ratio and salt (0.01M $caCl_2$) suspension with a glass electrode pH metre. Available P was determined by the Bray No. 1 method. The concentration of P in the extract was colorimetrically determined using a spectrophotometer (Bray and Kurtz, 1945). Exchangeable bases were extracted using the

ammonium saturation method (NH_4OAC). The readings for Na and K were obtained using the flame photometer/emission (Kundsen, *et al*., 1982) while Ca, Mg and micronutrients were determined with the use of Atomic Absorption Spectrophotometer (Perkin Elmer model 403). Walkley and Black wet oxidation method was utilized in determining the organic carbon (Juo, 1979). Cation exchange capacity was determined using ammonium displacement method, followed by distillation. Total nitrogen determination was done using the micro kjeldahl method (Bremner and Mulvaney, 1982). Particle size was determined using the hydrometer method (Day, 1965).

3.4. **Plant Analyses**

Each of the sap samples collected was analysed for ureide, nitrate and alpha amino-N. Concentration of ureide in RBS was measured colorimetrically as the phenylhydrazone derivative of glyoxalate, nitrate by the salicylic acid and ∝-amino-N colorimetrically with ninhydrin using a 1:1 asparagine:glutamate standard. The percentage of nitrogen derived from the atmosphere (% Ndfa) was calculated using procedures described in 3.1.12.

3.5. **Statistical Analyses**

Analaysis of Variance (ANOVA) was done for all data collected from various measurements using the Genstat V (1993) package for statistical analysis. The analyses were done at the Data Processing Unit of IAR, ABU, Zaria. Treatment differences were evaluated using the Least Significant Difference (LSD) at 5%.

CHAPTER FOUR

4.0. RESULTS AND DISCUSSIONS

4.1. Greenhouse Experiment

4.1.1. Characterization of the soil used

Some of the physiochemical properties of the soil used is presented in Table 1, which shows that the soil is loamy in texture. The soil test values presented show that the soil is loamy in texture and slightly acidic in reaction, low in organic carbon, nitrogen, available P and CEC (Table 1). The Guinea savanna soils are known to be low in organic matter, CEC, nitrogen and phosphorus (Goldsworthy, 1967). The low level of CEC is not surprising considering the low level of organic matter in these soils. This low organic matter indicates low microbial activities within the soil. The exchangeable bases and the micronutrients were also found to be low.

Generally, soil pH dropped slightly while other parameters like OC, N, Available P and exchangeable cations increased slightly after the two year cropping. Substantial increase in available P may be due to the P fertilizer added during the 2 year cropping.

Table 1: Physiochemical properties of the soil used.

Soil property	Soil samples	
	Initial values before 2 years cropping	Final values after 2 years cropping
% Silt	48	47
% Sand	32	33
% Clay	20	20
Textural Class	Loam	loam
pH (1:2.5 H_2O)	4.60	4.40
pH (1:2.5)(0.01M$Cacl_2$)	4.40	4.20
Organic Carbon (gkg^{-1})	4.40	5.00
Total N (gkg^{-1})	0.70	0.80
Available P ($\mu g/g$)	9.23	16.23
Exchangeable Bases ($Cmol\ kg^{-1}$)		
Calcium (Ca)	0.29	0.32
Magnesium (Mg)	0.47	0.50
Potasium (K)	0.26	0.26
Sodium (Na)	0.07	0.07
CEC	5.40	5.70

4.1.2. Morphological observations on the Effect of *Striga gesnerioides* and *Alectra vogelii* infection on Cowpea.

All the suseptible cowpea varieties displayed similar symptoms due to the PFP infections. Some of the above ground symptoms observed were necrosis (scorching) of leaflets, yellowing (chlorosis) between the veins of cowpea leaves and interveinal spots which are rusty brown to purplish in colour (observed 21 DAP) premature defoliation of leaves, stunted growth and eventual death of the cowpea plant. Similar symptoms have been reported (Adu *et al.*, 1989; Emechebe *et al.*, 1991).

4.1.3. Effect of *Bradyrhizobium* strains on the incidence of cowpea-*Striga* and -*Alectra* infection

The incidence of infection in cowpea by *A. vogelii* or *S. gesnerioides* was measured as the number of *Alectra* or *Striga* plants attached to the roots of cowpea (this included emerged as well as subterranean *Alectra* or *Striga* plants) and the number of *Alectra* or *Striga* plants that emerged above soil level. The results are presented in Tables 2a and 2b, Fig. 1a-d. The inoculation of cowpea varieties with *Bradyrhizobium* strain IRc 506c resulted in the lowest incidence of infection by these two parasitic flowering plants (Figs. 1c and 1d, Tables 2a and b). The above result have shown that the presence of *Bradyrhizobium* strain IRc 506c in cowpea infected by *Striga* or *Alectra* resulted in significant reduction of the adverse effects of their parasitism on cowpea growth and development. This is probably due to its efficiency in competing for nodule sites in the cowpea varieties used. The overall data suggest that strain IRc 461a was probably not efficient in competing for nodule sites in the present study.

Table 2a: Effect of *Bradyrhizobium* strains on the number of *Alectra* attached/emerged on four cowpea varieties in the greenhouse.

Cowpea Variety	*Alectra* Infested Pots							
	Attached/Plant				Emerged/Plant			
	Bradyrhozobium strains				*Bradyrhizobium* strains			
	IRc 291	IRc 461a	IRc 506	Mean.	IRc 291	IRc 461a	IRc 506	Mean
Sampea 7	7.67	8.67	6.67	7.67	5.33	5.67	4.67	5.22
B 301	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sampea 1	8.33	9.00	7.33	8.22	5.67	5.67	4.67	5.33
IT82D-849	9.33	10.00	8.33	9.22	6.67	7.33	5.33	6.44
Mean	6.33	6.92	5.58		4.17	4.67	3.67	

ANOVA (See Appendix 1) ANOVA (See Appendix 2)

LSD ($P \leq 0.05$):

Bradyrhizobium strain	=	0.15	=	0.12
Cowpea varieties	=	0.17	=	0.14
Bradyrhizobium strain * Varieties	=	NS	=	0.25
Bradyrhizobium strain * Parasite	=	0.25	=	0.21

Table 2b: Effect of *Bradyrhizobium* strains on the number of *Striga* attached/emerged on four cowpea varieties in the greenhouse.

Cowpea Variety	*Striga* Infested Pots							
	Attached/Plant				Emerged/Plant			
	Bradyrhizobium strains				*Bradyrhizobium* strains			
	IRc 291	IRc 461a	IRc 506	Mean.	IRc 291	IRc 461a	IRc 506	Mean
Sampea 7	7.33	7.33	6.67	7.11	4.33	5.33	3.67	4.44
B 301	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sampea 1	7.67	7.67	7.00	7.44	5.33	5.67	4.67	5.22
IT82D-849	5.33	5.67	4.67	5.22	3.00	4.00	3.00	3.33
Mean	5.08	5.17	4.58		3.17	3.75	2.82	

ANOVA (See Appendix 1) ANOVA (See Appendix 2)

LSD ($P \leq 0.05$):

Bradyrhizobium strain	=	0.15	= 0.12
Cowpea varieties	=	0.17	= 0.14
Bradyrhizobium strain * Varieties	=	NS	= 0.25
Bradyrhizobium strain * Parasite	=	0.25	= 0.21

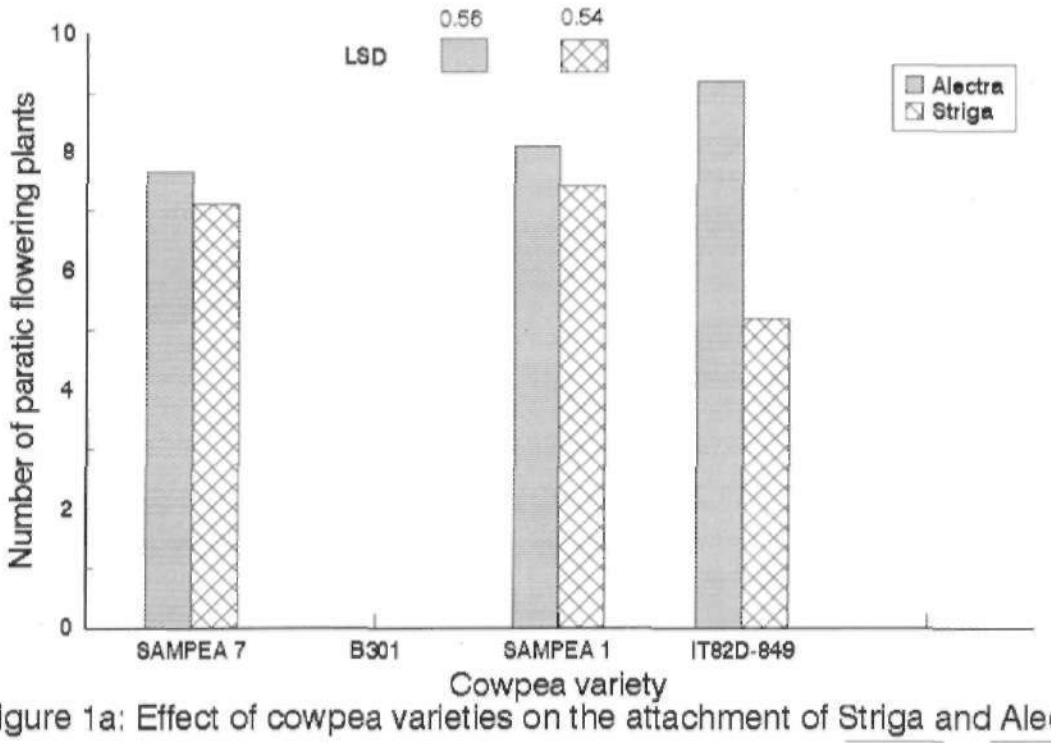


Figure 1a: Effect of cowpea varieties on the attachment of Striga and Alectra in the green house

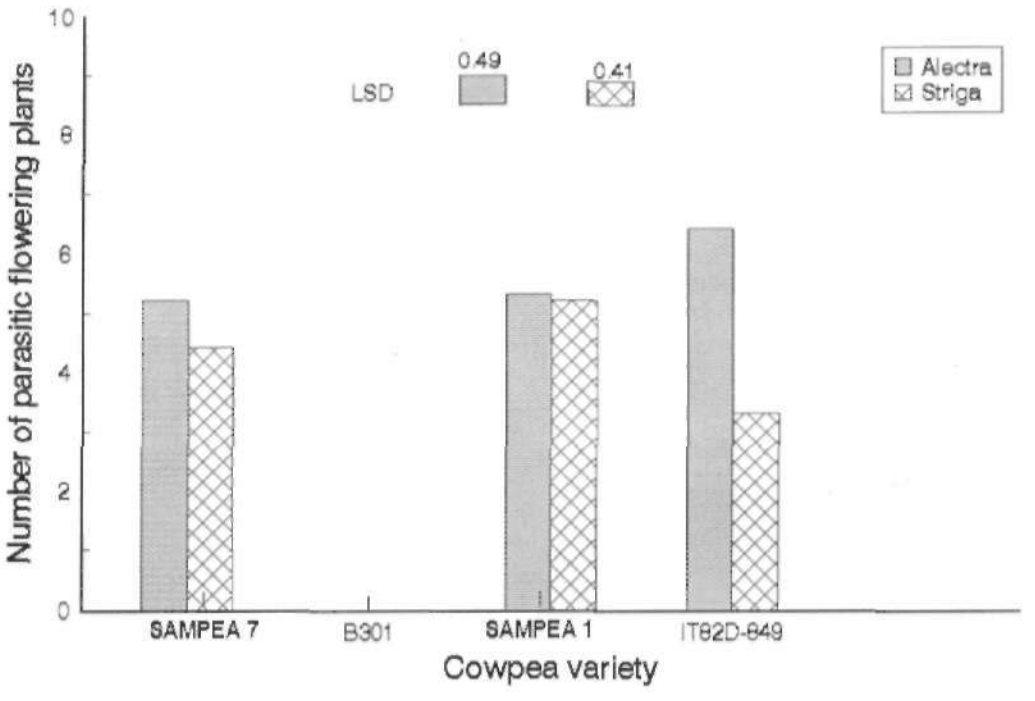


Figure 1b: Effect of cowpea varieties on the emergence of Striga and Alectra in the green house

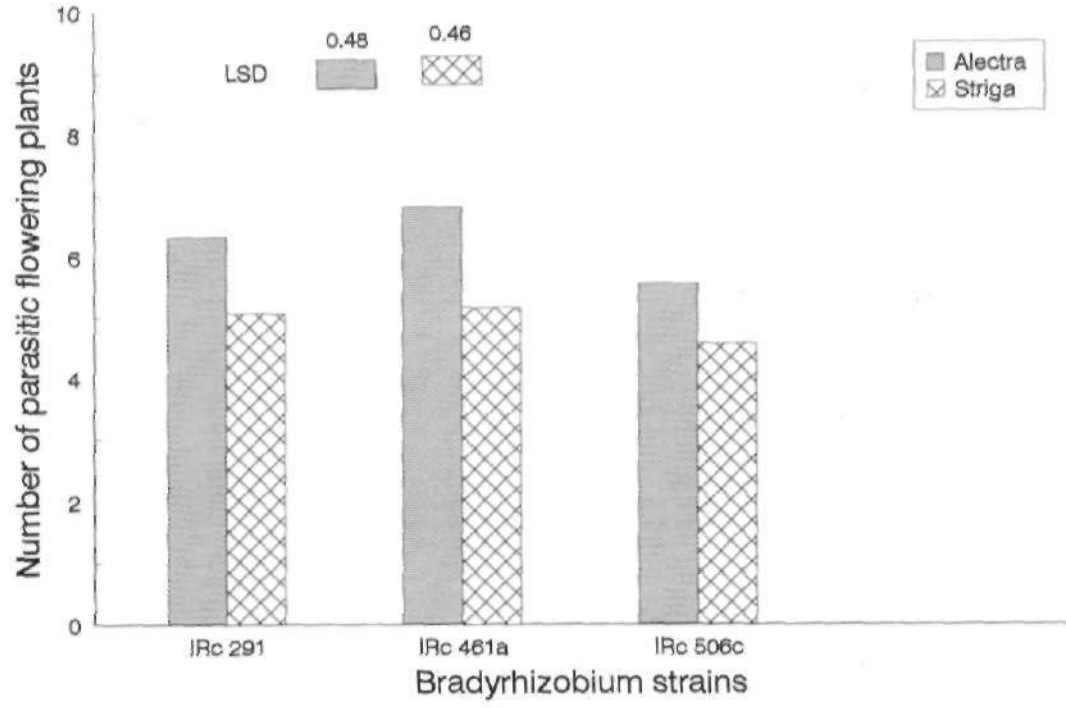


Figure 1c: Effect of Bradyrhizobium strains on Striga and Alectra attachment on cowpea irrespective of varieties in the green house

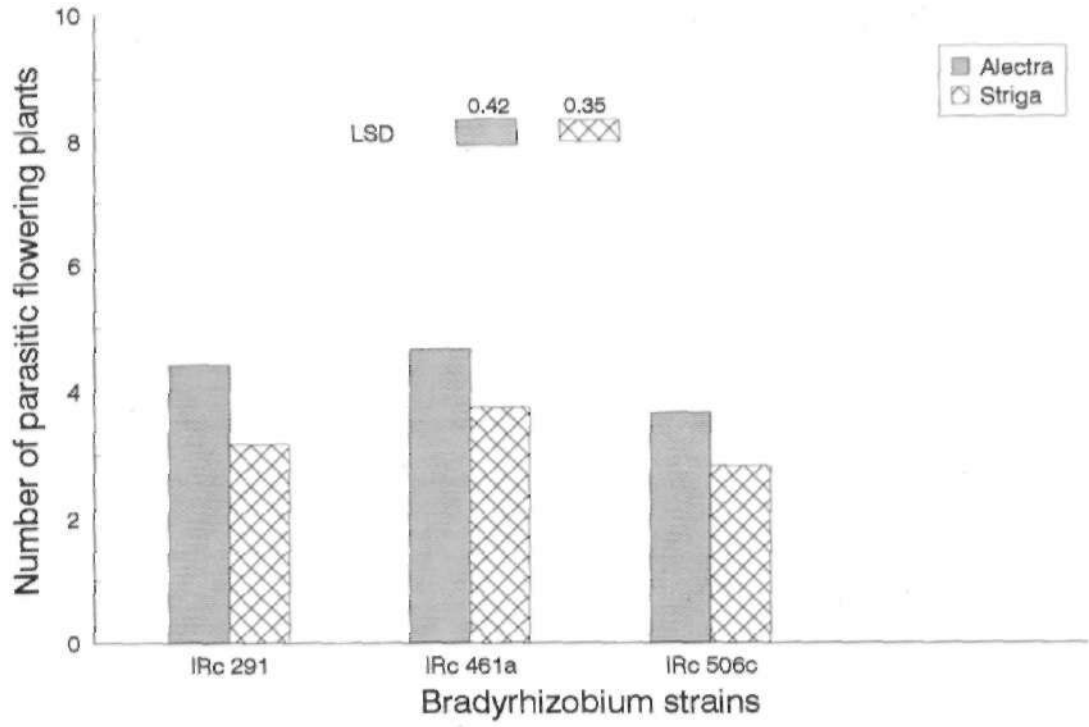


Figure 1d: Effect of Bradyrhizobium strains on Striga and Alectra emergence on cowpea irrespective of varieties in the green house

Among the cowpea varieties evaluated, B 301 did not support emergence and attachment of *Alectra* or *Striga*. Among the infected varieties, IT82D-849 significantly ($P \leq .05$) had higher *Alectra* attachment and emergence than SAMPEA-7 or SAMPEA-1. The result also shows that SAMPEA-7 and SAMPEA-1 were not significantly different from each other and supported lower *Alectra* attack than IT82D-849. In the *Striga* plots, IT82D-849 had lowest incidence of attack than SAMPEA-7 and SAMPEA-1, suggesting that IT82D-849 is the most susceptible to *Alectra* and least susceptible to *Striga Fig. 1a and b*. This high susceptibility to *Alectra* and low susceptibility to *Striga* had earlier been reported (Adu *et al.*,1989; Emechebe *et al.*, 1988, 1991); Lagoke *et al.*, (1991) and Adu and Emechebe (1991).

4.1.4. Effect of *Bradyrhizobium* strains and Parasitic Flowering Plants on Cowpea Total Dry Matter Yield.

The results in Table 3 and Fig. 2b, shows that when the *Bradyrhizobium* strains were evaluated, strain IRc 506c significantly ($P \leq 0.05$) produced higher total dry matter of cowpea than IRc 291 or IRc 461a in both the *Alectra* and *Striga* infested pots, and also in the uninfested pots (No parasite); this probably still suggest that plants inoculated with strain IRc 506c had a better capacity to compete for nodule sites with these parasitic flowering plants.

Among the cowpea varieties, Sampea-1 significantly ($P \leq 0.05$) produced the highest total dry matter yield in the pots not infested by *Alectra* or *Striga*; this was followed by SAMPEA-7, IT82D-849 and the B301 (Fig. 2a). This is attributable to the fact that SAMPEA-1 is a much larger plant than the other varieties under normal conditions (Emechebe, 1995 - Personal communication).

Table 3.1 Effect of *Bradyrhizobium* strains and parasitic flowering plants on cowpea total dry matter yield in the greenhouse.

Cowpea variety	Total cowpea dry matter (g/plant)											
	Control				Alectra Infested Pots				Striga Infested Pots			
	IRc 291	IRc 461a	IRc 506c	Mean	IRc 291	IRc 461a	IRc 506c	Mean	IRc 291	IRc 461a	IRc 506c	Mean
SAMPEA-7	6.44	5.94	7.13	6.51	5.21	4.84	5.66	5.24	4.38	3.99	5.52	4.63
B 301	4.67	3.66	5.28	4.54	4.10	3.68	5.23	4.34	4.05	3.66	5.34	4.35
SAMPEA-1	7.44	6.20	8.17	7.27	5.11	4.21	6.99	5.44	4.36	3.84	6.13	4.78
IT82D-849	6.01	4.51	6.52	5.68	3.37	3.36	4.75	3.83	5.09	4.57	5.83	5.16
Mean	6.14	5.08	6.78		4.45	4.02	5.66		4.47	4.02	5.71	

ANOVA (See Appendix 3)
LSD ($P \leq 0.05$):

Bradyrhizobium strain	=	0.11
Cowpea varieties	=	0.12
Bradyrhizobium strain * Varieties	=	0.21
Bradyrhizobium strain * Parasite	=	0.19

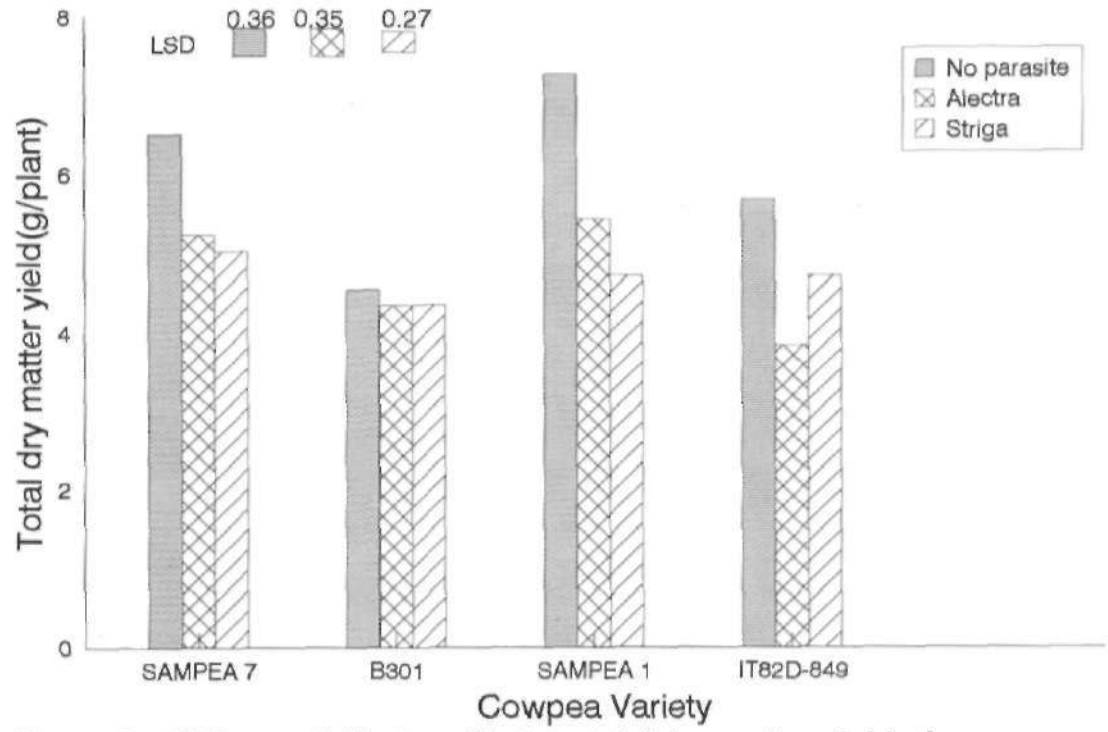


Figure 2a: Striga and Alectra effect on total dry matter yield of cowpea varieties in the green house

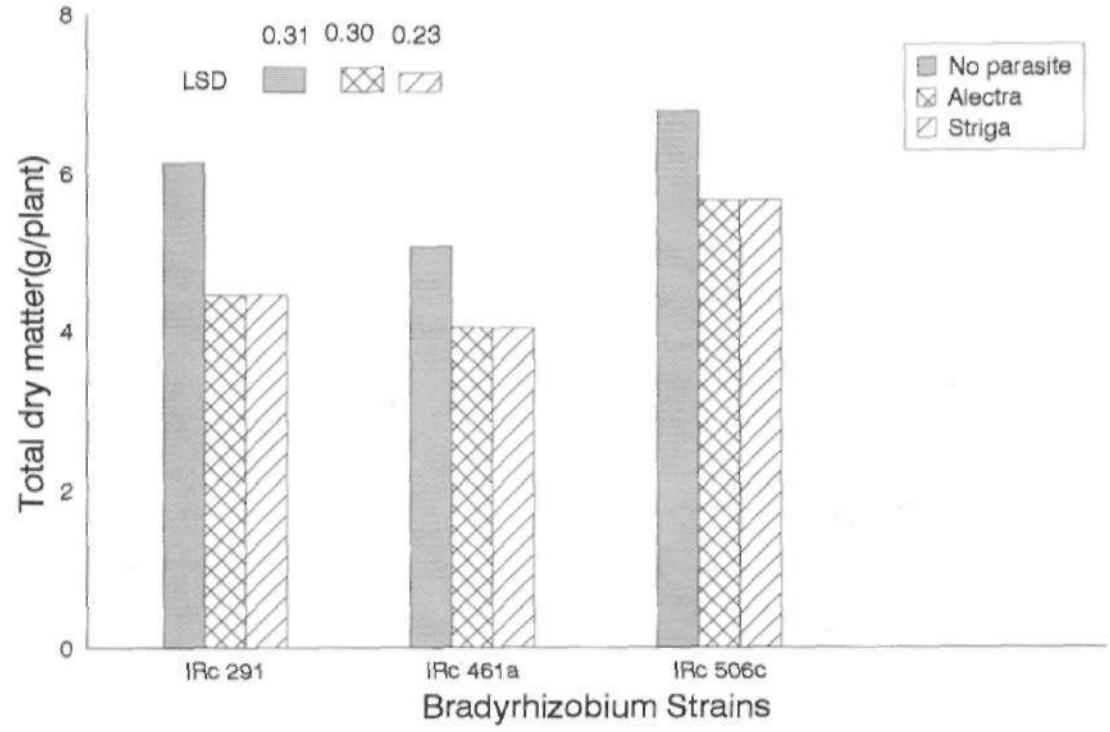


Figure 2b: Effect of Bradyrhizobium strains on total dry matter yield of cowpea varieties planted in Striga or Alectra infested pots in the green house

In the *Alectra* infested pots irrespective of *Bradyrhizobium* strains, IT82D-849 produced significantly the lowest total dry matter at 5% ($P \leq 0.05$) compared to the other varieties, while in the *Striga* infested pots, it produced the highest. This further goes to show that IT82D-849 is highly susceptible to *Alectra* but moderately resistant to *Striga*. Generally, cowpea plants that received strain IRc 506c produced more total dry matter than plants that received the other two strains. This further shows its efficiency in competing for nodule sites than the other strains.

4.1.5. Effect of *Bradyrhizobium* Strains and Parasitic Flowering Plants on Cowpea Nodulation and Nitrogen Fixation.

Tables 4 and 5 summarize the effect of *Bradyrhizobium* strains on four cowpea varieties planted in potted soil infested with *Alectra* or *Striga* in terms of number of nodules, nodule dry weight and percentage of nitrogen derived from the atmosphere (% Ndfa). For all *Bradyrhizobium* strains, the control produced significantly ($P \leq 0.05$) higher nodule number, nodule dry weights and percentage nitrogen fixed than those infested with the parasitic flowering plants. The highest number of nodules, nodule dry weights and percentage N fixed was produced by strain IRc 506c while IRc 461a produced the least, suggesting that strain IRc 461a was probably the least efficient in fixing atmospheric nitrogen with the cowpea varieties used, while IRc 506c was the most efficient in the present study. It is possible that nodulation by strain IRc 461a was suppressed resulting in this strain being less competitive in terms of nodulation than the other two strains. There appears to be no reference to this type of study in the literature.

When the *Bradyrhizobium* - inoculated cowpea varieties were evaluated in the control, varieties SAMPEA-7 and SAMPEA-1 were significantly not different from each other. In the *Alectra* - infested pots, cowpea variety B301 (the resistant variety) produced significantly ($P \leq 0.05$) the highest nodule number, nodule dry weight and percentage nitrogen fixed while IT82D-849 produced the lowest compared to the other two varieties. In the *Striga* - infested pots, B301 still produced the highest nodule number, nodule dry weight and percentage N fixed; it was followed by IT82D-849. This result again confirms the less susceptibility of IT82D-849 to *Striga* and high susceptibility to *Alectra* earlier indicated. Cowpea variety SAMPEA-1 produced the lowest nodule number, nodule dry weight and percentage N fixed compared to all varieties (Tables 4 and 5).

Table 4a. Effect of *Bradyrhizobium* strains and parasitic flowering plants on cowpea nodule number in the greenhouse.

Cowpea variety	Nodule number/plant											
	Control				Alectra Infested Pots				Striga Infested Pots			
	IRc 291	IRc 461a	IRc 506c	Mean	IRc 291	IRc 461a	IRc 506c	Mean	IRc 291	IRc 461	IRc 506c	Mean
SAMPEA-7	64.00	58.33	65.00	62.44	41.33	34.33	43.33	39.67	35.33	26.00	37.33	32.89
B 301	57.33	51.33	67.33	58.66	56.67	50.00	67.33	58.00	56.33	50.00	66.67	57.67
SAMPEA-1	62.67	60.33	65.67	62.89	33.67	30.00	41.00	34.89	24.00	21.00	33.33	26.11
IT82D-849	58.00	52.00	60.67	56.89	23.00	18.00	25.33	22.11	43.33	33.33	44.67	40.44
Mean	60.50	55.50	64.67		38.67	33.08	44.25		40.08	32.58	45.17	

ANOVA (See Appendix 4)

LSD ($P \leq 0.05$):

Bradyrhizobium strain	=	1.03
Cowpea varieties	=	1.19
Bradyrhizobium strain * Varieties	=	2.06
Bradyrhizobium strain * Parasite	=	NS

Table 4b. Effect of *Bradyrhizobium* strains and parasitic flowering plants on cowpea nodule dry weight in the greenhouse.

Cowpea vareity	Nodule dry weight (mg/plant)											
	Control				Alectra Infested Pots				Striga Infested Pots			
	IRc 291	IRc 461a	IRc 506c	Mean	IRc 291	IRc 461a	IRc 506c	Mean	IRc 291	IRc 461a	IRc 506c	Mean
SAMPEA-7	146.67	142.67	147.00	145.45	111.00	105.00	112.67	109.56	106.00	98.33	107.67	104.00
B 301	141.67	137.67	147.00	142.11	141.33	137.67	147.00	142.00	141.00	137.67	145.33	141.33
SAMPEA-1	145.33	143.33	147.67	145.44	104.67	102.00	109.00	105.22	99.00	93.00	104.67	98.89
IT82D-849	142.33	139.00	143.00	141.44	95.00	91.67	96.33	94.33	110.00	102.67	110.67	107.78
Mean	144.00	140.67	146.17		113.00	109.08	116.25		114.00	107.92	117.08	

ANOVA (See Appendix 5)

LSD ($P \leq 0.05$):

Bradyrhizobium strain	=	0.70
Cowpea varieties	=	0.80
Bradyrhizobium strain * Varieties	=	1.39
Bradyrhizobium strain * Parasite	=	1.20

Table 5. Effects of *Bradyrhizobium* strains and parasitic flowering plants on % Ndfa by cowpea in the greenhouse.

Cowpea variety	% Ndfa											
	Control				Alectra Infested Pots				Striga Infested Pots			
	IRc 291	IRc 461a	IRc 506c	Mean	IRc 291	IRc 461a	IRc 506c	Mean	IRc 291	IRc 461a	IRc 506c	Mean
SAMPEA-7	47.66	47.44	49.23	48.11	46.77	45.42	47.22	46.47	46.10	45.20	46.77	46.02
B 301	48.33	47.66	50.57	48.85	46.99	45.65	47.66	46.77	48.33	46.10	49.45	47.96
SAMPEA-1	47.89	47.89	48.56	48.11	44.98	44.30	46.10	45.13	44.53	44.53	45.43	44.83
IT82D-849	49.00	47.44	51.02	49.15	43.86	43.41	43.86	43.71	46.55	45.65	48.33	46.84
Mean	48.22	47.61	49.85		45.65	44.70	46.21		46.38	45.37	47.50	

ANOVA (See Appendix 6)

LSD ($P \leq 0.05$):

Bradyrhizobium strain	=	0.39
Cowpea varieties	=	0.50
Bradyrhizobium strain * Varieties	=	0.78
Bradyrhizobium strain * Parasite	=	NS

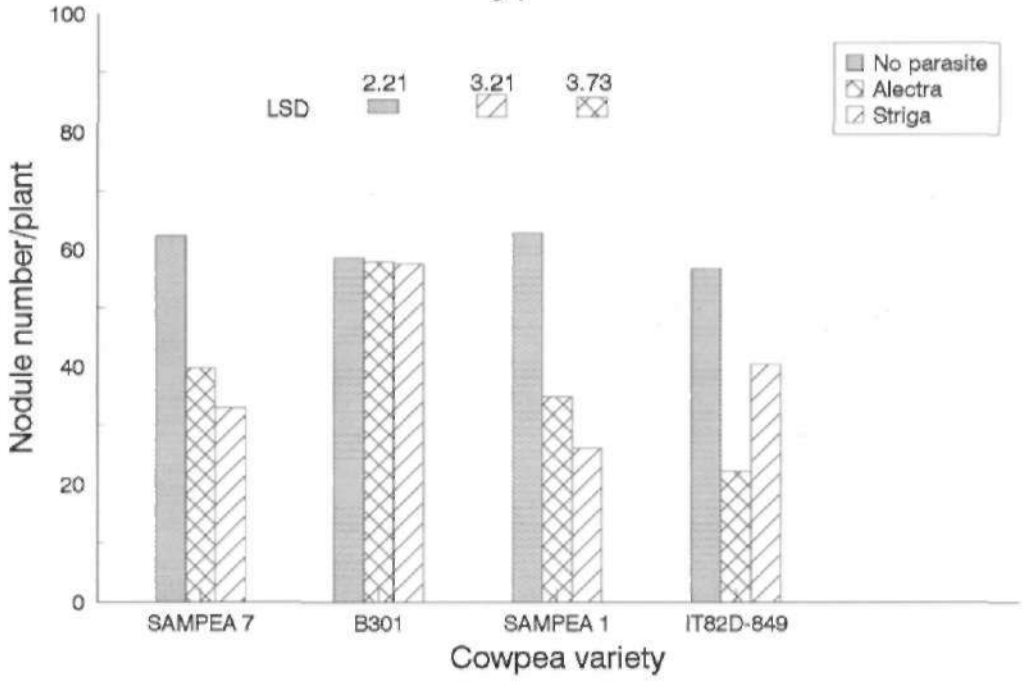


Figure 3a: Striga and Alectra effects on nodule number of cowpea varieties in the green house

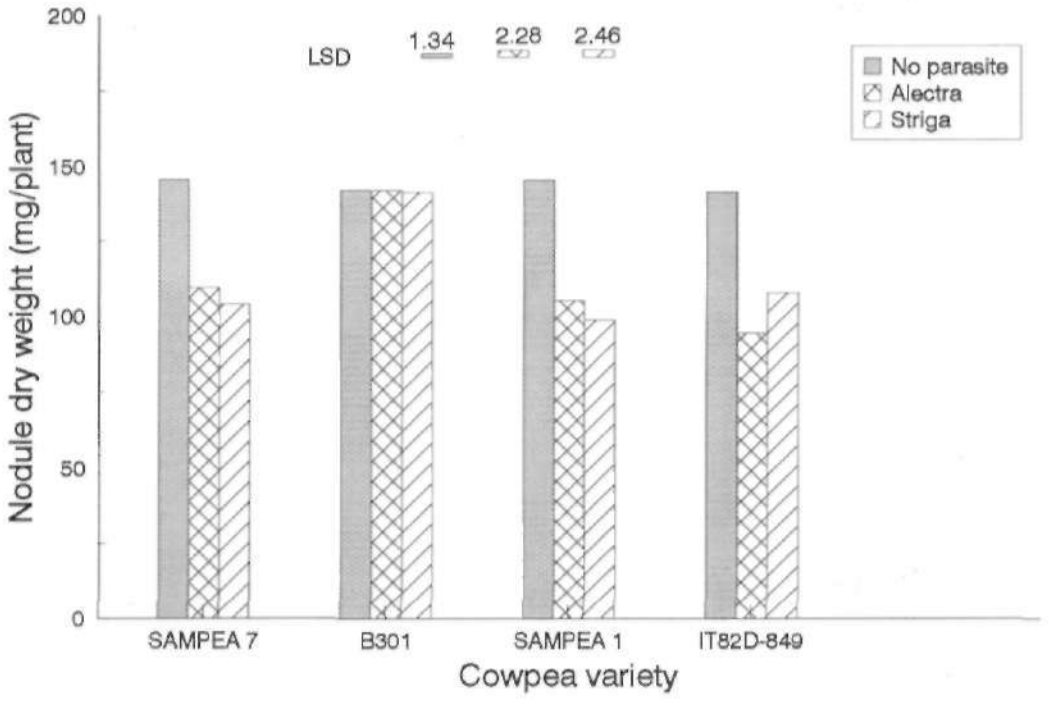


Figure 3b: Striga and Alectra effects on nodule dry weight of cowpea varieties in the green house

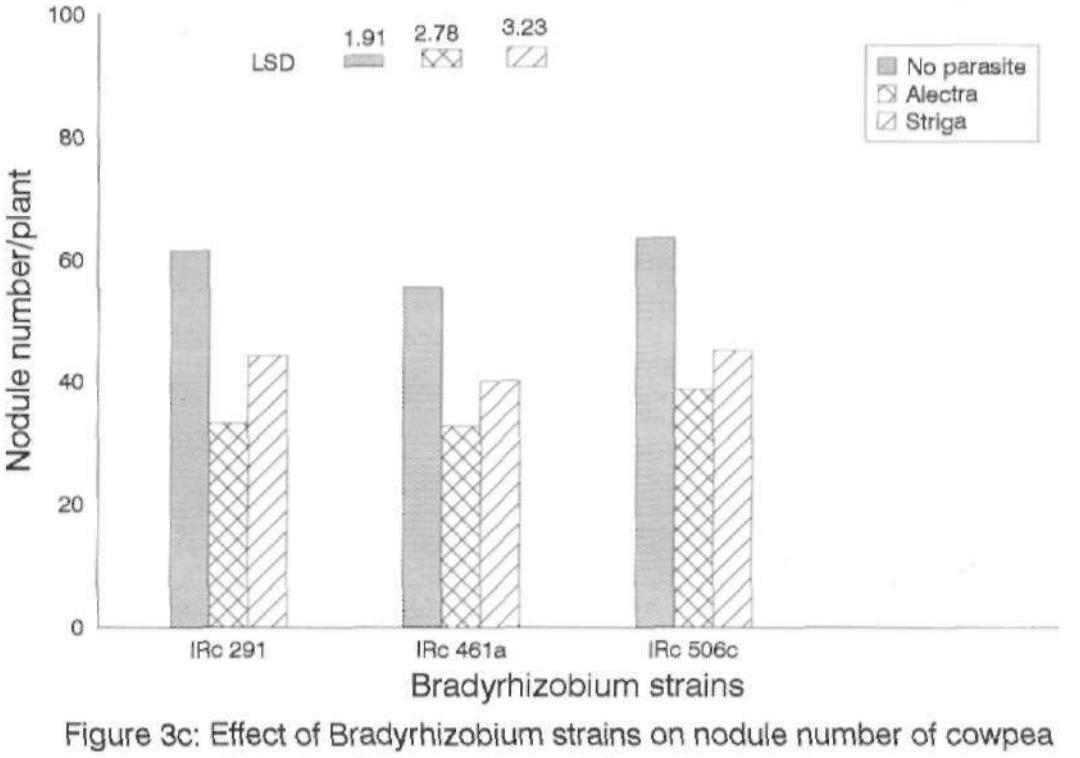


Figure 3c: Effect of Bradyrhizobium strains on nodule number of cowpea planted in Striga or Alectra infested pots in the green house

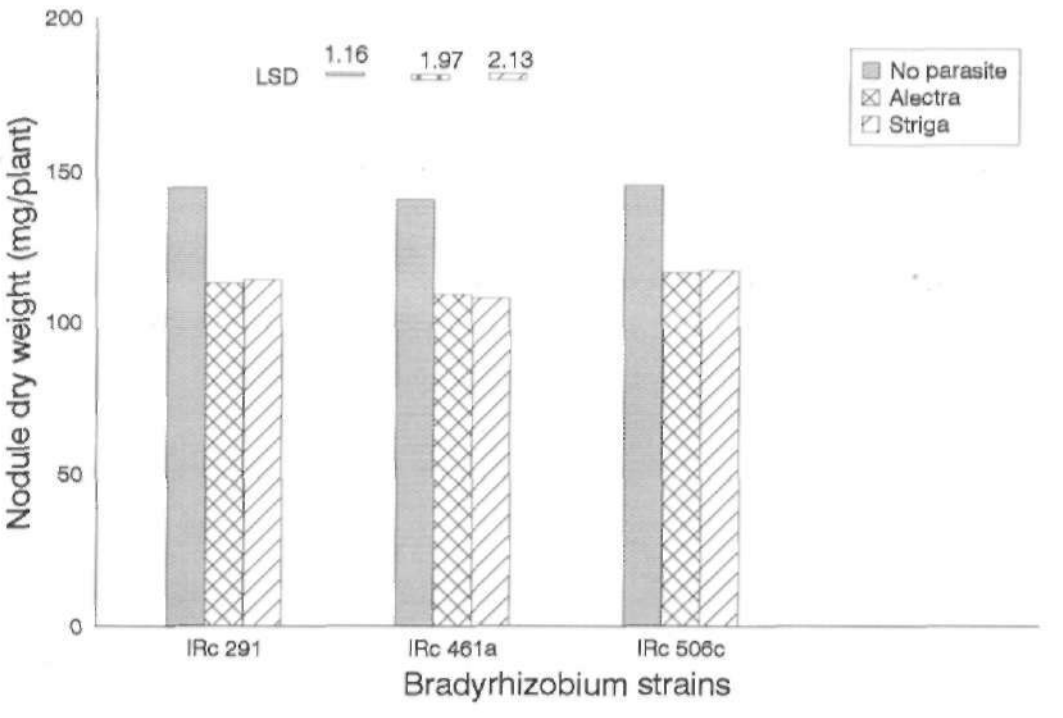


Figure 3d: Effect of Bradyrhizobium strains on Striga and Alectra on cowpea nodule dry weight in the green house

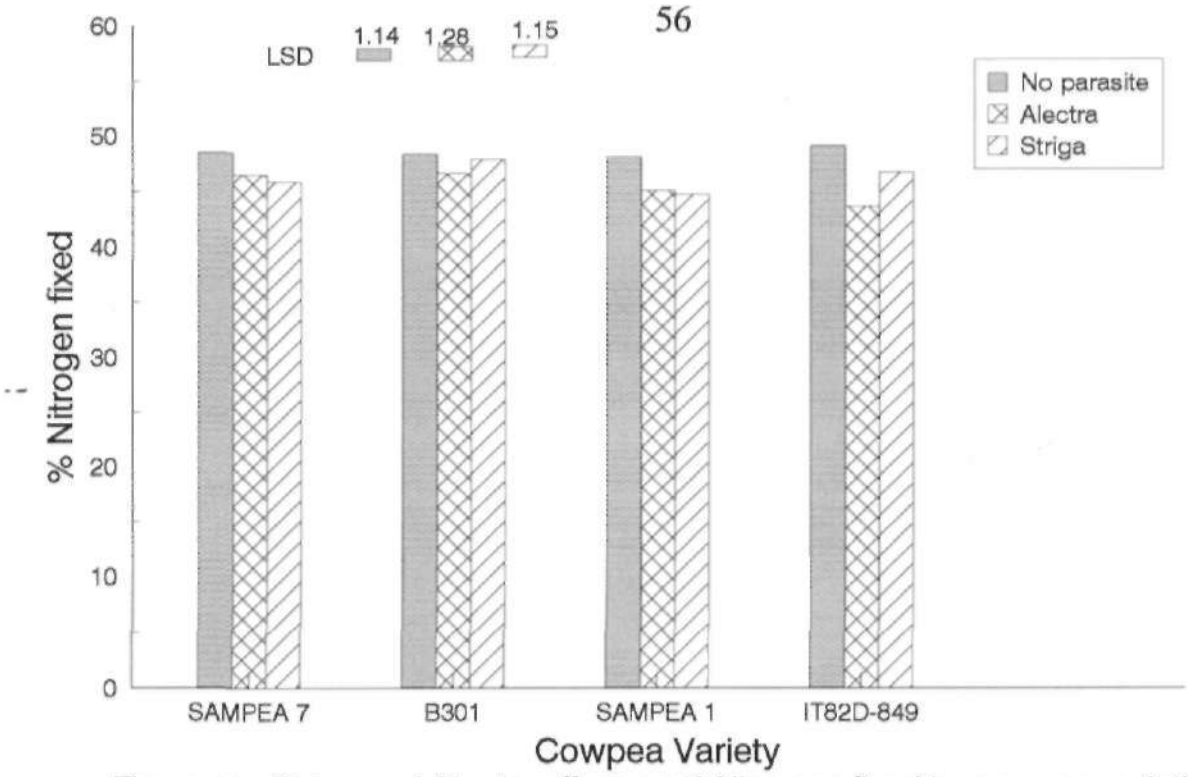


Figure 4a: Striga and Alectra effect on % Nitrogen fixed by cowpea varieties in the greenhouse

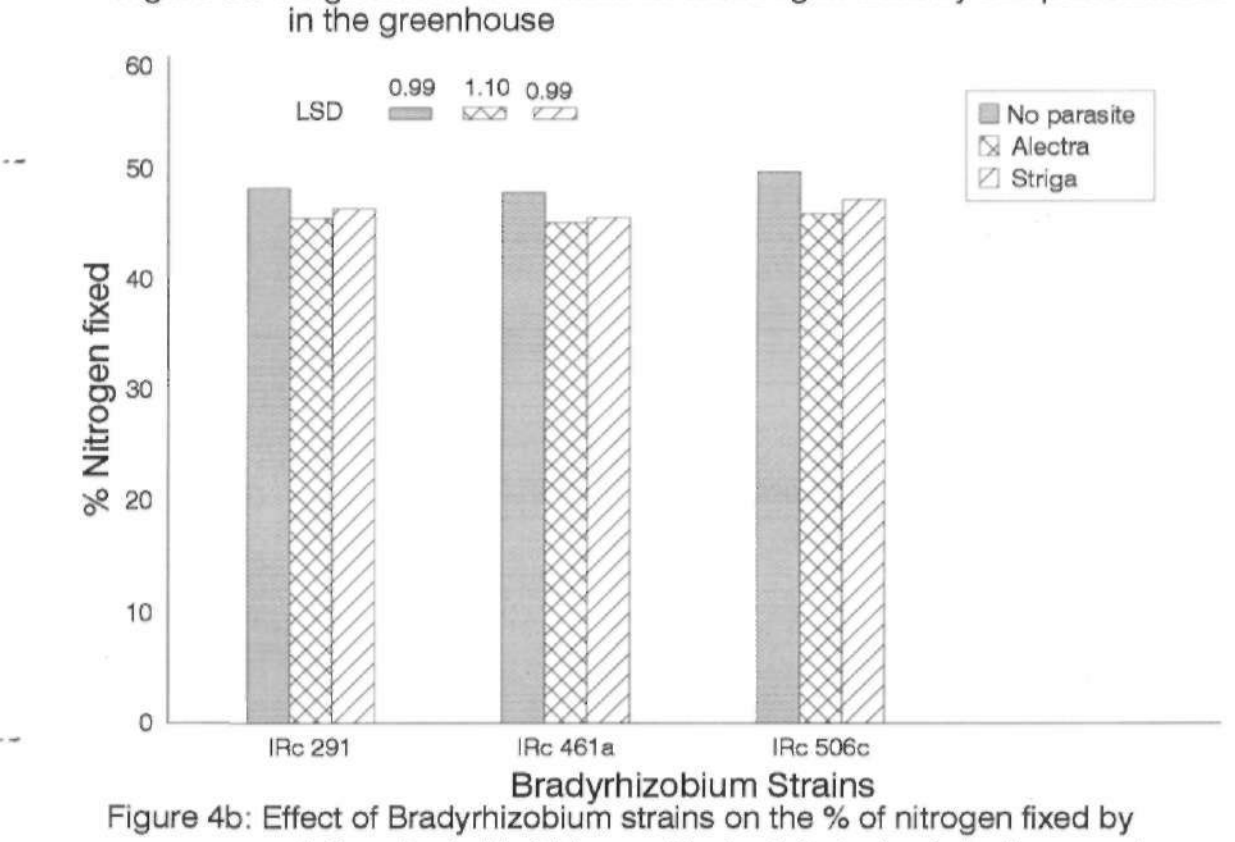


Figure 4b: Effect of Bradyrhizobium strains on the % of nitrogen fixed by cowpea varieties planted in Striga or Alectra infested pots in the greenhouse.

4.2. Field Experiments

4.2.1. Morphological Observations on the Effect of *Striga gesnerioides* and *Alectra vegelii* infection on Cowpea

Similar symptoms were observed as in the greenhouse experiment. The commonest symptom observed on these cowpea varieties is interveinal chlorosis. *Striga* or *Alectra* plants may or may not emerge above soil before the appearance of chlorosis. Foliar defoliation, stunted growth and eventual death of the cowpea plant occured when heavily infected by *Striga* or *Alectra*. These symptoms were observed on the susceptible varieties (SAMPEA-7, SAMPEA-1 and IT82D-849) at about 21 DAP. Most of the affected cowpea varieties were completely defoliated at the time of harvesting, this effect being more pronounced with the nitrogen treatment relative to the phosphorus and molybdenum treatment. *Striga* and *Alectra* emerged 50 DAP on the plots that received nitrogen at 7 DAP while both parasitic flowering plants emerged 40 DAP on the plots that received phosphorus and molybdenum applied at 7 DAP.

4.2.2. Effect of Urea Nitrogen fertilizer on the incidence of cowpea-*Striga* and -*Alectra* infection.

The result is presented in Table 6, shows that in 1995 on average, the number of emerged or attached *Striga* or *Alectra* plants were higher in susceptible plants that did not receive nitrogen fertilizer than in the plants that were fertilized with urea nitrogen. Similar trend was observed in 1996. When the 2 year results were pooled, similar results were obtained (Fig. 6). This showed that application of urea nitrogen had significant effects on the incidence of infection at 5% level of probability. In general, the fertilized plots had lower incidence of *Striga* infection compared to the *Alectra* plots, suggesting that urea nitrogen had more suppressive effect on *Striga* than *Alectra* infection in cowpea. However, Adu *et al.*, (1989), working with the *Striga* - cowpea system reported that nitrogen fertilizer would be a potential control of *Striga* especially as application of nitrogen fertilizer up to 60 kgN ha^{-1} reduced the incidence of cowpea attack by *Striga gesnerioides* without necessarily affecting grain yield. Previous studies on the effect of urea on *S. asiatica* (Okonkwo, 1991 and Raju *et al.* 1990), *S. hermonthica* (Bebawi *et al.*, 1991; Pesch and Pieterse, 1982; Kroschel, 1989; Igbinnosa *et al.*, 1996 and Igbinnosa, 1993) and *S. gesnerioides* (Emechebe *et al.*, 1991 and Lagoke *et al.*, 1991) confirmed results obtained in this study.

The explanations so far are that urea inhibited *Striga* seed germination and radicle extension growth and that increase in level of urea led to the supply of the reduced nitrogen. This is supported by the fact that the unfertilized plants, were yellowish and grew poorly during the earlier stage while the fertilized plants were dark green and had good growth. From the above result, it is possible that the accumulated ammonium ions in these parasitic flowering plants interferred with their growth substances such as required for good growth, adequate moisture, nutrient uptake and photosynthetic activities. Similarly, low enzyme activities in these parasitic flowering plants have been reported by McNally and Stewart (1987) and Igbinnosa *et al.*, (1996). They observed that accumulation of ammonium in cells of these parasitic flowering plants was increased due to the inability of the enzyme to remove the protons carried by ammonium ion leading to its reduced growth and development. Nitrate accumulation was observed to be non toxic to plants but leads to solute accumulation leading to enhanced water uptake and transportation, hence increased growth (Salsac *et al.*, 1987; Hunter and Visser, 1986; Simier *et al.*, 1993). This shows that these parasitic flowering plants can tolerate and utilize nitrate better than ammonium sources for their growth and development. Thus, this could be the reason why there are differences in results obtained in the use of nitrogen fertilizers as a control measure against cowpea - *Striga* and *Alectra*. It was observed that ammonium and organic nitrogen compounds suppressed the development of these parasitic seed plants unlike inorganic compounds like KNO_3, $NaNO_3$, Ca $(NO_3)_2$, $Mg(NO_3)_2$ and asparagine (Adu and Emechebe, 1991; Adu *et al.*, 1989; Igbinnosa *et al.*, 1996; McNally and Stewart, 1987; Hunter and Visser, 1986; Simier *et al*, 1993).

From the above findings therefore, it is clear that the toxic effect of urea on the growth and development of these parasitic flowering plants is due to ammonium ion. Subsequent field experiments have established that application of nitrogen as urea also suppress *Alectra* infection on cowpea (Adu *et al*, 1991; Lagoke *et al.*, 1991). The inhibition of *Striga* or *Alectra* by urea was not surprising as it is known that urea is converted to ammonium ion in most higher plant cells before assimilation and then to nitrate defending on the soil conditions (Beevers, 1976). This probably explains the effect of urea on these parasitic flowering plants.

Among the cowpea varieties evaluated, B301 did not support emergence or attachment of both *Striga* and *Alectra*. This is probably due to its mechanism for resistance. It was observed that the host tissue around the invading radicles may become necrotic, tubercles do not form and the parasite dies early or that the radicles infecting the roots, results in the formation of tubercles, but their subsequent growth is very limited and the parasite develops no further due to the abnormality of the tubercles and not due to failure or reduced parasite germination (Lane *et al.*, 1993; Reiss *et al.*, 1995 and Allen *et al.*, 1998). Cowpea varieties SAMPEA-7 and SAMPEA-1 supported high numbers of attached and emerged *Striga* or *Alectra* while IT82D-849 supported lower numbers of attached and emerged *Striga* but higher *Alectra* than SAMPEA-7 or SAMPEA-1 (Table 6, Fig. 5). These results suggested that application of 15kgNha^{-1} as urea nitrogen significantly affected the incidence of infection in susceptible varieties (SAMPEA-7, SAMPEA-1 and IT82D-849) but not in the resistant variety (B301). Hence the magnitude of resistance of the varieties to both parasitic flowering plants is B301 > IT82D-849 > SAMPEA-1, SAMPEA-7.

Table 6a. Effect of nitrogen fertilizer on the attachment **of *Striga* or *Alectra* infection of cowpea at Samaru in 1995 and 1996.**

Treatment[1]	Attached/plant									
	1995					1996				
	SAM-PEA-7	B301	SAM-PEA-7	IT82 D-849	Mean	SAM-PEA-7	B301	SAM-PEA-1	IT82 D-849	Mean
(Control) NoPo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NoS	10.67	0.00	10.67	9.00	7.59	10.33	0.00	9.67	7.33	6.83
NoA	10.67	0.00	11.00	11.67	8.34	10.33	0.00	10.33	10.67	7.83
N_{15}Po	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N_{15}S	8.33	0.00	8.33	7.67	6.08	9.33	0.00	8.33	6.33	6.00
N_{15}A	9.67	0.00	10.33	9.67	7.42	8.33	0.00	8.67	8.67	6.42
Mean	6.56	0.00	6.72	6.34		6.39	0.00	6.17	5.50	

1: NoPo = No nitrogen, no Striga or Alectra
NoS = No nitrogen plus Striga
No4 = No nitrogen plus Alectra
N_{15}Po = Nitrogen, no Striga or Alectra
N_{15}S = Nitrogen plus Striga
N_{15}A = Nitrogen plus Alectra.

ANOVA (See Appendix 7)
LSD ($P \leq 0.05$):
Treatment = 0.32
Cowpea vareity = 0.26
Treatment * Variety = 0.64

Table 6b. Effect of nitrogen fertilizer on the emergence of *Striga* or *Alectra* infection of cowpea at Samaru in 1995 and 1996.

Treatment[1]	Emerged/plant									
	1995					1996				
	SAM-PEA-7	B301	SAM-PEA-1	IT82 D-849	Mean	SAM-PEA-7	B301	SAM-PEA-1	IT82 D-849	Mean
(Control) NoPo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NoS	8.00	0.00	7.67	6.00	5.42	7.67	0.00	6.33	5.33	4.83
NoA	7.67	0.00	7.67	9.33	6.17	7.33	0.00	6.67	6.67	5.17
N_{15}Po	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N_{15}S	6.00	0.00	6.00	5.33	4.33	6.67	0.00	4.67	3.67	3.75
N_{15}A	6.00	0.00	6.33	8.00	5.08	5.33	0.00	5.33	5.67	4.08
Mean	4.61	0.00	4.61	4.78		4.50	0.00	3.83	3.56	

1: NoPo = No nitrogen, no Striga or Alectra
NoS = No nitrogen plus Striga
No4 = No nitrogen plus Alectra
N_{15}Po = Nitrogen, no Striga or Alectra
N_{15}S = Nitrogen plus Striga
N_{15}A = Nitrogen *plus* Alectra.

ANOVA (See Appendix 8)
LSD ($P \leq 0.05$):
Treatment = 0.31
Cowpea vareity = 0.26
Treatment * Variety = 0.62

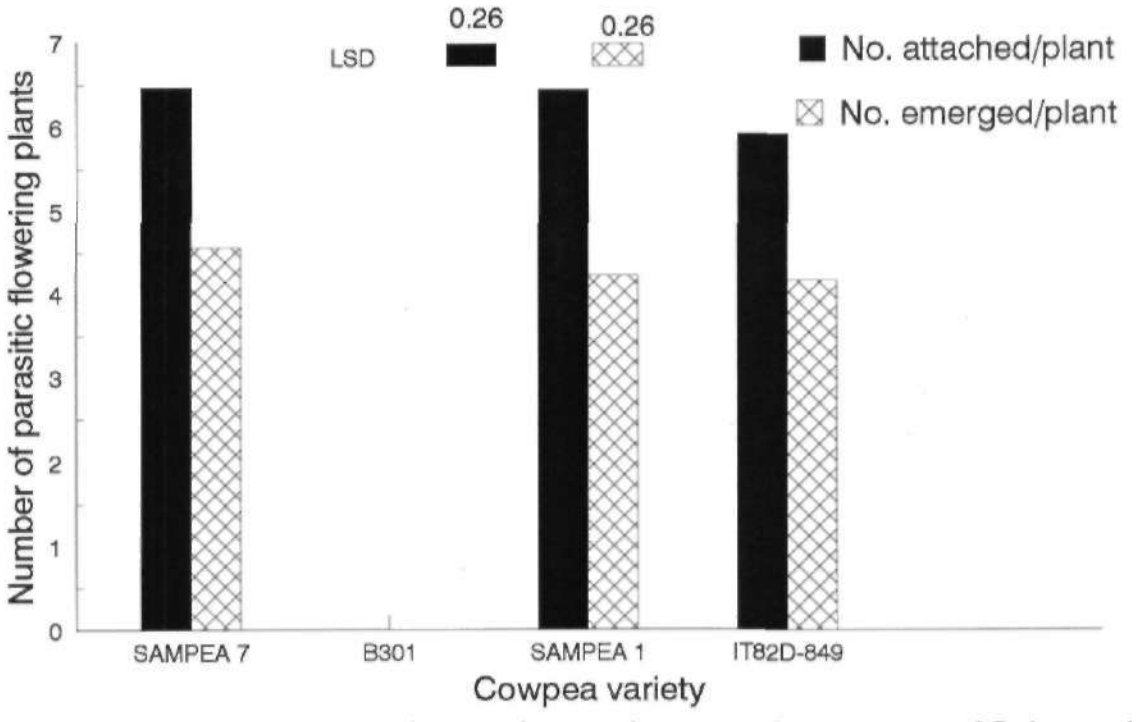


Figure 5: Effect of cowpea variety on the attachment and emergence of Striga and Alectra at Samaru (averaged over two years)

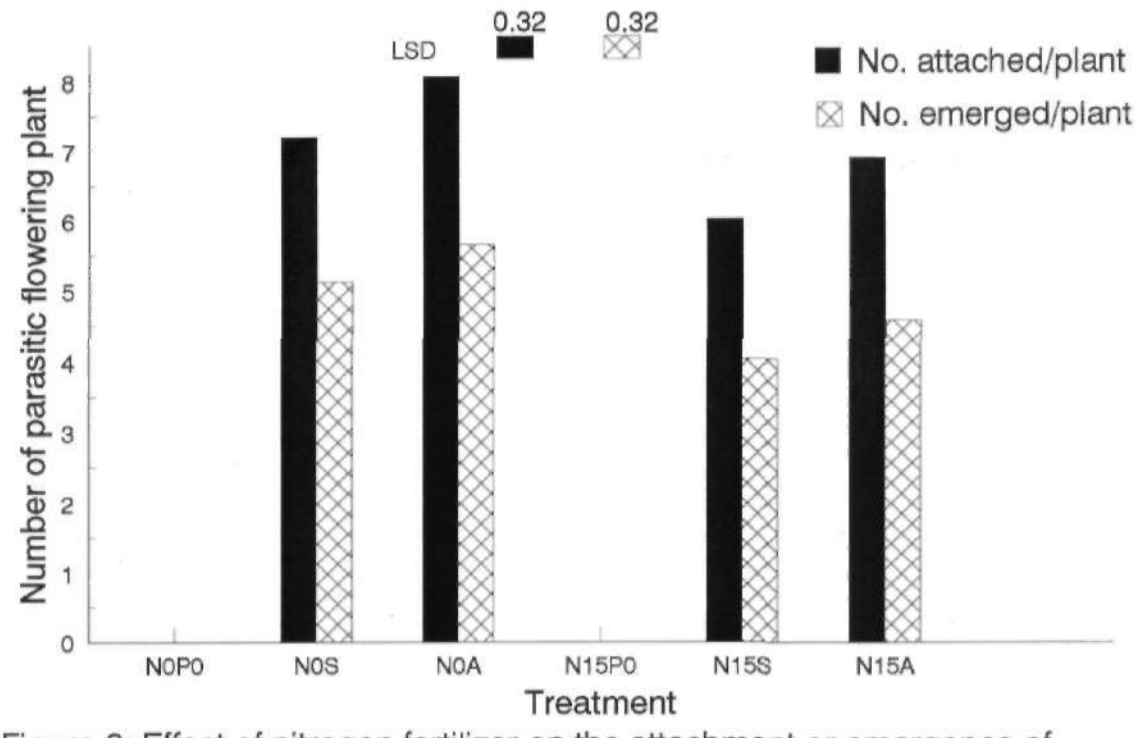


Figure 6: Effect of nitrogen fertilizer on the attachment or emergence of Striga and Alectra at Samaru (averaged over two years).

4.2.3. **Effect of Urea Nitrogen Fertilizer on Cowpea Total Dry Matter Yield**

The effect of urea nitrogen on cowpea total dry matter yield (TDMY) is shown in Table 7, Fig. 7&8. The result shows that the uninfested, unfertilized control plots gave significantly ($P \leq 0.05$) lower TDMY than the uninfested but fertilized plots, during the two years. In both years, the total dry matter yield on plots with N_2 fertilizer was much higher than on similar unfertilized plots (Table 7). The unfertilized and infested plots were not significantly different from each other. Similar trend was observed in the infested and fertilized plots, Table 7, Fig. 8. This tends to agree with the results presented in Table 5 in which the number of both attached and emerged *Striga* or *Alectra* were higher in the unfertilized infested plots compared to the fertilized infested plots. The total dry matter was significantly affected by the cowpea varieties at 5% level of probability (Fig. 7). Among the cowpea varieties evaluated, SAMPEA-7 significantly ($P \leq 0.05$) produced highest total dry matter; followed by B 301, IT82D-849 and then SAMPEA-1. When the treatments were evaluated, the fertilized uninfested plots had TDMY increase of about 11.5% while the infested and fertilized plots had yield increases of about 18.7% and 16.67% compared to the control. On the other hand, the unfertilized plots infested with *Striga* and *Alectra* had yield decreases of about 30.4% and 28.3% respectively compared to that of the control (Fig. 8). Previous field experiments have shown that application of urea nitrogen increased TDMY of cowpea planted on *Striga* or *Alectra* infested plots (Adu *et al.*, 1989; Lagoke *et al.*, 1991, Emechebe *et al.*, 1983, 1991; Emechebe, 1986). Also Graves *et al.*, (1989) observed reduction in leaf, stem and root weight by 70, 65 and 40 percent respectively due to parasitic flowering plant infestation.

Table 7. Effect of nitrogen fertilizer and parasitic flowering plants on total cowpea dry matter yield at Samaru in 1995 and 1996.

Treatment[1]	Total cowpea dry matter yield (g/plant)									
	1995					1996				
	SAM-PEA-7	B301	SAM-PEA-1	IT82 D-849	Mean	SAM-PEA-7	B301	SAM-PEA-1	IT82 D-849	Mean
NoPo (Control)	26.62	19.61	16.85	17.21	20.07	29.58	25.521	24.15	27.12	26.59
NoS	13.55	15.67	9.58	12.78	12.89	19.30	18.76	17.88	21.20	19.29
NoA	14.64	16.74	10.63	10.19	13.05	22.36	19.78	19.01	19.43	20.14
$N_{15}Po$	31.41	20.70	20.88	19.25	23.06	33.28	27.19	27.74	27.64	28.96
$N_{15}S$	17.36	17.81	12.48	16.38	16.01	22.51	22.27	21.31	24.12	22.55
$N_{15}A$	15.77	20.27	15.44	14.07	16.39	24.10	24.77	21.71	22.38	23.24
LSD (P=0.05)	19.89	18.47	14.31	14.98		25.19	23.05	21.97	23.65	

1: NoPo = No nitrogen, no Striga or Alectra
NoS = No nitrogen plus Striga
No4 = No nitrogen plus Alectra
$N_{15}Po$ = Nitrogen, no Striga or Alectra
$N_{15}S$ = Nitrogen plus Striga
$N_{15}A$ = Nitrogen plus Alectra.

ANOVA (see Appendix 9)
LSD ($P \leq 0.05$):
Treatment = 1.03
Cowpea varieties = 0.84
Treatment * varieties = 2.06

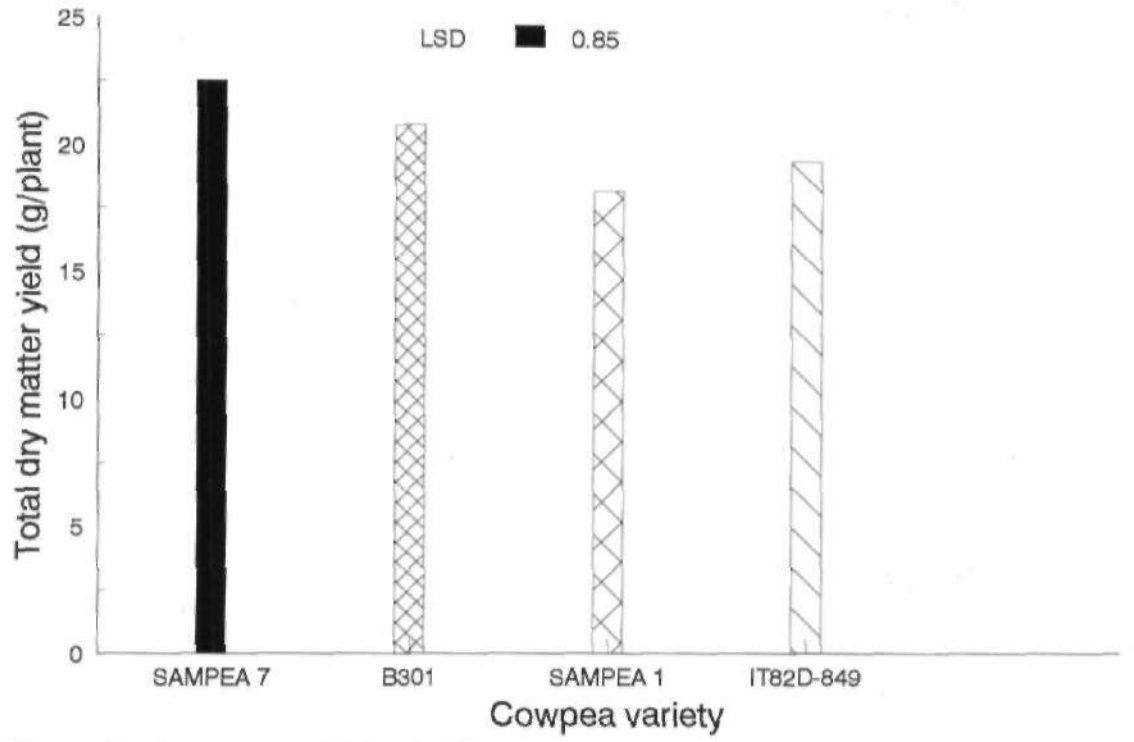


Figure 7: Dry matter yields of different cowpea varieties at Samaru (averaged over two years).

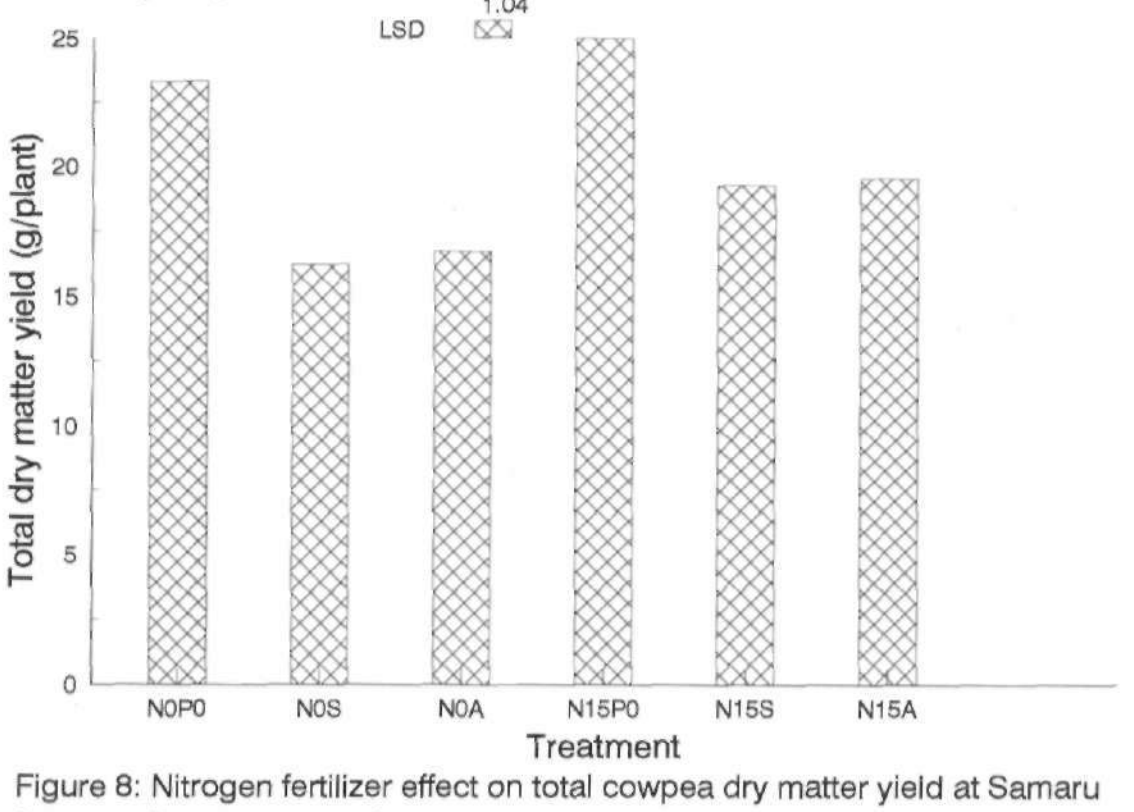


Figure 8: Nitrogen fertilizer effect on total cowpea dry matter yield at Samaru (averaged over two years).

4.2.4. Effect of Urea Nitrogen Fertilizer on Cowpea Grain Yield

The effect of urea nitrogen fertilization on grain yield in 1995 and 1996 is shown in Table 8. With the increase in the rate of urea nitrogen level from zero to 15 kgNha^{-1}, grain yield was generally increased in all treatments, during the two years. The control plots significantly ($P \leq 0.05$) yielded higher than the unfertilized and fertilized infested *Striga* or *Alectra* plots but lower than the fertilized control plots (Table 8). When the urea nitrogen levels were evaluated irrespective of cowpea varieties for the two year period, the same trend above was observed (Fig. 10). Among the cowpea varieties, B301 which did not support both emergence and attachment of *Striga* or *Alectra* produced significantly ($P \leq 0.05$) the highest grain yield compared to the other varieties which were not significantly different ($P \leq 0.05$) from each other (Fig. 9). Earlier studies with same varieties showed data that agree with the results of the present study (Emechebe *et al.*, 1983, 1988, 1991; Singh and Emechebe 1990; Adu and Emechebe, 1991).

Since these parasitic flowering plants obtain their mineral nutrients from their host plant, the more the number of attached or emerged *Striga* or *Alectra* per cowpea plant, the larger the depression in grain yield caused by parasite infection. For instance cowpea seed yield has been estimated to be decreased by 20 - 60% with an average of 30% in susceptible varieties (Singh and Emechebe 1990; Reiss et al., 1995).

Based on the 15 Kg N/ha^{-1} applied yield increase (computed from the pooled analysis) of 18.8% was obtained in the uninfested but fertilized plots compared to the control. In the fertilized *Striga*-infested plots, grain yield increase of 21.08% was

A72100

obtained while the corresponding value for *Alectra* was 9.73 compared to similar unfertilized plots. The above yield increases obtained is certainly enough to justify starter N application to the cowpea as suggested earlier by Agbenin *et al.*, (1990).

Table 8. Effect of nitrogen fertilizer and parasitic flowering plants on cowpea grain yield at Samaru in 1995 and 1996.

Treatment	Grain yield (kg/ha)									
	1995					1996				
	SAM-PEA-7	B301	SAM-PEA-1	IT82 D-849	Mean	SAM-PEA-7	B301	SAM-PEA-1	IT82D-849	Mean
NoPo (Control)	780.00	890.00	753.00	640.00	766.00	1047.00	1323.00	973.00	817.00	1040.00
NoS	393.30	906.70	330.00	413.30	511.00	473.00	1177.00	490.00	810.00	737.50
NoA	433.30	763.30	233.00	286.70	429.08	493.00	1220.00	620.00	493.00	706.50
N_{15}Po	1023.30	940.00	956.70	736.70	914.18	1310.00	1740.00	1280.00	1030.00	1340.00
N_{15}S	503.30	1083.30	526.70	570.00	670.83	520.00	1513.00	663.00	867.00	890.75
N_{15}A	410.00	1080.00	500.00	376.70	591.68	610.00	1463.00	630.00	570.00	818.25
Mean	589.53	943.88	549.9	503.9		742.17	1406.00	776.00	764.50	

ANOVA (See Appendix 10)

LSD ($P \leq 0.05$):

Treatment	=	79.79
Cowpea variety	=	65.14
Treatment * variety	=	159.59

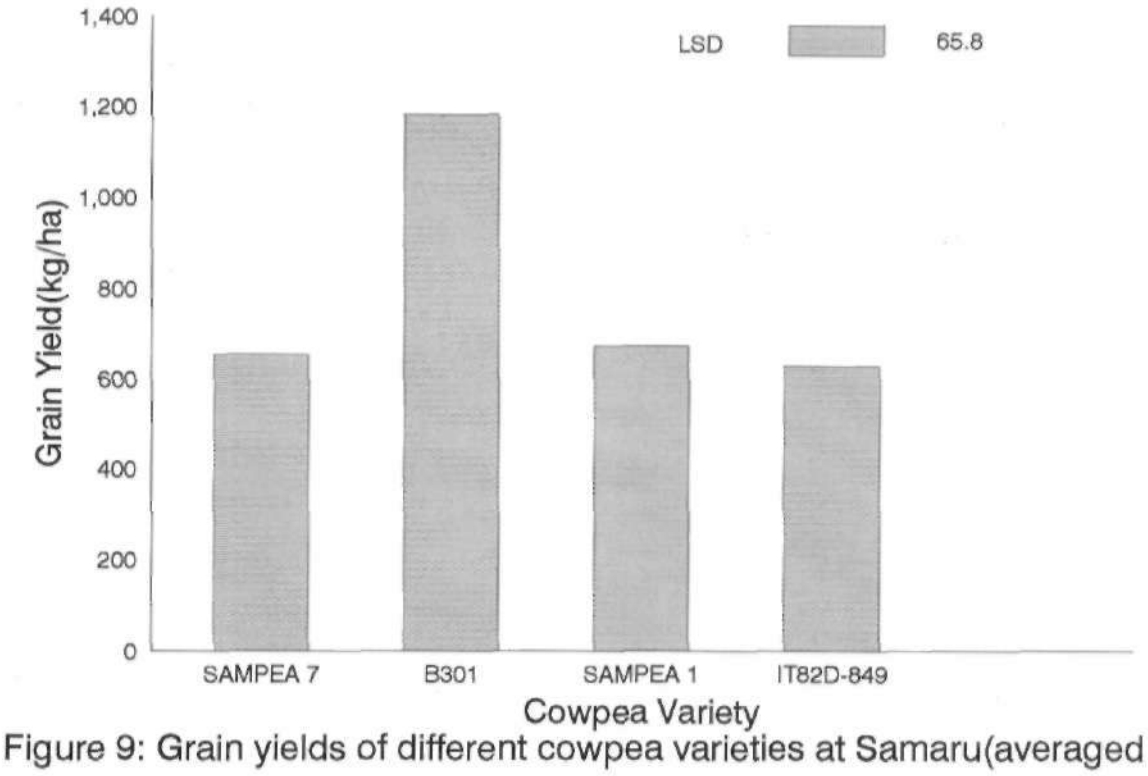


Figure 9: Grain yields of different cowpea varieties at Samaru(averaged over two years)

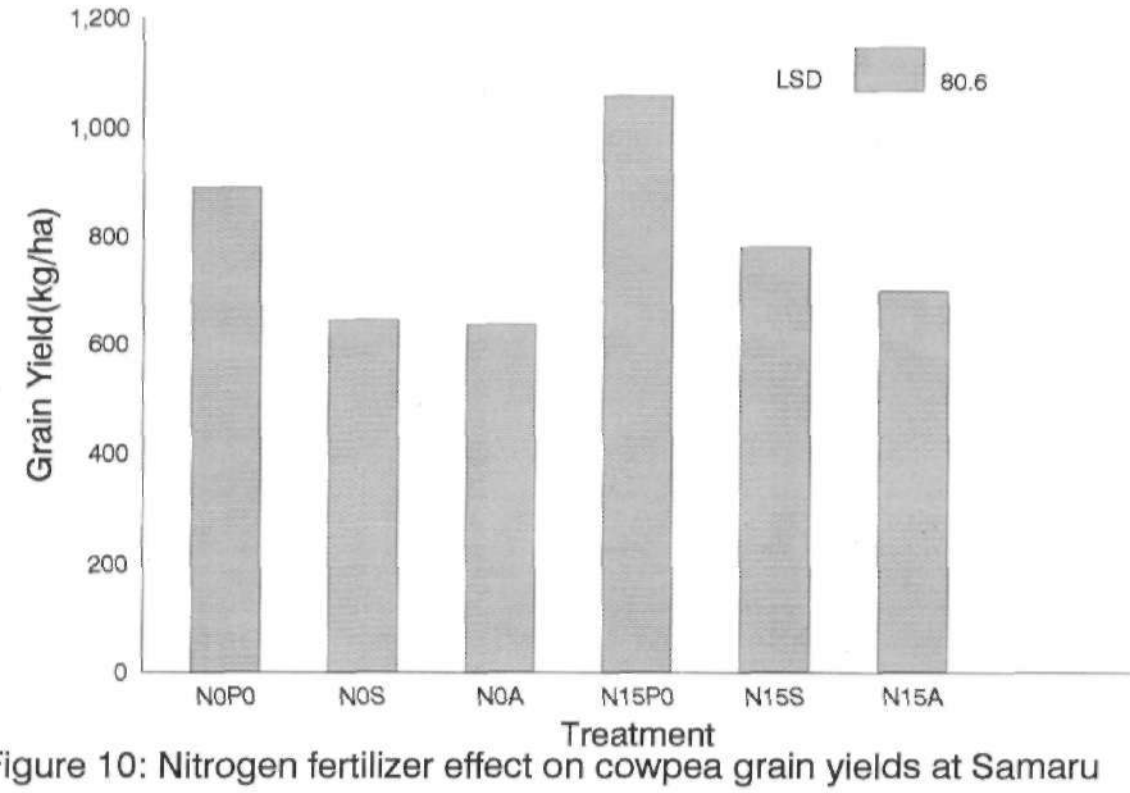


Figure 10: Nitrogen fertilizer effect on cowpea grain yields at Samaru (averaged over two years)

4.2.5. **Effect of Urea Nitrogen Fertilizer on Cowpea Nodulation**

Nodulation differed significantly between the two nitrogen levels in both non-infested and infested plots in 1995 and 1996 (Table 9a and b). Nodulation increased with application of nitrogen fertilizer. Results for both years showed that, variety B 301 significantly ($P \leq 0.05$) produced the highest nodule number and nodule dry weight (Fig. 11). The uninfected, unfertilized or fertilized cowpea varieties had significantly higher nodule number and dry weight than those infected by *Striga* or *Alectra* (Table 9a and 9b). This shows the adverse effect of these parasitic flowering plants on cowpea nodulation. These results also showed that application of $15kgNha^{-1}$ improved nodulation in all plots, suggesting that urea nitrogen had a prophylatic effect on *Striga* and *Alectra* infection of cowpea (Tables 9a and b, Fig. 12). Among the susceptible varieties, IT82D-849 significantly produced lower nodule number and dry weight in *Alectra* - infected than in *Striga*-infected plants compared to SAMPEA-7 or SAMPEA-1 this is probably associated with the moderate resistance of IT82D-849 to *Striga* and its high susceptibility to *Alectra*. Subsequent field experiments have established that application of nitrogen as urea suppressed *Alectra* and *Striga* infection on cowpea, thereby improving nodulation (Adu *et al.*, 1989; Lagoke *et al.*, 1991; Adu and Emechebe 1991). This study shows that nodulation was influenced by urea nitrogen fertilizer.

Table 9a. Effect of nitrogen fertilizer and parasitic flowering plants on cowpea nodule number at Samaru in 1995 and 1996.

Treatment	Number of nodules/plant									
	1995					1996				
	Sam-pea-7	B301	Sam-pea-1	IT82 D-849	Mean	Sam-pea-7	B301	Sam-pea-1	IT82 D-849	Mean
(Control) NoPo	47.00	55.00	48.00	51.00	50.25	56.33	57.00	60.67	56.67	57.67
NoS	17.33	47.00	22.33	25.00	27.92	27.67	53.33	32.00	40.00	38.25
NoA	20.67	53.67	25.67	20.67	30.17	33.00	57.33	40.33	30.00	40.17
N_{15}Po	54.33	58.00	52.00	54.67	54.75	63.00	60.33	62.00	60.67	61.50
N_{15}S	30.33	52.00	37.33	41.33	40.25	34.33	56.00	40.67	45.33	44.08
N_{15}A	32.67	58.00	33.33	30.00	38.50	40.00	62.67	43.33	36.00	45.50
Mean	33.72	53.94	36.44	37.11		42.39	57.78	46.50	44.78	

ANOVA (See Appendix 11)
LSD ($P \leq 0.05$):
Treatment = 2.25
Cowpea variety = 1.84
Treatment * variety = 4.50

Table 9b. Effect of nitrogen fertilizer and parasitic flowering plants on cowpea nodule dry weight at Samaru in 1995 and 1996.

Treatment	Nodule dry weight (mg/plant)									
	1995					1996				
	Sam-pea-7	B301	Sam-pea-1	IT82D-849	Mean	Sam-pea-7	B301	Sam-pea-1	IT82 D-849	Mean
(Control) NoPo	108.55	107.78	109.49	98.75	106.14	117.42	114.92	119.84	109.53	115.43
NoS	29.83	104.75	40.02	41.78	54.10	63.97	113.01	65.80	68.82	77.90
NoA	36.75	106.09	40.90	30.78	53.63	66.18	113.97	69.57	59.05	77.19
N_{15}Po	109.48	108.02	109.81	108.92	109.06	123.42	118.10	121.42	119.49	120.61
N_{15}S	34.18	104.96	41.01	43.32	55.87	68.04	115.06	71.62	73.82	82.13
N_{15}A	40.13	106.21	41.34	35.97	55.91	69.81	117.87	72.81	64.46	81.24
Mean	59.82	106.30	63.76	59.92		84.81	115.49	86.84	82.53	

ANOVA (See Appendix 12)
LSD ($P \leq 0.05$):
Treatment = 2.39
Cowpea variety = 1.95
Treatment * variety = 4.78

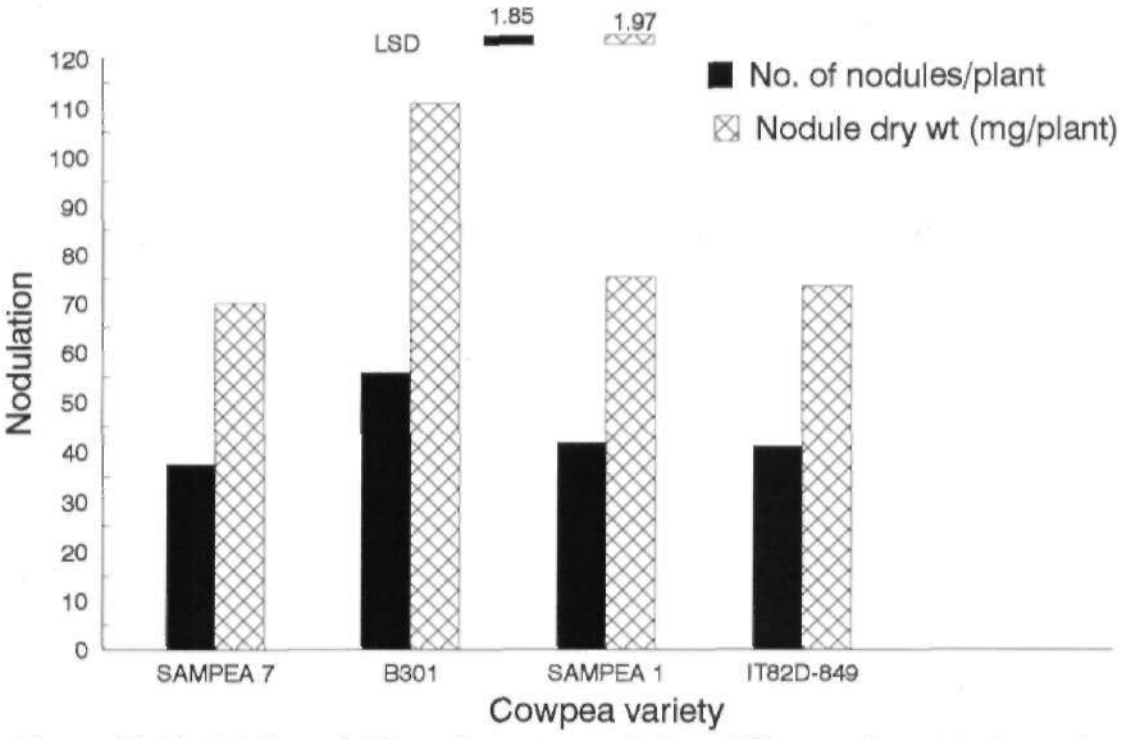


Figure 11: Nodulation of different cowpea varieties at Samaru (averaged over two years).

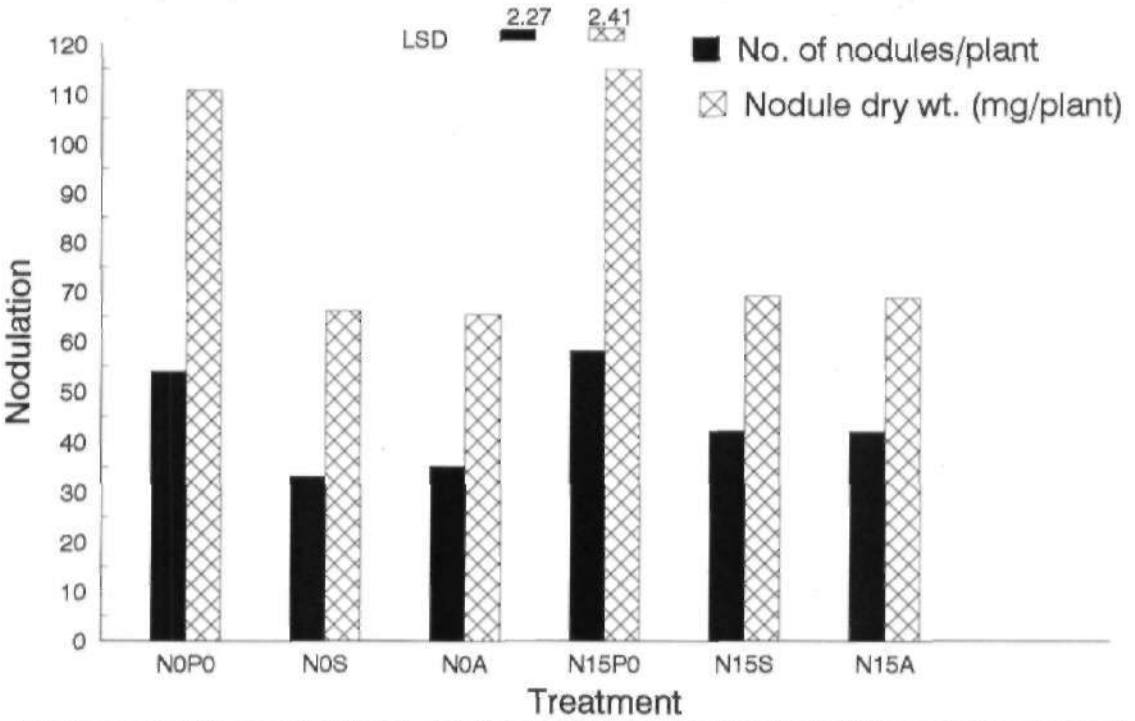


Figure 12: Nitrogen fertilizer effect on cowpea nodulation at Samaru (averaged over two years).

4.2.6. Effect of Urea Nitrogen Fertilizer on Cowpea Nitrogen Fixation

The results of percentage nitrogen derived from the atmosphere (based on root bleeding sap) is presented in Table 10. The application of 15kgNha^{-1} nitrogen fertilizer had significant effect on the percentage of nitrogen derived from the atmosphere during the two years (Tables 10). The nitrogen treated plots had higher percentage fixed N compared to the unfertilized plots in both *Striga* and *Alectra* infested plots. This is an indication of the importance of urea nitrogen in N_2 fixation of infected plants. The control plots had higher percentage N fixed compared to the plots infested and unfertilized by *Striga* or *Alectra* indicating the adverse effects of *Striga* or *Alectra* on nitrogen fixation (Figure 14, Table 10). Results in Table 10 also show greater level of percentage N fixed at 50% podding (Table 10).

When the varieties were compared, there were no significant differences between them in the amount of N fixed in 1995 and in the pooled analysis (Table 10, and Fig. 13). Among the cowpea varieties, B301 variety had the highest percentage N fixed compared to other varieties (Table 10).

This study shows that nitrogen fixation was also influenced by urea nitrogen fertilizer, though there were no significant differences among the percentage N fixed by the cowpea varieties. Since the process of N fixation doses not begin immediately upon germination, the use of small amount of starter N fertilizer for legume establishment has often been suggested (Kang, 1975; Eaglesham *et al.*, 1977; Sanginga *et al*, 1988; Agbenin *et al.*, 1990). The reason being that the small starter doses of nitrogen fertilizer applied will meet the plants requirement for nitrogen during any N-hunger period while nodules are developing. It will in addition produce a large young plant, that will maintain a high growth (Sanginga *et al.*, 1988; Minchin

et al., 1981). This may be important under *Striga* and *Alectra* infestation conditions, because many soils have low amounts of available N, which may be inadequate to satisfy the cowpea plants need during the N-hunger period.

Table 10. Effect of nitrogen fertilizer and parasitic flowering plants on cowpea nitrogen fixation at Samaru in 1995 and 1996

Treatment	% Ndfa Root bleeding sap at 50% podding									
	1995					1996				
	SAM-PEA-7	B301	SAM-PEA-1	IT82 D-849	Mean	SAM-PEA-7	B301	SAM-PEA-1	IT82 D-849	Mean
NoPo (Control)	51.24	52.14	57.50	55.27	54.04	52.81	53.93	57.95	57.06	55.44
NoS	45.87	50.79	49.45	50.79	49.23	49.00	57.28	54.60	54.60	53.87
NoA	50.79	51.46	48.78	47.89	49.73	53.25	59.07	53.03	51.47	54.21
N_{15}Po	58.30	56.61	54.15	55.04	56.03	59.97	57.95	54.37	58.18	57.62
N_{15}S	52.58	56.16	53.70	54.37	54.21	53.70	58.85	56.38	57.06	56.50
N_{15}A	57.28	57.50	55.04	50.57	55.10	58.85	59.07	59.52	53.48	57.73
Mean	52.68	54.11	53.10	52.32		54.60	57.69	55.98	55.31	

ANOVA (See Appendix 13)
LSD ($P \leq 0.05$):
Treatment = 1.57
Cowpea variety = 1.28
Treatment * variety = 3.14

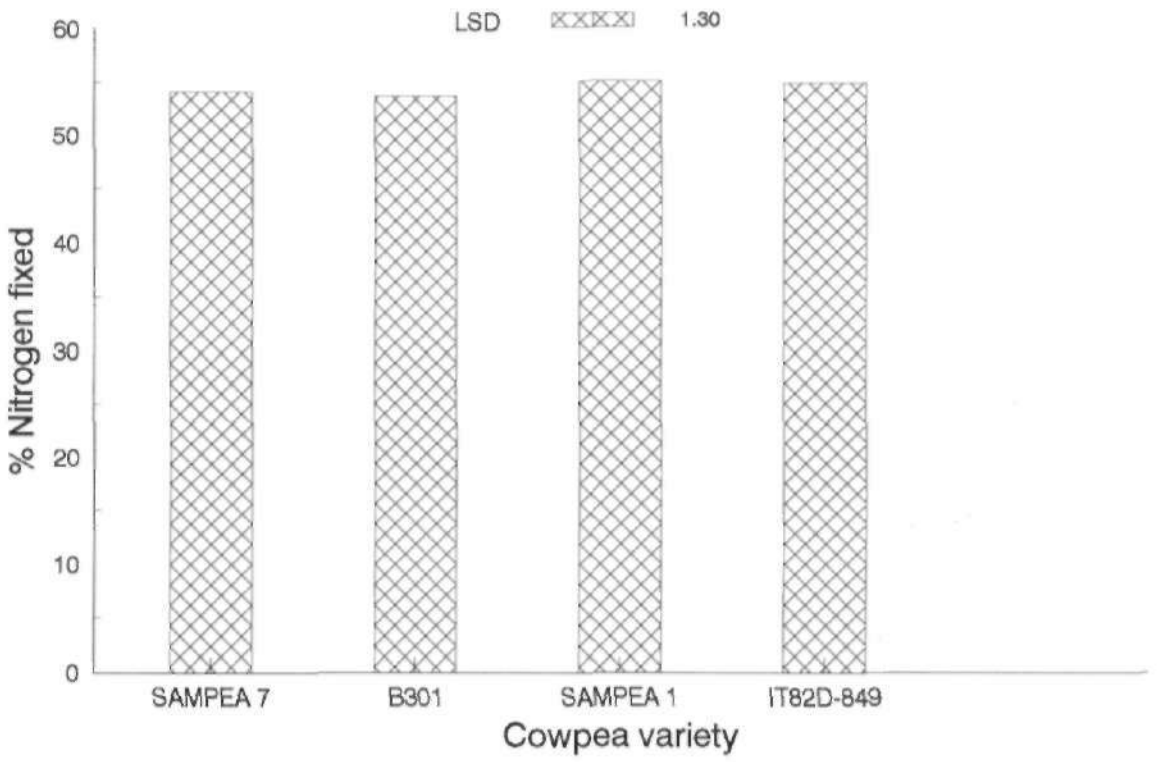


Figure 13: Percentage nitrogen fixed by cowpea varieties at 50% podding at Samaru (averaged over two years).

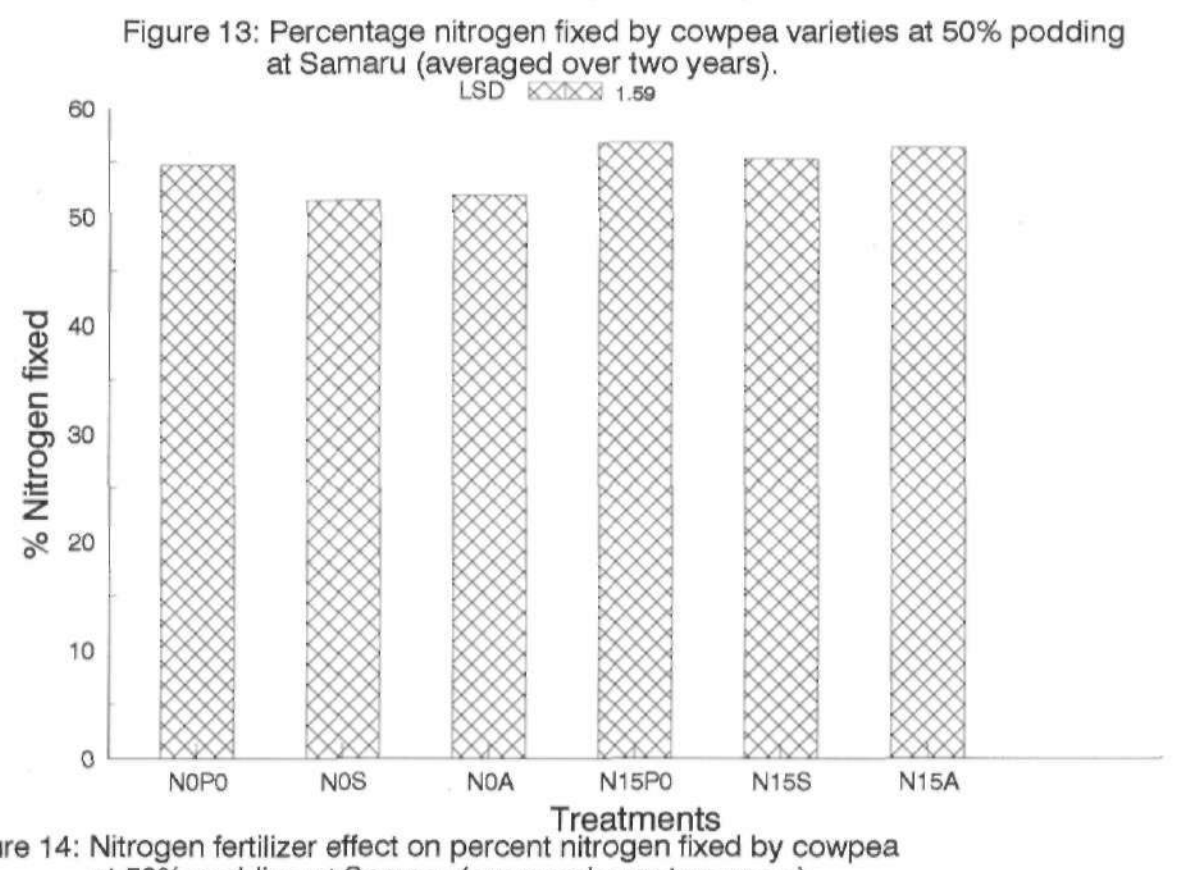


Figure 14: Nitrogen fertilizer effect on percent nitrogen fixed by cowpea at 50% podding at Samaru (averaged over two years).

4.2.7. Effect of Phosphorus and Molybdenum on the incidence of cowpea - *Striga* and- *Alectra* infection

The result for 1995 and 1996 are presented in Tables 11a and 11b while the results of the pooled analysis is shown in Fig. 15a-b. Phosphorus and molybdenum fertilizers had significant ($P \leq 0.05$) influence in both years on the susceptible variety, Sampea-7 in the *Striga* infested plots and only in 1995 in the *Alectra* infested plots. The application of P or Mo resulted in significantly offsetting the adverse effects of *Striga* or *Alectra* parasites on susceptible cowpea variety, SAMPEA-7 (Tables 11a and 11b, fig. 15a-b). When the P levels were compared during the two years, there were significant differences between 20, 40 and 80kgPha^{-1} in the number of attached/plant in the *Striga* infested plots. Application of 40 and 80kgPha^{-1} were not significantly different from each other but they were significantly lower than 20kgPha^{-1} and control. Application of P significantly affected the number of *Striga* that emerged/plant in both years and only in 1995 in the *Alectra* infested plots (Table 11a and b). Results of the pooled analysis showed that application of 40 and 80kgPha^{-1} significantly differed from 20kgPha^{-1} in both *Striga* and *Alectra* infested plots and they significantly suppressed the attack by these parasitic flowering plants compared to the control (Fig. 15a-b). Application of Mo significantly reduced the incidences of *Striga* and *Alectra* in both years. The differences between the two rates in both years were not significant (Table 11 a&b, Fig. 15a-b). When the combined application of P and Mo were compared to the control, application rate of 0.25kgMoha^{-1} and 40kgPha^{-1} was observed to be the best treatment combination (Table 11a and b, Fig. 15a-b). Results of this study showed that application of phosphorus and molybdenum to soil infested with cowpea *Striga* and *Alectra* resulted in significant reduction of the adverse effects of their parasitism. This could be a

result of the suppressive effect of P and Mo on *Striga* and *Alectra* growth and development. This is in consonance with the reports of previous workers (Lagoke *et al.*, 1991; Adu and Emechebe 1991; Magani *et al.*, 1991) while Mugabe (1983) observed similar response on *Alectra vogelii* in Zimbabwe.

Table 11a. Effect of phosphorus and molybdenum on the incidence of *Alectra* infection of cowpea at Samaru in 1995 and 1996.

Treatment[1]	No. attached/plant					No. emerged/plant				
	1995		1996			1995		1996		
	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean
Control (MoOPo)	17.50	0.00	15.50	0.00	8.25	12.00	0.00	11.00	0.00	5.75
$MoOP_{20}$	13.50	0.00	13.50	0.00	6.75	10.50	0.00	9.50	0.00	5.00
$MoOP_{40}$	13.0	0.00	11.50	0.00	6.13	9.00	0.00	9.50	0.00	4.63
$MoOP_{80}$	13.50	0.00	12.50	0.00	6.50	9.50	0.00	10.00	0.00	4.88
Mo0.25Po	12.00	0.00	10.00	0.00	5.50	9.50	0.00	7.50	0.00	4.25
$Mo0.25P_{20}$	13.50	0.00	12.50	0.00	6.50	10.50	0.00	9.00	0.00	4.88
$Mo0.25P_{40}$	11.50	0.00	11.50	0.00	5.75	9.00	0.00	8.00	0.00	4.25
$MoO.25P_{80}$	13.50	0.00	12.00	0.00	6.38	10.00	0.00	8.50	0.00	4.63
Mo0.50Po	14.50	0.00	10.50	0.00	6.25	10.50	0.00	7.00	0.00	4.38
$Mo0.50P_{20}$	15.00	0.00	13.50	0.00	7.13	11.50	0.00	9.50	0.00	5.25
$Mo0.50P_{40}$	12.50	0.00	10.50	0.00	5.75	10.50	0.00	8.00	0.00	4.63
$Mo0.50P_{80}$	14.50	0.00	12.50	0.00	6.75	11.00	0.00	8.50	0.00	4.88
Mean	13.71	0.00	12.17	0.00		10.29	0.00	8.83	0.00	

ANOVA (See Appendix 14)

ANOVA (See Appendix 15)

[1]: (MoOPO) = No molybdenum no phosphorus; $MoOP_{20}$ = No molybdenum but phosphorus at 20kgPha^{-1}
$MoOP_{40}$ = No molybdenum but phosphorus at 40kgPha^{-1}; $MoOP_{80}$ = No molybdenum but phosphorus at 80kgPha^{-1}
Mo0.25Po = Molybdenum at 0.25kgMoha^{-1}; $Mo0.25P_{20}$ = Molybdenum at 0.25kgMoha^{-1} and Phosphorus at 20kgPha^{-1}
$Mo0.25P_{40}$ = Molybdenum at 0.25kgMoha^{-1} and Phosphorus at 40kgPha^{-1}; $MoO.25P_{80}$ = Molybdenum at 0.25kgMoha^{-1} and Phosphorus at 80kgPha^{-1}; Mo0.50Po = Molybdenum at 0.50kgMoha^{-1} but No phosphorus; $Mo0.50P_{20}$ = Molybdenum at 0.50kgMoha^{-1} and Phosphorus at 20kgPha^{-1}; $Mo0.50P_{40}$ = Molybdenum at 0.50kgMoha^{-1} and Phosphorus at 40kgPha^{-1}; $Mo0.50P_{80}$ = Molybdenum at 0.50kgMoha^{-1} and Phosphorus at 80kgPha^{-1}

LSD ($P \leq 0.05$):
Treatment = 0.52; Variety = 0.21; Years = 0.21;
Treatment * variety = 0.74

LSD ($P \leq 0.05$)
Treatment = 0.54; Variety = 0.22; Years = 0.34;
Treatment * variety = 0.76

Table 11b. Effect of phosphorus and molybdenum on the incidence of *Striga* infection of cowpea at Samaru in 1995 and 1996.

Treatment1	No. attached/plant					No. emerged/plant				
	1995		1996			1995		1996		
	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean
Control (MoOPo)	17.00	0.00	16.00	0.00	8.25	12.50	0.00	10.50	0.00	5.75
MoOP2o	14.50	0.00	14.00	0.00	7.13	11.00	0.00	10.00	0.00	5.25
MoOP40	12.50	0.00	11.50	0.00	6.00	10.00	0.00	9.00	0.00	4.75
MoOP80	14.00	0.00	12.50	0.00	6.63	10.50	0.00	9.50	0.00	5.00
Mo0.25Po	12.50	0.00	11.00	0.00	5.88	8.50	0.00	8.00	0.00	4.13
Mo0.25P20	14.50	0.00	13.50	0.00	7.00	11.00	0.00	10.00	0.00	5.25
Mo0.25P40	13.00	0.00	11.50	0.00	6.13	10.00	0.00	9.00	0.00	4.75
MoO.25P80	13.50	0.00	13.00	0.00	6.63	10.00	0.00	10.00	0.00	5.00
Mo0.50Po	12.00	0.00	11.00	0.00	5.75	9.50	0.00	7.00	0.00	4.13
Mo0.50P20	14.50	0.00	14.50	0.00	7.25	10.50	0.00	10.50	0.00	5.25
Mo0.50P40	13.50	0.00	12.00	0.00	6.38	10.00	0.00	9.00	0.00	4.75
Mo0.50P80	14.00	0.00	12.50	0.00	6.63	10.50	0.00	9.00	0.00	4.88
Mean	13.79	0.00	12.75	0.00		10.33	0.00	9.29	0.00	

ANOVA (See Appendix 16)

1: (MoOPO) = No molybdenum no phosphorus; MoOP20 = No molybdenum but phosphorus at 20kgPha-1 MoOP40 = No molybdenum but phosphorus at 40kgPha-1; MoOP80 = No molybdenum but phosphorus at 80kgPha-1; Mo0.25Po = Molybdenum at 0.25kgMoha-1; Mo0.25P20 = Molybdenum at 0.25kgMoha-1 and Phosphorus at 20kgPha-1; Mo0.25P40 = Molybdenum at 0.25kgMoha-1 and Phosphorus at 40kgPha-1; MoO.25P80 = Molybdenum at 0.25kgMoha-1 and Phosphorus at 80kgPha-1; Mo0.50Po = Molybdenum at 0.50kgMoha-1 but No phosphorus; Mo0.50P20 = Molybdenum at 0.50kgMoha-1 and Phosphorus at 20kgPha-1; Mo0.50P40 = Molybdenum at 0.50kgMoha-1 and Phosphorus at 40kgPha-1; Mo0.50P80 = Molybdenum at 0.50kgMoha-1 and Phosphorus at 80kgPha-1

LSD ($P \leq 0.05$):
Treatment = 0.54; Variety = 0.22;;
Treatment * variety = 0.76

ANOVA See Appendix 17

LSD($P \leq 0.05$):
Treatment = 0.51; Variety = 0.21;
Treatment * variety = 0.72

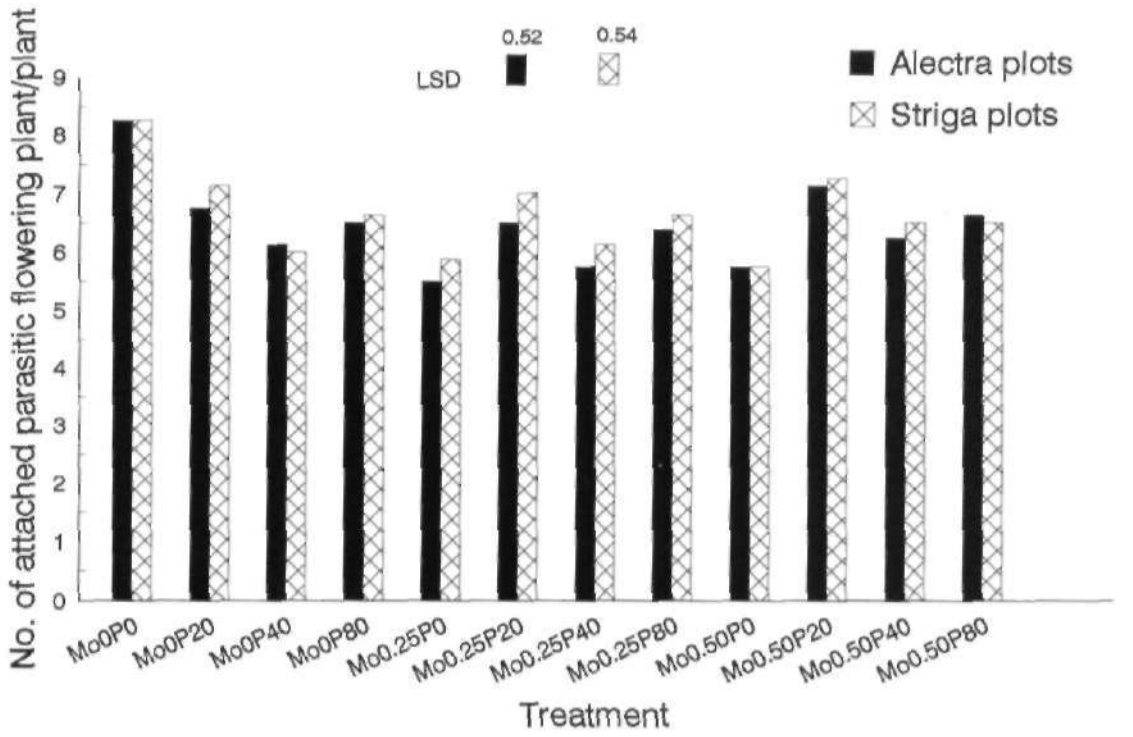


Figure 15a: Phosphorus and Molybdenum effects on cowpea Striga and Alectra attachment at Samaru (averaged over two years).

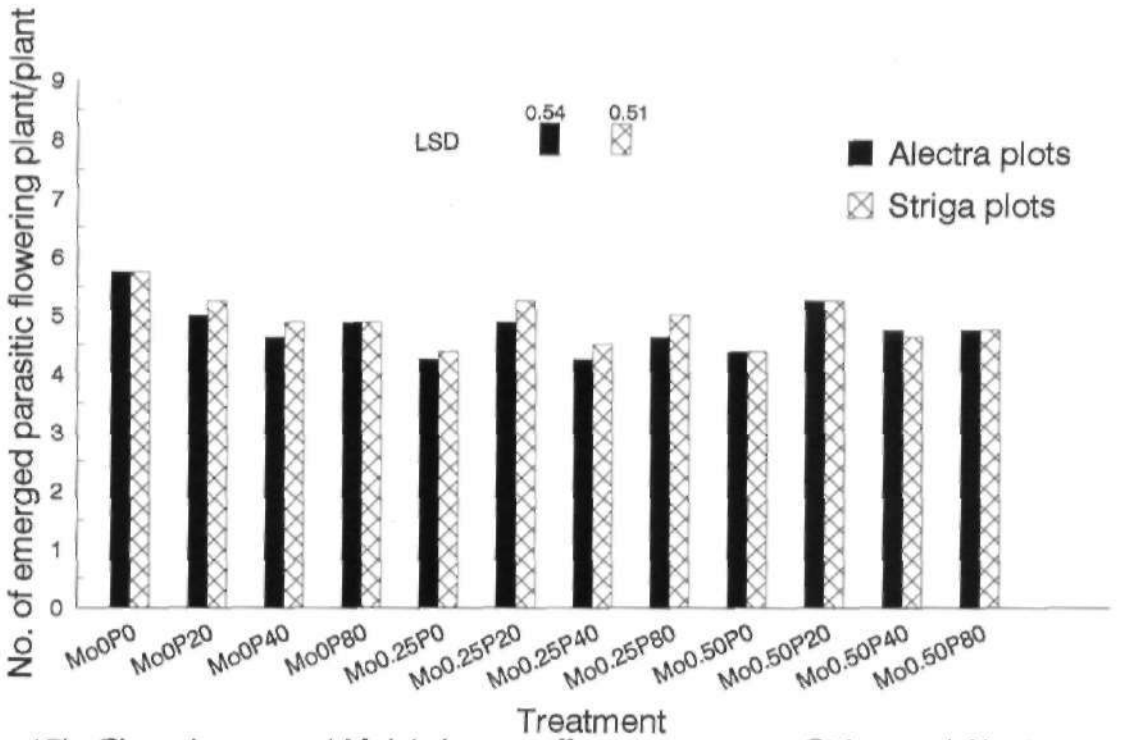


Figure 15b: Phosphorus and Molybdenum effects on cowpea Striga and Alectra emergence at Samaru (averaged over two years).

4.2.8. **Effect of Phosphorus and Molybdenum on Total Cowpea Dry Matter Yield**

The effect of phosphorus and molybdenum on total cowpea dry matter yield (TDMY) is shown in Table 12 (a&b) and the pooled analysis in figure 16. The result shows that there were no significant differences between the cowpea varieties in the *Striga* infested plots in both 1995 and 1996 and in 1995 alone in soil infested by *Alectra* (Tables 12 a&b). Result of the pooled analysis showed differences among the treatments (Figure 16). In 1996, SAMPEA-7 significantly ($P \leq 0.05$) produced higher dry matter than B301 in the *Alectra* infested plots (Table 12a). This is attributable to the fact that SAMPEA-7 is a much larger plant than B301 under normal conditions (Emechebe, 1995 - personal communication). Application of 80kgPha^{-1} produced significantly ($P \leq 0.05$) the highest dry matter in all treatments compared to 20 and 40kgPha^{-1}. Results of the pooled analysis also showed that application of 0.50 kgMoha^{-1} had significant effect on TDMY compared to 0.25kgMoha^{-1} in the *Alectra* infested plots (Fig. 16). However, application of Mo alone significantly ($P \leq 0.05$) produced more dry matter than the check plots (Table 12 a&b, Fig. 16). In respect to Mo fertilization, application of 0.25kgMoha^{-1} and 0.50kgMoha^{-1} to *Alectra* infested plots increased TDM by 33 and 44% respectively, the corresponding figures for *Striga* being 30 and 33% compared to the control (Fig. 16). The best treatment combination in terms of TDM production was Mo0.50P80.

As a result of the significant decrease in the number of both attached and emerged *Striga* or *Alectra* in the plots that received P and Mo, the addition of these two minerals resulted in higher total dry matter than the control. This suggests that

KASU-M IBRAHIN LIBRARY

the addition of P and Mo probably enhanced the tolerance of Sampea7 to infection by *Striga* or *Alectra*, since results of another study in this dissertation had shown that infection by *Striga* or *Alectra* in susceptible plants that received no mineral fertilization adversely affected the above yield parameter. Phosphorus application at the rate of 80kgPha^{-1} had the highest total dry matter. Previous field experiments have established that application of 80kgPha^{-1} significantly increased total dry matter yield of leguminous species (Sanginga *et al.*, 1988; Sanginga, 1992; Magani *et al.*, 1991; Mugabe 1983; Lagoke *et al.*, 1991; Adu and Emechebe, 1991).

Table 12a. Effect of phosphorus and molybdenum on total dry matter yield of cowpea planted on *Alectra* infested plots at Samaru in 1995 and 1996.

Treatment	Total dry matter (g/plant)				
	Alectra Infested Plots				
	1995		1996		
	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean
Control (MoOPO)	9.07	7.78	14.17	11.70	10.68
$MoOP_{20}$	13.92	12.99	17.44	14.47	14.71
$MoOP_{40}$	17.40	15.49	20.01	17.12	17.51
$MoOP_{80}$	18.65	17.08	21.47	18.44	18.91
Mo0.25Po	14.33	12.07	16.89	13.59	14.22
$Mo0.25P_{20}$	15.82	14.69	17.42	15.71	15.91
$Mo0.25P_{40}$	18.98	15.92	20.44	17.26	18.15
$MoO.25P_{80}$	19.94	17.24	21.84	19.05	19.53
Mo0.50Po	15.94	12.88	18.70	14.15	15.42
$Mo0.50P_{20}$	18.52	14.79	21.33	16.50	17.78
$Mo0.50P_{40}$	23.18	17.07	24.17	19.36	20.94
$Mo0.50P_{80}$	24.64	20.17	27.25	22.20	23.57
Mean	17.53	14.85	20.09	16.63	

ANOVA (See Appendix 18)

LSD ($P \leq 0.05$):

Treatment	=	**1.00**
Cowpea variety	=	1.41
Treatment * variety	=	1.42

Table 12b. Effect of phosphorus and molybdenum on total dry matter yield of cowpea planted on *Striga* infested plots at Samaru in 1995 and 1996.

Treatment	Total dry mattr (g/plant)				
	Striga Infested Plots				
	1995		1996		
	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean
Control (MoOPO)	7.85	8.39	9.40	9.69	8.83
$MoOP_{20}$	13.82	14.57	15.23	15.45	15.02
$MoOP_{40}$	15.70	14.84	16.89	18.38	16.45
$MoOP_{80}$	18.25	18.38	19.19	18.16	18.49
Mo0.25Po	13.25	8.80	11.87	12.01	11.48
$Mo0.25P_{20}$	14.70	13.46	15.64	14.72	14.63
$Mo0.25P_{40}$	17.47	15.38	18.58	16.86	17.07
$MoO.25P_{80}$	21.54	17.65	22.79	19.53	20.37
Mo0.50Po	13.02	9.58	12.05	12.17	11.70
$Mo0.50P_{20}$	16.20	13.50	16.69	17.10	15.88
$Mo0.50P_{40}$	19.55	16.17	21.64	20.53	19.45
$Mo0.50P_{80}$	23.58	19.64	25.63	22.70	22.89
Mean	16.24	14.28	17.12	16.44	

ANOVA (See Appendix 19)

LSD ($P \leq 0.05$):
Treatment = 1.63
Cowpea variety = 0.66
Treatment * variety = 2.3

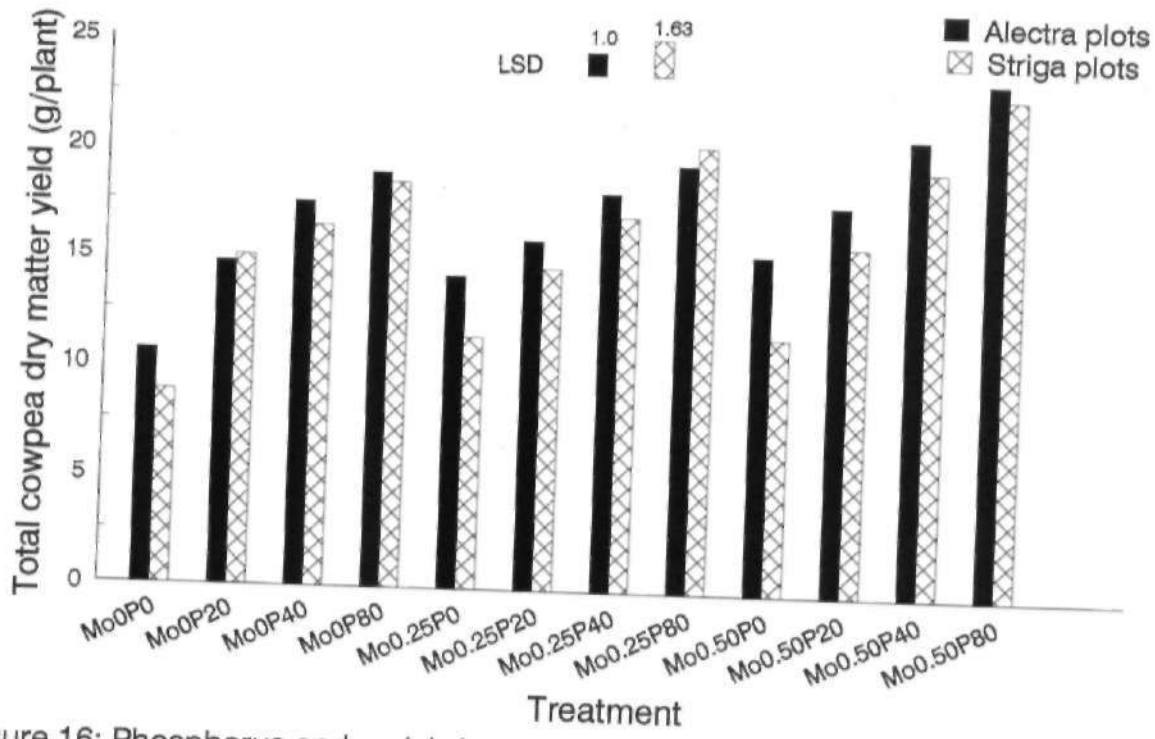


Figure 16: Phosphorus and molybdenum effects on total cowpea dry matter yields at Samaru (averaged over two years).

4.2.9. **Effect of Phosphorus and Molybdenum on Cowpea Grain Yield**

The result presented in Table 13 (a&b) shows that there are significant differences among the treatments and varieties. In both years, each of the plots that received either Mo or P fertilizer or both gave significantly ($P \leq 0.05$) higher grain yields than the check plots. Application of both P and Mo yielded significantly ($P \leq 0.05$) higher than those that received only the corresponding levels of P or Mo. The pooled data analysis showed similar trend (Fig. 17). In addition, grain yields increased significantly as P level increased from 20 to 40 and then a slight reduction at 80kgPha^{-1} that was not significant. Similarly, grain yields increased significantly with the application of Mo compared to the Control. (Tables 13a&b and Fig. 17).

Application of Mo at 0.50kgMoha^{-1} and P at 40kgPha^{-1} produced the highest grain yield among all the treatments. Compared to grain yields of the control, combined application of the above levels of Mo and P during the two year period resulted in 221% increase in grain yield in *Alectra* infested plots and 144% increase in *Striga* infested plots (Figure 17).

Since *Striga* and *Alectra* obtain their mineral nutrients from their host, the higher or more the number of attached or emerged *Striga* or *Alectra* per cowpea plant the larger the depression in yield caused by parasite infection. For instance an average of 30% decrease in seed yield in susceptible varieties (Adu and Emechebe 1991, Singh and Emechebe 1990; Lagoke *et al.*, 1991) have been reported for these parasites. Based on the quantities of P (20, 40 and 80kgPha^{-1}) and Mo (0.25 and 0.50kg Moha^{-1}) applied, the reported yield increases certainly suggests that application of these two elements may serve as a prophylatic measure that helps the crop

physiologically by increasing its vigour and enabling it withstand the *Striga* and *Alectra* infection. Field experiment on *Alectra vogelii* have established that application of phosphorus increased grain yield (Mugabe, 1983).

Table 13a. Effect of phosphorus and molybdenum on grain yield of cowpea planted on *Alectra* infested plots at Samaru in 1995 and 1996

Treatment	Grain yield (kg/ha)				
	Alectra Infested Plots				
	1995		1996		
	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean
Control (MoOPO)	740.0	385.0	910.0	450.0	621.3
$MoOP_{20}$	1250.0	885.0	1310.0	980.0	1106.3
$MoOP_{40}$	1500.0	1005.0	1605.0	1090.0	1300.0
$MoOP_{80}$	1415.0	930.0	1490.0	1000.0	1208.8
Mo0.25Po	1075.0	790.0	1190.0	870.0	981.3
$Mo0.25P_{20}$	1595.0	1025.0	1660.0	1140.0	1355.0
$Mo0.25P_{40}$	1825.0	1050.0	1855.0	1245.0	1493.8
$MoO.25P_{80}$	1730.0	1035.0	1800.0	1175.0	1435.0
Mo0.50Po	1145.0	820.0	1200.0	925.0	1022.5
$Mo0.50P_{20}$	1705.0	1160.0	1990.0	1320.0	1543.8
$Mo0.50P_{40}$	2440.0	1425.0	2610.0	1495.0	1992.5
$Mo0.50P_{80}$	2020.0	1265.0	2220.0	1375.0	1720.0
Mean	1536.7	981.3	**1653.3**	**1088.8**	

ANOVA (See Appendix 21)

LSD ($P \leq 0.05$):

Treatment	=	65.04
Cowpea variety	=	26.54
Treatment * variety	=	91.98

Table 13b. Effect of phosphorus and molybdenum on grain yield of cowpea planted on *Striga* infested plots at Samaru in 1995 and 1996

Treatment	Grain yield (kg/ha)				
	Striga Infested Plots				
	1995		1996		
	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean
Control (MoOPO)	765.0	635.0	900.0	670.0	742.5
$MoOP_{20}$	870.0	735.0	930.0	900.0	858.8
$MoOP_{40}$	1030.0	1115.0	1160.0	1325.0	1157.5
$MoOP_{80}$	960.0	1025.0	1125.0	1195.0	1076.3
Mo0.25Po	1065.0	725.0	1110.0	820.0	930.0
$Mo0.25P_{20}$	1105.0	995.0	1310.0	1065.0	1118.8
$Mo0.25P_{40}$	1665.0	1190.0	1960.0	1520.0	1583.8
$MoO.25P_{80}$	1490.0	1090.0	1745.0	1390.0	1428.8
Mo0.50Po	1090.0	725.00	1120.0	770.0	926.3
$Mo0.50P_{20}$	1125.0	1175.0	1330.0	1240.0	1217.5
$Mo0.50P_{40}$	1860.0	1505.0	2150.0	1745.0	1815.0
$Mo0.50P_{80}$	1470.0	1250.0	1675.0	1320.0	1428.8
Mean	1207.9	1013.7	1376.3	1163.3	

(ANOVA See Appendix 21)

LSD ($P \leq 0.05$):

Treatment	=	53.16
Cowpea variety	=	21.70
Treatment * variety	=	75.18

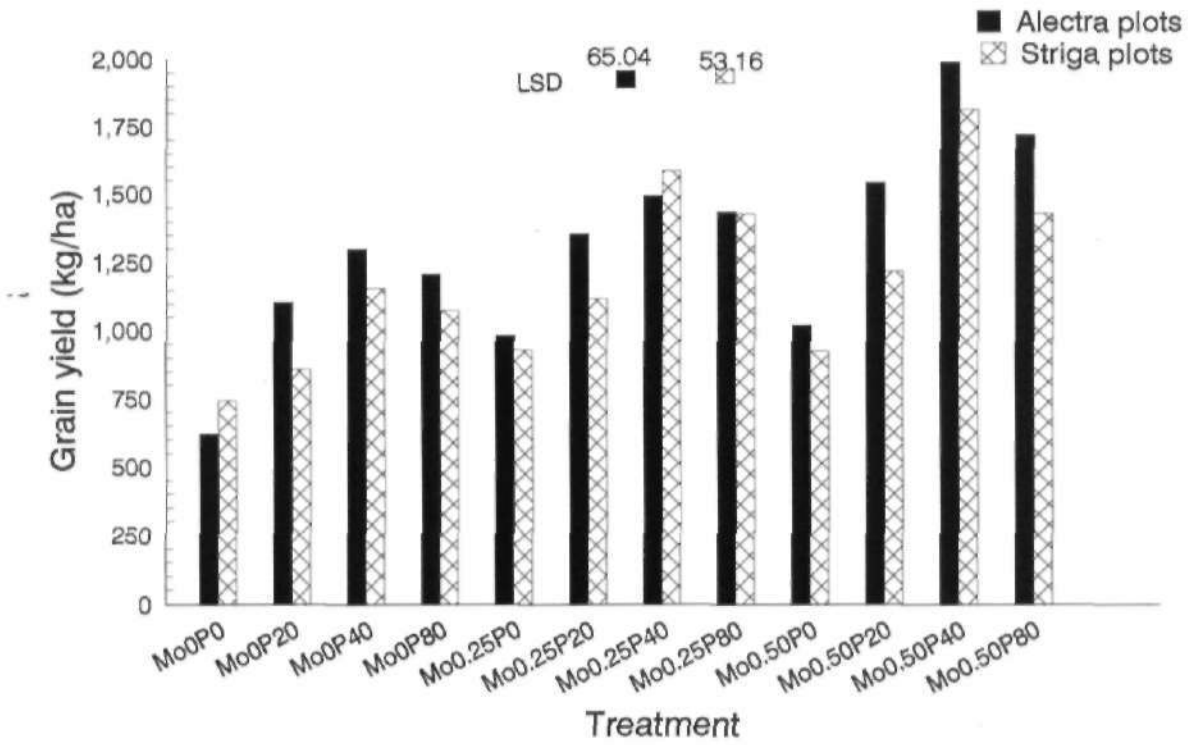


Figure 17: Phosphorus and molybdenum effects on cowpea grain yields at Samaru (averaged over two years).

4.2.10. Effect of phosphorus and molybdenum on cowpea nodulation and nitrogen fixation

In both 1995 and 1996, phosphorus fertilization significantly ($P \leq .05$) increased nodulation at 50% podding stage compared to the control that did not receive P fertilization in either *Striga* or *Alectra* infested plots (Table 14 (a-d). The result of the pooled data analysis shown in figure 18(a&b) gave similar trend. Application of Mo alone resulted in increase in nodulation in both years compared to control. In general, increasing levels of Mo at the same P level did not significantly affect nodulation (Table 14 (a-d) and Figure 18 (a&b). In both years, too, *Alectra* infested plants tended to have higher nodule number and dry weight compared to *Striga* infected plots (Table 14 (a-d) and figure 18 (a&b). These results show that 40kgPha^{-1} produced the highest nodulation suggesting that this level is probably the optimum level of P required for nodulation by these cowpea varieties under Samaru conditions.

Application of P was found also to increase nitrogen fixation in cowpea (Tables 15(a&b), Figure 19). The application of 40kgPha^{-1} resulted in significantly higher nitrogen fixation than the control, it was then followed by 80 and then 20 kgPha^{-1} (Table 15(a&b) and Figure 19). These results also suggest that 40kgPha^{-1} is probably the optimum level of P required for both nodulation and nitrogen fixation by the cowpea varieties under Samaru conditions.

Molybdenum application alone had no significant effect on nitrogen fixation (Table 15 (a&b) and figure 19). Cowpea needs phosphorus for vigorus growth and nitrogen fixation (Sanginga *et al.*, 1988, 1989; Sanginga, 1992; Benge, 1982); root

growth, initiation of nodules, nodule growth, duration of nodulation and the general efficiency of the *Bradyrhzobium* - Legume symbiosis (Franco 1977; Freire, 1977). Moreover, nodules form a strong sink for P (Graham and Rosas, 1979; Wan Othman *et al.*, 1991) while Mo is required for nitrogenase activity and maximum efficiency of nitrogen fixation by *Rhizobium* (Andrew 1978; Sanginga *et al.*, 1988). However, Mo had no effect on nitrogen fixation in this study, but the application of Mo to P (interaction) suggested that for growth all plants were entirely dependent on nitrogen fixation, but those with higher nodule activity had better growth rates, nodulations and nitrogen fixation than control. These results therefore suggest that, P and Mo treatments may serve as a prophylatic measure that helps the crop physiologically by increasing its vigour and enabling it withstand the *Striga* and *Alectra* infection.

KASHIM IBRAHIM LIBRARY

Table 14a. Effect of phosphorus and molybdenum on nodule number of cowpea planted on *Alectra* infested plots at Samaru in 1995 and 1996

Treatment	Nodule number/plant				
	Alectra Infested plots				
	1995		1996		
	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean
Control (MoOPO)	35.50	59.50	58.00	63.50	54.12
$MoOP_{20}$	55.50	68.50	63.00	76.50	65.88
$MoOP_{40}$	56.50	78.00	65.50	85.50	71.38
$MoOP_{80}$	62.50	71.50	69.00	77.00	70.00
Mo0.25Po	48.50	61.50	59.00	67.50	59.12
$Mo0.25P_{20}$	62.50	65.50	66.50	78.50	68.25
$Mo0.25P_{40}$	67.50	79.00	76.00	90.00	78.13
$MoO.25P_{80}$	59.50	69.00	72.00	81.50	70.50
Mo0.50Po	47.50	59.50	61.00	69.00	59.25
$Mo0.50P_{20}$	61.00	66.50	66.00	80.00	68.38
$Mo0.50P_{40}$	66.50	86.50	77.00	87.50	79.38
$Mo0.50P_{80}$	61.00	74.50	68.00	79.00	70.63
Mean	57.00	69.96	66.75	77.96	

ANOVA (See Appendix 22)

LSD ($P \leq 0.05$):

Treatment	=	2.1
Cowpea variety	=	0.86
Treatment * variety	=	2.97

Table 14b. Effect of phosphorus and molybdenum on nodule dry weight of cowpea planted on *Alectra* infested plots at Samaru in 1995 and 1996

Treatment	Nodule dry weight (mg/Plant)				
	Alectra Infested Plots				
	1995		1996		
	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean
Control (MoOPO)	114.00	124.00	125.00	126.50	122.38
$MoOP_{20}$	132.50	135.50	135.50	147.00	137.63
$MoOP_{40}$	132.50	143.00	137.00	150.50	140.75
$MoOP_{80}$	135.00	138.50	138.50	147.00	139.75
Mo0.25Po	119.50	124.00	125.50	129.00	124.50
$Mo0.25P_{20}$	135.50	135.50	136.50	148.00	138.88
$Mo0.25P_{40}$	136.50	147.00	141.50	153.00	144.50
$MoO.25P_{80}$	134.00	136.50	139.50	149.00	139.75
Mo0.50Po	119.00	124.00	126.00	130.00	124.75
$Mo0.50P_{20}$	134.00	135.50	136.50	148.50	138.63
$Mo0.50P_{40}$	136.50	150.00	142.00	152.00	145.13
$Mo0.50P_{80}$	134.50	141.00	138.00	148.50	140.50
Mean	130.29	136.21	135.13	144.08	

ANOVA (See Appendix 24)

LSD ($P \leq 0.05$):

Treatment	=	0.91
Cowpea variety	=	0.37
Treatment * variety	=	1.29

Table 14c. Effect of phosphorus and molybdenum on nodule number of cowpea planted on *Striga* infested plots at Samaru in 1995 and 1996

	Nodule number/plant				
	Striga Infested Plots				
	1995		1996		
	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean
Control (MoOPO)	20.00	45.50	33.00	50.50	37.25
$MoOP_{20}$	45.50	59.00	48.50	61.00	53.50
$MoOP_{40}$	55.00	67.50	58.50	73.00	63.50
$MoOP_{80}$	45.50	65.50	53.00	70.50	58.63
Mo0.25Po	41.00	54.50	39.50	59.00	48.50
$Mo0.25P_{20}$	46.50	61.00	47.50	63.00	54.50
$Mo0.25P_{40}$	51.00	72.50	57.00	81.00	65.38
$MoO.25P_{80}$	48.50	67.00	51.00	76.00	60.63
Mo0.50Po	44.50	51.50	48.00	61.00	51.25
$Mo0.50P_{20}$	49.00	61.00	51.00	71.50	58.13
$Mo0.50P_{40}$	59.00	74.00	63.00	82.00	69.50
$Mo0.50P_{80}$	51.50	69.00	55.00	77.50	63.25
Mean	46.42	62.33	50.42	68.83	

ANOVA (See Appendix 23)

LSD ($P \leq 0.05$):

Treatment	=	1.84
Cowpea variety	=	0.75
Treatment * variety	=	2.60

Table 14d. Effect of phosphorus and molybdenum on nodule dry weight of cowpea planted on *Striga* infested plots at Samaru in 1995 and 1996

Treatment	Nodule dry weight (mg/plant)				
	Striga Infested Plots				
	1995		1996		
	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean
Control (MoOPO)	109.00	119.00	109.50	119.50	114.25
$MoOP_{20}$	127.00	133.50	128.00	134.50	130.75
$MoOP_{40}$	130.00	138.00	131.00	139.50	134.63
$MoOP_{80}$	128.00	136.00	130.00	138.50	133.13
Mo0.25Po	118.50	121.50	118.00	129.50	121.88
$Mo0.25P_{20}$	127.00	134.00	128.00	135.00	131.00
$Mo0.25P_{40}$	131.50	140.50	132.50	143.50	137.00
$MoO.25P_{80}$	129.00	136.50	129.50	140.50	133.88
Mo0.50Po	119.50	121.00	122.00	130.00	123.13
$Mo0.50P_{20}$	128.00	132.00	129.50	140.00	132.38
$Mo0.50P_{40}$	133.50	140.50	134.50	143.00	137.88
$Mo0.50P_{80}$	129.50	138.00	130.00	141.00	134.63
Mean	125.88	132.54	126.88	136.21	

ANOVA (See Appendix 25)

LSD ($P \leq 0.05$):

Treatment	=	0.54
Cowpea variety	=	0.22
Treatment * variety	=	0.76

Table 15a. Effect of phosphorus and molybdenum on nitrogen fixation of cowpea at 50% podding planted on *Alectr*a infested plots using the root bleeding sap method at Samaru in 1995 and 1996.

Treatment	% Ndfa				
	Alectra Infested Plots				
	1995		1996		
	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean
Control (MoOPO)	46.10	43.75	48.44	45.76	46.01
$MoOP_{20}$	46.44	47.78	49.45	48.78	48.11
$MoOP_{40}$	51.13	53.15	54.82	55.16	53.56
$MoOP_{80}$	48.78	49.79	52.81	51.13	50.63
Mo0.25Po	45.42	46.44	46.44	47.10	46.35
$Mo0.25P_{20}$	49.12	48.11	50.80	51.13	49.79
$Mo0.25P_{40}$	55.30	54.15	55.83	56.50	55.44
$MoO.25P_{80}$	51.47	49.12	53.30	53.15	51.76
Mo0.50Po	45.76	43.08	46.77	45.76	45.34
$Mo0.50P_{20}$	49.78	49.12	51.13	51.13	50.29
$Mo0.50P_{40}$	55.15	55.16	55.83	57.17	55.83
$Mo0.50P_{80}$	50.45	49.79	53.30	53.48	51.75
Mean	49.58	49.12	51.57	51.35	

ANOVA (See Appendix 26)

LSD ($P \leq 0.05$):

Treatment	=	1.30
Cowpea variety	=	0.53
Treatment * variety	=	1.84

Table 15b. Effect of phosphorus and molybdenum on nitrogen fixation of cowpea at 50% podding planted on *Striga* infested plots using the root bleeding sap method at Samaru in 1995 and 1996.

	% Ndfa				
	Striga Infested Plots				
	1995		1996		
	SAM-PEA-7	B301	SAM-PEA-7	B301	Mean
Control (MoOPO)	43.41	43.75	45.43	42.07	43.50
$MoOP_{20}$	44.08	46.10	48.78	46.43	46.18
$MoOP_{40}$	49.12	49.78	55.16	51.47	50.29
$MoOP_{80}$	46.77	48.10	51.13	47.78	47.94
Mo0.25Po	44.42	43.41	47.10	46.09	45.26
$Mo0.25P_{20}$	47.78	47.44	51.13	49.79	48.78
$Mo0.25P_{40}$	52.81	52.48	56.50	54.82	53.82
$MoO.25P_{80}$	48.78	49.11	53.15	49.78	49.53
Mo0.50Po	43.76	45.43	45.76	47.44	46.19
$Mo0.50P_{20}$	48.78	46.10	51.13	48.44	48.36
$Mo0.50P_{40}$	53.15	52.81	53.48	55.49	54.32
$Mo0.50P_{80}$	51.47	48.78	51.81	50.79	50.71
Mean	47.86	47.72	50.18	49.20	

ANOVA (See Appendix 27)

LSD ($P \leq 0.05$):

Treatment	=	1.17
Cowpea variety	=	0.48
Treatment * variety	=	1.66

KASHIM IBRAHIM LIBRARY
RECEIVED
20 JUN
ZARIA NIGERIA
472100

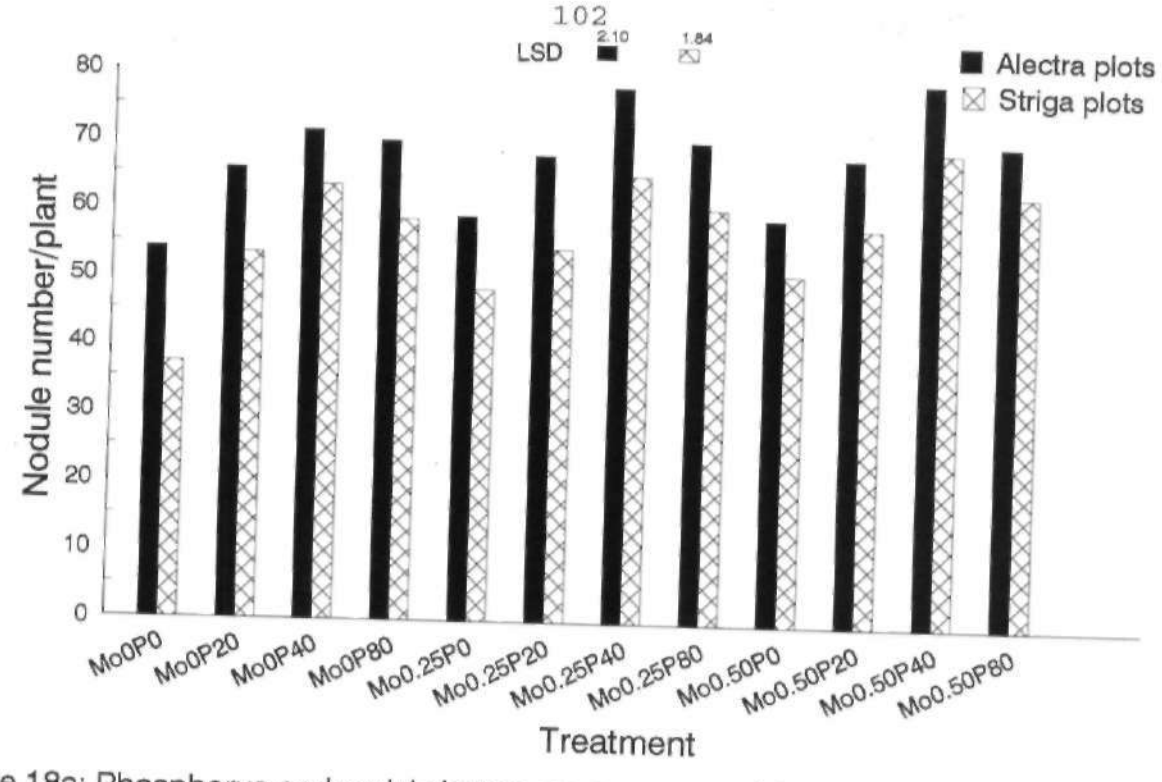


Figure 18a: Phosphorus and molybdenum on cowpea nodule numbers at Samaru (averaged over two years).

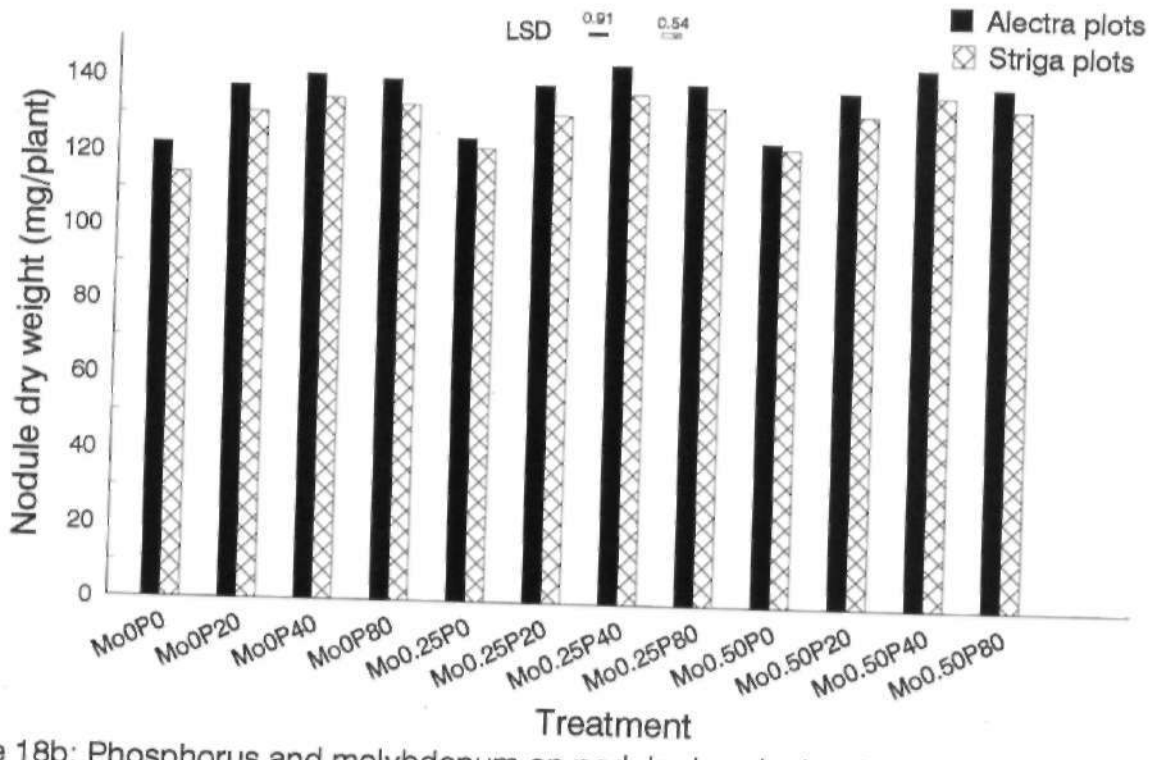


Figure 18b: Phosphorus and molybdenum on nodule dry wieght of cowpea at Samaru (averaged over two years).

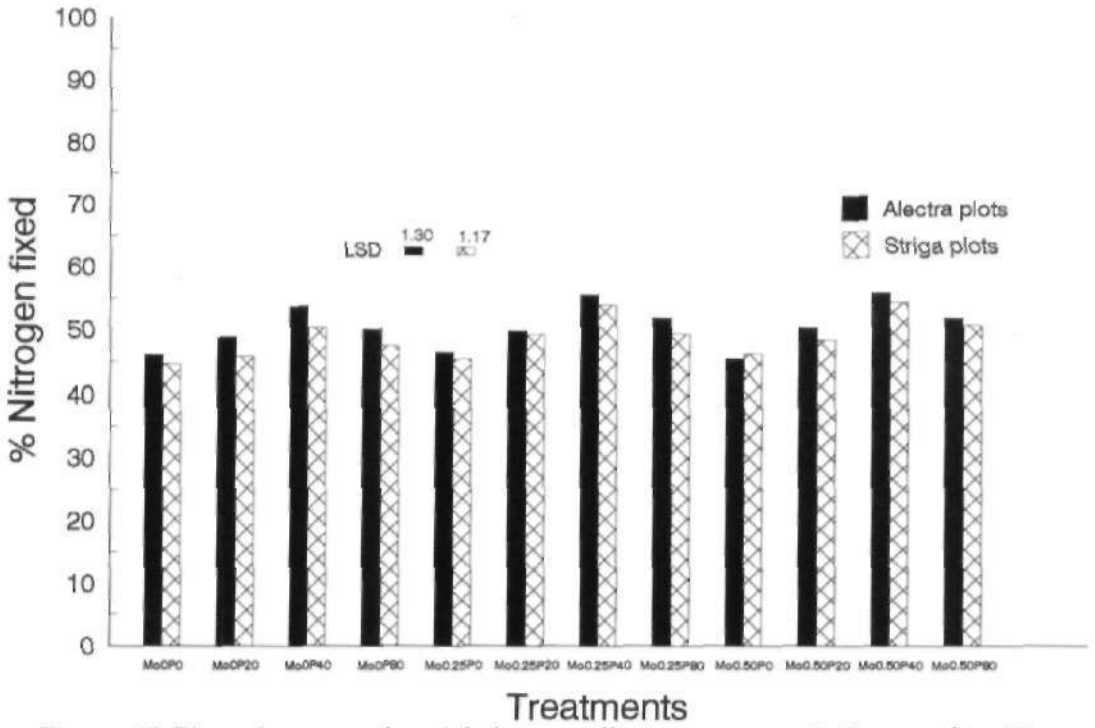


Figure 19: Phosphorus and molybdenum effects on percent nitrogen fixed by cowpea at 50 % podding using root bleeding sap method at Samaru (averaged over two years).

CHAPTER FIVE

SUMMARY AND CONCLUSION

Cowpea has been of relative importance and grown extensively in the northern Guinea savanna zone of Nigeria and presently inoculation is not practised by farmers. Cowpea varieties susceptible to *Striga* and *Alectra* were found to benefit from *Bradyrhizobium* inoculation. This study also has shown that in order to derive some benefit from biological nitrogen fixation (BNF) and hence to maximize cowpea productivity in this soil, it is necessary to inoculate with *Bradyrhizobium* strain IRc 506c.

It has been observed that urea fertilizer suppressed the attack of *Striga* and *Alectra* while improving crop yield. From this study, the application of urea to *Striga* and *Alectra* infested fields, reduced the severity of their attack, even after emergence, thus improving total dry matter, nodulation, nitrogen fixation and crop yield.

The inhibition of *Striga* and *Alectra* by urea was not suprising as it is known that urea is converted to ammonium ion in most higher plant cells before assimilation (Beevers, 1976). This probably explains the effect of urea on these parasitic flowering plants. Hence, the possible use of urea to control *Striga* and *Alectra* infestation of crops is suggested depending on the economic implications of the practice.

From the work done so far on the P and Mo experiment in this study, P, had positive effect on cowpea dry matter, grain yield, nodulation and nitrogen fixation, while Mo had positive effect on dry matter, grain yield, nodulation and little or no effect on nitrogen fixation. The combined application of Mo and P suggested that for growth all plants were entirely dependent on nitrogen fixation, but those with

higher nodule activity had better growth rates, total dry matter, grain yields, nodulation and nitrogen fixation than control. These results suggest that, although P and Mo treatments reduced the incidence of *Striga* and *Alectra* attack, they also served as a prophylactic measure that helps the crop physiologically by increasing its vigour and enabling it withstand the *Striga* and *Alectra* infection. The present study has not provided adequate explanation of the mechanism of suppression of growth of these parasitic flowering plants in the presence of P and probably Mo. But the work shows that the effects of these parasitic flowering plants could be reduced by the application of P and Mo to soils used for growing cowpea.

In conclusion, it is therefore hoped that these contributions would improve confidence in *Bradyrhizobium* inoculation, urea, P and Mo fertilizer use and also help in designing control packages for *Striga* and *Alectra* in the field especially when using the phosphatic and nitrogenous fertilizer regimes.

RECOMMENDATION FOR FUTURE WORK

Future work should investigate the practical details of controlling cowpea parasitic flowering plants with the application of nutrients (Urea, P and Mo) both on-station and on-farm paying special attention to the benefit cost analysis of the recommended practices. Also the results of the work on *Bradyrhizobium* strains obtained in the greenhouse should be validated under field conditions.

REFERENCES

Adu, J.K., Leleji, O. and Emechebe, A.M. (1989). Nitrogen fertilizer effects on *Striga* attack of cowpea in Northern Nigeria. Paper presented at the maize and cowpea joint Workshop of SAFRAD at Lome, Togo, March 20 - 24.

Adu, J.K. and Emechebe, A.M. (1991). Parasitic weed infection of cowpea as influenced by nitrogen sources. A report submitted to Legumes and Oilseeds Programme, cropping scheme (1991), Institute for Agricultural Research (IAR), Ahmadu Bello University, Zaria, Nigeria, pp. 106-108.

Adu, J.K.; Leleji, O.I.; Singh, B.B. and Atokple I.D.K. (1991). Cowpea *Striga* problems and research in Nigeria. In: Kim, S.K. (ed.) combating *Striga* in Africa. International Institute of Tropical Agriculture, Ibadan, Nigeria, pp. 18-28.

Adu-Gyamfi, J.J., Fujita, K., and Ogata, S. (1989). Phosphorus absorption and utilisation efficiency of pigeon pea (Cajanus cajan L. Mill sp) in relation to dry matter production and nitrogen fixation. Plant and Soil 119, 315-324.

Agbenin, J.O., Lombin, G. and Owonubi, J. (1990). Effect of boron and nitrogen fertilization on cowpea nodulation, mineral nutrition and grain yield. Fertilizer Research Vol. 22:71-78.

Agbobli, C.A. (1991). Striga gesnerioides - a new threat to cowpea culture in southern Togo. Pages 26-27 in Proceedings, 5th International Symposium on Parasitic Weeds. 24-30 June, 1991, Nairobi, enya, edited by J.K. Ransom, L.J., Musselman, A.D. Worsham, and C. Parker. The International Maize and Wheat Improvement enter (CIMMYT), Mexico, D.F. Mexico.

Aggarwal, M.D. (1985). Cowpea Striga Research. In: S.R. Singh and K.O. Rachie (Eds) Cowpea Research Produciton and Utilization. John Wiley and Sons, Pp. 335-340.

Aggarwal V.D. (1991). Research on Cowpea-*Striga* Resistance at IITA. In: Kim S.K. (ed) Combating *Striga* in Africa. Poceedings of the International Workshop organised by IITA, ICRISAT and IDRC. August 22-24, 1988. IITA, Ibadan, Nigeria, pp. 90 - 95.

Aggarwal, V.D. and Ouedraogo, J.T. (1989). Estimation of cowpea yield loss from Striga infestation. Trop. Agric. 66: 91-92.

Alexander, M. (1977). Introduction to soil microbiology. John Wiley Publ. New York.

Allen, O.N. and Allen, E.K. (1981). The Leguminosae. A source book of characteristics, uses and nodulation. Macmillan, London.

Allen, D.J.; Thottapphilly, G.; Emechebe, A.M. and Singh B.B. (1998). Diseases of Cowpea pg 267-324, In, Allen D.J. and Lenni J.M. (eds). The Pathology of food and pasture legumes. CAB International in association with ICRISAT.

Allison, F.E. and Ludwig, C.A. (1934). The cause of decreased nodule formation on legumes supplied with abundant combined nitrogen. J. Soil Sci. 37, 431-443.

Aliyu, I.Y. (1988). The effect of watering regime and inoculum density on the incidence of infection in cowpea. A thesis submitted to the Department of Crop Protection, Faculty of Agriculture, Ahmadu Bello University, Zaria.

Andrew, C.S. (1978). Mineral characterisation of tropical forage legumes. In: Mineral nutrition of legumes in Tropical and Sub-tropical soils. Eds. C.S. Andrew and E.G. Kamprath Pp. 93-111. CSIRO, Australia.

Atokple, I.D.K., Singh, B.B. and Emechebe, A.M. (1991). Yield loss in cowpea due to Striga infection. Paper presented at the 19th annual conference of Weed Science Society of Nigeria held at IAR/ABU, Zaria, December 1-5, 1990.

Atokple, I.D.K.; Singh, B.B. and Emechebe, A.M. (1992). Independent inheritance of *Striga* and *Alectra* resistance in cowpea genotype B 301. Crop Science 33, 714-715.

Ba, A.T. (1984). Morphology, anatomy and ultrastructure of some parasitic species of the genus Striga (Scrophulariaceae). Pages 47 - 61 in *Striga gesnerioides* biology and control, edited by E.S. Ayensu, H. Doggett, R.D. Keynes, J. Marton-Lefevre, L.J. Musselman, C. Parker, and A. Pickering. ICSU Press and the International Development Research Centre, Paris, France.

Bagnall-Oakeley, H., Gibberd, V. and Nyongesa, T.E. (1991). The incidence and control of *Alectra vogelii* in Embu District, Kenya. Pages 340-345 in Ransom J.K., Musselman L.J., Worsham A.D., and Parker C. (eds). Proceedings of the 5th International Sympotium of Parasitic Weeds. Nairobi: CIMMYT.

Bebawi, F.F.; Khalid, S.A. and Musselman, L.J. (1991). Effects of urea nitrogen on stimulant activity of sorghum and germination capacity of *Striga*. Pp. 458-461. Proceedings in Ransom J.K., Musselman L.J., Worsham A.D., and Parker C. (eds). Proceedings of the 5th International Sympotium of Parasitic Weeds. Nairobi: CIMMYT

Becker, M., Dickmann, K.H., Ladha, J.K., DeDatta, S.K. and Ottow, J.C.G. (1991). Effect of NPK on growth and nitrogen fixation of *Sesbania rostrata* as green manure for lowland rice (*Oryza sativa* L.). Plant and Soil 132(1) 149.

Beevers, L. (1976). Nitrogen metabolism in plants. Edward Arnold (Publishers) Ltd., London, 333pp.

Benge, M.D. (1982). The miracle tree: Reality or myth? In Leucaena Research in the Asian-Pacific Region, IDRC pp 95 - 98. Ottawa, Ontario, Canada.

Bergersen, F.J. (1971). Biochemistry of symbiotic nitrogen fixation in Legumes. Ann. Rev. Pl. Physiol., 22, 121-39.

Berner, D.K., Awad, A.E., and Aigbokhan, E.I. (1994a). Potential of imazaquin seed treatment for control of *Striga gesnerioides* and *Alectra vogelii* in cowpea (Vigna unguiculata). Plant Disease 78: 18-23.

Berner, D.K., Cardwell, K.F., Faturoti, B.O., Ikie, F.O., and Williams, O.A. (1994b). Relative roles of wind, crop seeds, and cattle in dispersal of Striga spp. Plant Disease 78: 402-406.

Bray, R.H. and Kurtz, L.T. (1945). Determination of Total, Organic and available forms of phosphorus in soils. J. Soil Sci. 59, 39-45.

Bremner, J.M., and Mulvaney, C.S. (1982). Nitrogen total. In: Methods of soil analysis (A.L. page, ed.). Part II, Agronomy 9, pp. 595-624. Amer. Soc. of Agronomy, Inc. Madison, Wisconsin.

Bussler, W. (1970). Symptoms of Molybdenum deficiency and their development 2. Pflernatrs Bodenk, 125: 50-64 (EE Tech Univ Berlin).

Carson, A.G. (1988). Weeds and their control in Ghana. In Akobundv, I.O. (ed) Weeds and their control in the humid and subhumid Tropics, Ibadan, Nigeria, IITA, Proceedings Series 3, 150-158.

Chukwuezi, B.N. (1986). Interaction between cowpea lines and *Alectra vogelii* under screenhouse conditions. A thesis submitted to the College of Agriculture, Crop Protection Department, Division of Agricultural Colleges, Ahmadu Bello University, Zaria.

Dart, P.J. (1974). Development of root-nodule symbiosis. 1. The infection process. In: The Biology of Nitrogen Fixation eds). A. Quispel. Pp. 382-429. North Bolland, Amsterdam.

Dart, P.J. and Mercer, F.V. (1975). The effect of growth, temperature, level of ammonium nitrate and light intensity on the growth and nodulation of cowpea (Vigna sinensis). Aust. J. Agric. Res. 16, 321-345.

Day, P.R. (1965). Particle Fractionation and particle size analysis p. 545-566. In C.A. Black (ed). Methods of Soil Analysis Part 1. Agronomy Monograph No. 9, American Society of Agronomy, Madison, Wisconsin.

Dazzo, F.B. and Drill, W.J. (1978). Regulation of fixed nitrogen by host symbiont recognition in the Rhizobium clover symbiosis. Plant Physiol. 62, 18-21.

Dazzo, F.B., Hollingworth, R.I., Sherwood, J.E., Abe, M., Hrabak, E.M., Gardiol, E.E., Pankratz, H.S., Smith, K.B. and Yang, H. (1985). Recognition and infection of clover root hairs by Rhizobium trifolii. In: Nitrogen fixation Research Progress. Proc. 6th Interntl. Symp. Nitrogen fixation, Corvallis, OR 97331, August 4-10, 1985. Eds: H.J. Evans, P.J. bottomley and W.E. Newton, Pp. 239-245. Martinus Nijhoff Publishers, Dordrecht, the Netherlands.

Demory, C.Y. (1970). Molybdenum response to soyabean (Glycine max (L.) Merrill) in Iowa, Agronomy Journal 62, 195-197.

Dhingra, K.K., Sekhon, H.S., Sandhu, P.S., and Bhandari, S.C. (1988). Phosphorus-rhizobium interaction studies on biological nitrogen fixation and yield of lentils. J. Agric. Sci. Camb. 110, 141-144.

Dorr, I. (1995). Resistance in different parasitic systems. Page 26 in Final Report, International Workshop on Parasitic Plants: Biology and Resistance. IARCR-Long Ashton Research Station, Bristol, U.K. (Abstract).

Dorr, I., Visser, J.H., and Albers, F. (1977). On the parasitism of *Alectra vogelii* Benth. (Scrophulariaceae) II. Origin of lateral roots in the contact area of the haustorium. Zeitschrift for Pflanzenphysiologie 85: 349-359.

Dorr, I., Visser, J.H., and Kollmann, D. (1979). On the parasitism of *Alectra vogelii* Benth. (Scrophulariaceae). III. The occurrence of Pholem between host and parasitic. Seitschrift for Pflanzenphysiologie 94:427-439.

Eaglesham, A.R.J., Minchin, F.R., Summerfield, R.J., Dart, P.J., Juxley, P.A. and Day, J.M. (1977). Nutrition of cowpea (Vigna unguiculata). II. Distribution of nitrogen within effectively nodulated plants. Exp. Agric. 13, 365-390.

Elkan, G.H. (1992). Taxonomy of the rhizobia. Can. J. Microbiol. 38: 446-450.

Emechebe, A.M. (1981). cowpea pathology: notes on cowpea and grain legume improvement programme. Paper presented for a cropping scheme meeting, Institute for Agricultural Research, Samaru, Zaria, Nigeria.

Emechebe, A.M. (1986). Assessment of crop losses in cowpea caused by natural infection by *Alectra vogelii* at Samaru, pp. 33-34. In: Cropping scheme meeting, 1986; Legumes and Oilseeds Research Programme, IAR, Samaru, Zaria.

Emechebe, A.M., Leleji, O., and Salako, E.A. (1983). Control of roots-parasitic weeds in cowpea and groundnuts. Paper presented at IAR Symposium on Striga and its control, May 23, 1983.

Emechebe, A.M., Singh, B.B., Atokple, I.D.K., and Adu, J.K. (1988). The current status of cowpea *Striga* problem in Nigeria. Paper presented at the *Striga* Workshop at IITA, Ibadan, Nigeria, August 22-24.

Emechebe, A.M., Singh, B.B., Leleji, O., Atokple, I.D.K., and Adu, J.K. (1991). Cowpea-*Striga* problems and Research in Nigeria. In: Kim S.K. (Ed) Combating *Striga* in Africa. Proceedings of the international Workshop organised by IITA, ICRISAT and IDRC. August 22-24. IITA, Ibadan, Nigeria, pp. 18-28.

Emechebe, A.M., Lagoke, S.T.O., and Adu, J.K. (1991). Research towards integrated control of *Striga* in West and Central Africa. Paper presented at SAFGRAD Joint Maize, Cowpea, Sorghum and Millet Workshop, March 8-14.

Eplee, R.E. (1981). *Striga's* status as a plant parasite in the United States. Plant Disease Reporter 65: 951-954.

Eplee, R.E. and Norris, R.S. (1987). Chemical control of *Striga*. Chapter 12, in: Parasitic weeds in Agriculture Vol. 1. *Striga*, edited by L.J. Musselman, CRC Press, Boca Raton, USA.

Fist, A.J., Smith, F.W. and Edwards, D.G. (1987). External Phosphorus requirements of five tropical grain legumes grown in flowing solution culture. Plant and Soil 99, 73-84.

Franco, A.A. (1977). Nutritional restraints for tropical grain legume symbiosis. In Vincent, J.M.; Whitney, A.S. and Bose, J. (eds). Exploiting the Legume - *Rhizobium* symbiosis in Tropical Agriculture, pp. 237 - 274. Honolulu, Hawaii: University of Hawaii, College of Tropical Agriculture, Miscellaneous Publication 145.

Freire, J.R.J. (1977). Inoculation of soybeans. In Vincent, J.M.; Whitney, A.S. and bose, J. (eds). Exploiting the Legume - *Rhizobium* Symbiosis in Tropical Agriculture, pp. 335-379. Honolulu, Hawaii, University of Hawaii, College of Tropical Agriculture, Miscellaneous Publication, 145.

Graham, P.H. and Rosas J.C. (1979). Phosphorus fertilization and symbiotic nitrogen fixation in common beans. Agron. J. 71: 925-926.

Graves, J.D., Press, M.C. and Stewart, G.R. (1989). A carbon balance model of the sorghum-*Striga hermonthica* host-parasite association. Plant cell and Environment 12: 101-109.

Gupta, V.K., and Potalia, B.S. (1987). Effect of molybdenum and zinc on yield, Mo and Zn concentration in peanut. Journal of the Indian Society of Soil Science (India) 35(1), p. 82-84.

Goldsworthy, P.R. (1967). Responses of cereals to fertilizers in Northern Nigeria. Empire J. Expl. Agric. 31: 351-361.

Harpstead, M.I. (1973). The classification of some Nigeria soils. Soil Sci. 116:437-442.

Hart, A.L. (1989). Nodule phosphorus and nodule activity in white clover. N.Z.J. Agric. Res. 32, 145-149.

Hagstrom, G.R. and Berger, K.C. (1965). Molybdenum deficiencies of Wisconsin soils. Soil Sci. 99, 52-56.

Heathcote, R.G. (1972). Potassium fertilization in the savanna zone of Nigeria. Potash rev. subject. 16: Suite St pp. 10.

Heathcote, R.G. and Smithson, B. (1974). Boron deficiency in cotton in northern Nigeria 1. Factors affecting occurrence and methods of correction. Expt. Agric. 10: 199-208.

Hewitt, E.J.; Bolle-Jones, E.W. and Miles, P. (1954). The production of copper, zinc and molybdenum deficiencies in crop plants grown in sand culture with special reference to some effects of water supply and seed reserves. Plant and Soil 5, 205-222.

Humphreys, L.R. (1987). Tropical pastures and fodder crops. Pages viii - 135 in Intermediate Tropical Agriculture Series.

Hunter J.J. and Visser J.H. (1986). Nitrate reductase activity (NRA) oc cultivated schrophulariacean root parasites. S. Afr. J. Bot. Vol. 52: 246-248.

Igbinnosa, I. (1993). The effect of nitrogen fertilizers on host/parasite relationships between *Striga hermonthica* Benth. and *Zea mays*.

Igbinnosa, I., Cardwell, K.F., and Okonkwo, S.N.C. (1996). The effect of nitrogen on the growth and development of giant witchweed, *Striga hermonthica* Benth: effect on cultured germinated seedlings in host absence. European Journal of Plant Pathology Vol. 102: 77-86.

IITA (International Institute of Tropical Agriculture), 1982. Screening for resistance to *Striga gesnerioides*. Page 148 in Annual Report for 1981. IITA, Ibadan, Nigeria.

IITA (International Institute of Tropical Agriculture). 1983. *Striga gesnerioides* resistance. Page 69-70 in Annual Report for 1982. IITA, Ibadan, Nigeria.

Israel, D.W. (1987). Investigation of the role of phosphorus in symbiotic dinitrogen fixation. Plant Physiol. 84, 835-840.

Iwuafor, E.N.O. (1986). The effect of tillage and residue managements practices on soil properties and crop performance in the Southern Guinea Savanna Zone of Nigeria. Unpublished Ph.D Thesis, Ahmadu Bello University, Zaria, 254 pp.

Jones, M.J. (1973). The organic matter content of Savanna Soils of West Africa. J. Soil Sci. 24, 42-53.

Jones, M.J. and Wild, A. (1975). Soils of the West African Savanna. Tech. Comm. No. 55. Comm. Wealth Bureau of Soils Harpenden, England, 246pp.

Jordan, D.C. (1982). Transfer of Rhizobium japonicum Buchana 1980 to Brahyrhizobium gen. nov., a genus of slow-growing root nodule bacterial from leguminous plants. Int. J. Syst. Bacteriol. 32: 136-39.

Juo, A.S.R. (1979). Selected methods for soil and plant analysis. IITA Manual Series No. 1. Ibadan, Nigeria.

Kang, B.T. (1975). Effect of inoculation and nitrogen fertilizer on soybean in western Nigeria. Exp. Agric. 11, 23-31.

Klinkenberg, K. and G.M. Higgins (1968). An outline of northern Nigeria Soils Nig. J. Sci. 2: 91-111.

Kroschel J. (1989). Der einfluss von stickstoff auf phanerogame wurzelparasiten und ihre wirtspflanzen unter besonderer beriicksichtigung von *Striga hermonthica* (Del.) Benth. (Schrophulariaceae). Plits 7(3): 1-154.

Kuijt. J. (1969). The biology of parasitic flowering plants. University of California Press, Berkeley, CA USA, 346pp.

Kundsen, D., Peterson, G.A. and Prett, P.F. (1982). Lithium, Sodium and potassium. In Methods of Soil analysis (A.L. Page ed.).

Lagoke, S.T.O. (1989). *Striga* in Nigeria. In: T.O. Robson and H.R. Broad (Eds). *Striga*-Improved management in Africa. Proceedings of the FAO/OAU. All African Govt. Consultation and Striga control. Maroua, Cameroon, October 20-24, 1988.

Lagoke, S.T.O.; Parkinson, V., and Agunbiade, R.M. (1991). Parasitic weeds and control methods in Africa. In: Kim, S.K. (ed.) Combating *Striga* in Africa. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, pp. 3-14.

Lagoke, S.T.O., Shebayan, J.Y., Weber, G., Olufajo, O., Elemo, K., Adu, J.K., Emechebe, A.M., Singh, B.B., Zaria, A., Awad, A., Ngawa, L., Olaniyan, G.O., Olafare, S.O., and Adeoti, A.A. (1994). Survey of Striga problems and evaluation of Striga control methods and packages in crops in the Nigerian savanna. Pages 91-120 in Improving Striga Management in Africa. Proceedings, 2nd General Workshop on Pan-African Striga Control Network (PASCON), edited by S.T.O. Lagoke, R. Hoevers, S.S. M'boob and R. Trabouisis, 23-29 June, 1991, Nairobi, Kenya, FAO/PASCON, Accra, Ghana.

Lane, J.A., Bailey, J.A., and Terry, P.J. (1991). An in vitro growth system for studying the parasitism of cowpea (*Vigna unguiculata*) by *Striga gesnerioides*. Weed Research 31: 211-217.

Lane, J.A., Bailey, J.A., Butler, R.C. and Terry, P.J. (1993). Resistance of cowpea (*Vigna unguiculata*) (L.) Walp) to *Striga gesnerioides* (Willd.) Vatke, a parasitic angrosperm. New Phytologist 125, 405-412.

Lane, J.A., Moore, T.H.M., Child, D.V., Cardwell, K.F., Singh, B.B., and Bailey, J.A. (1994). Virulence characterisitcs of a new race of the parasitic angiosperm Striga gesnerioides from southern Benin on cowpea. Euphytica 72(3): 183-188.

Lane, J.A., Moore, T.H.M., Child, D.V. and Cardwell, K.F. (1996). Characterization of Virulence and geographic distribution of *Striga gesnerioides* on cowpea in West Africa. Plant Disease (in press).

Lie, T.A. (1974). Environmental effects on nodulaiton and symbiotic nitrogen fixation. In: The Biology of Nitrogen fixation. (Eds) A. Quispel. pp. 555-583. North Holland Publishing Company, Amsterdam.

Lombin, L.G., Adepetu, J.A. and Ayotade, K.A. (1991). Complementary use of organic manures and inorganic fertilizers in arable crop production. Paper presented at the organic fertilizer seminar held at Durbar Hotel, Kaduna, March 6-8, 1991.

Loneragan, J.F. and Arnon, D.I. (1954). Molybdenum in the growth and metabolism of Cholerlla. Nature 174, 427 and 459.

Magani, E.I., Lagoke, S.T.O., Emechebe, A.M., Singh B.B., and Adu, J.K. (1991). A report submitted to Legumes and Oilseeds Programme, cropping scheme, Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria, pp. 53-56.

McNally S.F. and Stewart G.R. (1987). Inorganic nitrogen assimilation by parasitic angiosperm. In: Weber H.C. and Forstreuter W. (eds). Proceedings of the Fourth International Symposium on Flowering Parasitic Plants (pp. 539-546). Marburg, Germany.

Mengel, K. and Kirkby, E.A. (1979). Principles of plant nutrition.

Minchin, F.R., Summerfield, R.J. and Neves, M.C.P. (1981). Nitrogen nutrition of cowpea (Vigna unguiculata): Effects of timing of inorganic nitrogen applications on nodulation, plant growth and seed yield. Trop. Agric. (Trinidad), 58, 1-12.

Moberg, J.P. and Esu, I.E. (1989). Characteristics and composition of soils in Northern Nigeria. Report submitted to the Institute for Agricultural Research, A.B.U., Zaria.

Mohammad, I., Tariq, M. and Kavser, A.M. (1989). The response of field-grown chickpea (Cicer arietinum L.) to phosphorus fertilization for yield and nitrogen fixation. Plant and Soil 114 (1), 135-138.

Mugabe, N.R. (1983). Effect of Alectra vogelii Benth. On cowpea (Vigna unguiculata (L.) Walp). I. Some aspects of reproduction to cowpea. Zimbabwe Journal of Agricultural Research 21: 135-147.

Munns, D.N. (1977). Mineral nutrition and the legume symbiosis. In: A Treatise on Dinitrogen fixation. Section IV. Agronomy and Ecology. Eds. R.W.F. Hardy and A.H. Gibson. John Wiley and Sons, New York.

Musselman, L.J., Baarathalakshmi, S.B., Safa, D.A., Knepper, K.I., Mohammed and White, C.L. (1991). Recent research on the biology of Striga astatica, S. gesnerioides and S. hermonthica. Pages 31-41 in combating Striga in Africa, edited by S.K. Kim, IITA, Ibadan, Nigeria.

Nayak, B.K., Mishra, S.N. and Dixit, L. (1989). Response of soyabean to molybdenum and fertilizer level. Indian Journal of Agronomy 34(4), 454-455.

Nutman, P.S. (1965). In soil Nitrogen (eds.) W.V. Bartholomew, and F.E. Clark, Agronomy No. 10, Amer. Soc. of Agron., Wisconsin, pp. 360-383.

O'Hara, G.W., Boonkerd, N. and Dilworth, M.J. (1988). Mineral constraints to nitrogen fixation. Plant and Soil 108(1): 93-110.

Okonkwo, S.N.C. (1991). The germination of Striga - a review. Pages 144-154 in Proceedings, 5th International Symposium of Parasitic Weeds, 24-30 June, 1991. Nairobi, Kenya, edited by J.K. Ransom, L.J. Musselman, A.D. Worsham, and C. Paker. The International Maize and Wheat Improvement Center (CIMMYT), Mexico, D.F. Mexico.

Okonkwo, S.N.C. and Nwoke, F.I.O. (1978). Initiation, development and structure of the primary haustorium in Striga gesnerioides (Scrophulariaceae). Annals of Botany 42: 455-463.

Okonkwo, S.N.C. and Nwoke, F.I.O. (1978). Structure and development of primary haustorium in Alectra vogelii Benth. (Scrophulaniaceae). Annals of Botany 42, 447-454.

Pal, U.R., Olufajo, O.O., Nnadi, L.A. and Singh, L. (1989). Response of soyabean to phosphorus, potassium and molybdenum application. Journal of Agric. Sci. Comb. 112, 131-136.

Parker, C. and Polniaszek, T.I. (1990). Parasitism of cowpea by Striga gesnerioides: variation in virulence and discovery of new source of host resistance. Annals of Applied Biology 116: 305-311.

Parker, C. and Riches, C.R. (1993). Parasitic weeds of the world: biology and control. CAB International. Wallingford, Oxon, UK.

Park, K.Y., OH, S.K., Jenoy, B.C., Pho, S.P., Choi, W.Y., and Hong, E.H. (1987). Effect of molybdenum and nitrogen application on nodulation and dry matter production in soyabean. Research Reports on the rural development admin. crops, Korea Republic 29 (L) 140-145.

Peoples, M.B., Faizan, A.W., Rerkasem, B. and Herridge, D.F. (1989). Methods for evaluating nitrogen fixation by nodulated legumes in field. ACIAR Monograph No. 11 ACJAR Canberro.

Pesch C. and Pieterse, A.H. (1982). Inhibition of germination in *Striga* by means of urea. Experimentia Vol. 38: 559-560.

Quin F.M. (1997). Introduction, pages ix - xv. Singh, B.B., Mohan Raj D.R., Dashiell K.E., and Jackai L.E.N. (eds). 1997. Advances in cowpea research. Copublication of International Institute of of Tropical Agriculture (IITA) and Japan International Research Center for Agricultural Sciences (JIRCAS). IITA, Ibadan, Nigeria.

Rachie, K.O. (1985). The nutritional role of grain legume in the lowland humid tropics. In: Ayanaba, A., and Dart, P.J. (eds), Biological nitrogen fixation in farming systems of the tropics, Chickester, UK, John Wiley and Sons, 45-60.

Raju, P.S.; Osman, M.A.; Soman, P. and Peacock, J.M. (1990). Effects of N, P and K on *Striga asiatica* (L.) Kuntze seed germination and infestation of sorghum. Weed Research 30: 139-144.

Rao, A.V., Sharma, R.L., and Dur, F.S. (1978). Effect of foliar application of Mo and Co on soyabean Rhizobium synthesis. Legume Research (1(2), 97-100.

Reid, D.C. and Parker, C. (1979). Germination requirements of Striga species. Pages 202-210 in Proceedings, 2nd International Symposium on Parasitic Weeds, edited by L.J. Musselman, A.D. Worsham and R.E. Eplee. North Carolina State University, Raleigh, NC, USA.

Reiss, G., Pring, R.J., Lane, J.A. and Bailey, J.A. (1995). *Striga gesnerioides*: mechanisms of infection and resistance. Aspects of Applied Biology 42, 301-306.

Riches, C.r. (1989). The biology and control of *Alectra vogelii* Benth. (Scrophulariaceae) in Botswana. Ph.D thesis, University of Reading, U.K. 208pp.

Robson, A.D. (1978). Mineral nutrients limiting nitrogen fixation in legumes. In: The Mineral Nutrition of Legumes in Tropical and Sub-tropical soils. Eds. C.S. Andrew and E.J. Kamprath, pp. 277-293. CSIRO Melbourne.

Salsac, L., Chaillou, S., Morot-Gaudry, J.F., Lesaint, C. and Jolivet, E. (1987). Nitrate and ammonium nutrition in Plants. Plant Physio. Biochem. Vol. 25: 805-812.

Sanginga, N. (1992). Early growth and N_2 fixation of *Leucaena leucocephala* and *Gliricidia sepium* at different levels of P application. Fertilizer Research Vol. 31: 165-173.

Sanginga, N. (1985). Nodulation of *Leucaena leucocephala* (Lam) De Wit and its contribution to nitrogen status of soils. Ph.D thesis. Faculté des sciences Agronomiques, Yangambi, Zaire.

Sanginga, N., Mulongoy, K., and Ayanaba, A. (1988a). Nodulation and growth of Leucaena leucocephala (Lam) de Wit as affected by inoculation and N fertilizer. Plant and soil 112(1), 129-135.

Sanginga, N., Mulongoy, K. and Ayanaba, A. (1988). Response of Leucaena/Rhizobium symbiosis to mineral nutrients in southwestern Nigeria. Plant and Soil, Vol. 112(1), 121-127.

Sanginga, N., Danso, S.K.A., Bowen, G.D. (1989). Nodulation and growth response of Allocasuarina and Casuarina species to phosphorus fertilization. Plant and Soil 118 (1-2): 125-132.

Sanginga, N., Danso, S.K.A., Zapata, F. and Bowen G.D. (1995). Phosphorus requirements and nitrogen accumulation by N_2 - fixing and non- N_2-fixing leguminous trees growing in low P soils.

Sauerborn, J. (1991). The economic importance of phytoparasites Orobanche and Striga. In: Ransom, J.K., Musselman L.J., Worsham, A.D. and Parker, C. (eds) Proceedings of the Fifth International Symposium on Parasitic Weeds, (oo. 137-143), CIMMYT, Nairobi.

Sillanpaa, M. (1982). Micronutrients and the nutrient status of soils: a global study. FAO Soils Bulletin 48.

Simier P., Fera and Renaudin S. (1993). Identification of the main osmotically active solutes in the unstressed and water-stressed root-hemiparasitic angiosperm *Thesium humile* and its host *Triticum* vulgare. Aust. J. Plant Physiol. Vol. 20: 223-230.

Singh, B.B., Chambliss, O.L. and Sharma, B. (1997). Recent Advances in cowpea breeding. Pages 30-49. Singh, B.B., Mohan Raj D.r., Dashiell K.E., and Jackai L.E.N. (eds). 1997. Advances in cowpea research. Copublication of International Institute of Tropical Agriculture (IITA) and Japan International Research Center for Agricltural Sciences (JIRCAS), IITA, Ibadan, Nigeria.

Singh, B.B. and Emechebe, A.M. (1990). Inheritance of *Striga* resistance in cowpea genotype B 301. Crop Science 30, 879-881.

Singh, B.B., and Emechebe, A.M. (1991). Breeding for resistance to Striga and Alectra in cowpea. Pages 303-305 in Proceedings, 5th International Symposium in Parasitic Weeds, 24-30 June, Nairobi, Kenya, edited by J.K. Ransom, L.J. Musselman, A.D. Worsham, and C. Parker. The International Maize and Wheat Improvement Centre (CIMMYT), Mexico, D.F. Mexico.

Singh, B.B. and Emechebe A.M. (1997). Advances in research on cowpea *Striga* and *Alectra* Pages 215-224, Singh, B.B., Mohan Raj D.R., Dashiell K.E., and Jackai L.E.N. (eds). Advances in cowpea research. Copublication and International Institute of Tropical Agriculture (IITA) and Japan International Research Center for Agricultural Sciences (JIRCAS) IITA, Ibadan, Nigeria.

Singh, B.B., Emechebe, A.M., and Atokple, I.D.R. (1993). Inheritance of Alectra vogelii resistance in cowpea genotype B 301. Crop Science 33: 70-72.

Singh, B.B. and Singh, S.R. (1982). Objectives and achievements of IITA research programme on cowpea and soyabean. Paper presented at the 3rd FAO/SIDA seminar on field crops in Africa and near East, Nairobi, June 6-24.

Smith, H.C. (1970). Agronomy department - University of Tennessee, (unpublished report).

Summerfield, R.J., Dart, P.J., Juxley, P.A., Eaglesham, A.R.J., Minchin, F.R., and Day, J.M. (1977). Nitrogen nutrition of cowpea (Vigna unguiculata). 1. Effects of applied nitrogen and symbiotic nitrogen fixation on growth and seed yield. Expt. Agric. 13: 129-142.

Tiwan, G.P. (1965). Effect of nitrogen, phosphorus and potassium on nodulation in cowpea. Expt. Agric. 1:257-9.

Tomlinson, P.R. (1965). Soils of northern Nigeria. Samaru Misc. Paper Series No. 11.

USDA Soil Survey Staff, (1976). Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys. USDA Agric. Hanbook. 436: US Govt. Printing Office, Washington D.C. 754 pp.

Vincent, J.M. (1980). Factors controlling the Legume-Rhizobium symbiosis. In: Nitrogen fixation, II. Eds. W.E. Newton and W.H. Orme-Johnson, pp. 103-120. University Park Press, Baltimore.

Visser, J.H. (1975). Germination stimulants of Alectra vogelii Benth. Seed, Zeitschrift fur Planzenphysiologie 75: 464-469.

Visser, J.H. (1978). The biology of Alectra vogelii Benth., an angiospermous root parasite. Beitrage zur Chemischen Kommunikation in Bio-und Okosystemen, Witzenhausen pp: 278-294.

Wan-Othman, W.M., Lie, T.A., t'Mannetze, L. and Wassink, G.Y. (1991). Low level P supply affecting nodulation, N_2 fixation and growth of cowpea (Vigna unguiculata (L.) Walp). Plant and Soil 135 (1): 67-74.

Weerarth, C.S. (1988). Studies of molybdenum application on soyabean. Beitrage Zur Tropischen Landwirt scharf und veterinar medizin 18(2), 131-134.

Wien, H.C. and Summerfield, R.J. (1980). Adaptation of cowpeas in West Africa: effects of photoperiod and temperature responses in cultivars of diverse origin. In: Summerfield, R.J. and Bunting, A.H. (eds) Advances in Legume Science. HMSO, London, UK, pp. 405-417.

Yaduarjrut, N.T. and Hosmani, M.M. (1979). *Striga* control in sorghum. PANS 25(2): 163.

APPENDICES

Appendix 1. Analysis of variance table showing the effect of Parasite flowering plants attachment on cowpea varieties inoculated with *Bradyrhizobium* strains in the greenhouse in 1996.

Source	DF	SS	MS	VR.
Rep	2	0.1296	0.0648	0.33
Variety	3	506.1481	168.7160	851.46
Parasite	2	787.6296	393.8148	1987.48
Rhizobia	2	7.1852	3.5926	18.13
Variety * Parasite	6	297.1852	49.5309	249.97
Variety * Rhizobia	6	2.5185	0.4198	2.12
Parasite * Rhizobia	4	5.9259	1.4815	7.48
Variety*Parasite*Rhizobia	12	2.1481	0.1709	0.90
Residual	70	13.8704	0.1981	
Total	107	1622.7407		

Appendix 2. Analysis of variance table showing the effect of Parasite flowering plants emergence on cowpea varieties inoculated with *Bradyrhizobium* strains in the greenhouse in 1996.

Source	DF	SS	MS	VR.
Rep	2	0.3889	0.1944	1.42
Variety	3	226.4074	75.4691	549.66
Parasite	2	355.5000	177.7500	1294.60
Rhizobia	2	6.2222	3.1111	22.66
Variety * Parasite	6	141.5370	23.5895	171.81
Variety * Rhizobia	6	2.1481	0.3580	2.61
Parasite * Rhizobia	4	5.4444	1.3611	9.91
Variety*Parasite*Rhizobia	12	3.7407	0.3117	2.27
Residual	70	9.6111	0.1373	
Total	107	751.0000		

Appendix 3. Analysis of variance table showing the effect of Parasite flowering plants on total dry matter of cowpea inoculated with *Bradyrhizobium* strains in the greenhouse in 1996.

Source	DF	SS	MS	VR.
Rep	2	0.4978	0.2489	2.36
Variety	3	37.0863	12.3621	117.05
Parasite	2	39.3758	19.6879	186.41
Rhizobia	2	51.2445	25.6223	242.59
Variety * Parasite	6	17.6096	2.9349	27.79
Variety * Rhizobia	4	4.4158	0.7360	6.97
Parasite * Rhizobia	12	2.0504	0.5126	4.85
Variety*Parasite*Rhizobia	70	1.9482	0.1624	1.54
Residual	107	7.3932	0.1056	
Total		161.6216		

Appendix 4. Analysis of variance table showing the effect of Parasite flowering plants on nodule number of cowpea inoculated with *Bradyrhizobium* strains in the greenhouse in 1996.

Source	DF	SS	MS	VR.
Rep	2	2.000	1.000	0.10
Variety	3	5617.296	1872.432	191.81
Parasite	2	10844.222	5422.111	555.44
Rhizobia	2	2063.389	1031.694	105.69
Variety * Parasite	6	5564.37	927.395	95.00
Variety * Rhizobia	6	341.204	56.867	5.83
Parasite * Rhizobia	4	76.056	19.014	1.95
Variety*Parasite*Rhizobia	12	137.796	11.483	1.18
Residual	70	683.333	9.762	
Total	107	25329.666		

Appendix 5. Analysis of variance table showing the effect of Parasite flowering plants on nodule dry weight of cowpea inoculated with *Bradyrhizobium* strains in the greenhouse in 1996.

Source	DF	SS	MS	VR.
Rep	2	1.685	0.843	0.19
Variety	3	12932.630	4310.876	972.44
Parasite	2	22653.408	11326.704	2555.05
Rhizobia	2	917.852	458.926	103.52
Variety * Parasite	6	8536.370	1422.728	320.94
Variety * Rhizobia	6	65.926	10.988	2.48
Parasite * Rhizobia	4	70.926	17.731	4.00
Variety*Parasite*Rhizobia	12	67.074	5.590	1.26
Residual	70	310.315	4.433	
Total	107	45556.184		

Appendix 6. Analysis of variance table showing the effect of Parasite flowering plants on percentage nitrogen derived from the atmosphere by cowpea inoculated with *Bradyrhizobium* strains in the greenhouse in 1996.

Source	DF	SS	MS	VR.
Rep	2	1.748	0.874	0.63
Variety	3	40.515	13.505	9.68
Parasite	2	175.587	87.793	62.91
Rhizobia	2	39.797	19.899	14.26
Variety * Parasite	6	64.662	10.777	7.72
Variety * Rhizobia	6	29.065	4.844	3.47
Parasite * Rhizobia	4	5.047	1.262	0.90
Variety*Parasite*Rhizobia	12	19.423	1.619	1.16
Residual	70	97.69	1.396	
Total	107	473.534		

Appendix 8. Analysis of variance table showing the effect of urea nitrogen fertilizer on *Striga* and *Alectra* emergence on cowpea at Samaru in 1995 and 1996

Source	DF	SS	MS	F-value
Yrs	1	10.0278	10.0278	15.362
Residual	4	2.6111	0.6528	2.193
Total	5	12.6389	2.5278	8.491
Var	3	505.8611	168.6204	566.400
Trts	5	789.2222	157.8445	530.204
Var*trts	15	291.2222	19.4148	65.215
Yrs*Var	3	8.9722	2.9907	10.046
Yrs* trts	5	6.0556	1.2111	4.068
Yrs*Var*trts	15	8.6111	0.5741	1.928
Residual	92	27.3889	0.2977	
Total	138	1637.3334	11.8647	
Grand Total	143	1649.9723		

Appendix 9. Analysis of variance table showing the effect of urea nitrogen fertilizer on cowpea total dry matter yield at Samaru in 1995 and 1996

Source	DF	SS	MS	F-value
Yrs	1	1544.621	1544.621	143.416
Residual	4	43.081	10.770	3.307
Total	5	1587.702	317.540	97.509
Var	3	389.290	129.763	39.847
Trts	5	1741.287	348.257	106.942
Var*trts	15	401.624	26.775	8.222
Yrs*Var	3	100.330	33.443	10.270
Yrs* trts	5	3.533	0.707	0.217
Yrs*Var*trts	15	82.753	5.517	1.694
Residual	92	299.599	3.257	
Total	138	3018.417	21.873	
Grand Total	143	4606.118		

Appendix 10. Analysis of variance table showing the effect of urea nitrogen fertilizer on cowpea grain yield at Samaru in 1995 and 1996

Source	DF	SS	MS	F-value
Yrs	1	2725251	2725251	71.092
Residual	4	153336	38334	1.967
Total	5	2878587	575717	29.546
Var	3	7612952	2537651	130.233
Trts	5	3213270	642654	32.981
Var*trts	15	2792110	186141	9.553
Yrs*Var	3	440941	146980	7.543
Yrs* trts	5	82337	16467	0.845
Yrs*Var*trts	15	797721	53181	2.729
Residual	92	1792664	19485	
Total	138	16731995	121246	
Grand Total	143	19610582		

Appendix 11. Analysis of variance table showing the effect of urea nitrogen fertilizer on cowpea nodule number at Samaru in 1995 and 1996

Source	DF	SS	MS	F-value
Yrs	1	2055.11	2055.11	90.528
Residual	4	90.81	22.70	1.467
Total	5	2145.92	429.18	27.744
Var	3	7054.44	2351.48	152.008
Trts	5	12076.92	2415.38	156.138
Var*trts	15	3337.64	222.51	14.384
Yrs*Var	3	189.00	63.00	4.073
Yrs* trts	5	171.14	34.23	2.213
Yrs*Var*trts	15	228.75	15.25	0.986
Residual	92	1423.19	15.47	
Total	138	24481.08	177.40	
Grand Total	143	26627.00		

Appendix 12. Analysis of variance table showing the effect of urea nitrogen fertilizer on cowpea nodule dry weights at Samaru in 1995 and 1996

Source	DF	SS	MS	F-value
Yrs	1	14352.24	14352.24	1051.013
Residual	4	54.62	13.66	0.783
Total	5	14406.86	2881.37	165.137
Var	3	39412.19	13137.40	752.931
Trts	5	66859.56	13371.40	766.372
Var*trts	15	20905.55	1393.70	79.876
Yrs*Var	3	1581.02	527.01	30.204
Yrs* trts	5	1686.06	337.21	19.326
Yrs*Var*trts	15	589.77	39.32	2.253
Residual	92	1605.25	17.45	
Total	138	132639.39	961.16	
Grand Total	143	147046.25		

Appendix 13. Analysis of variance table showing the effect of urea nitrogen fertilizer on cowpea nitrogen fixation by the root bleeding sap method at 50% podding stage at Samaru in 1995 and 1996

Source	DF	SS	MS	F-value
Yrs	1	290.078	290.078	6.224
Residual	4	186.430	46.608	6.166
Total	5	476.508	95.302	12.609
Var	3	53.282	17.761	2.350
Trts	5	598.637	119.727	15.840
Var*trts	15	596.252	39.750	5.259
Yrs*Var	3	5.177	1.726	0.228
Yrs* trts	5	59.415	11.883	1.572
Yrs*Var*trts	15	64.881	4.325	0.572
Residual	92	695.379	7.558	
Total	138	2073.022	15.022	
Grand Total	143	2549.529		

Appendix 14. Analysis of variance table showing the effect of phosphorus and molybdenum on cowpea *Alectra* attachment at Samaru in 1995 and 1996.

Source	DF	SS	MS	VR
Yrs	1	15.0417	15.0417	55.538
Residual	2	0.5417	0.2708	1.000
Total	3	15.5833	5.1944	19.179
trts	11	46.8333	4.2576	15.720
vars	1	4004.1665	4004.1665	14784.617
trts*vars	11	46.8333	4.2576	15.720
yrs*trts	11	6.4583	0.5871	2.168
yrs*vars	1	15.0417	15.0417	55.538
yrs*trts*vars	11	6.4583	0.5871	2.168
Residual	46	12.4583	0.2708	
Total	92	4138.2500	44.9810	
Grand Total	95	4153.8335		

Appendix 15. Analysis of variance table showing the effect of phosphorus and molybdenum on cowpea *Alectra* emergence at Samaru in 1995 and 1996.

Source	DF	SS	MS	VR
Yrs	1	12.7604	12.7604	18.846
Residual	2	1.3542	0.6771	2.369
Total	3	14.1146	4.7049	16.463
trts	11	16.0313	1.4574	5.100
vars	1	2194.5938	2194.5938	7679.339
trts*vars	11	16.0312	1.4574	5.100
yrs*trts	11	7.8646	0.7150	2.502
yrs*vars	1	12.7604	12.7604	44.651
yrs*trts*vars	11	7.8640	0.7150	2.502
Residual	46	13.1458	0.2858	
Total	92	2268.2915	24.6553	
Grand Total	95	2282.4060		

Appendix 16. Analysis of variance table showing the effect of phosphorus and molybdenum on cowpea *Striga* attachment at Samaru in 1995 and 1996.

Source	DF	SS	MS	VR
Yrs	1	6.5104	6.5104	9.615
Residual	2	1.3542	0.6771	2.369
Total	3	7.8646	2.6215	9.173
trts	11	43.3646	3.9422	13.795
vars	1	4226.7603	4226.7603	14790.310
trts*vars	11	43.3646	3.9422	13.795
yrs*trts	11	1.6146	0.1468	0.514
yrs*vars	1	6.5104	6.5104	22.781
yrs*trts*vars	11	1.6146	0.1468	0.514
Residual	46	13.1458	0.2858	
Total	92	4336.3755	47.1345	
Grand Total	95	4344.2402		

Appendix 17. Analysis of variance table showing the effect of phosphorus and molybdenum on cowpea *Striga* emergence at Samaru in 1995 and 1996.

Source	DF	SS	MS	VR
Yrs	1	6.5104	6.5104	21.552
Residual	2	0.6042	0.3021	1.168
Total	3	7.1146	2.3715	9.170
trts	11	15.2813	1.3892	5.372
vars	1	2310.8438	2310.8438	8935.802
trts*vars	11	15.2813	1.3892	5.372
yrs*trts	11	6.6146	0.6013	2.325
yrs*vars	1	6.5104	6.5104	25.175
yrs*trts*vars	11	6.6146	0.6013	2.325
Residual	46	11.8958	0.2586	
Total	92	2373.0415	25.7939	
Grand Total	95	2380.1560		

Appendix 18. Analysis of variance table showing the effect of phosphorus and molybdenum on total dry matter yield of cowpea planted on *Alectra* infested plots at Samaru in 1995 and 1996.

Source	DF	SS	MS	VR
Yrs	1	113.274	113.274	498.103
Residual	2	0.455	0.227	0.226
Total	3	113.729	37.910	37.681
trts	11	1012.855	92.078	91.522
vars	1	226.689	226.689	225.322
trts*vars	11	34.410	3.128	3.109
yrs*trts	11	14.733	1.339	1.331
yrs*vars	1	3.658	3.658	3.636
yrs*trts*vars	11	4.125	0.375	0.373
Residual	46	46.279	0.202	
Total	92	1342.750	1.006	
Grand Total	95	1456.479	14.595	

Appendix 21. Analysis of variance table showing the effect of phosphorus and molybdenum on grain yield of cowpea planted on *Striga* infested plots at Samaru in 1995 and 1996.

Source	DF	SS	MS	VR
Yrs	1	606426	606426	167.050
Residual	2	7260	3630	1.285
Total	3	613687	204562	72.389
trts	11	9013128	819375	289.956
vars	1	994301	994301	351.858
trts*vars	11	800086	72735	25.739
yrs*trts	11	161711	14701	5.202
yrs*vars	1	2109	2109	0.746
yrs*trts*vars	11	43878	3989	1.412
Residual	46	129990	2826	
Total	92	11145203	121144	
Grand Total	95	11758890		

Appendix 23. Analysis of variance table showing the effect of phosphorus and molybdenum on nodule number of cowpea planted on *Striga* infested plots at Samaru in 1995 and 1996.

Source	DF	SS	MS	VR
Yrs	1	661.500	661.500	57.942
Residual	2	22.833	11.417	3.385
Total	3	684.333	228.111	67.625
trts	11	6709.000	609.909	180.811
vars	1	7072.667	7072.667	2096.730
trts*vars	11	339.333	30.848	9.145
yrs*trts	11	118.500	10.773	3.194
yrs*vars	1	37.500	37.500	11.117
yrs*trts*vars	11	117.500	10.682	3.167
Residual	46	155.167	3.373	
Total	92	14549.666	158.149	
Grand Total	95	15233.999		

Appendix 26. Analysis of variance table showing the effect of phosphorus and molybdenum on cowpea nitrogen fixation at 50% podding on *Alectra* infested plots using the root bleeding sap method at Samaru in 1995 and 1996.

Source	DF	SS	MS	VR
Yrs	1	107.675	107.675	73.701
Residual	2	2.922	1.461	0.865
Total	3	110.597	36.866	21.833
trts	11	1065.415	96.856	57.362
vars	1	2.785	2.785	1.649
trts*vars	11	28.361	2.578	1.527
yrs*trts	11	20.428	1.857	1.100
yrs*vars	1	0.344	0.344	0.204
yrs*trts*vars	11	21.751	1.977	1.171
Residual	46	77.671	1.688	
Total	92	1216.754	13.226	
Grand Total	95	1327.351		

Appendix 27. Analysis of variance table showing the effect of phosphorus and molybdenum on cowpea nitrogen fixation at 50% podding stage on *Striga* infested plots using the root bleeding sap method at Samaru in 1995 and 1996.

Source	DF	SS	MS	VR
Yrs	1	86.640	86.640	41.092
Residual	2	4.217	2.108	1.532
Total	3	90.857	30.286	21.999
trts	11	886.877	80.625	58.565
vars	1	7.515	7.515	5.459
trts*vars	11	60.430	5.494	3.991
yrs*trts	11	16.165	1.470	1.067
yrs*vars	1	4.200	4.200	3.051
yrs*trts*vars	11	24.871	2.261	1.642
Residual	46	63.327	1.377	
Total	92	1063.386	11.559	
Grand Total	95	1154.242		