VARIABILITY WITHIN COWPEA GENOTYPES TO APPLIED PHOSPHORUS AND RESIDUAL EFFECT ON SORGHUM PRODUCTION ON P DEFICIENT SOILS OF SUDAN AND SAHEL SAVANNAS.

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VARIABILITY WITHIN COWPEA GENOTYPES TO APPLIED PHOSPHORUS AND RESIDUAL EFFECT ON SORGHUM PRODUCTION ON P DEFICIENT SOILS OF SUDAN AND SAHEL SAVANNAS.

By

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A Thesis submitted to the Postgraduate School, Ahmadu Bello University in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in Soil Science

October, 2005

DECLARATION

I hereby declare that the contents of this thesis are products of my imagination, formulation and execution. Extraneous sources of information have been duly acknowledged through references, and citations. The subject matter herein has not been presented in any previous application for a higher degree at the Ahmadu Bello University or any other University.

Addam Kiari Saidou — Date

The above declaration is confirmed

Dr E. N. O. Iwuafor — Date
Chairman, Supervisory Commitee

CERTIFICATION

This thesis entitled '' Variability within cowpea genotypes to applied P and residual effect on sorghum production on P-deficient soils of Sudan and Sahel Savannas'', by Addam Kiari Saidou, meets the regulations governing the award of the degree of DOCTOR OF PHILOSOPHY of the Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

To my wife Rahama, my son Momo, my daughters Lati and Yani whom all together made it a reality.

To my parents, brothers, sisters, friends, colleagues and all farmers of the world

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ABSTRACT

Variability within cowpea genotypes to applied phosphorus and residual effects on local sorghum production were studied in the field and screen house on P-deficient soils of Sudan and Sahel Savannas in West Africa. The soils are infertile, acidic and present deficiencies of phosphorus and nitrogen. Identification of some new cowpea breeding genotypes with tolerance to low P or response to added P fertilizer is an alternative to P deficient soils. In the field 147 cowpea genotypes were screened for tolerance to low P soils or response to applied P fertilizer as Single Super Phosphate (SSP) and Rock Phosphate (RP) at Minjibir (Sudan savanna, Nigeria) and Toumnia (Sahel savanna, Niger Republic). The rate of 90kg P ha^{-1} for RP and 30kg P ha^{-1} as SSP were used after being determined in a P calibration curve study in the screen house. The design was a strip plot design with the phosphorus as vertical (A) factor and the cowpea genotypes as horizontal (B) factor and replicated four times. Results obtained after cropping the 147 genotypes indicated the relationships between the cowpea genotypes for P use efficiency at low P (0P) and high P (RP and SSP) was significant and led to the separation of the cowpea genotypes into four groups: the tolerant non responders (TN); the tolerant responders (TR); the sensitive responders (SR) and the sensitive non responders (SN). The P use efficiency ratio was highly significant among the cowpeas and varied from 9 to 45 kg grain kg^{-1} P applied at Toumnia and 10 to 43 at Minjibir under SSP application and from 5 to 13 kg grain kg^{-1} P at Minjibir and from 4 to 10 kg grain kg^{-1} P at Toumnia under rock P conditions. Fifteen cowpea genotypes were selected for further P use efficiency screening in the field and screen house experiments. These 15 selected were screened at both locations in new fields for tolerance to low P soils or response to applied P.

The design was the same as the previous screening. The results indicated that there was highly significant variability among the cowpea genotypes in terms of grain and fodder yields. There was correlation (r = 0.59**) between grain yield and AMF infection rate even though P suppressed AMF infection rate in more than 50% of the cowpea genotypes; there was correlation between the fodder (r = 0.59**) and the percentage nitrogen fixed. The cowpea genotype IT98K-476-8 was observed to be efficient responder at both sites and IT97K-813-21 was recorded as non-responder. The root length was correlated with grain yield (r = 0.56**); as well as to AMF infection rate (r = 0.54**). The root length density was well correlated (r = 0.63**) to grain yield and to fodder (r = 0.55**). Significant difference was observed in relative P use efficiency ratio that varied from –7 to 38 kg grain kg P^{-1} applied. Significant effect of P to shoot: root ratio was recorded among the cowpea genotypes. The percentage N fixed increased with P applied at Toumnia and not at Minjibir.

The 15-cowpea genotypes screened in the screen house were carried out in river sand in pot experiment using similar treatments as in the field in a randomised strip plot design with 3 replications. Results showed highly significant ($P < 0.001$) difference for root length variation among cowpea genotypes; P had significant effect ($P < 0.05$) on shoot: root ratio. P had highly significant ($P < 0.001$) effect on the biomass.

Test of the performance of sorghum on pots previously grown to fifteen cowpea genotypes in pot was carried out. The results have shown significant ($P < 0.001$) growth of the sorghum in rotation. Sorghum performance and yield following cowpea and different residual sources of P in rotation in the field was conducted. No significant difference was observed at Toumnia in grain yield whereas at Minjibir, significant

difference (P= 0.05) was observed in terms of grain and stover production. The trend of response was in the order RP > SSP > Control. Residual P had significant effect on the AMF infection rate at Minjibir but not at Toumnia. Strong correlation (r = 0.99***) was recorded between the AMF infection rate and grain yield.

Contributions have been towards the farmers of the Sahel and Sudan savannas by giving some information on the cowpea genotypes tolerance and responsive to P that are relevant to their areas. For example the genotypes TN256-87, TN28-87, ALOKA, IT99K-826-119, 97K-819-154 and 97K-819-170 are relevant to the Sahel savanna farmers because of their tolerance to low P soils and response to applied P fertilizer and adaptability to that area. On the other hand the cowpea genotypes such as IT90K-277-2, Danila, IT98K-1399 and 99K-213-21 are adapted to Sudan savanna area.

TABLE OF CONTENTS

Page

Title Page ii

Declaration iii

Certification iv

Dedication v

Acknowledgement vi

Abstract viii

Table of contents xi

List of tables xviii

List of figures xx

List of Appendices xxi

CHAPTER ONE

1.0 INTRODUCTION 1

CHAPTER TWO

2.0 LITERATURE REVIEW 6

2.1 Characteristics of the cowpea production in dry Savannas 6

2.1.1 Climate 6

2.1.2 Soil 6

2.1.3 Phosphorus deficiencies 7

2.1.4 Phosphorus fractions 8

2.2 Rock phosphates 10

2.2.1 Source of Rock 10

2.2.2 Fineness of grinding.....11

2.2.3 Soil type 12

2.2.4 Soil reaction.....12

2.2.5 Soil Phosphate Status.....13

2.2.6 Climatic factors.....13

2.2.7 Crop to be grown 14

2.2.8 Residual value.....14

2.2.9 Analytical Methods.....15

2.3 The test crop, cowpea (Vigna unguiculata L. Walp).....15

2.3.1 Soil fertility improvements after cowpea production 16

2.3.2 Effect of cowpea production on soil fertility improvement 18

2.3.3 Response of cowpea production on soil fertility 19

2.4 Plant root activity and phosphorus acquisition in low phosphorus soils 20

2.4.1 Phosphorus acquisitions by grain legumes.....21

2.5 Role of mycorrhizae in P deficient soils 23

2.5.1 Mycorrhizal dependencies.....26

2.5.2 Selection of plant genotypes for AMF infection 27

2.5.3 AMF, crop and Phosphorus in soil 27

2.5.4 Factors affecting the crop- AMF association system.....28

2.6 Characters required for an effective symbiotic nitrogen fixation 30

2.7 Residual effects of legume crops on cereal crops 34

CHAPTER THREE

3.0 MATERIALS AND METHODS 37

3.1 Introduction 37

3.2 Description of experimental locations 38

3.3 Experiment 1: Screenhouse 40

Phosphorus calibration study to select desirable levels of P for use in the field trials 40

3.3.1 Site description 40

3.3.2 Selection, collection and sampling of low P soils 40

3.3.2.1 Selection of low P soils 40

3.3.2.2 Soil sample collection and preparation 40

3.3.3 Treatments and experimental design 41

3.3.4 Screenhouse procedure 41

3.3.5 Measurements 42

3.4 Physicochemical characterization of the soils and river sand 42

3.5 Biological characterization of the soils 43

3.6 Measurement of nitrogen fixation 43

3.7 Plant analysis 43

3.8 Experiment 2: Field 44

Screening of cowpea genotypes for tolerance or response to applied P on low P soils at Minjibir and Toumnia 44

3.8.1 Site history 44

3.8.2 Land preparation 44

3.8.3 Experimental design 45

3.8.4 Fertilizer application, planting and management practices 45

3.8.5 Observations and measurements 47

3.9 Experiment 3: Field 47

Screening of the selected cowpea genotypes on low P soils in the fields at Minjibir and Toumnia 47

3.9.1 Site history 47

3.9.2 Land preparation, experimental design, treatment and plots layout 47

3.9.3 Fertilizer application, planting and management practices 48

3.9.4 Observations and measurements 48

3.9.5 Description of grouping of cowpea genotypes 49

3.10 Experiment 4: Field 49

Sorghum performance and yield following the cropping of the selected cowpea genotypes in the fields 49

3.10.1 Land preparation, experimental design, treatment and plot layout 49

3.10.2 Fertilizer application, planting and management practices 50

3.10.3 Measurements 50

3.11 Experiment 5 : Screehouse 51

Screening of field selected cowpea genotypes for tolerance or response to applied P fertlizer sources in river sand 51

3.11.1 Experimental design and treatments 51

3.11.2 Screenhouse procedure and management 51

3.11.3 Measurements 51

3.12 Experiment 6 : Screenhouse 52

Performance of sorghum on pots previously grown to 15-cowpea genotypes 52

3.12.1 Experimental design and treatment 52

3.12.2 Screenhouse procedure and management 52

3.12.3 Measurements 52

3.13 Statistical analysis 52

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS 54

4.1 Phosphorus calibration study with some cowpea genotypes and maize in two contrasting low P soils 54

4.1.1 Phosphorus fractions of selected Minjibir and Toumnia soils 55

4.1.2 Effect of P application on total root and shoot dry matter production.....56

4.1.3 Effect of P application on nodule development.....58

4.1.4 Conclusion 59

4.2 Screening of cowpea genotypes for tolerance or response to applied P on low P soils at Minjibir and Toumnia 60

4.2.1 Size of rhizobia and AMF spore populations in experimental soils 60

4.2.2 Genotypic differences in response to P application 62

4.2.3 Genotypic differences to P use efficiency at Minjibir and Toumnia 72

4.2.4 Conclusion 75

4.3 Screening of selected cowpea genotypes for tolerance or response to P sources in river sand in the screenhouse 76

4.3.1 Characteristics of the river sand 76

4.3.2 Effect of P sources on root and shoot dry matter in pots 76

4.3.3 Effect of P source on total biomass and percentage relative cowpea response in pots 77

4.3.4 Effect of P source on cowpea genotype shoot: root ratios in river sand in pot 78

4.3.5 Effect P source on the shoot: root ratios of cowpea genotypes in the field 79

4.3.6 Effect of P source on root length of cowpea genotypes and relative cowpea response in pot 83

4.4 Screening of selected cowpea genotypes for P use efficiency under field conditions 85

4.4.1 Effect of P source on root length of cowpea genotypes in the field 86

4.4.2 Effect of P source on specific root length of cowpea genotypes in the field 88

4.4.3 Effect of P source on grain yield of cowpea genotypes in the field 90

4.4.4 Effect of P source on relative P use efficiency (RPUE) of cowpea genotypes in the field 92

4.4.5 Effect of P source on fodder yield of cowpea genotypes in the field 95

4.4.6 Effect of P source on AMF infection rate of cowpea roots in the field 98

4.4.7 Effect of P source on uptake efficiency of cowpea genotypes in the field 101

4.4.8 Effect of P source on incorporation efficiency of cowpea genotypes in the field.....103

4.4.9 Effect of P source on Phosphorus utilization efficiency of cowpea genotypes in the field 105

4.4.10 Relationships between P use efficiency criteria 107

4.4.11 Effect of P source on Nitrogen derived from atmosphere in the field 108

4.4.12 Total N in shoot of cowpea genotypes in the fields.....111

4.4.13 Conclusion.....114

4.5 Yield of sorghum following cowpea genotypes and changes in soil pH in the screenhouse 115

4.5.1 Shoot dry weight (SDW).....115

4.5.2 Root dry weight (RDW).....116

4.5.3 Soil pH after sorghum following cowpea in pot.....118

4.6 Sorghum performance and yield following cowpea genotypes and different sources of P fertilizer at Minjibir and Toumnia....120

4.6.1 Grain yield....120

4.6.2 Stover yield....126

4.6.3 Root dry matter production....131

4.6.4 Arbuscular Mycorrhizal Fungi infection of roots of sorghum grown after cowpea genotypes. 134

4.6.5 Conclusion....138

CHAPTER FIVE

5.0 SUMMARY AND CONCLUSION....139

REFERENCES....141

APPENDICES....179

LIST OF TABLES

Page

1 Cowpea genotypes used in the 2002 field trials at Minjibir and Toumnia 46

2 Physico-chemical properties of Minjibir (M), Toumnia (T) soils and River sand (RS) 0-10cm 55

3 Sequentially extractable P fractions of Minjibir and Toumnia soils 56

4 Effect of SSP on the total dry matter (TDM) of cowpea genotypes in potted soils from Minjibir (M) and Toumnia (T) 57

5 Effect of P source on Rhizobial cells and AMF Spores count from Minjibir and Toumnia soils before planting and after harvest 62

6 Grain yield (kg ha^{-1}) of selected cowpea genotypes to SSP application at Minjibir and Toumnia, 2002 69

7 Grain yield (kg ha^{-1}) of selected cowpea genotypes to RP application at Minjibir and Toumnia, 2002 71

8 Genotypic differences to P use efficiency of field screened cowpea genotypes at Minjibir (M) and Toumnia (T) based on SSP and RP application, 2002 74

9 Effect of P source on root and shoot dry matter in pots..... 77

10 Effect of P source on total biomass and relative cowpea response (RCR) in pots.. 78

11 Effect of P source on shoot: root ratio of cowpea genotype in the field and screenhouse 82

12 Effect of P on root length and relative cowpea genotypes response (RCR) in screenhouse 85

13 Effect of P on the root length of the selected cowpea genotypes and relative response (RCR) in the field (Minjibir)..... 88

14 Effect of P source on specific root length of cowpea genotypes and relative cowpea response (RCR) in the field 90

15 Effect of P source on the grain yield variability of selected cowpea genotypes in the field 92

16 Effect of P source on relative P use efficiency of the selected cowpea genotypes in the field 95

17 Effect of P source on the fodder yield variability of selected cowpea genotypes in the field 97

18 Effect of P source on AMF of selected cowpea genotypes in the field 100

19 Effect of P source on P uptake efficiency of cowpea genotypes in the field 102

20 Effect of P source on P incorporation efficiency of cowpea genotypes in the field 104

21 Effect of P source on the P utilization efficiency of cowpea genotypes in the field 106

22 Correlations between growth parameters and P use efficiency criteria 107

23 Variations in N_2 fixation of cowpea genotypes at two locations, 2003 111

24 Effect of P source on N accumulation in cowpea genotype shoot in the field 114

25 Shoot and root dry weight (SDW, RDW) of sorghum grown after cowpea genotypes in pots 117

26 Soil pH under sorghum after cowpea genotypes in pot 119

27 Residual benefits on Sorghum grain (kg ha^{-1}) after cowpea genotypes in the field, 2004 125

28 Residual benefits on Sorghum stover (kg ha^{-1}) following cowpea genotypes in the field 130

29 Residual benefits on Sorghum root dry weight after cowpea genotypes in the field 133

30 Residual benefits on Sorghum AMF (%) after cowpea genotypes in the field 137

LISTE OF FIGURES

Page

1 West African Semi Arid Climatic Zones showing the two locations 39

2 Effect of SSP rates on cowpea genotypes NDW in potted soil of Minijibir(M) and Toumnia(T), 2002 59

3a Biplot of cowpea grain yield (kg ha^{-1}) at low (0P) and high P (SSP) : (A) at Minjbir field and (B) at Toumnia field in 2002 cropping season 64

3b Biplot of cowpea genotypes grain yield (kg ha^{-1}) at low (0P) and high P (RP) : (C) at Minjbir field and (D) at Toumnia field in 2002 cropping season 65

4a Biplot of cowpea genotypes fodder yield (kg ha^{-1}) at low (0P) and high P (SSP) : (E) at Minjbir field and (F) at Toumnia field in 2002 cropping season 66

4b Biplot of cowpea genotypes fodder yield (kg ha^{-1}) at low (0P) and high P (RP) : (G) at Minjbir field and (H) at Toumnia field in 2002 cropping season 67

5 Relationship between the root length and PUE 108

6 Relationship between the selected cowpea grain yield and P uptake 108

7 Relationship between the grain yield and relative P use efficiency of cowpea genotype in the fields 108

LISTE OF APPENDICES

Page

1 Rainfalls and soil temperatures of experimental sites 174

2 Different groups of response due to SSP effect on cowpeas grain (kg ha^{-1}) in the field 175

3 Different groups of response due to SSP effect on cowpeas fodder (kg ha^{-1}) in the field 176

4 Different groups of response due to RP effect on cowpeas grain (kg ha^{-1}) in the field.....177

5 Different groups of response due to RP effect on cowpeas fodder (kg ha^{-1}) in the field 178

6 Phosphorus use efficiency of cowpea genotypes screened in based SSP and RP at Minjibir and Toumnia in 2002 179

7 Phosphorus calibration study with maize (obber super one) in low P soil 180

8 Screening of 147 cowpea genotypes in low P soils.....181

9 Effect of 0P and applied P on improved and local genotypes growth 182

10 Effect of 0P and applied P on improved and local genotypes root 183

11 Drying effect of phosphorus on cowpea in the field 184

12 Sorghum following cowpea in the pot experiment.....185

13 Genotypic effect on sorghum following cowpea in the field.....186

14 Phosphorus benefit to sorghum following cowpea in the field.....187

CHAPTER ONE

1.0 INTRODUCTION

Cowpea (*Vigna unguiculata* L. Walp.), an annual legume, is grown in many parts of the world where it is called other names such as, black eye pea, Crowder pea, or niebe, (FAO, 2004). The total worldwide production of cowpea is estimated at 3.3 million tons of dry grain (FAO, 2001). Out of this 64% is produced in Africa where it originated. The largest production countries in Africa are Nigeria and Niger with 2,200,000 Mt and 400,000 Mt respectively, and then followed by Burkina Faso (330,000 Mt) (FAO 2004). Cowpea is chiefly used as grain crop that provides a rich and inexpensive source of protein for both human food and fodder for live stock (Buffet, 1994; Nielsen, 1996; Nwokolo and Smartt, 1996). The history of cowpea dates to ancient West African cereal farming, 5 to 6 thousand years ago, where it was closely associated with the cultivation of sorghum and pearl millet in dry areas as intercrop (Davis et al., 2003). The traditional cropping systems in the dry savannas are diverse and not only differ from region to region but also from farmer to farmer within the same region. The mean cowpea grain yield in intercrop of millet and sorghum is reported to be in the range of 149 and 170 kg ha^{-1}, respectively (Singh, 1993). Other cropping systems also revealed the low grain yields of cowpea, which ranged from 0-132 kg ha^{-1} (Van Ek et al. 1997).

Of the soil related constraints on cowpea production, low soil fertility is the most severe on more than half of the arable land in the Tropics (Sanchez and Salinas, 1981). Infertile soils are usually acidic and present deficiencies of phosphorus (P) and nitrogen (N) (Carsky and Iwuafor, 1999); potassium (K), toxicity of aluminium (Al) and high P fixation capacity (Sanchez et al., 1979).

A number of soil management technologies have been proposed to counteract these effects (Sanchez and Salinas, 1981), but agricultural research in the last decade has shown that the crop production constraint in West Africa are most likely to be transformed by technologies based on biological processes. For example, Bagayoko et al. (2000) in Sahelian zone of Mali reported that P availability governed dry matter and root colonization by AMF in millet, cowpea and sorghum. Compared with millet, cowpea and sorghum may benefit much more from AMF inoculation because of their coarser rooting system. This explains the research efforts in recent times has concentrated on the development of improved crops and biologically based crop production systems, which are appropriate to the actual ecological conditions of the areas and the socio-economic situation of the farmers who cannot afford to buy fertilizers in the required quantities. Legumes generally play a major role in these production systems since they possess the ability to fix atmospheric nitrogen and thus improve soil fertility and productivity of the subsequent or associated crop in the cropping system. However, legumes need phosphorus as a key element to accomplish the biological process (Danso, 1992). It is therefore important that some external source of P be applied to these inherently low P soils and legume crops with high capacity to acquire P from less available forms are used in the systems. Another option is the use of cheap source of P like Rock P (RP). This may be more feasible considering the fact that farmers in the region are poor and may not be able to afford the expensive soluble P fertilizers (Mahamane et al., 1997).

The most common cropping system in West Africa involves growing several crops in association as mixtures (intercrop) or in rotation. In the Sahelian countries such as Niger, the cropping system is millet-based, with millet/cowpea and millet/groundnut

being the most prevalent and important cropping patterns (Steiner, 1984). Field experiments at several sites in Sahel region of West Africa have shown cereal yield increases in cereal/legume rotations ranging between 15 and 79% over yields from continuous cereal monocropping systems. However, the degree to which N and P were involved as driving forces in these effects remained obscure (Bagayako et al., 2000; Bationo et al., 1998) but the observed legume rotation effects on cereal plots included site specific increases in mineral N, mycorrhizal infection and decrease in nematodes infestation (Bagayako et al., 2000).

Until about 20 years ago, arbuscular mycorrhizal fungi (AMF) were virtually ignored by most soil and plant scientists and were not considered as a soil microbiological resource for crop production. However, since under controlled green house conditions it was demonstrated that AMF or "root fungus" increase P uptake and play a role in uptake of other plant nutrients, nitrogen fixation by rhizobium, biological control of root pathogen and drought resistance of plant (Powell and Bagiyaraj, 1984), AMF could be of significance to field grown crops. The major effect of AMF on plant growth is the increase in P uptake (Thompson, 1990) because the roots of mycorrhizal plants are more efficient than the roots of non-mycorrhizal plants in P uptake from the soil (Stribley, 1989). And hence, a bio fertility strategy could be developed for improving cowpea varieties especially suitable for cropping systems of the savannas.

Cowpea response to RP fertilization may lead to achieve high yields at reduced cost through the combined use of low cost reactive RP materials, the selection of cowpea varieties with high efficiencies for uptake and utilization of P from soil and RP (Geethukumari and Kunju, 1984; Islam et al., 1980), and may also lead to good AMF

association. However, the response of leguminous crop to AMF depends on the legume, the rhizobium, the fungus and the environment (Bethlenfalvay et al., 1985). Reports of interactions involving different soybean genotypes, *Bradyrhizobium* strains, AMF species and isolates, on P-deficient soil in the derived savanna have been given (Abdelgadir, 1998). Furthermore, Sanginga et al. (2000), observed that two high yielding cowpea breeding lines, IT81D-715 (non P responder) and IT82D-849 (P responder) had different relationships between plant growth characteristics and P uptake efficiency, P use efficiency and % AMF root infection in the moist zone of derived savanna. In both cases, intra specific differences were shown, in moist zone of derived savanna, for tolerance to low P levels to soybean (Abdelgadir, 1998) and cowpea (Sanginga et al., 2000). Therefore, to improve N and P nutrition of grain legumes in low fertile soils of the dry savanna, identification of low soil P-tolerant genotypes as well as the efficient users of P fertilizers may be a productive strategy. No such a work has been carried out in dry savanna especially the Sahel zone of Niger and Sudan of Northern Nigeria to screen cowpea genotypes for tolerance or response to P. In addition the use of locally mined RP and N nutrition on P-deficient soil, to improve soil fertility and hence the improvement of the productivity of cowpea-based cropping systems have been some how explored in these zones (Bationo et al., 2002). The P efficient genotypes can play a role in solubilizing the sparingly soluble P in low P available soils. By so doing the efficient cultivars recycle the P in the soil making it available to an inefficient subsequent cereal crop. Therefore the poor farmers who cannot afford to buy expensive P fertilizers can potentially use such efficient genotypes. The identified good cowpea genotypes can therefore be used in breeding programme for introgression in genotypes, which might have other useful traits.

The general objective of the study is therefore to enhance the productivity of cowpea-based cropping systems in dry savannas of West Africa through the identification of cowpea genotypes with improved P-acquisition, use efficiency and P- cycling in low P soils.

The specific objectives of the study are:

1. To screen cowpea genotypes for tolerance or response to P through P-use efficiency.
2. To elucidate the mechanisms involved in P-acquisition, tolerance to low P or response to P application.
3. To assess the potential contribution of P efficient genotypes and P fertilizer to a succeeding sorghum.

Testable hypotheses:

- Phosphorus is a limiting factor for cowpea production in farmers' fields in Sudan and Sahel areas.
- There is a large difference in growth habit for tolerance to low P or response to applied P among cowpea genotypes and soil types can affect this.
- Arbuscular mycorrhizal fungi (AMF) can be of good effects on cowpea productivity in that this may be of help in P, and other nutrients uptake as well as improving N_2 fixation.
- Cultivation of such cowpea genotypes will have substantial effect on soil fertility status and therefore influence the cropping system positively.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Characteristics of the cowpea production in dry Savannas.

2.1.1 Climate

Northern Nigeria and Niger Republic are the major growing areas of cowpea in dry Savannas. The dry Savannas in this case include Sudan and Sahel Savannas. In these regions, particularly the Sahel Savanna, evapotranspiration exceeds rainfall during at least 5 months of the year. Temperatures are warm (annual mean 25^{o} C). The rainfall is generally low (annual range 300-1000mm), variable, and undependable. End-of-season drought is common (Bationo et al., 1982). The reduction in the mean annual rainfall in Niger from 1969 was geographical mean pattern, not an isolated occurrence. The intensity of rainfall is normally very high, and the aggressiveness of rainstorms has important implications for crop and soil management (Sivakumar, 1989).

2.1.2 Soil.

The productivity of the soil is reduced with continuous cultivation because of lowering of organic matter below critical levels, physical removal of soil by wind or water erosion, leaching of nutrients, especially in light-textured soils, and exhausting of soil nutrients by crop removal (Bationo et al., 1982). The soils are predominantly sand to sandy loam. Clay content ranges from 1-5% and the soils have a weakly coherent massive to sub angular blocky structure. Due to their sandy nature, the surface soils have a friable consistence and they can crust when dry. The sandy soils of the Sahelian zone have bulk densities ranging from 1.4-1.7 kg m^{-3}, corresponding to a porosity of 36-43% (Sivakumar et al., 1990). The dune soils of the Sahelian zone have a very high hydraulic conductivity (150-

200 cm day^{-1}) and therefore a rapid internal drainage. However, in the Sudanian zone, with increase clay content and the formation of crusts, the internal drainage is reduced (Bationo et al., 1982).

The low soil fertility is expressed through the low level of organic carbon, total nitrogen, and effective cation-exchange capacity. Among 31 topsoils samples (0-15cm) of this zone, total N value ranged from 31 to 1800 mg kg^{-1}, with a mean of 266 mg kg^{-1} (Bationo et al., 1989). The value of exchangeable acidity is very low, indicating that these soils are likely to have little problem related to aluminium toxicity. Phosphorus has been shown to be one of the most limiting nutrients. The low levels of available P are due to low levels in soil parent material and organic matter (Bationo et al., 1982).

2.1.3 Phosphorus deficiencies

Phosphorus deficiency affects an area estimated at over 2 x 10^9 ha (Fairhust et al 1999) and this is one of the largest constraints to food production in tropical Africa, Latin America and Asia as most of these tropical soils are low in native P and have high fixation capacities (Mokwunye et al., 1986; Warren, 1992). Kaola et al., 1988 reported that, 65% of 500 soil samples collected from 42 countries in the tropics could be classified as acutely deficient in P, 27% as moderately deficient, and only 8% of the samples were classified as not deficient.

In major parts of Africa, P deficiency is so severe that crop seedlings die as soon as they have exhausted the seed P reserves. Furthermore, fertiliser P applied to P fixing soils is used relatively inefficiently since as little as 10-20% is taken up by crops in the season of application and therefore do not become available for plants' uptake. The rest

are usually fixed into soil forms by Fe and Al oxide and in some cases by recalcitrant organic matter, found in tropical soil (Sanchez and Salinas, 1981).

Several investigators have shown that P deficiency constitutes the major constraint to food production in the Sudano-Sahelian area in West Africa (Pichot and Roche, 1972; Bationo, 1982). The low organic matter content in the sandy soils of the areas contributes to the P problem (Agboola and Oko, 1976). It has been reported that the use of Kpene rock phosphate in Togo, Tahoua rock P in Niger Republic and Tilemsi rock P in Mali (Charoy, 1980; Thibout et al., 1980) and even recently the Sokoto rock P in Nigeria can significantly increase yields.

2.1.4 Phosphorus Fractions

Much of the total soil P is unavailable for immediate plant uptake. Hence, there have been many attempts to quantify the relationship between unavailable and available soil P. The amount of P applied that does not remain in soil solution, or is not removed by plants, is thus retained on the soil in some fractions Hitherto, hypotheses about P cycling and transformation in weathered tropical soils underscore the importance of organic phosphorus (Po) in replenishing the plant available P pool (resin extractable P) in low fertilizer P input agricultural systems (Tiessen et al., 1984).

Hedley et al. (1982) however developed a procedure to separate inorganic P (Pi) and organic P (Po) into different bio available forms, and also allowed differentiation into some chemical groupings. Theoretically, this procedure removes progressively less available soil P with each subsequent extraction, and as the levels of the various P forms increase or decrease during fertilization or crop removal, these forms of soil P can be implicated as P sinks or sources, respectively, for plant available P. In the sequential

extraction, resin- Pi and HCO_3-Pi are the labile fractions consisting of exchangeable Pi, while NaOH-Pi and Po are moderately labile and can buffer the resin and HCO_3-Pi. The HCO_3-Po is the most labile P form while the more stable Po forms which are probably involved in long term P transformation and turnover in soils are extracted with NaOH. Dilute HCl-extractable Pi represents P from calcium phosphates, which comprise a large portion of total Pi on young soils but are relatively unimportant on highly weathered soils unless these soils are amended with Rock Phosphate (RP).

Agbenin and Goladi (1997) reported significant decreases in all P pools under continuous cultivation with no manurial treatment when compared with the natural site. The residual (HCl) P pool declined by 82%, the HCO_3-Po decreased by 77% and OH-Po by 75%. The resin P pool decrease of 39% was smallest probably due to replenishment by the other pools. They also recorded increases of 31% for OH-Pi and between 57% and 80% for HCl-Pi pools under continuous cultivation complemented with inorganic P fertilization above that of the native site. The HCO_3-Pi and OH-Pi are supposedly Pi forms adsorbed to the surfaces of Al and Fe oxides and are the major P sinks in weathered soils. Increases in HCl-Pi with inorganic P fertilization were attributed to the effects of exchangeable Ca^{2+} or Mg^{2+} which can exert significant influence on P adsorption in tropical soils including Savanna soils. Agbenin and Goladi (1997) also stated that the enrichment of labile Pi pools indicates that inorganic P fertilization had been in excess of crop requirement.

Although other workers showed increases in extractable Po after a few months and 26 years of inorganic P fertilization respectively, Agbenin and Goladi (1997) however reported decreases in Po pools and residual P fraction in the soil despite

inorganic fertilization. In the P fertilised soil, HCO_3-Po decreased by 51%, OH-Po by 36% and the residual P pool by 43% compared with the uncultivated site. The decrease in the Po pool despite inorganic P fertilization can be partly explained by mineralization resulting from declines in soil organic matter (Agbenin and Goladi 1997).

Several studies have related the P fractions in Tropical soils to plant growth (Friesen et al., 1997; Guo and Yost, 1998; Oberson et al., 1999, 2000; Phiri et al., 2001 a, b; Lehmann et al., 2001; Buhler et al 2002). The results obtained in these studies suggest that the P in different pools are controlled by physico chemical factors such as sorption and desorption and by biological reactions such as immobilization and mineralization.

2.2 Rock phosphates

A large proportion of the world's output of RP is chemically processed to produce a variety of materials which are more soluble than the original rock.

In developing countries, correcting soil P deficiency with large application of P-fertilizer is not a viable option. The inexpensive rock phosphate reserve remaining in the world could be depleted in as little as 60-80 years (Runger-Metzger, 1995).

The value of this material as fertilizer appears to be influenced by a number of factors; those concerned with the material itself ie source of RP, fineness of grinding; and those related to the properties of the land on which it is applied ie soil type, soil reaction (pH), soil phosphate status, climatic condition and crops to be grown. A study of RP would not be complete without checking its residual effect for the following year.

2.2.1 Source of Rock

The majority, if not all, of the rock being used in the United Kindom at present originates from North Africa ie Gafsa (Tunisia), Morocco and Constantine (Algeria).

Cooke, (1956), in pot experiments with an acid soil and using radishes as test crop, reported that Gafsa was superior to other rocks but that materials from Morocco, Algeria, Java, Egypt and Curacao were of considerable value. On the other hand, samples of ground RP from Nauru, Taplow, Nigeria, Christmas Island, Kola, Uganda and Rhodesia were of little value. In field experiments (Cooke, 1956) he confirmed the superiority of Gafsa rock, although that from Curacao gave similar responses and from Morocco slightly lower yield; Florida pebble phosphate proved to be markedly inferior. In pot experiments with barley grown in sandy soil of pH 6.3, Jensen (1956) found that Gafsa rock was superior to that from Kalaa Djerda with that from Florida being markedly inferior to the other two. He quoted a figure of 60-70% as the efficiency of Gafsa rock compared with superphosphate.

Rock phosphate in Nigeria has been extensively reported by Adegoke et al. (1991). They indicated that phosphates have been discovered from lower tertiary state in the Dahomey basin, the Sokoto basin etc…

The two main types of phosphates found by Adegoke et al. (1991), the granular type phosphates has 31.38 wt. % P_2O_5. They reported that the total reserve is estimated to be over 100,000 tons of R.P.

2.2.2 Fineness of grinding

Rock phosphate is normally ground so that 80-90% will pass through a B.S. 100 mesh sieve. A much finer ground rock phosphate, often known as Hyperphosphate, is marketed in Great Breatin and elsewhere. As a result of pot experiments with radishes (Cooke, 1956) and field experiment with grass, kale and Swedes (Cooke, 1956; 1959), stated that there was no justification for grinding the rock finer than 100 mesh. Neller and

using two grades of Florida phosphate, 50 and 85% passing a 200 mesh sieve, and growing millet in an acid soil of pH 5.8 could find no differences in phosphate response between the two materials. Similarly Neenan (1962), testing materials varying between 100 and 500 mesh, also concluded that fineness of grinding had only small and inconsistent effects.

2.2.3 Soil type

Starostka (1955) carried out pot experiments with a range of soils and phosphate sources, including RP. Only in a very few soils ground RP was effective, the most responsive being a sandy loam soil of pH 6.1; there was no response on a sandy loam and a loamy sand, both of pH 4.8, and a fine sandy loam of pH 6.6. On a loam soil of pH 5.1 a small response was obtained. Bennett (1957) grew Sudan grass and Ladino clover on two soils originally of pH 5, Cecil clay loam and Eutan clay, both unlimed and limed. Responses to various RP varied on the two soils.

2.2.4 Soil reaction

Starostka (1955), Karlovsky (1961) all show that ground RP is of little importance on alkaline soils. Similar conclusions have been arrived at in experiments Neenan (1962), Jones (1964). It is of more interest to determine the pH of the soil above which it is undesirable to apply ground RP. Franck (1957) stated that it is 67% as efficient as superphosphate at pH 6.1 but only 33% as efficient at pH 6.5. Scheffer et al. (1957) found that at pH 6.5 RP was unsatisfactory but at pH 4.0 it was a good fertilizer. Cooke (1956) reporting on the joint investigation by Rothamsted staff and NAAS Soil Chemists, concluded that over pH 5.5 the efficiency of the material fell rapidly. Mattinggley (1960) with ryegrass in pots found that at pH 5.3 Gafsa phosphate and superphosphate were

equally efficient. Ellis et al (1960) working with sand and acidified clay in pots, found that pH must below 6.0 and preferably below 5.5. Ansarge (1966) also found that with a pH over 6.0 the value of ground RP was low. Van der Paauw (1965) went further than this, concluding, as a result of experiments with potatoes and rye on acid humic soils, that the pH needed to be so low for the efficient use of ground RP as a fertilizer that it was below the soil reaction required for optimum growth of most crops.

2.2.5 Soil Phosphate Status

Franck (1957) in a series of experiments in Sweden, concluded that at very low phosphorus level in the soil hyperphosphate was very inferior to superphosphate; at an unsatisfactory phosphate level in the soil hyperphosphate was 39% as efficient as superphosphate and at a moderate level it was 63% efficient. Similarly Van der Paauw (1965) stated that the availability of RP is dependant on the degree by which the water soluble phosphorus in the soil is increased by the applied rock phosphate. With Prummel (1949) he showed that with repeated dressings of RP efficiency increased nearer to that of superphosphate.

2.2.6 Climatic Factors

Jones (1964) found that RP was satisfactory fertilizer in Wales and at Trawscoed EHF (1966) a single large dressing of RP was effective for several years. Wilkinson (1966) in experiments in northern England found responses to this material were better on the west side of the Pennines than on the east. Also, in Sudan savanna area of Gaya in Niger republic, the Tahoua RP was more effective than the Sahel savanna zone of the country (Mahaman et al. 1997) due to the difference in rainfall.

2.2.7 Crop to be grown

There has been considerable amount of work on the relative ability of different crops to utilize the phosphate in ground RP. Thus McLean (1956) reported that RP was not very effective for oats and Lucerne but proved to be better for buckwheat. Edwards (1956) found that brassica crops responded well to RP but for potatoes it was ineffective.

Bottini (1958) was able to put crops in decreasing order of responsiveness ie peas, millet, oats, flax and tomatoes. In a further paper, he stated that RP was better for legumes than cereals. Robertson and Hutton (1958) put several crops in order of the efficiencies of utilization – 82% as effective as supers for maize, 88% for peanuts, 64% for sorghum and 80% for oats.

2.2.8 Residual value

It has been well established that ground RP is much slower in action than a water soluble phosphate such as superphosphate. The residual value is that portion which is left in the soil after the growth of at least one crop, and it is invariably compared with the residual value of superphosphate or basic slag.

Yield and uptake date has been used to measure residual effects and evidence is more conflicting. McLean (1956) after two crops following single dressing found that RP was very nearly as good as superphosphate. Almeida and Balbino (1960) worked with wheat grown in a ferrallitic soil of pH 5.6; in the first years supers were superior to RP but in the second year an increased yield was obtained from RP but not from superphosphate. Jackson and Burton (1960) found that after four years the residual value from RP was greater than that from superphosphate.

2.2.9 Analytical Methods

No method of analysis of the ground RP can forecast what will happen in the field. Many of the agronomic factors dictate field performance far more than the material itself. However, a suitable analytical method should at least be able to separate the better materials from the not so good.

The extractants mainly used to give the relative values of these materials have been dilute organic acids – citric, tartaric, formic or acetic. Gisiger and Pulver (1955) suggested either citric or formic acids; Scheffer et al. (1957) advocated any of the four organic acids.

2.3 The test crop, cowpea (Vigna unguiculata L. Walp)

Cowpea is a Dicotyledonea belonging to the order Faboideae, tribe Phaseoleae, subtribe Phaseolinae, genus Vigna, and section catiang (Verdcourt, 1970; Maréchal et al., 1978). Previous speculation on the origin and domestication of cowpea had been based on botanical and cytological evidence, information on its geographical distribution and cultural practices and historical records (Steel and Mehra, 1980; Ng and Marechal, 1985; Ng, 1995). Ng (1995) postulated that during the process of evolution of V. unguiculata, there was a change of growth habit, from perennial to annual breeding and from predominantly out-breeding to inbreeding, while cultivated cowpea (subsp. Unguiculata) evolved through domestication and selection of the annual wild cowpea (var. dekindtiana). The wide geographical distributions of var dikindtiana throughout sub Saharan Africa suggest that the species could have been brought under cultivation in any part of the region. However, the center of maximum diversity of cultivated cowpea is found in West Africa, in an area encompassing the savanna region of Nigeria, southern

Niger, part of Burkina Faso, northern Benin, Togo, and the northwestern part of Cameroon (Ng and Marechal, 1985; Ng, 1995). Yet the crop is facing some constraints in the fields.

Several studies show that cowpea hybrids can exhibit considerable heterosis for many traits. Heterosis was demonstrated for dry matter yield (Lodhi et al., 1990). Several researchers have studied traits influencing nitrogen fixation and mycorrhizal colonization. Miller et al. (1986) investigated traits influencing nitrogen fixation efficiency. The following Hetorosis for nodule estimates: nodule number, 55%, nitrogenase activity, 62%; nodule weight, 39%; and top dry weight 17%. They also demonstrated that additive gene action is important for nodule number and nitrogenase activity, and that dominance and interallallelic gene action was important for nodule weight and top dry weight. Dayap and Rasco (1988) published the following Hetorosis in biomass estimates: nitrogenase activity, 24%; secondary root nodule weight, 38%; and secondary root nodule number, 9.5%. They noted that additive gene action was important for all three traits. Roquib and Patnaik (1990a) studied the inheritance of effective root nodules at 30 and 65 days after planting (DAP). They reported the following Hb estimates for effective root nodules: main root at 30 DAP, 6%; branch root at 30 DAP, 21%; main root at 65 DAP, 36%; and branch root at 65 DAP, 11%. Pemberton et al (1990) reported that a single recessive gene, Cpi, conditioned the inheritance of an ineffective nodulation trait.

2.3.1 Soil fertility improvements after cowpea production

Research results in West Africa have shown the importance of the improvement of soil fertility for crop production (Sedogo, 1993). In the sahelian zone, soil fertility

appears to be more limiting to grain and fodder production than rainfall and the use of fertilizer will increase water use efficiency (Penning de Vries and Djiteye, 1991).

Significant cowpea responses to nitrogen applied as urea has been obtained in different agro ecological zones of West Africa. These significant responses indicate that the predominantly sandy soils of the zone may be deficient in molybdenum required for efficient symbiotic nitrogen fixation (Hafner et al., 1992). For example on the sandy acidic soil at Bengou in the Sudanian zone of Niger, significant molybdenum response was obtained at different levels of soil fertility management for cowpea (Bationo, et al. 2002).

Cowpea has a high P requirement. P is reported to stimulate root and plant growth, initiate nodule formation, as well as influence the efficiency of the rhizobium-legume symbiosis (Danso, 1982). It is also involved in reaction with energy transfer, more specifically ATP in nitrogenase activity (Israel, 1987). Research conducted at Ikenne in the humid zone and Kamboinse in the Sudanian zone of West Africa indicated a strong differential response to P by cowpea cultivars (Bationo et al., 2002). The local Kamboinse variety is a fodder type and the application of P resulted in higher fodder yield but lower grain production. As reported by several scientists including Khan and Zende (1977), the application of P resulted in significant decrease of Zinc concentration in the cowpea grain, which can affect the nutritional quality (Buerkert et al. 1998). Despite the importance of P in these soils, the use of commercial P fertilizers in West Africa is limited due to high cost of imported fertilizers. Several countries in the region, however, are known to have natural phosphate deposits. (Bationo et al. 2002). Direct application of indigenous rock phosphate (RP) can be an alternative to the use of more

expensive water-soluble phosphorus fertilizers especially if cowpea cultivars capable of utilizing the PR could be identified. The effectiveness of RP in the soil depends on its chemical and mineralogical composition, soil factors, and the crop to be grown (Chien and Hammond, 1978). The relative agronomic effectiveness of Tahoua RP and Kodjari RP in different agro ecological zones of West Africa has been evaluated (Mahamane et al., 1997). The data indicated that Tahoua RP outperformed Kodjari RP from Burkina faso in agronomic effectiveness at two of the three sites. They concluded that the results reflected the chemical composition of the two rocks where the molar PO_4/CO_4 ratio was 25 for Kodjari RP and 4.9 for Tahoua RP. Also, they concluded that the agronomic effectiveness of cowpea was not better than that of the cereal pearl millet crop. This was in contradiction to other reports where legumes have highest strategy to solubilize RP than cereals by rhizosphere acidulation (Hedley et al., 1982) and exudation of organic acids (Ohwaki and Hirata, 1992).

2.3.2 Effect of cowpea production on soil fertility improvement.

Despite the need to apply chemical fertilizer for high yields, the use of mineral fertilizers in West Africa is blocked by lack of capital, inefficient distribution systems, and other socio economic parameters. Cheaper means of improving soil fertility and productivity is therefore necessary. Cereal-legume rotation effects on cereal yields have been reported for the West Africa Semi Arid Tropics (Bagayoko et al., 1996; 2000; Bationo et al., 1998; Klaij and Ntare, 1995; Bationo and Ntare 2002). In all cases, they pointed out that the yield of cereal after cowpea was significantly higher than in continuous cereal cultivation. Cowpea yields also significantly responded to crop rotation, indicating that factors other than N alone contributed to the yield increases in

cereal-legume rotations. Selection of cowpea tolerant to low available soil P and high nitrogen fixing will contribute more positively to these rotation systems in dry areas of West Africa.

2.3.3 Response of cowpea production on soil fertility.

Phosphorus, although not required in large quantities, is critical to cowpea yield because of its multiple effects on nutrition (Muleba and Ezumah, 1985). It does not only increase seed yields but also nodulation (Luse et al., 1975; Kang and Nangju, 1983) and thus nitrogen fixation. P application influences the contents of other nutrients in cowpea leaves (Kang and Nangju, 1983) and seed. Application of P is therefore recommended for cowpea production on soils low in P (Sellschop, 1962; Rachie and Roberts, 1974). However, inorganic P fertilizers are often expensive and not readily available to resource-poor farmers. Furthermore, Fe and Al oxides found in tropical soils can fix P fertilizer into forms unavailable to plants (Samples et al., 1980). Application of inorganic P-fertilizers cannot therefore be relied upon to adequately alleviate P-deficiency for improved cowpea production. Nevertheless, certain minimum levels to which cowpea respond could be investigated to increase the yield in low P soils in farmers' fields in dry areas of West Africa. Furthermore, the genotypic differences in the effect of P on nodulation (Ankomah et al., 1995) and yield (Jain et al., 1986; Tenebe et al., 1995; Sanginga et al., 2000) of cowpea have been reported. In this regard, variability within cowpea breeding genotypes for tolerance to low available P in the field would be helpfull in areas where P-fertilizers are scarce.

The grain legume and P fertilization system is influenced by the initial soil P status as shown by Raij (1979). He has therefore suggested that soil testing for P could prove to be

an effective aid in making decision about rates of fertilizer to apply. Legume crop response to P addition can also be influenced by annual rainfall. Matar (1977) found that the yield response of lentil to P fertilization varied with moisture supply.

2.4 Plant root activity and phosphorus acquisition in low phosphorus soils.

Root growth and distribution are particularly important for P acquisition because of the relative immobility of soluble P within the soil environment and the continual depletion of available P in the root rhizosphere. Root systems themselves are exceedingly complex structures, typically being composed of thousands of individual root axes that vary developmentally, physiologically and morphologically. Deep rooting can be important in accessing nutrients in soil zones that cannot be reached by shallow rooted crop species. Deep-rooted crops such as pigeon pea are reported to extract nutrient from deeper soil layers and make them available for cycling through surface soil (Chanhan et al., 1981). For nutrients of limited mobility such as P, distribution is often stratified with concentration in the upper soil layers in association with soil organic matter, in this case, shallower rooting may increase availability of soil organic P to the plant. Genetic differences have been reported in common beans for root biomass and root: shoot ratio (Fawole et al., 1982) and root biomass distribution among distinct root types.

Lynch and Van Beem (1993) observed substantial genetic variation in the growth and architecture of bean root system, with preliminary evidence that P efficient genotypes have a vigorous highly branched root system with many growing points. A root trait that may also be important for P efficiency is plasticity, or the ability to sense and respond to localized or temporary changes in P availability. Bean genotypes contrast in their degree of root plasticity in response to P stress. Bean roots may also change their geotropic

curvature in response to low P availability thereby changing the total volume of soil exploited by the umbrella of the basal roots. Similarly, with cowpea some kinds of soil exploration were identified including the umbrella architecture, the deep root or lateral exploration by a local genotype (Danila) while some improved cowpea genotypes were observed to form densed root system around the soil surface (Singh et al. 1997).

2.4.1 Phosphorus acquisitions by grain legumes

ustainable P management in agriculture requires additional information on the mechanism in plants that enhance P acquisition in order to make plants more efficient at acquiring P, development of P efficient germplasm and advanced crop management system that increase soil P availability (Vance, 2001).

Studies by Fohse et al. (1988) indicate that species differ in their ability to extract soil P depending upon the potential of roots to absorb P, their active lifetime and the amount of root per unit of shoot.

Some of the mechanisms investigated so far include 1) soil P exploration by cowpea roots (Singh et al. 1997); 2) the soybean root interaction with soil microorganisms such as Arbuscular Mycorrhizal Fungi (AMF) (Abdelgadir, 1998). From the recent work carried out (Sanginga et al., 2000), two high yielding cowpea breeding lines, IT81D-715 (non P responder) and IT82D-849 (P responder) were used to illustrate the different relationships between plant growth characteristics and P uptake efficiency, P use efficiency and % AMF root infection in the moist zone of derived savanna .

Root hair production as mechanism for cowpea to get nutrient including P was studied in growth pouch to screen cowpea accessions for differences in root hair (Omwega et al., 1988) Cowpea genotypes have been detected (Melakh and IT82E-18)

that produce more longer root hairs under low soil P conditions than the other cowpea genotypes using the growth pouch technique.

Relevant studies have described the exudation of piscidic acid by pigeon pea root which is reported to facilitate release of P from normally plant unavailable iron-bound soil P (Ae et al., 1990,1991; Ae and Otani, 1997), and the exudation of citric acid by white lupin (Gardner et al., 1981) and banksias (Grierson, 1992). In the same order, Arihara et al., (1991) demonstrated in pot studies that this ability of pigeon pea to release P from Fe-P could also result in increased P availability to maize subsequently grown in the same pots. This indicate the possibility of pigeon pea being able to introduce otherwise unavailable P into the nutrient cycles of cropping systems. Other mechanism was the root exudates compounds (daidzein, genistein and coumestrol) that induce rhizobial genes and/ or fungal development on cowpea (Dakora, 1989).

Phosphorus-deficient plants exhibit reduced shoot growth and increased root: shoot dry weight ratio (Whiteaker et al., 1976). The decrease in shoot growth of P-deficient plants is a direct consequence of a reduction of leaf expansion and reduced leaf initiation (Lynch et al., 1997), possibly caused by decreased root hydraulic conductance (Radin and Eidenbrock, 1984) and reduced transport of cytokinins from root to shoot (Hergro and Warelug, 1980).

The performance of plants when grown on soils with low P availability is determined by their P-efficiency. Here, efficiency is defined as plant growth and seed yield with suboptimal P availability. Several possible root-related mechanisms have been proposed for improving the P efficiency of crop plants, such as reduced tissue P requirements and increased seed reserves (Lynch and Beebe, 1995), mycorrhizal

symbiosis (Koide, 1991) and root architecture and plasticity (Bonser et al, 1996; Kirk and Du, 1997; Vanvauren et al., 1997). Furthermore, since root systems are composed of various root types that have distinct properties with respect to nutrient uptake (Eshel and Waisel, 1996) and construction cost (Eisenstat, 1992); a change of root system composition may also improve its P uptake efficiency. Variation in growth and architecture of roots among genotypes within a species has been observed in a wide range of species for example barley (Grando and Ceccarelli, 1995), bean (Lynch and Van Beem, 1993), rye (Baon et al., 1993), soybean (Pantalone et al., 1996), white clover (Caradus et al., 1995), and the desert shrub *Gutierrezia sarothrae* (Wan et al., 1996). Plasticity in root properties such as root growth, root architecture, root system composition, and mycorrhizal infection could be beneficial for plant adapting to unfavorable soil condition, such as low P as often observed in weathered tropical soils (CIAT, 1987).

2.5 Role of mycorrhizae in P deficient soils

Mycorrhiza literally means "fungus root", and the name is derived from the Greek words "mykes"(mushroom) and "rhiza"(root). The word describes the union of two different beings to form a single, morphological organ, in which the plant nourishes the fungus and vice versa. Today, two main types of mycorrhizae are distinguished: the endomycorrhizae and the ectomycorrhizae (Harley and Smith, 1983). In the ectomycorrhiza, the fungus grows inter- cellularly in the cortex of the plant's root (so-called hartig net), but never intra-cellularly. On the other hand, in the endomycorrhiza, the fungus grows both inter- and intra-cellularly and forms within the cortical cells specific fungal structures: the vesicles and arbuscules hence the name vesicular-

arbuscular mycorrhiza fungi (AMF) and if the vesicles are lacking, it becomes arbuscular mycorrhiza fungi (AMF), (Smith, 1995; Walker, 1995). AM fungi produce types of soil hyphae including thick 'runner' or 'distributive' hyphae as well as thin absorptive hyphae (Friese and Allen, 1991). The finer hyphae can produce 'branched absorptive structures' where fine hyphae proliferate (Bago et al., 1998). Hyphae of AMF have been observed to proliferate in soil microsites where nutrients are concentrated (St John et al., 1983).

The major effect of AMF on plant growth is due to increased nutrient, particularly P, uptake (Thompson, 1990). Phosphate is polymerised into polyphosphate granules and transported by cytoplasmic streaming through the fungal hyphae to the arbuscules, where exchange with the host takes place (Cooper, 1984). As the plant matures, and particularly at low P level (Thompson, 1986), vesicles (terminal swellings of the hyphae, spherical or ellipsoidal in shape and similar in size to the extraradical spores.) form within the cortex. On the other hand, Chlamydospores are formed in the soil as mycorrhiza matures. Spores production is stimulated by physiological changes in the host plant as an annual crop matures or the tops of mature perennial plant are pruned (Ferguson and Woodhead, 1982). In addition, the effect of AMF on damage caused by Striga hermontica has been pointed out on two contrasting cultivars of sorghum, sorghum bicolour (Lendzemo and Kuper, 2001). It has also been shown that AMF alleviate aluminium toxicity in banana plants (Rufyikiri et al., 2002) and the metal binding capacity of AMF has been shown by Joner et al., (2000). The roots of mycorrhizal plants are more efficient than the roots of non-mycorrhizal plants in P uptake from the soil (Stribley, 1989). In most soils, P is relatively immobile and diffuses slowly to the root, and hence the rate-limiting step in the movement of P to the root is the rate of diffusion (Abbot and Robson, 1984). Therefore

rapid absorption of P by the growing plant soon creates P depletion zones around the roots and consequently the external hyphae of those mycorrhizal roots that extend beyond these zones absorb P from the undepleted zones (Cooper, 1984).

AMF mycorrhizal colonisation is most notably affected by P nutrition of the host (Stribley, 1989). Plants growing in low-P environments and deficient in tissue P are more readily colonised by mycorrhizal fungi than plants of high P status. Host carbon must cross the plasma membrane at the host –fungus interface before becoming available to the fungus. In low-P soils, rate of colonisation is often correlated with growth responses (Abbott and Robson, 1984). It is also indicated that enhanced AMF association of crop through cultivation of mycorrhizal crop in the previous season showed significant growth and yield promotion on soils of high P fixation capability (Arihara and Karasawa 2000).

Several mechanisms have been put forward to explain the increased P uptake by mycorrhizal plants. Fungal hyphae acting as an extension of the root system explore a much greater soil volume than non-mycorrhizal roots and can increase nutrient uptake by reducing the distance that nutrients must diffuse to the plant roots (Cooper, 1984). Mycorrhizae may also modify the availability of nutrients in the rhizosphere for plant uptake. Harley and Smith (1983) reported that mycorrhizal roots could exploit sources of P in soils not normally available to plants (e.g., rock phosphate, fixed inorganic phosphate or organic phosphate). They reported that mycorrhizal maize responded to the application of rock phosphate or tricalcium phosphate whereas non-mycorrhizal maize did not respond. They speculated that the enhanced uptake might involve proton (H+) extrusion, excretion of organic acids or release of extracellular enzymes (e.g., phytases or phosphatases) by the fungal hyphae. Dodd et al. (1987) have investigated and pointed out

a phosphatase activity associated with the roots and the rhizosphere of plants infected with AM fungi. Phosphatase activity of extra radical arbucular mycorrhizal hyphae has been recently reviewed (Joner et al., 2000). The external mycelia of AMF have been shown to mobilize sparingly soluble inorganic phosphates (Qing et al., 2001).

In field experiment of Sudano-Sahelian of West Africa, Bagayoko et al. (2000) and Alvey et al. (2001) reported the role of AMF in rotation effects. In a research work on the effect of agricultural practices on the development of indigenous arbuscular mycorrhizal fungi in field studies in an Indonesian ultisol, Boddington and Dodd (2000) pointed out the significance of the abundance of AMF for subsequent benefits to plant growth and development, and ultimately the sustainability of tropical agro-ecosystems.

All this elaboration was considered on AMF because it has been shown that many crops including cowpea depend on AMF for P uptake especially in low P soils.

2.5.1 Mycorrhizal dependencies

Gerdeman (1975) defined mycorrhizal dependency (MD) as the degree to which a host relies on the fungus condition to produce maximum growth at a given level of soil fertility. Baylis (1975) drew attention to the relation between root morphology and AMF dependency. Furthermore, attempts have been made to quantify MD. Menge et al. (1978) calculated a MD index as the dry mass of the mycorrhizal plants expressed as a percentage of that of the nonmycorrhizal plants. Plenchette et al. (1983) proposed another index with values constrained below 100%, termed relative field mycorrhizal dependency (RFMD) calculated as (mass of the mycorrhizal plants - mass of the nonmycorrhizal / mass of the nonmycorrhizal) x 100.

2.5.2 Selection of plant genotypes for AMF infection.

Although the extent of root colonization and responsiveness to AM fungi are known to differ from one plant species to another, much less is known about the differences among genotypes within a plant species. Heckman and Angle (1987) examined 15 soyabean cultivars for colonisation by a heterogeneous field population of AM fungi at two P levels and found that colonization varied significantly with cultivar. Krisna et al. (1985) found that root colonisation by indigenous AM fungi differed among 30Pearl millet genotypes. In another, with two male-sterile lines, restorer lines, and their derived crosses, Krishna et al. (1985) also found that root colonization differed significantly among pearl millet genotypes, suggesting that the trait for AMF colonization is heritable. Furthermore, Mercy et al. (1990) also pointed out that mycorrhizal colonization in cowpea is host dependent and heritable. Recently, the effect of white clover (Trifolium repens) genotype on mycorrhizal symbiosis with Glomus mosseae has been revealed by Eason et al. (2001).

2.5.3 AMF, crop and Phosphorus in soil.

AMF may play a critical role in low-input systems due to their function in linking plant and soil processes (Eason et al., 1999).

Young et al. (1986) studied the effect of rock phosphate application and mycorrhizal inoculation on corn grown in two soils, Houli and Wanlaum soil, with available P levels of 6.3 and 60 mg kg^{-1}, respectively. They observed that AMF inoculation increased corn yield significantly in both soils with the effect being more pronounced in soil with low available P. They hypothesised that the fungus produced compounds that dissolved rock phosphate. The importance of inoculation with vesicular

arbuscular mycorrhiza to increase P utilisation by cowpea and groundnut was reported by Sanni (1976) and Islam et al. (1980).

Rock P might improve the residual value of applied P in soil and it does not reduce the level of AMF infection as soluble P fertilizer does (Barea et al., 1980).

Due to the low mobility of P ions, AMF can increase uptake of P in soils of moderate or low P status, as the AMF hyphae tap soluble P beyond the P depletion zone around the root surface (Hayman, 1993). Moderate rates of P fertilization do not depress AMF infection. For example, in pot experiments, two isolates of G. clarum showed different efficiency in increasing growth and AMF colonization of soyabean, but both isolates showed the highest AMF colonization in plants supplemented with a low level of P (Louis and Lim, 1988). A similar response to P has been found in Ladino clover infected by Acaulospora louis (Wilson, 1988). The length of hyphae of G. fasciculatum was also maximum in subterranean clover fertilized with a low P level (Abott et al., 1984). However, increased root infection with increasing P application has also been observed. For example, Cassava roots showed increased infection by Glomus manihotis with increasing P application up to 200 kg P ha^{-1}, although infection by other AM F decreased with increasing P application (Sieverding and Howeler, 1985). Clark and Mosse (1981) compared indigenous and introduced AM fungi in their response to P application (82.6 kg P ha^{-1}) and found that in barley roots, added P depressed infection by indigenous AMF more than it depressed infection by the introduced AM F.

2.5.4 Factors affecting the crop-AMF association system.

Various physical, chemical and biological factors affect the AMF association system. Ligth and temperature are known to affect plant-AMF balance (Hayman and

Tavares, 1985). Since AMF and Rhizobacteria coexist in agricultural lands and both microorganisms affect plant growth, their interactions can easily be visualised (Meyer and Linderman, 1986). Nevertheless, light, temperature, pH and microbiological components can be manipulated only to a limited extent in the field. On the other hand it is much easier to alter the soil environment of agricultural land by changing cropping pattern, nutrient status and cultivation method. Black and Tinker (1979) measured the root colonization and spores numbers of AMF with different crop rotations of barley and fallow. Spore number and subsequent infections of a barley crop were the largest following barley; both kale and fallow breaks reduced spores population and infection similarly. Harinikumar and Bagyaraji (1989) showed that cropping with groundnut resulted in higher AMF colonization; sporulation and infection propagules in the soil than cropping with cowpea and finger millet and these effects were carried over the next season when sunflower was grown. Excessive secondary tillage and traffic reduced the colonization of common bean (Phaseolus vulgaris) root by AMF (Milligan et al., 1985). It has also been found that the effect of soil oxygen was more pronounced in mycorrhizal plants than in non-mycorrhizal plants. The effects of tillage practices on AMF infection have been studied in relation to P absorption by plants. Evans and Miller (1988) demonstrated that disturbance of previously zero tilled soil reduced AMF infection to a degree such that plant P uptake was reduced. Similarly, Anderson et al. (1987) have shown that plant P uptake was significantly greater under zero tillage than under conventional tillage, and AMF infection in the surface layer under zero tillage was greater than in any other layer under either zero or conventional tillage. Jasper et al.

(1989) have shown that soil disturbance reduces the infectivity of external hyphea of AMF.

2.6 Characters required for an effective symbiotic nitrogen fixation

Genotypes that mature in 90 days have short time to nodulate and fix nitrogen before flowering and pod-fill occur, whereas long duration, indeterminate genotypes have a substantially longer period of nitrogen fixation (Giller, 2001). The ability to form nodules and to begin fixing nitrogen quickly is particularly important for short duration genotypes. In some grain legumes, such as soybeans (Glycine max) and Bean (Phaseolus vulgaris) the timing of nodule senescence often coincides with seed development, and the period of active nitrogen fixation will be longer if senescence of the nodules is delayed so that nitrogen fixation continues during pod-fill.

Early maturing pigeon pea varieties appear to nodulate and fix nitrogen poorly compared with long duration varieties (Kumar Rao et al., 1995; 1996). In Australia, pigeon pea exhibits highly variable nodulation even when inoculated and is often considered to poorly fix nitrogen (Brockwell et al., 1991), although estimates from India and Africa show that it can often fix large amounts of nitrogen. The smaller amounts of fixation with Vigna unguiculata and Phaseolus vulgaris tend to be for shorter season, determine types and the larger amounts are found with spreading or climbing varieties.

There has been considerable debate on the specific requirements for P in symbiotic legumes (Vance et al., 2000). Some data indicate a direct effect of P deficiency on nodule development and function, (Vance et al., 2000) whereas other data show the effects are indirect via changes in plant growth and metabolism (Graham and Vance, 2000; Vance et al., 2000). Recently, Almeida et al. (2000) reported results showing

severe P deficiency prevented nodulation of white clover, and inhibited growth of established nodules in nodulated plants subjected to severe P deficiency. These authors have proposed that at low P supply an N feedback mechanism is induced which down-regulates or even prevents nodulation and nodule growth. Phosphorus application can increase the number, volume, and dry weight of nodules and nitrogen fixation of legumes (Koala, 1985). In experiments conducted in low P soils at Bozeman, Montena, USA, increasing P supply increased faba bean, common bean and green pea nodule numbers and dry weights (Koala, 1985). In a study, Adelson and Marcelo (2000) have pointed out the ontogenic variations on absorption and utilisation of phosphorus in common bean cultivars under biological nitrogen fixation.

Symbiotic N_2-fixation increases plant demand for P and the most common nutritional disorders in legumes are related to P deficiency (Munns and Thorre, 1980). Nodular tissue in legumes may contain up to five times the concentration of P in the other plant tissue and nitrogenase activity has a high P demand, with about 21 mol ATP converted to ADP mol^{-1} N_2 reduced (Barea and Azcon-guilar, 1983). Therefore, the P requirement for some strains of root nodule bacteria has been shown to be very low, less than 0.5µmol/l P in the external environment, and growth rate can be affected by concentration of available P (Watkin et al., 1997). Thus, P has a key role in bacterial signalling systems through receptors involving kenases and non-kenases and other metabolic processes requiring phosphorylation steps such as the regulation of intracellular enzymes and the binding of protein to DNA for gene regulation (Moat and Foster, 1995).

Pioneering work by Asai (1944) indicated that nodulation of several legumes by rhizobia depended on their roots being mycorrhized. There have been several works on AMF and legumes (Munns and Thorre, 1980; Barea and Azcon-Aguilar, 1983). Smith et al., (1979) found the earliest effects of AMF in Subterranean clover were to increase root P concentration, nodulation and nitrogenase activity (Smith et al., 1979) through an increased, steady supply of P from the roots to adjacent developing nodular tissue. Therefore, the effects of AMF on N_2-fixation and growth of legumes results largely from improved P nutrition (Abott and Robson, 1984), although other mechanisms have been considered.

The effectiveness of AMF on plant N acquisition depended on the AMF involved, Glomus intraradices was found to be effective, particularly at the highest N rate (Vazquez et al., 2001). On the other hand, N_2-fixation enhanced by AMF colonization, contributed to N acquisition when a moderate N quantity was available in the soil. Dominique et al. (1997) reported that plants colonized with AM fungi showed a greater ability to take up soil nitrate than those that were not.

The effect of dual inoculation with AMF and Rhizobium on P nutrition, N_2-fixation and yield of chickpea was illustrated by the work of Subba Rao et al. (1986). Similar results were shown on soybean in West African moist savanna (Abdelgadir, 1998). Manjunath and Bagyaraj (1984) studying the response of pigeonpea to factorial combinations of inoculation with Glomus fasciculatum and Rhizobium and application with P fertilizer (22 kg P ha^{-1}) in pots of nonsterilized sandy loam soil of pH 5.6 observed AMF substantial increase in dry mass of tops and their content of P and N.

The effect of phosphorus and nitrogen on growth of pasture plants and AM fungi in S.E Australian soils with contrasting fertilizer histories (conventional and biodynamic) were given by Megan and Julian (1999). Furthermore, Sanginga et al. (2000) studied the phosphorus use efficiency and nitrogen balance of cowpea breeding lines in a low P soil of the derived Savanna zone in West Africa and found significant correlation between AMF and P-use efficiency.

An impact of soil nitrogen concentration on Glomus *spp*. Sinorhizobium interaction as affecting growth, nitrate reductase activity and protein content of Medicago sativa was pointed out by Vazquez et al. (2001).

On the other hand, Smith et al. (1979) showed the effect of early mycorrhizal infection on nodulation and nitrogen fixation in Trifolium subterranean *L*. Then after, Kirsten and Richard (1999) have indicated the effects of mycorrhizal colonisation on biomass production and nitrogen fixation of black locust (Robinia pseudoacacia) seedlings grown under elevated atmospheric carbon dioxide. This led to the review by Treseder and Allen (2000) showing that mycorrhizal fungi have a potential role in soil carbon storage under elevated CO_2 and nitrogen deposition.

Mader et al. (2000) in a study pointed out the transport of ^{15}N from a soil compartment separated by a polytetrafluoroethylene menbrane to plant roots via the hyphae of AMF. On the other hand, Barea et al. (1989) showed the time course of N_2-fixation (^{15}N) in the field by clover growing alone or in mixure with ryegrass with AM fungi inoculation to improve pasture productivity.

It has been shown by Abdelgadir (1998) that soyabean varieties differed markedly in their response to P, the time of response to P, grain yield potential,

nodulation, mycorrhizal colonization, P absorption, and N_2-fixation. On the other hand, Zhu and Smith (2001) have pointed out that seed phosphorus (P) content affects growth and P uptake of wheat plants and their association with AMF. Mycorrhizal plants grown from seed low in P accumulated similar amounts of P compared with those grown from seeds with high P content. Abott and Robson (1984) strongly recommended comparing mycorrhizal plants and nonmycorrhizal plants over a range of applied P rates so that full response curves could be obtained.

In another study, Islam et al. (1980) showed a response of cowpea (Vigna unguiculata) to inoculation with AMF and rock phosphate fertilization in some unsterilised soils of Nigeria. Nodulation, nitrogen fixation and utilization of rock P were increased by inoculation in pot but not in field experiment.

2.7 Residual effects of legume crops on cereal crops

Substantial quantitative information on the amount of N and P available to crops succeeding legumes in a rotation and other treatment like phosphate rock application are available (Bagayoko et al., 2000). The beneficial effects of legumes on succeeding crops can often arise due to a variety or other effects, such as reduction of disease incidence (Marcellos et al 1997) or by reducing attack by striga, a parasitic weed that can often devastate yields of cereal crops (Reddy et al 1994).

In northern Nigeria, maize grain yields were found to be greater following a groundnut crop than after crops of cowpea, cotton or sorghum. The yield increase was related to an increase availability of mineral N in the soil after groundnuts (Jones, 1974). No such beneficial effect was found after growth of cowpea in the same experiment. In Zimbabwe, the yield of maize was greater after bambara groundnut (7.6 t ha^{-1}) than after

groundnut (6.2 t ha^{-1}), unplanted fallow (4.3 t ha^{-1}) or maize (3.9 t ha^{-1}) (Mukurumbira, 1985). Groundnut and cowpea were found to have roughly equal residual effects on the growth of a subsequent maize crop in northern Ghana equivalent to the addition of 60 kg fertilizer N ha^{-1}. This was despite the fact that 68 kg N ha^{-1} was left behind in above-ground residues after groundnut and 150 kg N ha^{-1} after cowpea (Dakora et al., 1989).

Direct evidence of the benefits from nitrogen fixation was obtained where yields of sorghum grown after nodulating varieties of chickpeas were better than yields after non-nodulating chickpeas (Kumar Rao and Rupela, 1998). As most of the aboveground parts of grain legumes like cowpea are removed at harvest, residual effects must come from the below-ground parts (roots and decaying nodules) and leaves that fall to the soil during growth of the crop. In India, pigeon pea was found to give a residual benefit to subsequent maize crop of 38-49 kg N ha^{-1} (Kumar Rao et al., 1983), which was partially attributed to a contribution of N from peageon pea leaf fall of 30-40 kg N ha^{-1}. The amount of N in leaves that fall during growth of long duration pigeon pea may be as much as 68-84 kg N ha^{-1} (Kumar Rao et al., 1996). Over 12 years, yields of sorghum were consistently higher following a sorghum/pigeon pea intercrop or than after an oilseed crop, and the soil N content had increased significantly where pigeon pea had been grown (Rego an Rao, 2000).

Yields of maize grown after soybean on an Alfisol were increased from 2.5 to 4 t ha^{-1}, compared with only 1.8 t ha^{-1} in continuous maize cropping where all the stover had been removed (Kasasa et al., 1999), but this may be partly due to other rotational effects and not simply nitrogen fixation. The below-ground contribution that specifically came from nitrogen fixation in groundnut was estimated by comparing N uptake by maize

following nodulating and non-nodulating varieties (McDonagh, 1993). The amounts were small ranging from 0 to 10 kg N ha^{-1} and included inputs from roots and fallen leaves. On station trials on sandy granitic soil, the yield of maize was almost doubled from 2.5 to 4.6 t ha^{-1}, after a groundnut crop that yielded only 0.4 t grain ha^{-1}even though most of the Stover was removed by cattle (Waddington and Karigwindi, 2001).

Smallholder farmers do not have choice than to carry away the whole aboveground dry matter of the grain legumes at harvest for rearing animals anyway. However the alternative is to put effort on the belowground production that will improve the fertility status of the soil.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

Series of trials were carried out in the screenhouse and the field, while soil and plant analysis and microbiological tests were caried out in the laboratory during the period 2002 to 2004.

The following trials were conducted under screenhouse conditions.

1. Phosphorus (P) calibration study to select the desirable level of P to be used in the field trials.
2. Screening of 15 selected cowpea genotypes for response to P fertilizer sources.
3. Residual benefits of 15 cowpea genetotypes to subsequent sorghum.

In addition, the following trials were also conducted under field conditions.

1. Screening of 147 cowpea genotypes for tolerance to low P or response to applied P.
2. Further screening of 15 selected genotypes for tolerance to low P or response to P on newly selected low P soils.
3. Residual benefits of 15 cowpea genotypes grown under low and high P conditions to subsequent sorghum..

The Laboratory tests consisted of routine analysis of soil samples, P fractionation of the soils of Minjibir and Toumnia fields before cropping, Microbiological observations of AMF infection rate of the root of selected cowpea genotypes and sorghum, Nitrogen fixation of the 15 selected genotypes by the ureide

method (Herridge, 1988) and total root elongation measurement by The Delta-T Area Meter Type AMB2.

3.2 Description of experimental locations

The field experiments were conducted at Minjibir (12º 8.73' N 8º 39.97' E) in the Sudan savanna of Nigeria and Toumnia (13º 28.76' N 9º 1.79' E) in the Sahel savanna of Niger Republic in the 2002, 2003 and 2004 cropping seasons. At Minjibir, rainfall is monomodal, beginning in May and ending in early October with mean annual total ranging between 600-1000mm. Mean temperature ranges from 26°C- 33°C. In their natural state, the soils are latosols. The soils largely reflect the influence of parent materials. Intensive use of the soils and addition of manure and chemical fertilizers have altered their character, profile, texture, structure and chemical characteristics. The natural vegetation consists of the Sudan savanna vegetation composed of farmed parkland, dotted with patches of shrub savanna (Matlon, 1987).

At Toumnia the average annual rainfall ranges from 200-400mm. Toumnia experiences great temporal variation in rainfall amount and duration. In this part of the world evapo-transpiration exceeds rainfall during at least 5 months of the year (Siva Kumar, 1989). Temperatures are warm (annual mean 25ºC-40ºC) and end-of-season drought is common (Bationo et al., 1982). The productivity of the soil is reduced with continuous cultivation because of lowering of organic matter below critical levels, physical removal of soil by wind or water erosion, leaching of nutrients, especially in light-textured soils, and exhausting of soil nutrients by crop removal. The soils are predominantly sand to sandy loam. Clay content ranges from 1 to 5% and the soils have a

weakly coherent massive to sub angular blocky structure. Due to their sandy nature, the surface soils have a friable consistence and they can crust when dry. They are classified as Aridosols (Stoop, 1981). The natural vegetation consists of the Sahel savanna vegetation basically prairie vegetation of annual grasses but with larger and more numerous trees and shrubs than the area further to the north. In addition to the tree woody species, one commonly finds Acacia albida, A. raddiana, A. seyal, Balanites aegyptica, Zizyphus mauritiana, and Boscia senegalensis.

Soil samples for all the screenhouse studies and characterizations were collected from the locations shown in Fig. 1.

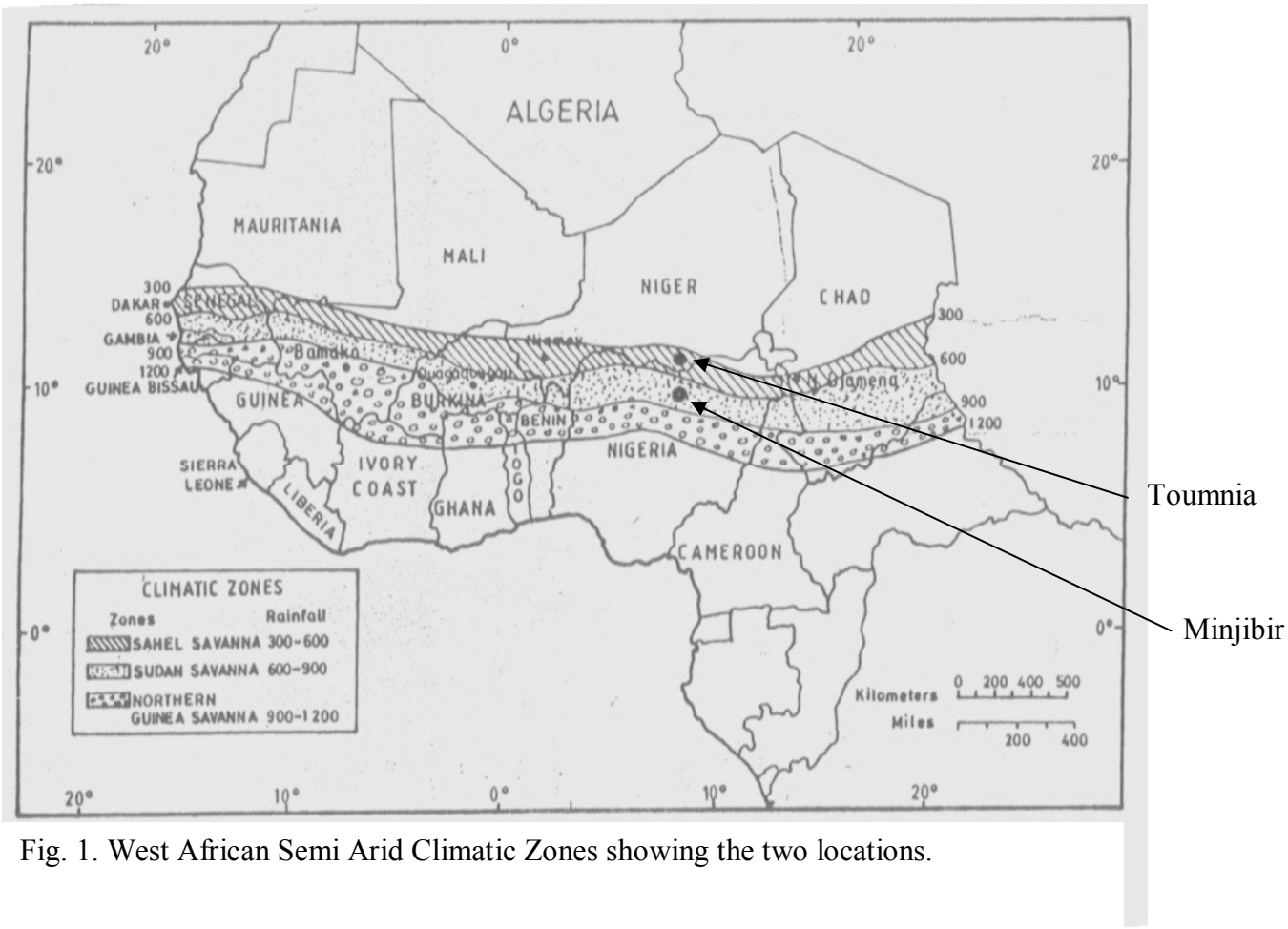


Fig. 1. West African Semi Arid Climatic Zones showing the two locations.

3.3 Experiment 1: Screenhouse

Phosphorus calibration study to select desirable levels of P for use in the field trials.

The objective of this experiment was to select desirable P rates that would be used in the field for the screening of a large number of cowpea genotypes in the field.

3.3.1 Site description

All screenhouse experiments and laboratory analyses were conducted at the International Institute of Tropical Agriculture (IITA) Kano station, between May 2002 and November 2004. The temperature ranged between 30 and 34^{o}C and relative humidity between 50 and 70%.

3.3.2 Selection, collection and sampling of low P soils

3.3.2.1 Selection of low P soils

Soils and landscape positions most appropriate for low P tolerant cowpea were selected from Minjibir and Toumnia. This involves avoiding the best fields in terms of high native fertility especially high P availability (Sanchez and Salinas, 1984). Efforts were made to select fields low in P around settlements where rainfall is acceptable. Acid and infertile soils with severe physical limitations such as shallow depth or steep slopes and coarse sandy soils were avoided.

3.3.2.2 Soil sample collection and preparation

Soil samples were collected before land preparation from the two locations at 0-10 cm depths for available P analysis. These were air dried, ground and sieved with 2 mm sieve and used for routine analysis to characterize the fields. The data were also used as guide for the selection of sites for field experimentation and collection of soil for screen

house trials. The samples were also used for P fractionation. Sub samples of river sand collected around Minjibir for screenhouse studies were also characterized along with these soil samples.

3.3.3 Treatments and experimental design

The treatments were 4 levels of P (0, 3.25, 6.5 and 13 mg P kg^{-1} soil) as SSP, two soils (Minjibir and Toumnia), 9 cowpea genotypes (IT82D-849, IT86D-715, IT89KD-374, IT89KD-349, IT89KD-391, IT90K-59, Danila and IT90K-277-2) and maize (Oba super one) as test crops. There were 80 treatment combinations arranged in a randomized complete block design (RCBD) and replicated 4 times.

3.3.4 Screenhouse procedure

Three kilogrammes of the soil from the designated locations and corresponding amount of fertilizer were added in each pot (15cm in height and 13cm in diameter) and the content mixed thoroughly. Basal application of 13 mg K kg $soil^{-1}$ (30 kg K ha^{-1}) as KCl was applied to all pots while only pots cropped with maize received 75 ppm of $(NH_4)_2SO_4$. The soils were brought to field capacity by watering them with tap water. Later, all the pots were watered daily using the same quantity of tap water that was used to bring them to field capacity. The trial started in May 2002. Four seeds of each cowpea genotype and five seeds of maize were sown. The seedlings were thinned to two plants pot^{-1} after emergence. Insecticide Sheper plus (active ingredient as Cypermethrine 30g l^{-1} + Dimethoate 250g l^{-1}) was sprayed to check insect attack on the cowpea. The crops were grown for six weeks.

3.3.5 Measurements

All the above ground biomass cut at soil level using a secateur and put in well-labeled paper bags. The roots were harvested by washing off all soils on them under a gentle running tap water. For the cowpea, the nodules were separated, counted and enveloped. All samples were put in an oven at 65^{o} C and dried for 48 hours. The shoot, root and nodule dry weights were then measured using a mettler balance.

3.4 Physicochemical characterization of the soils and river sand

The particle size distribution was determined by the hydrometer method as described by Day (1965) while soil pH was determined using a 1:2.5 (soil in water and soil in KCl) ratio with a glass electrode pH meter. Total nitrogen was determined in soil samples by the micro-kjeldahl method described by Bremner (1965). P extraction was determined by wet digestion method using perchloric, nitric and sulphuric acids as compiled by Juo (1974). The colour was developed by the Vanado-molybdate method and the available P was determined by the Olsen method (Olsen et al, 1954). Total carbon was also determined by the method described by Dalal (1979) and modified by Amato et al. (1987). Exchangeable cations K, Ca, Mg and Na were determined by ammonium acetate (NH_4OAC) extraction method of Jackson (1958). Ca and Mg were determined using the AAS while the K and Na were determined using the flame photometer (Thomas, 1982).

Sequential P fractionation was carried out using the modified Hedley procedure (Tiessen et al., 1984). Murphy-Riley (1962) method was used directly on the same set of soils for the P recovery from the resin strip and for Pi determination in the 2M HCl extracts.

3.5 Biological characterization of the soils

Mycorrhizal spores were enumerated in the soils before field study. Similar enumerations were carried out on the soils collected after the field evaluation of the 147 cowpea genotypes using the method of Brundrett et al. (1996). Mycorrhizal infection rate was determined using the method of Giovanetti and Mosse (1980). Rhizobial population count in both soils was also determined by the Most Probable Number (MPN) technique (Woomer et al. 1990).

3.6 Measurement of N_2 -fixation.

The sap samples were collected on the field between 11 a.m and 1 p.m by cutting the stem of the cowpea plant at 2 to 3 cm above soil level and by placing a rubber tube to collect the bleeding sap (xylem exudates sample). A sterile syringe was used to withdraw the sap from the rubber tube and dispensed into a tube containing an equal volume of absolute alcohol. The sap was analysed using three different analytical procedures, the results of which were combined to estimate the amount of N_2 fixed. Total ureide was determined by the method described by Young and Conway (1942). The determination of total amino acid was carried out following the method of Yemm and Cocking (1955) and Herridge, (1984). Nitrate determination was carried out by the salicylic acid method (Cataldo et al., 1975, Herridge, 1984).

3.7 Plant analysis

At early pod filling stage, plant shoots were cut at the surface of the soil. The plant samples were oven-dried at 65° C for 48 hrs and ground using a stainless pestle and mortar. Percentage N and P were determined in ground and sieved dry shoot by the wet

digestion method. The total nitrogen was determined by the micro-kjeldahl method described by Bremner (1965).

Phosphorus in the plant samples was extracted by digestion with perchloric, nitric and sulphuric acids as compiled by Juo (1974). The N and P concentrations in the plant samples were multiplied by the dry matter yield to obtain the total N and P uptake or accumulation in the tissue.

3.8 Experiment 2: Field

Screening of cowpea genotypes for tolerance or response to applied P on low P soils at Minjibir and Toumnia.

3.8.1 Site history

Two field experiments were established for screening cowpea genotypes for tolerance or response to applied P on low P soils. One experiment was established at the Institute for Agricultural Research (IAR) research field located at Minjibir, in 2002. The plot was relatively flat and was planted to sorghum in 2001. The second experiment was established at Toumnia. The trial was established in a farmer's field which was planted to millet and cowpea in 2001. Initial soil analysis showed that the soils at the 2 sites were very low in Olsen P.

3.8.2 Land preparation

In 2002, fields at both Minjibir and Toumnia were cleared of small shrubs. At Minjibir site, the field was ploughed and disc harrowed twice. Before the second harrowing, the field was sprayed with the herbicide gramoxone (ingredients as Paracoat Dichloride 276g l^{-1}) at the rate of 9.44 L ha^{-1}. Ridges were made at 1 m apart using a chisel plow while at Toumnia; the topography of land was maintained but with inters row

distance as reported for Minjibir. The 1 m spacing was made to avoid the mixture between the crawling genotypes.

3.8.3 Experimental design

A strip plot design was used with 2 P sources (RP and SSP) (+P) and without P (0P) as main factor while the 147-cowpea genotypes (Table 1) were randomly allocated to the main factors as sub factors. Each experimental unit was replicated four times.

3.8.4 Fertilizer application, planting and management practices

In 2002, Tahoua RP at 90 kg P ha^{-1} and SSP at 30kg P ha^{-1} as the sources of P fertilizers were applied by banding along the ridges and planting strips at about 0-3 cm depths before planting. The mined RP deposits consist of apatite with the following empirical formula: $Ca_{9.79}Na_{0.15}Mg0_{0.06}$ $(CO_3)_{0.61}(PO_4)_{5.39}F_{2.24,}$ consisting of 36% P_2O_5, 52%Ca, 0.5% H_2O, 0.1% sulfur and 3.7% fluorine. Because of its low carbonate substitution for phosphate in the apatite structure, it is considered as low reactivity RP (Bationo et al., 1982). Muriate of potash was applied at 30 kg K ha^{-1} in blanket application. The gross area of P application was 4 m x 1m = 4 m^2. Seeds of cowpea were sterilized using alcohol and hydrogen peroxide for 10 mins and 3 mins respectively (Vincent, 1970), and 3-5 seeds of cowpea were sown manually $hill^{-1}$ at a planting spacing of 0.25m within and 1m between rows. One week after emergence (WAE), the plants were thinned to 2 $hill^{-1}$. The plots were kept weed free from the onset by hand weeding to avoid disturbances of AMF establishment. Pest control especially Maruca (Maruca vitrata), the major pest in the area was done by the use of Delphos (Monocrotophos AC-E2) at the rate of (1L ha^{-1}) sprayed on the top of leaves. The fields were sprayed two to three times depending on the severity or frequency of pest attack.

Table 1: Cowpea genotypes used in the 2002 field trials at Minjibir and Toumnia.

S/N	GENOTYPES	S/N	GENOTYPES	S/N	GENOTYPES	S/N	GENOTYPES
1	*TN256-87	26	IT98K-1045-5	51	IT98K-128-3	76	IT98K-463-6
2	91A100-1	27	IT97K-506-15	52	TVX-3236	77	IT98K-131-2
3	TN93-80	28	IT95K-825-3	53	IT98K-409-5	78	TVX-1059-O3E
4	*TN28-87	29	IT95K-1091-3	54	IT97K-825-3	79	IT82-E-32
5	TN121-80	30	IT99K-210-2	55	IT97K-499-38	80	IT82-E-18
6	TN3-78	31	IT95K-1090-12	56	IT95K-181-9	81	IT84S-2246-4
7	TN88-63	32	IT97K-819-180	57	IT98K-205-15	82	IT89KD-391
8	IT97K-499-39	33	IT97K-1034-81	58	IT97K-568-18	83	IT89KD-260
9	IT98K-690	34	IT90K-82-2	59	*IT99K-826-119	84	IT89KD-349
10	IT98K-205-10	35	IT81D-994	60	*IAR-48	85	IT00K-1147
11	*IT97K-819-154	36	*DANILA	61	IT97K-818-28	86	*IT00K-1148
12	IT98K-205-9	37	IT97K-1034-94	62	IT99K-1369	87	IT00K-1150
13	IT90K-76	38	IT98K-415-6	63	IT98K-506-1	88	IT93K-452-1
14	IT97K-1021-15	39	IT95K-1075-3	64	IT86D-719	89	*IT98K-476-8
15	IT99K-718-6	40	IT99K-573-2	65	IT97K-837-8	90	93KZ-2-8-21-23-6
16	IT98K-394-20	41	IT98K-96-39	66	TVU-12349	91	IT95K-1093-5
17	IT98K-399-32	42	IT97K-1069-6	67	IT97K-837-8	92	IT88D-867-11
18	IT97K-819-172	43	B-301	68	IT98K-568-11	93	IAR-01-1007
19	IT97K-209-4-1	44	IT98K-422-2-2	69	TVU-7778	94	IAR-01-1011
20	*IT97K-819-170	45	IT95K-193-12	70	IT97K-1069-5	95	IAR-01-1020
21	IT95K-501-12-1	46	IT99K-98-1	71	IT99K-206-2-1	96	IT99K-1060
22	*IT97K-813-21	47	IT99K-573-2-1	72	IT97K-499-3	97	IT99K-718-6
23	IT97K-499-8	48	IT97K-1034-39	73	IT94K-440-3	98	IT98K-131-1
24	IT97K-819-220	49	IT98K-1099-5	74	IT98K-598-1	99	*IT98D-1399
25	IT98K-1093-5-2	50	IT97K-377-4	75	IT97K-1021-24-2	100	IT98K-642-2
101	*IT99K-213-21	113	IT97K-1068-7	125	IT96D-733	137	IAR-01-1068
102	IT98K-205-29	114	IT97K-820-13	126	TVU-13464	138	IAR-01-1049
103	*IT90K-277-2	115	IT97K-819-178	127	IT97K-1075-7	139	IAR-01-1051
104	IT97K-556-4	116	IT99K-1365	128	IT98K-503-1	140	IAR-01-1063
105	IT98K-463-7	117	IT97K-819-45	129	ACHISHIRU	141	IAR-01-1065
106	IT98K-452-1	118	*IT97K-340-1	130	IT98K-419-3	142	IAR-01-1069
107	IT98K-409-4	119	IT97K-497-2	131	IT98K-317-8	143	IAR-01-1071
108	IT97K-1021-24	120	IT95K-105-2	132	IT99K-451-5	144	IAR-01-1074
109	*ALOKA	121	IT97K-819-14	133	IT99K-529-2	145	IAR-01-1015
110	IT97K-1034-92	122	IT96D-748	134	IT98K-205-8	146	IAR-01-1080
111	IT97K-1034-89	123	IT97K-819-118	135	IAR-01-1083	147	IT89KD-374-57
112	IT97K-1034-81	124	IT97K-1069-5	136	93KZ-2-8-21-23-3		

*Selected genotypes for further screening.

3.8.5 Observations and measurements

Cowpea harvest started at phenological growth stages. The pods of the matured cowpeas were hand picked as they dry and put in well labeled harvesting cloth bags assigned to each cowpea genotype. The gross plot of $4m^2$ was harvested. The above ground biomass or fodder was harvested using a secateur to cut at soil level and it was rolled on the plot to dry. After drying, the fodder of each cowpea genotype was weighed using top loading scale. The pods were manually threshed and the grain was weighed using a mettler balance.

3.9 Experiment 3: Field

Screening of the selected cowpea genotypes on low P soils at Minjibir and Toumnia.

3.9.1 Site history

The experiment was established in new location in IAR research farm at Minjibir. The plot was relatively flat and has been under fallow for 2 to 3 years. At Toumnia, the experiment was established in another farmer's field, which was planted to cowpea in 2002. Initial soil analysis showed that the soils in the 2 sites were also very low in Olsen P (0.7 mg P kg $soil^{-1}$ at Toumnia and 2.1 mg P kg $soil^{-1}$ at Minjibir).

3.9.2 Land preparation, experimental design, treatment and plot lay out

In 2003, at Minjibir ridges were made at 0.75 m apart using a chisel plow while at Toumnia, flat land was maintained with inter row distance of the same 0.75 m. The row spacing here differed from the first screening because the number of genotypes was reduced to 15. A strip plot design was used with two P rates (90 kg ha^{-1} RP and 30 kg ha^{-1} as SSP) and without P (0P) as main factor while the 15-cowpea genotypes, (TN256-87,

IT98K-476-8, IT98K-819-170, IT98K-819-154, IT99K-826-119, IT98D-1399, IT99K-213-21, IT98K-813-13, IT00K-1148, TN28-87, IT90K-277-2, Aloka, Danila, IAR-48, and IT98K-340-1) was randomly allocated to the main factors as sub factors. Each experimental unit was replicated three times. The 15-cowpea genotypes were screened for tolerance, response to applied P, nitrogen fixation, AMF infection rate as well as the residual effect on subsequent sorghum. In order to recall the starting point the following season stones were placed at each corner in the fields. However, at Minjibir the previous ridges made it possible to recall the starting points.

3.9.3 Fertilizer application, planting and management practices

In 2003, Fertilizer was applied the same way as in 2002; 3-5 seeds previously sterilized according to (Vincent, 1970) were planted at a spacing of 0.25m within and 0.75m between genotypes. One WAE, the plants were thinned to 2 $hill^{-1}$. The plots were kept weed free during the season by hand weeding to avoid disturbances of AMF establishment. Pest control was done by spraying Delphos (Monocrotophos AC-E2) at the rate of 1L ha^{-1}. The fields were sprayed two to three times depending on the severity or occurrence of the pest.

3.9.4 Observations and measurements

Cowpea genotypes were observed for flowering initiation and harvested at early pod filling growth stage to measure nitrogen fixation and mycorrhizal infection rates. The above ground shoot biomass was cut using a secateur.

The bleeding sap was collected using rubber tubes of different diameters to size the stems of the different cowpea genotypes and syringes were used in sampling the sap and kept in vacutainer containing the same volume of absolute alcohol to

preserve the sap for a long period of time. Root samples were carried out in the field at early Pod-filling stage of the plants by gentle digging with a hand fork. The fine root (about 5 g) of the plants was sampled for the mycorrhizal infection rate analysis. The same plant samples were kept for total N and P analysis in the shoot.

Harvest was started at physiological maturity growth stages. The pods of the matured cowpeas were removed with hand from the two middle rows of each plot and kept in well labeled harvesting cloth bags assigned to each cowpea genotype. The net plot area harvested was about 4m x 1.5m = $6m^2$. The harvested pods were weighed in this case before threshing. The grains were weighed using an electronic sensitive balance. The fodder was weighed in the field using a top loading scale. The fodder was cut from the same middle rows of each cowpea genotype using a secateur and it was rolled over on the plot to dry under the sun.

3.9.5 Description of grouping of cowpea genotypes

The grouping of the genotypes was based on tolerance to low P soils, sensitivity or response to applied P. The cowpea genotypes are grouped as tolerant or efficient non responder when the growth in low P (0P) is significantly higher than the growth under high P conditions (90 kg ha^{-1} RP or 30 kg ha^{-1} SSP). The genotypes are sensitive or responders if the growth under high P condition is higher than the low P condition (0P).

3.10 Experiment 4: Field

Sorghum performance and yield following the cropping of the selected cowpea genotypes in fields.

3.10.1 Land preparation, experimental design, treatment and plot lay out

In 2004, the land was cleared of small shrubs at both locations. At Minjibir site, the fields were sprayed with gramoxone (Paracoat Dichloride 276 g l^{-1}) at the rate of

9.44 L ha^{-1} and ridges were made manually at 0.75 m apart using a hoe while at Toumnia, flat land was maintained with inter row distance of the same 0.75 m. The land was prepared to crop sorghum after the screening of 15 selected cowpea genotypes.

This experiment was established at both locations where the 15-cowpea genotypes were screened in 2003. During the 2002 season when the 15 cowpea genotypes were screened, sorghum plots were inserted so as to maintain a treatment of sorghum following sorghum in 2003. The sorghum was planted on four ridges with the same size as the cowpea plots, only that, the geometry of 0.5 m between sorghum plants and 0.75 m between ridges, was not the same as in cowpea plot. The design, treatment and layout remained the same except that at Minjibir, sorghum (Var. Kaura) and at Toumnia (Var. Dawan gona) were planted in these plots.

3.10.2 Fertilizer application, planting and management practices

In 2004 experiment, only Urea was split applied to the sorghum at the rate of 50kg N ha^{-1} (1/3 at 3WAP and the 2/3 6WAP). Seeds of sorghum were sown manually at a spacing of 0.50m within and 0.75m between lines. After emergence, the plants were thinned to 2 $hill^{-1}$. The plots were weeded at the onset by hand weeding to avoid disturbances of AMF establishment.

3.10.3 Measurements

Root samples were collected in the field at 8 weeks growth stage of the plants by gentle of digging with a hand fork (Daniels and Skipper, 1982). The fine roots of the plants were sampled for mycorrhizal infection rate analysis from the middle rows of each plot. The net plot area harvested was 3 m^2. The grain, stover and root dry weigth were measured.

3.11 Experiment 5: Screenhouse

Screening of field selected cowpea genotypes for tolerance or response to P fertilizer sources in River sand.

3.11.1 Experimental design and treatments

The main factors (A) were the P fertilizers given at the rates of 90 kg P ha^{-1} or (39 mg kg^{-1} soil) for RP and 30kg P ha^{-1} or (13 mg kg^{-1} soil) for SSP. The sub factors (B) were the 15-cowpea genotypes used in the field above. The pots were arranged in a randomized strip plot design with 3 replications.

3.11.2 Screenhouse procedure and management

In to each pot was weighed 3 kg of the river sand. Appropriate weights of each of the fertilizer were applied in to corresponding pots to the depth of about 0-3cm. The soils were brought to field capacity by watering them with tap water. Basal application of 30 kg K ha^{-1} as KCl was applied to all pots. The trial was planted in July 2003. Four seeds of each cowpea genotype were sown. The seedlings were thinned to one-plant pot^{-1} after emergence. Each pot was watered daily with the same volume (250 ml) of tap water; insecticide (Shepa plus) was sprayed to control insect attack.

3.11.3 Measurements

The crops were grown for six weeks and the following parameters were taken: The shoot and the roots were separated at soil level with a secateur. Shoots were bagged. The roots and nodules were washed and separated. They were all dried in the oven at 60^{o} C for 48 hours. After drying, the shoot, root and nodule dry weight were taken using a sensitive balance. The shoot: root ratio, the total biomass, specific root length, root length density as well as the root mass density were calculated.

3.12 Experiment 6: Screenhouse

Performance of sorghum on pots previously grown to 15 cowpea genotypes.

3.12.1 Experimental design and treatment

During the previous cropping when the 15-cowpea genotypes were screened, sorghum pots were included so as to maintain a treatment of sorghum following sorghum in this experiment. The treatment and design remained as previous except that here sorghum was cropped. Basal application was given to the sorghum a week after germination as ammonium sulphate at the rate of 60 mg kg^{-1} of soil.

3.12.2 Screenhouse procedure and management

The river sand from experiment 5 was carefully returned to appropriate pots. 60 mg kg^{-1} soil of $(NH_4)_2SO_4$ was added to each pot, mixed and brought to field capacity by water. The trial was planted in November 2003. Five seeds of sorghum were sown pot^{-1}. The seedlings were thinned to one-plant pot^{-1} after emergence. Each pot was watered daily with the same volume (250 ml) of tap water.

3.12.3 Measurements

All the above ground biomass was cut using a secateur after pulling out the whole plant. The roots were washed to remove the remaining adhering soil. The shoot and root biomass were separately enveloped and dried in an oven at 65^{o}C for 48hrs. After drying, the shoot, root and total biomass were measured using a sensitive balance. The shoot: root ratios were also calculated.

3.13 Statistical Analysis

All the data generated from field and screen house studies and Laboratory tests were submitted to the Genstat package system for analysis of variances (ANOVA)

(Genstat, 5, 1995). Least significant differences, Standard errors of means from the different experiments were computed to be able to differentiate between the different treatments means. Correlation matrixes were derived from the Statistical analytical system (SAS, 2001) package. Correlation was used to see the relationship between some selected paired parameters.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Phosphorus calibration study with some cowpea genotypes and maize in two contrasting low P soils.

Phosphorus, although not required in large quantities, is critical to cowpea yield due to its multiple effects on nutrition (Muleba and Ezumah 1985). In this experiment total dry matter (shoot + root dry weight) was measured; also nodule dry weight, and shoot: root ratio were determined. The objective of this experiment was to select desirable P rates that will be used in field screening of a large number of cowpea genotypes.

Twenty eight sites were surveyed at Toumnia and Minjibir and the Olsen P content varied from 0.73 to 2.01 mg P kg soil^{-1} at Toumnia and from 1.41 to 8.89 mg P kg soil^{-1} at Minjbir. The fields at Minjibir were relatively higher in Olsen P than the Toumnia fields. At Toumnia the farmer's field with 0.73 mg P kg soil^{-1} was selected while at Minjibir the field with 2.30 mg P kg soil^{-1} was selected based on the availability of land larger enough for the P screening trial.

The available Olsen P values from the selected fields in Sahel and Sudan are showing that these areas are low in P due probably to low levels in parent materials and organic matter as reported by Bationo et al. (1982). In the report the range of 0.1 to 0.3 mg P kg soil^{-1} reported previously was even lower than what was measured at Toumnia.

The Olsen P at Minjibir was generally higher than soils in Toumnia. The total N contents were similar at both locations. Soil pH (H_2O) from Minjibir were weakly acidic while the soils in Toumnia were neutrals (Table 2). Levels of organic carbon at Minjibir

were 0.25 g kg^{-1} and 0.24g kg^{-1} at Toumnia. The CEC (1.6 cmol kg^{-1}) was low and seemed to be the same at both Toumnia and Minjibir.The exchangeable Ca^{++} was higher in Minjibir soil (0.9 cmol kg^{-1}) than that of Toumnia soil (0.8 cmol kg^{-1}). The exchangeable magnesium (Mg^{++}) in Toumnia soil (0.3 cmol kg^{-1}) was higher than that of Minjibir soil (0.2 cmol kg^{-1}) and the exchangeable potassium was the same in both Minjibir and Toumnia soils. The texture of the selected soils was showing that Toumnia was more sandy (91% sand) than Minjibir (88%)

Table 2: Physico-chemical properties of Minjibir (M), Toumnia (T) soils and River sand (RS) 0-10cm.

	Field		Screenhouse
Characteristic	M	T	RS
pH(H_2O)	6.5	7.3	6.5
pH(KCl)	5.4	6.5	6.2
Organic Carbon (g kg $soil^{-1}$)	0.25	0.24	0.061
Total N (g kg $soil^{-1}$)	0.013	0.01	0.021
Olsen P (mg kg $soil^{-1}$)	2.3	0.7	1.3
NH_4-Acetate-extratable Cations (cmol kg^{-1})			
Ca	0.9	0.8	1.21
Mg	0.2	0.3	0.32
K	0.1	0.1	0.04
Na	0.4	0.4	0.17
Texture			
Sand (%)	88	91	93
Silt (%)	5	2	1
Clay (%)	7	7	6

4.1.1 Phosphorus fractions of selected Minjibir and Toumnia soils

The amount of P applied that is not taken up by plant root, or lost to the soil is retained in the soil in different pools. Hedley et al. (1982**)** developed a procedure to separate inorganic P (Pi) and organic P (Po) into different bioavailable forms, and also

allowed differentiation into some chemical groupings. This procedure was used to determine the different soil P pools of Minjibir and Toumnia before planting (Table 3). The total inorganic P fraction at Minjibir (63.97 mg P kg soil^{-1}) was higher than that at Toumnia (25.33 mg P kg soil^{-1}). The total organic pool at Toumnia (12.81 mg P kg soil^{-1}) was lower than that of Minjibir (21.69 mg P kg soil^{-1}). The available P pool were lower than the unavailable P pools both at Minjibir and Toumnia and this may probably be the result of continuous cultivation without adequate replacements as reported by Agbenin and Goladi (1997**).** In their study, there was significant decrease in all P pools under continuous cultivation with no manurial treatment. Again Table 2 shows that the resin available P was higher in Minjibir (4.42 mg P kg soil^{-1}) than that of Toumnia (1.73 mg P kg soil $^{-1}$). The unavailable P was also higher in Minjibir than in Toumnia.

Table 3: Sequentially extractable P fractions of Minjibir and Toumnia soils.

	P fractions					
	Inorganic		Organic		Total	
Extractants	M	T	M	T	M	T
	mg P kg soil^{-1}					
Resin	4.42	1.73	-	-	4.42	1.73
NaHCO3	2.84	0.26	4.97	2.86	7.81	3.12
NaOH	8.36	1.30	16.72	9.95	25.08	11.26
1MHCl	7.04	2.34	ND	ND	7.04	2.34
Conc.HCl	13.55	5.50	ND	ND	13.55	6.77
Residual	27.76	14.20	ND	ND	27.76	14.20
Total	63.97	25.33	21.69	12.81	85.66	38.14

M: Minjibir; T: Toumnia ND = Not determined

4.1.2 Effect of P application on total root and shoot dry matter production

Generally, the cowpea genotypes tested in the low P soils of Minjibir and Toumnia responded to P application (Table 4). The mean total dry matter was significantly increased from 5.17 g pot^{-1} to 6.85 g pot^{-1} at Minjibir while at Toumnia it

was increased from 4.16 g pot^{-1} to 6.56 g pot^{-1} with the application of SSP as 13 mg P kg $soil^{-1}$ (30kg P ha^{-1}). The interaction between the genotypes and the site was also significant (P= 0.05) and the mean P treatments varied from 4.49 g pot^{-1} (IT90K-59) to 6.7 g pot^{-1} (IT82D-849). The performance mean of the genotypes was higher at Minjibir (6 g pot^{-1}) than that of performance mean at Toumnia (5 g pot^{-1}). The response patterns of the genotypes revealed that some genotypes were non responsive (e.g IT90K-59), responsive (e.g Danila, IT82D-849, IT89KD-374-57, and IT89KD-391) and others as tolerant or sensitive (e.g IT82D-716, IT89KD-349, IT86D-715). The response parttern showed that the mean response of the genotypes was lower at Toumnia than that of Minjibir under low P (0P) condition but the situation was reversed under high P condition (13 mg P kg $soil^{-1}$) .

Table 4: Effect of SSP on the total dry matter (TDM) of cowpea genotypes in potted soils from Minjibir (M) and Toumnia (T).

Genotypes	M	GROUP*	T	GROUP	Mean
IT90K-277-2	6.21	R	5.15	NR	5.68
IT82D-716	5.74	T	4.16	S	4.95
IT82D-849	6.85	R	6.56	R	6.7
IT86D-715	4.99	S	4.73	S	4.8
IT89KD-374-57	6.03	R	5.32	R	5.68
IT89KDKD-349	5.17	T	5.78	R	5.47
IT89KD-391	6.36	R	5.39	R	5.88
IT90K-59	4.72	NR	4.27	NR	4.49
Danila	6.85	R	5.98	R	6.42
Mean	5.88		5.26		
SE(G)	0.365				
SE(S)	0.211				
SE(SXG)	0.576				

R, Responsive; T, Tolerant; S, Sensitive; NR, Non responsive.

4.1.3 Effect of P application on nodule development

The nodule dry weight (NDW) of cowpea genotypes in this study varied from 47.8 mg pot^{-1} to 145.9 mg pot^{-1} in both soils and this led to the different groups of NDW response to P application (Fig 2). The basis for grouping was the comparison between the mean weight at low and high P condition. At Minjibir, under maximum rate (13 mg P kg $soil^{-1}$), the responsive genotypes were: IT89KD-374-57, Danila, IT90K-277-2 and IT89KD-349 while the non-responsive were: IT90K-59, IT82D-849, IT89KD-391, IT82D-716 and IT86D-715. Under the same high P condition, at Toumnia, the following genotypes were judged responsive: IT82D-849, IT89D-391, IT90K-59 and IT89KD-374-57 while the remaining genotypes seemed to be non responsive except Danila which was at par because the local genotype responded half way (at 3.25 mg P kg $soil^{-1}$). This also demonstrates genotypic differences in the effect of P on nodulation were detected as previously reported by Ankomah et al. (1995).

The results have shown that, P application can increase dry weight of nodules of legumes (Koala, 1985; Luse et al., 1975; Kang and Nangju, 1983) but the response could vary from one soil to another. Phosphorus application significantly ($P = 0.05$) and positively affected nodule weight in cowpea and this varied from 86.0 mg pot^{-1} under low P conditions to 118.3 mg pot^{-1} under high P conditions. Similarly, in different experiments in Nigeria, it was shown that the application of P fertilizer increased nodulation of cowpea **(**Olofuntoye, 1986). In experiments conducted in low P soils at Bozeman, Montena, USA, increasing P supply increased faba bean, common bean and green pea (NDW) (Koala, 1985). Recently, Almeida et al. (2000) reported results

showing severe P deficiency prevented nodulation of white clover, and inhibited growth of established nodules in nodulated plants subjected to severe P deficiency.

Root dry weight was positively and significantly correlated (r = 0.66**) to nodule dry weight at Toumnia but this was lower at Minjibir (r = 0.24*). Similarly, there was positive correlation (r = 0.33*) between the SDW and NDW at Toumnia and that was lower (r = 0.16ns) at Minjibir.

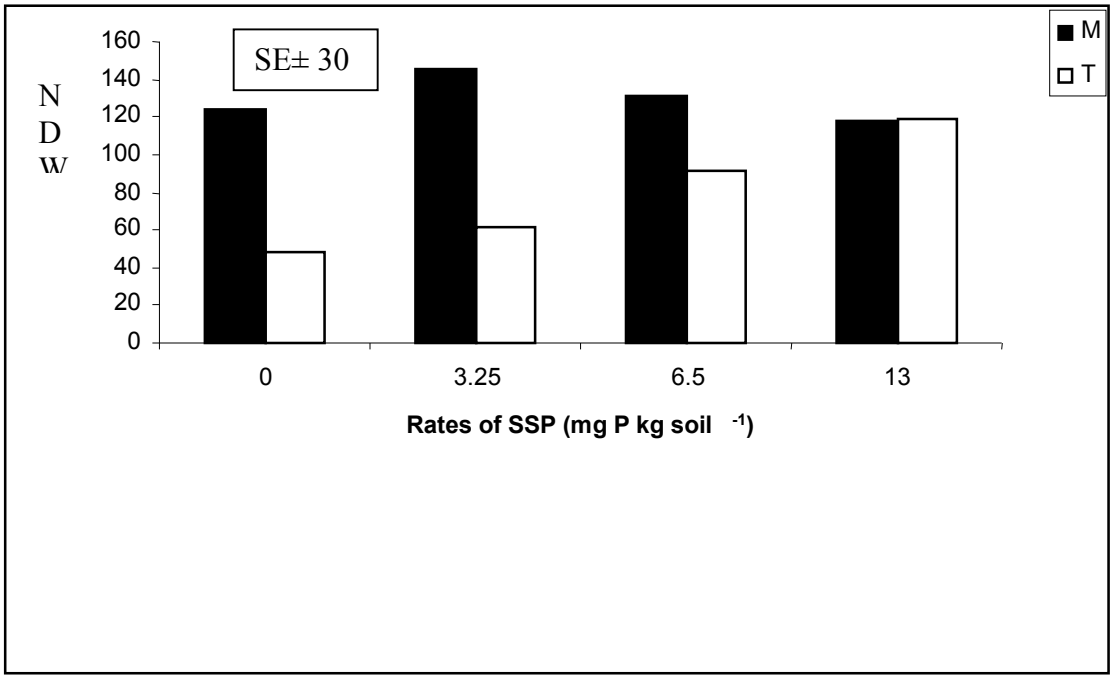


Fig 2: Effect of SSP rates on cowpea genotypes NDW in potted soil of Minijibir (M) and Toumnia (T), 2002.

4.1.4 Conclusion

It has been observed that, the P level of 30 kg ha^{-1} was suitable for further screening of a large number of cowpea genotypes in the fields.

4.2 Screening of cowpea genotypes for tolerance or response to applied P on low P soils at Minjibir and Toumnia.

A large number of cowpea genotypes (147) were screened under low and high P conditions (0P and 30 kg ha^{-1} respectively). In addition to soluble P fertilizer (SSP), another source of P treatment was added as RP at 90 kg ha^{-1} due to its sparingly soluble nature and a higher rate was used for RP than SSP because information from experiments at IAEA (Zapata, 1986) showed that the relative P effectiveness of rock P is about 3-5 times less than that of artificial P-fertilizers on annual crops. The Rhizobia and AMF spore populations were determined in the experimental soils. Basis for grouping was defined as the grain, fodder or dual purpose yield of the cowpea genotypes and the genotypic differences in respect to P application were determined. Also the genotypic differences to P use efficiency were calculated.

4.2.1 Size of rhizobia and AMF spore populations in experimental soils.

The rhizobia populations of Minjibir and Toumnia soils were estimated before and after harvest of cowpea in the fields.

The population of rhizobia in soil of Minjibir before planting (7.0×10^6 cells g $soil^{-1}$) was significantly higher than that of Toumnia (3.0×10^6 cells g $soil^{-1}$). This could be due to the more unfavorable conditions such as higher temperature, lack of moisture before planting. On the other hand, the rhizobia populations were significantly higher in Toumnia soil after harvest (11.0×10^{-6}) without P addition than the rhizobia cells in Minjibir soil (8.0×10^6) after harvest (Table 5). This result indicated that the restoration of favorable conditions such as optimum temperature and moisture and the presence of the host legume crop increased the rhizobia population in the soils without P application

at both sites because the soil without P after harvest contain higher population than the soil before planting (e.g. at Toumnia 11x 10^6 > 3x 10^6 cells of rhizobium). Furthermore, the application of RP significantly increased the bacteria population at both sites. However, the increase was higher at Minjibir (25 x 10^6) than at Toumnia (17 x 10^6) and this was probably due to the rainfall, which was higher at Minjibir than at Toumnia (Appendix 1). Similarly, the application of SSP increased the number of rhizobia at both sites. This has to do with the fact that nodule bacteria need P to multiply (Danso, 1992). Nevertheless, the rhizobial population at Toumnia (23 x 10^6) after SSP application was significantly higher than that of Minjibir (15 x 10^6).

That is to say, the P application together with other favorable conditions like optimum temperature and rainfall which favors moisture condition increased the number of rhizobia in the soil of both Minjibir and Toumnia.

In Minjibir soil before planting cowpea, the spore population was estimated at 509 spores g soil^{-1} and this was significantly lower than that of Toumnia (892 spores g soil^{-1}) (Table 5). These results were probably related to the Olsen available P and cropping history of the different sites and also might be related to the climatic conditions (Appendix 1) of Sudan and Sahel Savannas. Various physical, chemical and biological factors affect the AMF association system. Light and temperature are known to affect plant-AMF balance (Hayman and Tavares, 1985). After harvesting cowpea in the different areas without P application, it was observed that the spores count at Toumnia (1181 spores g soil^{-1}) was significantly higher than that at Minjibir (923 spores g soil^{-1}). However, the count after harvest was significantly higher than before planting. These results indicated that after a cropping season there was an increase of the AMF spores. P

application reduced the number of spores at both sites but the reduction was higher at Minjibir than at Toumnia due to the difference in rainfall (Appendix-1), which could be related to P solubilization (Bationo and Anan Kumar, 2002).

The reduction in spore count could be due to the increase in availability of P in the soil as AMF colonization is notably affected by P nutrition of the host plant (Stribley et al., 1989).

Table 5: Effect of P source on Rhizobial cells and AMF Spores count from Minjibir and Toumnia soils before planting and after harvest

Soil sources	Rhizobia: 10^6 cells g $soil^{-1}$	AMF Spores: g $soil^{-1}$
Minjibir before planting	7	509
Minjibir 0P after harvest	8	923
Minjibir RP after harvest	24	783
Minjibir SSP after harvest	15	344
Toumnia before planting	3	892
Toumnia 0P after harvest	11	1182
Toumnia RP after harvest	17	1122
Toumnia SSP after harvest	23	973
Means	14.0	841
SE±	0.1	2

4.2.2 Genotypic differences in response to P application

There were differences in grain and fodder yields due to P (RP and SSP) applications in this study as has been observed by other workers (Kolawale et al., 2002; Bationo et al., 2002; Jain et al., 1986; Tenebe et al., 1995). Cowpea genotypes were grouped based on the yields of grain , fodder or both at both low (0P) and high P (90kg ha^{-1} RP and 30kg ha^{-1} SSP) using the classification scheme of Gerloff (1977) and Caradus et al. (1980). The different groups were as follows: The tolerant to P (T) comprising the

genotypes with high mean yield under low P (0P) soils > than its mean under high P condition and were not responsive to P applications; the responders (R) as those with higher mean yield under P addition than the 0P situation; the inefficient responders or sensitive (S) comprising genotypes that did not perform under low P condition but responded to P application; and the non-responders (N) as those that performed with low yield under both low and high P conditions. The classification in Fig 3a indicated that there are 46 efficient responders and 53 inefficient non-responders based on the application of SSP on grain yield. These numbers are higher than those of the inefficient responders and the efficient non-responders. Similar classification based on the application of RP on grain yield is shown in Fig 3b. Classification based on the application of SSP and RP on foder yield is shown in Figs 4a and 4b respectively.There were some other genotypes that did not belong to the four groups and were called intermediate genotypes, their mean performance were not significantly diferent from the overall mean performance of the genotypes.The result clearly suggested a number of cowpea genotypes that were good in grain production (IT97K-819-154, IT97K-819-170, IT90K-277-2, IT97K-340-1, and IT98K-476-8); fodder production (Danila, Aloka, IT98K-476-8, TN256-87, TN28-87, and IT98D-1399) and yet other genotypes were of dual-purpose production because they gave both grain and fodder (TN256-87, IT98K-476-8, IT99K-213-21, IT97K-813-21, IAR-48 and IT98D-1399).

Fifteen cowpea genotypes were selected based on the grain and fodder, production at low P (0P) or at high P (RP and SSP) for further work.

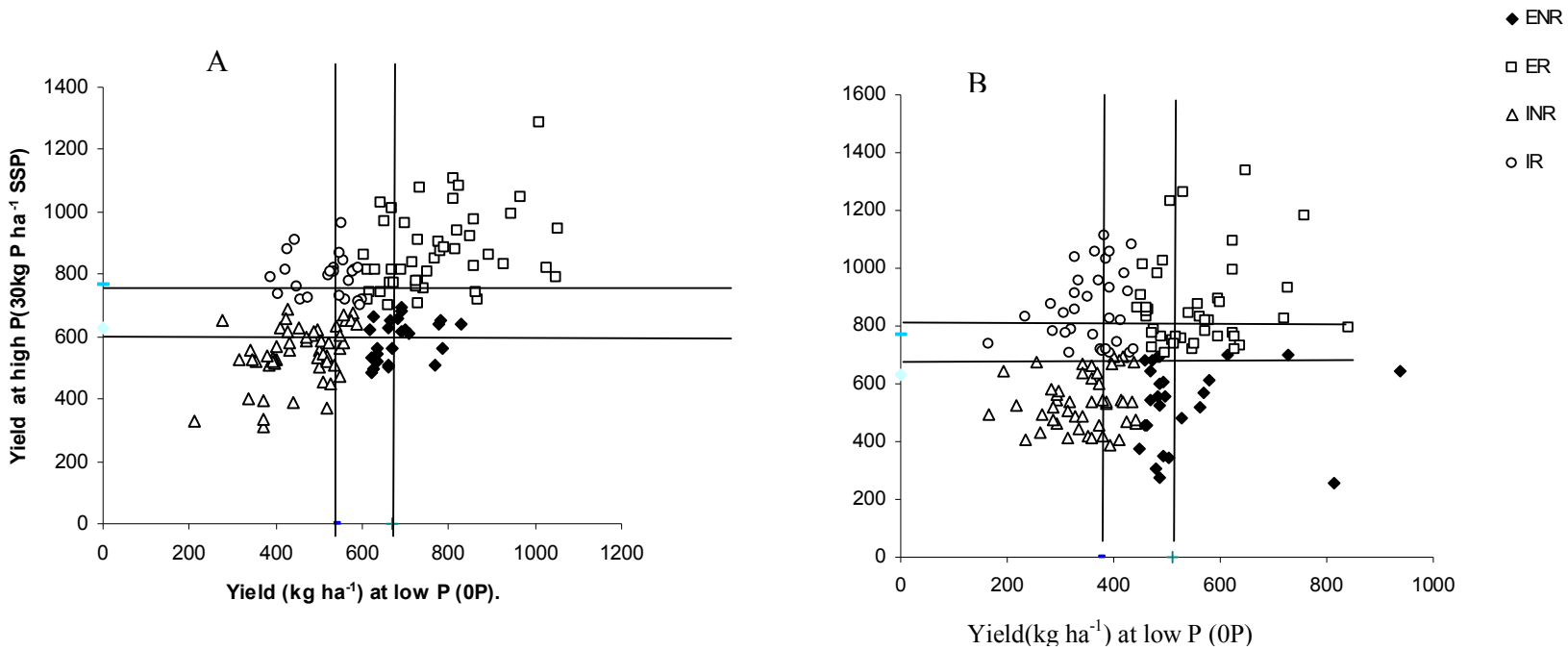


Figure 3a: Two different Biplot of cowpea grain yield (kg ha^{-1}) at low P (0P) and high P (30 kg ha^{-1}, SSP): (A) at Minjibir field and (B) at Toumnia field in 2002 cropping season.
The four lines at the middle represent the mean separation (lsd).

- ENR, Efficient non responder; ER, Efficient responder; INR, Inefficient non responder; IR, Inefficient responders.

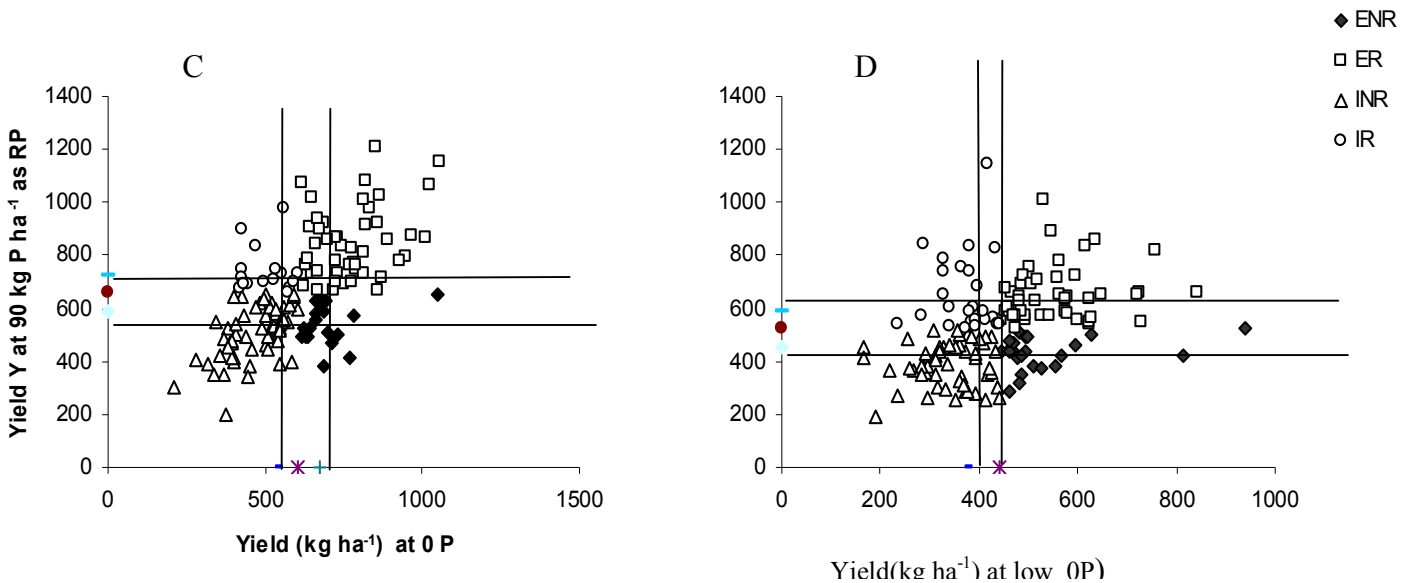


Fig 3b: Two different Biplot of cowpea grain yield (kg ha^{-1}) at low P (0P) and high P (RP): (C) at Minjibir field and (D) at Toumnia field in 2002 cropping season. The four lines at the middle represent the mean separation (lsd).

- ENR, Efficient non responder; ER, Efficient responder; INR, Inefficient non responder; IR, Inefficient responders

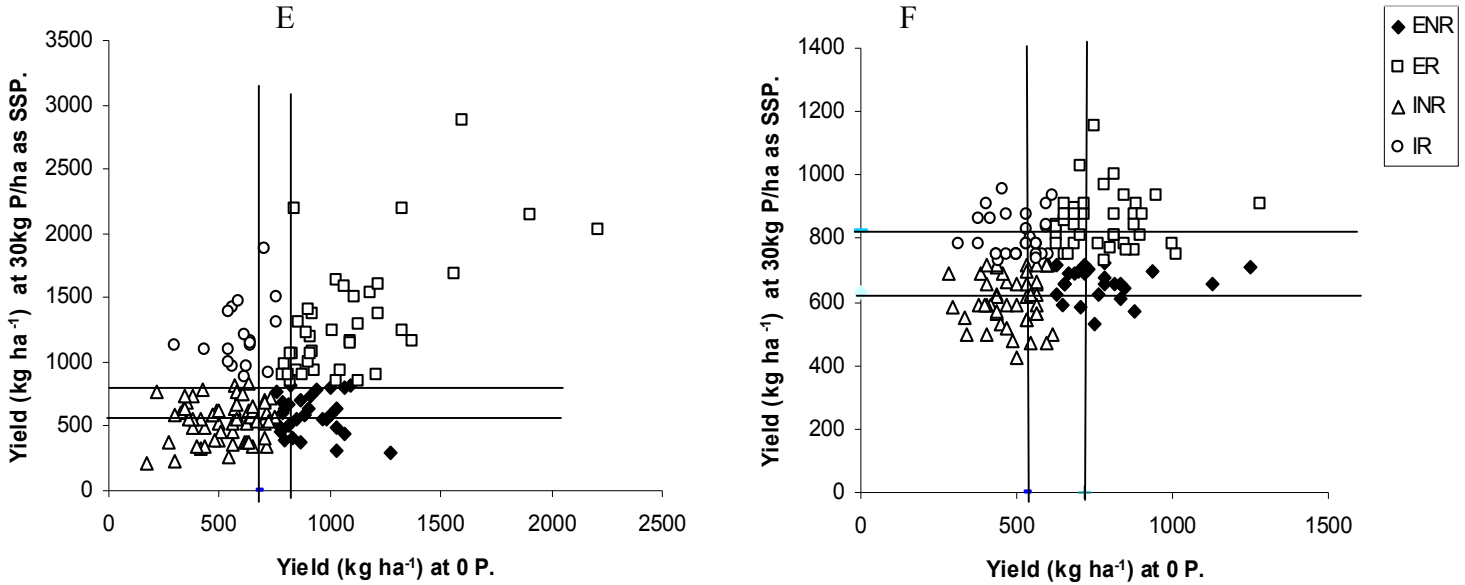


Fig 4a: Two different Biplot of cowpeas fodder yield (kg ha^{-1}) at low P (0P) and high P (SSP): (E) at Minjibir field and (F) at Toumnia field in 2002 cropping season.

The four lines at the middle represent the mean separation (lsd).

- ENR, Efficient non responder; ER, Efficient responder; INR, Inefficient non responder; IR, Inefficient responders

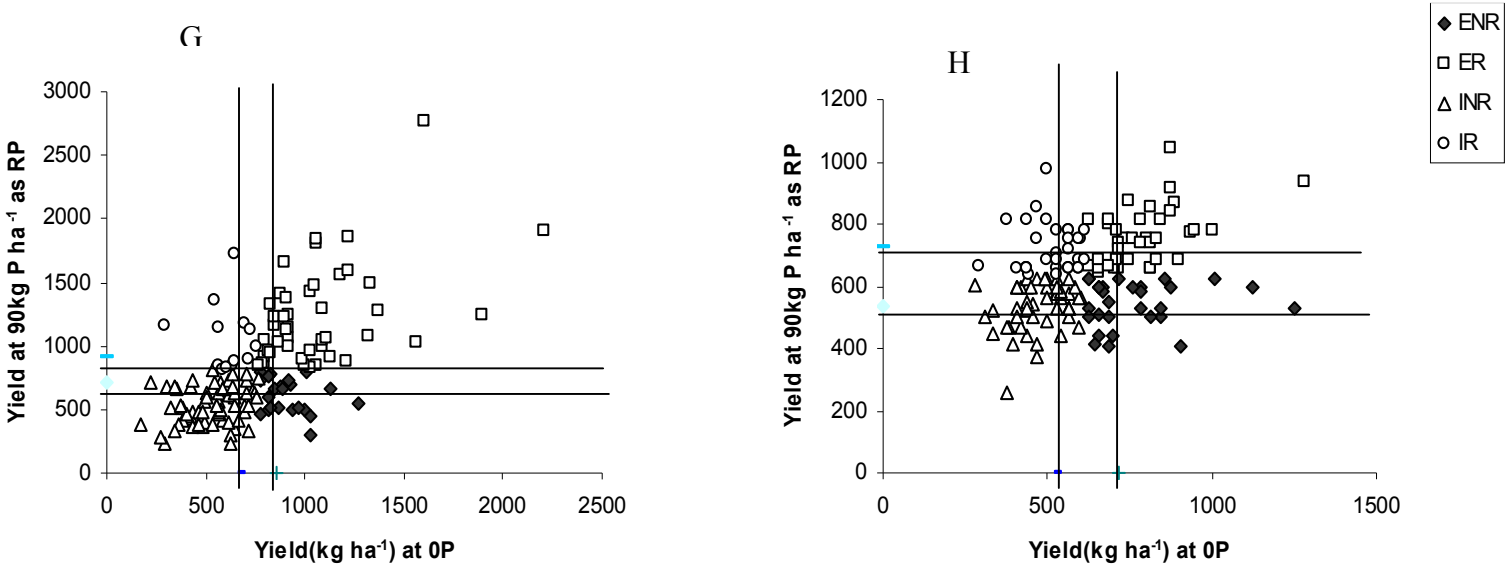


Fig 4b: Two different Biplot of cowpeas fodder yield (kg ha-1) at low P (0P) and high P (RP): (G) at Minjibir field and (H) at Toumnia field in 2002 cropping season. The four lines at the middle represent the mean separation (lsd).

- ENR, Efficient non responder; ER, Efficient responder; INR, Inefficient non responder; IR, Inefficient responders

Among the 15 genotypes, TN256-87, IT97K-340-1 and IT99-213-21 were observed to be tolerant responders to SSP in both locations; IT97K-813-21 was classified as tolerant non-responder while IAR-48 was classified as sensitive non-responder in both locations (Table 6). The remaining genotypes fell into different categories in both locations. Interestingly, Aloka local, which is indigenous to Toumnia, was found to be sensitive non-responder in Minjibir but tolerant responder in Toumnia. This proves the adaptability of the genotype to its indigenous locality. In comparison with the soils from the two locations, the grain production at Minjibir (652 kg ha^{-1}) was higher than that of Toumnia (555 kg ha^{-1}). Cowpea genotypes IT99K-826-119 and IT97K-813-21 were tolerant while TN256-87 was efficient responder at both locations. IT98K-476-8 was tolerant at Minjibir while it was an efficient responder at Toumnia (Table 6). The relative mean yield increase due to SSP application was 15% at Minjibir and 58% at Toumnia. That was probably due to the difference in rainfall, which favored a wach off process of the applied SSP at Minjibir than at Toumnia.

The existence of a cowpea genotype X P source interaction in the 2002 field experiment indicated that cowpea genotypes differed in the relative performance under different P source. This treatment also suggested that there might be differences among the cowpea genotypes with respect to P nutrition (Caradus et al. 1980). Probably because of the weak correlation of cowpea yield at high versus low P, the variability among cowpea genotypes is apparently big. Direct application of indigenous phosphate rocks can be an alternative to the use of more expensive water-soluble phosphorus fertilizers especially if cowpea cultivars capable of utilizing RP could be identified as seen in the case of this grouping and confirms previously observations by

Bationo et al. (2002). Further investigation is required to determine if the differences are specifically due to differences in P nutrition and P use efficiency.

Table 6: Grain yield (kg ha^{-1}) of selected cowpea genotypes to SSP application at Minjibir and Toumnia, 2002.

	MINJIBIR				TOUMNIA		
Genotypes	0P	SSP	GROUPS*	Genotypes	0P	SSP	GROUPS
TN256-87	849	921	TR	TN28-87	722	823	TR
IT97K-340-1	813	1043	TR	IT98K-476-8	726	931	TR
IT99K-213-21	1010	1287	TR	IT00K-1148	649	1338	TR
IT98K-476-8	1026	819	TN	ALOKA	636	734	TR
TN28-87	627	494	TN	IAR-48	623	996	TR
IT97K-819-170	623	487	TN	TN256-87	532	1264	TR
IT99K-826-119	621	535	TN	IT97K-819-170	455	1011	TR
IT97K-813-21	831	638	TN	IT97K-813-21	840	795	TN
IT98D-1399	424	811	SR	IT99K-213-21	481	307	TN
DANILA	548	868	SR	IT98D-1399	447	372	TN
IT97K-819-154	498	535	SN	IT99K-826-119	938	643	TN
IT00K-1148	401	527	SN	IT97K-340-1	433	1084	SR
ALOKA	540	636	SN	IT97K-819-154	382	1115	SR
IT90K-277-2	370	313	SN	IT90K-277-2	322	785	SR
IAR-48	595	702	SN	DANILA	380	420	SN
*MEANS: P	603	696			442	701	
SITE	652				555		
LSD (P) = 68							
G = 157							
S = 18							
PXG= 277							
PXS = 69							
GXS = 218							
PXGXS= 381							

Mean of 147 field screened cowpea genotypes.

T= Tolerant; R = Responding to applied P; N = Not responding to applied P;

S = Sensitive to low P. LSD (P), for comparing between the 0P and SSP; LSD (S), for comparing the two sites; LSD (G) for comparing genotypes; LSD (PXG, GXS and PXGXS), for comparing between the different interactions.

The cowpea genotypes IT97K-819-170 and TN28-87, were observed as tolerant and non responsive to P while cowpea genotypes such as TN256-87, IT97K-340-1, IT97K-813-21, IT98K-476-8, IT99K-213-21and IT99K-826-119 were recorded as tolerant responder (Table 7). Danila, IT98D-1399, IT97K-819-154 and IAR-48 belonged to the same group of inefficient responder (Sensitive responders); Aloka, IT90K-277-2 and IT00K-1148 were the sensitive non responders (SN). At Toumnia, IT98D-1399, IT99K-213-21 and IT99K-826-119 were tolerant non responders and IT00K-1148, IT97K-813-21 and IT98K-476-8 were tolerant responders IT98K-476-8 was tolerant at Minjibir while it was efficient responder at Toumnia (Table 7).The RP application generally increased grain yield of the cowpea genotypes at Minjibir. The relative yield increase due to RP application on the grain yield was 9% at Minjibir while it was 18% at Toumnia. Cowpea genotype IT99K-826-119 was recorded as tolerant to RP while the genotype TN256-87 was recorded as efficient responder to RP for grain production (Table 7).

Table 7: Grain yield (kg ha^{-1}) of selected cowpea genotypes to RP application at Minjibir and Toumnia, 2002.

	Minjibir				Toumnia		
Genotypes	0P	RP	GROUP	Genotypes	0P	RP	GROUP
IT97K-819-170	623	524	TN	IT98D-1399	447	435	TN
TN28-87	627	517	TN	IT99K-213-21	481	322	TN
IT97K-340-1	813	812	TR	IT99K-826-119	938	521	TN
IT97K-813-21	831	982	TR	IT00K-1148	649	652	TR
IT98K-476-8	1026	1066	TR	IT97K-813-21	840	662	TR
IT99K-213-21	1010	865	TR	IT97K-819-170	455	678	TR
IT99K-826-119	621	681	TR	IT98K-476-8	726	662	TR
TN256-87	849	1210	TR	ALOKA	636	856	TR
IT00K-1148	401	395	SN	IAR-48	623	636	TR
IT90K-277-2	370	354	SN	TN256-87	532	1013	TR
ALOKA	540	476	SN	TN28-87	722	649	TR
IT97K-819-154	497	698	SR	IT90K-277-2	322	453	SN
IT98D-1399	424	899	SR	IT97K-340-1	433	824	SR
DANILLA	548	881	SR	IT97K-819-154	382	589	SR
IAR-48	595	834	SR	DANILLA	380	741	SR
MEANS (TRT)	603	658			442	522	
(SITES)	652				555		
LSD (P)= 68							
(G)= 157							
LSD (S)= 18							
LSD (PXC)= 277							
LSD (PXS)= 69							
LSD (CXS)= 218							
LSD (PXCXS)= 381							

Mean of 147 field screened cowpea genotypes.

T= Tolerant; R = Responding to applied P; N = Not responding to applied P;

S = Sensitive to low P. LSD (P), for comparing between the 0P and SSP; LSD(G) for comparing between genotypes; LSD(S), for comparing the two sites; LSD (PXC, CXS and PXCXS), for comparing between the different interactions.

4.2.3 Genotypic differences to P use efficiency at Minjibir and Toumnia.

Phosphorus use efficiency of field grown cowpea genotypes was calculated as the grain yield (kg ha^{-1}) per unit of the fertilizer SSP and RP applied (kg ha^{-1}) as defined by Moll et al. (1982). The performance of plants when grown on soils with low P availability was determined by their P-efficiency. The 15 cowpea genotypes selected for further screening or tolerance and response to P demonstrated P use efficiencies that were location specific (Table 8). Highly significant differences ($P < 0.01$) were recorded between the cowpea genotypes. The mean genotype P use efficiency coefficient (23) was observed to be the same at both locations for SSP and that was used for the classification of genotypes as efficient or inefficient in each location. Therefore any P use efficiency value above 23, indicated genotype efficiency otherwise it was inefficient. For example under SSP at Toumnia the P efficient genotypes included IT00K-1148, IT97K-819-154, IT97K-340-1, IT97K-476-8, IT97K-819-170, and IT90K-277-2 while at Minjibir, the P efficient genotypes were IT99K-213-21, IT97K-340-1, TN256-87, and Danila. On the other hand the P inefficient genotypes at Toumnia were Danila, IT99K-213-21 and IT98D-1399 while at Minjibir the P inefficient genotypes were: IT90K-277-2, TN28-87, and IT00K-1148. At Minjibir, when the genotypes were ranked (descending order), the genotype IT99K-213-21, IT97K-340-1, TN256-87, Danila, IT98K-476-8 and IT98D-1399 were observed among the best P user genotypes. The genotypes IT90K-277-2, IT97K-819-170, IT97K-819-154, IT99K-819-119 and TN28-87 were observed to be among the least P user genotypes at Minjibir. On the other hand, the ranking according to the highest at Toumnia gave the genotypes IT00K-1148, IT97K-819-154, IT97K-819-170, IAR-48 and IT98K-476-8 as being among the highest P user genotypes. The genotypes IT99K-213-21, IT98D-1399 and Danila were recorded to be part

of the least (Table 8). The cowpea genotype IT98K-476-8 genotype was identified as P efficient user at both locations. P use efficiency was related to rainfall (Appendix 1) and crop genotypes by the grain yield in these areas because of the positive correlation (r = 0.39) between the rainfall and P use efficiency as shown by Bationo and Anand Kumar, (2002). In this study 39% of the effects on P use efficiency came from rainfall.

Under the RP conditions, the mean P use efficiency coefficient (7) was lower than that of SSP due to the more soluble nature of SSP compared with the sparingly soluble nature of RP. The mean genotype P use efficiency coefficients were higher at Minjibir than at Toumnia due probably to the difference in rainfall that help in RP solubilization (Mahamane et al. 1997). Similarly, the means P use efficiency coefficients at both locations were used to differentiate between the responsive genotypes under RP application. At Minjibir, the genotypes IT90K-277-2, TN28-87, IT97K-819-170 and IT00K-1148 were not responsive compared with the rest. At Toumnia, IT90K-277-2, IT98D-1399 and IT99K-213-21 were not responsive compared with the rest.

Table 8: Genotypic differences to P use efficiency of field screened cowpea genotypes at Minjibir (M) and Toumnia (T) based on SSP and RP application, 2002.

Genotypes	SSP		RP	
	M	T	M	T
	-------kg grain ha^{-1} kg^{-1}P applied ha^{-1}----------			
IT00K1148	18	45	4	7
TN256-87	31	42	13	11
IT97K-819-154	18	37	8	7
IT97K-340-1	35	36	9	9
IT97K-819-170	16	34	6	8
IAR-48	23	33	9	7
IT98K-476-8	27	31	12	7
TN28-87	16	27	6	7
IT97K-813-21	21	27	11	7
IT90K-277-2	10	26	4	5
ALOKA	21	24	5	10
IT99K-826-119	18	21	8	6
DANILA	29	14	10	8
IT98D-1399	27	12	10	5
IT99K-213-21	43	10	10	4
Means[a]	23	23	7	6
SSP		RP		
SE± (S)= 0.41		SE± (S)= 0.2		
SE± (G) = 3.71		SE± (G) = 1.85		
SE± (GXS) = 5.13		SE± (GXS) = 1		

a, Mean of 147 cowpea genotypes from the fields.
G= Genotypes; S = Site and GXS = Interaction between G and S.

4.2.4 Conclusion

There was differential performance of cowpea genotypes under low and high P conditions at the locations. Classification based on grain, fodder and dual purpose yields, yielded four P efficiency groups and the most popular of which was efficient responders group. The farmers who do not possess the capacity to apply fertilizer P to their farms have the choice of using such cowpea genotypes that are tolerant efficient non-responders on low P soils. Farmers from both Minjibir and Toumnia could use IT97K-813-21 as an efficient non-responder and IT98K-476-8 as an efficient, responsive and dual-purpose cowpea genotype. Farmers from Toumnia could use TN256-87 for both high grain and fodder yields; the cowpea genotypes IT97K-819-154 and IT97K-819-170 for high grain yield while Danila could be used at both Minjibir and Toumnia for high fodder yields. Aloka could be used at Toumnia for both grain and fodder yields.

4.3 Screening of selected cowpea genotypes for tolerance or response to P sources in river sand in the screenhouse

In order to elucidate the mechanisms why some cowpea genotypes were tolerant to low P soils and other sensitive or responsive to P application, further investigations were carried out using the selected 15-cowpea genotypes in screenhouse. Studies were designed to examine among other parameters, root morphology as P use efficiency trait in the cowpea genotypes.

4.3.1 Characteristics of the river sand

The river sand has pH of 6.4, organic carbon of 0.06 g kg^{-1}, CEC of 1.7 cmol kg^{-1}, an Olsen P of 1.3 mg P kg soil $^{-1}$ and a total N of 0.021 g kg $soil^{-1}$ (Table 2).

4.3. 2 Effect of P sources on root and shoot dry matter in pots

In general, all the cowpea genotypes responded to P application but it was more pronounced under SSP than the RP. The overall mean root dry weight (RDW) response varied from 0.23 g pot^{-1} at 0P to 0.65g pot^{-1} under SSP while the mean shoot dry weight (SDW) varied from 0.93 to 4.19 g pot^{-1} for the shoot (Table 9). Under 0P condition, the cowpea genotypes IT97K-813-21, IT99K-826-119 and IT00K-1148 produced the highest RDW (0.38, 0.35 and 0.31 g pot^{-1}) while under SSP condition, the following genotypes: IT99K-826-119 and IT97K-813-21 (1.65 and 1.11 g pot^{-1}) produced the highest RDW . Similar results were obtained between 0P and the application of RP.

On the other hand, under 0P condition, IT97K-340-1, IT97K-813-21 and IT99K-213-21 were observed to give highest shoot dry weight while under SSP conditions, the genotypes IT99K-826-119, IT97K-823-21 and IT97K-340-1 gave the highest shoot dry weight (Table 9). The result suggests that the genotypes IT97K-823-21 and IT97K-340-1

were efficient responders because they have performed very well under both low and high P conditions.

Table 9: Effect of P source on root and shoot dry matter in pots.

	RDW (g pot^{-1})				SDW (g pot^{-1})			
Genotypes	0P	RP	SSP	Means	0P	RP	SSP	Means
IT90K-277-2	0.12	0.17	0.54	0.28	0.44	0.78	4.06	1.76
97K-340-1	0.29	0.19	0.88	0.45	1.65	1.39	5.21	2.75
97K-813-21	0.38	0.32	1.11	0.60	1.55	1.17	6.25	2.99
97K-819-154	0.17	0.16	0.57	0.30	0.69	0.93	4.91	2.18
97K-819-170	0.21	0.12	0.32	0.22	0.75	0.61	3.47	1.61
98K-1399	0.14	0.16	0.64	0.31	0.60	0.69	4.61	1.97
98K-476-8	0.21	0.19	0.43	0.28	0.62	1.03	3.81	1.82
99K-213-21	0.31	0.42	0.57	0.43	1.68	2.81	3.68	2.72
99K-826-119	0.35	0.46	1.65	0.82	1.02	2.34	6.92	3.43
ALOKA	0.25	0.21	0.35	0.27	1.09	0.99	2.93	1.67
DANILA	0.11	0.26	0.56	0.31	0.52	1.16	3.27	1.65
IAR-48	0.22	0.25	0.86	0.44	0.59	0.98	4.74	2.10
OOK-1148	0.31	0.12	0.41	0.28	0.81	0.56	2.76	1.38
TN256-87	0.19	0.17	0.63	0.33	1.12	1.10	4.10	2.11
TN28-87	0.17	0.12	0.31	0.20	0.88	0.79	2.12	1.26
Means	0.23	0.22	0.66	0.37	0.93	1.16	4.19	2.09
		RDW				SDW		
SE± (G)		0.05				0.25		
SE± (P)		0.03				0.14		
SE± (PXG)		0.10				0.45		

4.3.3 Effect of P source on total biomass and percentage relative cowpea response in pots

The overall mean biomass was significantly increased ($P < 0.01$) with the application of P and varied from 1.1 to 4.8 g pot^{-1} (Table 10). Similar values (< 2.0 g pot^{-1}) were observed in all the cowpea genotypes at 0P and RP except two genotypes IT99K-213-21 and IT99K-826-119 which had values above 2.5 g pot^{-1}. All the cowpea genotypes responded to SSP with percent relative cowpea response (RCR) between

113.52% to 715.96% (Results not shown on Table 10). However, wide variability existed between the cowpea genotypes with the application of SSP and IT99K-826-119 and TN28-87 having the highest (8.57) and the lowest (2.43) g pot^{-1} respectively. It should be noted total biomass increased significantly in IT99K-826-119 with the application of both RP and SSP.

Table 10: Effect of P source on total biomass and relative cowpea response (RCR) in pots.

Genotypes	0P	RP	SSP		RP	SSP
	----------Biomass(g pot^{-1})----------			Means	----------% RCR----------	
IT90K-277-2	0.56	0.95	4.60	2.04	68.44	715.96
IT97K-340-1	1.94	1.58	6.09	3.21	-18.43	213.54
IT97K-813-21	1.93	1.50	7.36	3.60	-22.56	280.86
IT97K-819-154	0.86	1.09	5.48	2.48	26.98	537.67
IT97K-819-170	0.96	0.73	3.78	1.82	-23.82	295.19
IT98D-1399	0.74	0.85	5.24	2.28	13.71	604.84
IT98K-476-8	0.83	1.22	4.24	2.09	47.28	412.33
IT99K-213-21	1.99	3.23	4.25	3.16	62.36	113.52
IT99K-826-119	1.38	2.80	8.57	4.25	103.34	522.29
ALOKA	1.34	1.20	3.28	1.94	-10.46	144.88
DANILA	0.63	1.43	3.84	1.96	126.91	510.67
IAR-48	0.81	1.23	5.59	2.55	51.29	588.07
ITOOK-1148	1.12	0.68	3.17	1.66	-39.68	182.30
TN256-87	1.31	1.27	4.73	2.44	-2.98	261.93
TN28-87	1.06	0.91	2.42	1.46	-14.27	129.21
Means	1.16	1.38	4.84	2.46		
SE± (G)	0.29					
SE± (P)	0.12					
SE± (PXG)	0.50					

4.3.4 Effect of P source on cowpea genotype shoot: root ratios in river sand in pot

There was a significant difference ($P < 0.05$) in the shoot: root of cowpea genotypes (Table 11). Genotypic differences have also been reported in common beans (Fawole et al., 1982) and in cowpeas by Sanginga et al. (2000). Irrespective of P source,

four genotypes namely IT97K-819-154, IT97K-819-170, TN256-87 and TN28-87 had the highest shoot: root ratio of 7 while IT99K-826-119 had the lowest value of 4. The remaining genotypes fell between 5-6. P source also had a significant difference ($P < 0.05$) on the shoot: root of the genotypes. The overall mean values were in the order of SSP > RP > 0P. Wide variation was observed in the response of the genotypes to P sources based on the shoot: root ratio. At 0P, the least genotypes had 3 as shoot: root ratio while the highest had 6. Similar order was observed with the application of RP while highest shoot: root values were recorded with the application of SSP and wider variability was observed among the genotypes.

Shoot: root ratio has been used to assess P efficient genotypes (Yan et al. 1995). In this study IT97K-819-154, which was found to be P efficient in Toumnia was found to have high shoot: root ratio in the screen house. Similarly TN256-87 which has high shoot: root ratio was found to be tolerant responder at Toumnia and Minjibir.

Shoot: root ratio may not be a good index of identifying P use efficient genotypes because the value can be influenced by changes in either shoot or root biomass. For exemple if 2 genotypes have similar shoot biomass, the genotype with the highest root biomass will have a lower shoot: root ratio.

4.3. 5 Effect P source on the shoot: root ratios of cowpea genotypes in the field.

There was a significant difference ($P<0. 001$) in the shoot: root of field grown cowpea genotypes (Table 11). At Minjibir, Irrespective of P source, TN256-87 had the highest shoot: root ratio of 14 while IAR-48 had the lowest value of 5. The remaining genotypes fell in between 5-12. P source had no significant difference on the shoot: root of the genotypes. The overall mean values were in the order of SSP > RP = 0P. Wide

variation was observed in the response of the genotypes to P sources based on the shoot: root ratio. At 0P, the least genotype (IAR-48) had 5 as shoot: root ratio while the highest TN256-87, had 14. At RP, the least genotype had 4 as shoot: root ratio while the highest genotypes (TN28-87 and TN256-87) had 14. At SSP, the least genotype had 6 as shoot: root ratio while the highest genotypes (TN256-87) had 14. At Toumnia, Irrespective of P source, Aloka had the highest shoot: root ratio of 18 while IT90K-277-2 had the lowest value of 7. The remaining genotypes fell in between 7-17. P source had no significant difference on the shoot: root of the genotypes. The overall mean values were in the order of SSP < RP = 0P. Wide variation was observed in the response of the genotypes to P sources based on the shoot: root ratio. At 0P, the least genotypes (IAR-48 and ITK-277-2) had 8 as shoot: root ratio while the highest IT97K-819-154, had 22. At RP, the least genotype had 8 as shoot: root ratio while the highest had 24. At SSP, the least genotype had 8 as shoot: root ratio while the highest genotypes had 17.

In this study TN256-87, which was found to be P efficient in Toumnia was found to have high shoot: root ratio in the field. Similarly TN256-87 which has high shoot: root ratio was found to be tolerant responder at Toumnia and Minjibir. In comparison between the cowpea genotypes, IT97K-819-154, IT97K-819-170, TN256-87, TN28-87, IT98K-476-8 and Danila behaved as tolerant genotypes for shoot: root ratio while IT00K-1148 and IT98D-1399 behaved like inefficient responders. Aloka local was at par and behaved like an efficient responder.

With regards to P effects on the shoot: root ratio in the field, the group of cowpea genotype with high shoot: root ratio under low P condition at both locations comprised only IT98D-1399 and IT98K-476-8, while this was true for IT99K-826-119 and Aloka

under RP conditions. The cowpea genotypes IT90K-277-2 at Minjibir, and IT00K-1148 at Toumnia produced high shoot: root ratio with SSP application. The last group was made up of genotypes that provided high shoot: root ratio under both low and high P conditions and comprised only Danila recorded at both sites.

One of the most commonly observed effects of nutrient deficiency on plant development is a decrease in the shoot: root ratio (Chapin, 1980). Genetic differences have been reported in common beans for root: shoot ratio (Fawole et al., 1982). The P efficient genotype should have high root: shoot ratio (Yan et al. 1995).

At Minjibir, the genotype TN256-87 had the highest shoot: root ratio of 14 and 16 at Toumnia. Also, TN256-87 had 14, IT98K-813-21, 13, IT98D-1399, 13 and Danila, 12 under low P conditions. On the other hand only cowpea genotype IT98K-476-8 gave high response across locations. The results suggest that high shoot: root ratio means increase in aboveground biomass relative to below ground biomass. This result indicated that the cowpea genotype IT98K-476-8 was good at both locations because it gave higher shoot: root ratios under low P conditions (Table 11). There was negative correlation($r = -0.40$) between the shoot: root ratio and grain yield that is 40% of the effect on grain production was due to shoot: root ratio. Deficiency in P results in a shift of dry matter allocation in favor of root growth (Ericsson, 1995). Shoot: root ratio was one of the mechanisms explaining the variability of cowpea genotype response to P-application (Sanginga et al. 2000; Narang et al 2001) but not a good index in P use efficiency evaluation. Phosphorus-deficient plants exhibit reduced shoot growth and increased root: shoot dry weight ratio (Whiteaker et al 1976) similar to this case.

Table 11: Effect of P source on shoot: root ratio of cowpea genotype in the field and screenhouse.

Genotypes	Minjibir				Toumnia				Screenhouse				
	0P	RP	SSP	Means	0P	RP	SSP	Means	0P	RP	SSP	Means	R*
	Shoot: root ratio												
IT97K-819-154	8	9	10	9	22	13	17	17	4	6	10	7	SR
ALOKA	9	12	11	11	19	24	10	18	6	6	7	6	TR
IT97K-819-170	10	10	12	11	16	19	10	15	4	5	12	7	TR
TN256-87	14	14	14	14	16	14	15	15	6	8	7	7	TR
DANILA	12	12	11	12	13	13	11	12	5	5	9	6	SR
TN28-87	12	14	11	12	13	10	9	11	5	7	8	7	TR
IT00K-1148	12	12	12	12	12	13	13	13	3	5	8	5	TR
IT98D-1399	13	8	11	11	12	11	7	10	5	4	7	5	TN
IT97K-813-21	13	8	11	11	11	15	11	12	4	4	6	5	TN
IT99K-826-119	6	7	6	6	10	11	8	10	3	5	4	4	TN
IT98K-476-8	10	9	8	9	9	8	8	8	3	6	9	6	TR
IT90K-277-2	6	7	8	7	8	5	8	7	4	5	8	6	SR
IAR-48	5	4	6	5	8	13	11	11	5	5	6	5	TR
Means	10	10	11	10	13	13	11	12	4	5	7	5	
Field :									Screenhouse				
SE ± (P) M = 1									SE ± (P)=1				
SE± (PXG) M = 3									SE± (PXC)=2				
SE± (P) T = 1													
SE± (PXG) T = 5													

4.3.6 Effect of P source on root length of cowpea genotypes and relative cowpea response in pot

Root length is an elongation of the root due to growth and development of the root in response to soil environment and it is expressed in cm. Important differences were found among the cowpea genotypes for this trait. Root lengths ranged from 63 cm to 269 cm under 0P conditions and from 53 cm to 357 cm under P conditions (RP and SSP) (Table 12). Percentage relative cowpea response (RCR) in root length was used to assess the cowpea genotypes such that genotypes with values above 100% did not respond to P source based on their root length. In comparing between the genotypes for root length in the pot, only one genotype showed response to RP by giving relative root length response of 150% for IAR-48 compared with the control without P (Table 12). Only four genotypes showed a response in root length with the application of SSP. These included Aloka, 187%, IT97K-340-1, 203%; T97K-819-154, 122%; and IT90K-277-2,136%. The negative RCR values showed sensitivity to P (RP or SSP) application and tolerance to inherent low P soils. In respect to the effect of P source on the root length, among the cowpea genotypes, differences were observed as follows: (1) those that got root length increased significantly ($P< 0.01$) under low P conditions e.g. IT00K-1148, IT97K-819-170, and TN28-87 (Table 12). (2) Cowpea genotypes (IT99K-826-119 and IAR-48) that increased their root length under RP conditions. RP reduced root length generally due probably to its binding or clayee nature. However, it is important to notice that the RCR in root length of genotypes IT99K-826-119 and IT90K-277-2 were higher under RP than under SSP conditions indicates that the genotypes need sparingly soluble RP than the

soluble SSP. (3) Cowpea genotypes (IT90K-277-2, IT97K-340-1, Aloka, and TN256-87) that gave long roots under SSP conditions. (4) Comprised those that gave elongated root at both low P and high P conditions (e.g. IT97K-813-21, IT98K-476-8 and Danila). The result indicates that phosphorus efficient genotypes had probably greater gravitropic sensitivity as suggested by Hong et al. (2001) on bean. From all indication, as far as root length was concerned in the pot, the P use efficient genotypes were: IT99K-826-119 and IAR-48, (under RP), Aloka, IT90K-277-2, IT97K-340-1(under SSP conditions) and IT97K-813-21, IT98K-476-8 (under high and low P conditions). The negative cowpea responses were due to the higher yields in 0P than in P plots (Table 12). Some of the mechanisms for P acquisition investigated so far include soil P exploration by cowpea roots (Singh, 1997) and root length, (Bonser et al, 1996; Kirk and Du, 1997**;** Vanvauren et al., 1997). The more P efficient genotypes should have greater root length as reported by Yan et al., (1995). Available Phosphorus regulates root gravitropism and that this response may be important for plant adaptation to low phosphorus soils (Hong et al., 2001). Probably low phosphorus availability increases APase secretion to the rhizosphere by the cowpea genotypes as in many plants including maize (Zea mays, Clark, 1975), tomato (Lycopersicon esculatum; Golstein et al., 1988a, 1988b), wheat (Tricicum aestivu*m* and Clover (Trifolium spp.; Tarafdar and Jungk, 1987), lupin Lipinus spp., rice Oryza sativa, and soybean Glycin max; (Tadano et al., 1993).

Table 12: Effect of P on root length and relative cowpea genotypes response (RCR) in screenhouse*

Genotypes	0P	RP	SSP	RP	SSP
	----------cm pot^{-1}----------			----------%RCR---------	
IT00K-1148	269	67	101	-75	-63
IT97K-813-21	253	218	346	-14	36
IT99K-826-119	128	224	155	75	21
IT99K-213-21	127	101	199	-21	56
IT98K-476-8	126	75	146	-41	16
ALOKA	125	161	357	29	187
IT97K-819-170	119	61	79	-49	-34
IT97K-340-1	118	80	357	-32	203
DANILA	103	80	109	-23	5
TN256-87	97	77	139	-20	43
TN28-87	89	48	57	-46	-36
IT97K-819-154	79	61	176	-23	122
IT90K-277-2	79	107	186	36	136
IAR-48	66	166	102	150	54
IT98D-1399	63	53	105	-16	66
Means	123	106	174	134	138

SE± (G) = 28.80
SE± (P) = 19.52
SE± (PXG) =52.00

* Planted in May 2003 for 6 weeks
SE (P) for the P sources means; SE (G) for genotypes
SE (PXG) for the interaction means between the P sources and cowpea lines.

4.4 Screening of selected cowpea genotypes for P use efficiency under field conditions.

In order to further screen for P use efficiency, the selected cowpea genotypes were further evaluated under field conditions. P use effiency of the selected cowpea genotypes were further investigated based on some mechanisms such as root elongation, specific root length, and root infection by AMF, P uptake efficiency, P incorporation efficiency

and P utilization efficiency. Relationships were established between these possible P use efficiency criteria.

4.4.1 Effect of P source on root length of cowpea genotypes in the field

There was highly significant difference ($P < 0.001$) in root length in field grown cowpea (Table 13). Root length varied from 78 cm to 392 cm and genotypes could be evaluated based on root length differences.Irrespective of P source, genotype IT98K-476-8 had highest root length in the field and that genotype was foud previously to be P use efficient. There was significant ($P < 0.01$) of the P source on root length and the trend was SSP > 0P > RP. There significant variation among the cowpea genotypes after P sources application. At 0P , the highest had 392 cm while the lowest had 78 cm. At RP the higest genotype had 255 cm while the lowest had 65 cm. It seems that the RP was inhibiting the root elongation. At SSP, the highest had 284 cm while the lowest genotype had 127 cm. The result indicates that the genotypes IT98K-476-8 that was found P use efficient had higher root length in this situation. The genotypes (IT98K-476-8, TN256-87, Danila, IAR-48, IT99K-826-119 and IT97K-813-21 had longest root (206 to 392 cm) under low P (0P). A relationship could therefore be established between the root length and P use efficiency by calculating the percentage relative cowpea response (RCR) in root length (Table 13). Aloka was induced to produce RCR of 77% by RP and 228% by SSP. The main strategy is to sense the presence of P and root elongation towards the immobile P. The main strategies of soil P acquisition by the plants are the development of roots and root hairs, establishment of concentration gradient over root membrane, root induced processes dissolving soil P (Gitte et al., 2003). Since available P from RP and SSP is normally highest near the soil surface, the production of a shallower root system

was the main strategies while under P stress production of longer root is likely to be an important strategy to the efficiency of P acquisition (Ge et al., 2000) like the one observed under inherent low P soils of Toumnia and Minjibir. In the same order with this, a bean genotype with high efficiency of P capture under field conditions had basal roots that were much more responsive to P stress than did a P –inefficient genotype (Liao and Yan, 2000) like what was observed with IT97K-819-154 in this study. The results of this work indicates that availabe P in the root zone create changes to root elongation and this is in accordance with findings in cowpea (Gitte et al., 2003), in pigeonpea (Ae et al., 1990; Subbbarao et al., 1997) and common bean (Beebe et al., 1997). Increased root growth due to P application is associated with greater rooting depth and deeper extraction of moisture during dry spells (Payne et al., 1995). Genotypic variation in root gravitropism may represent adaptation to divergent selection regimes (Hong et al., 2001). The capacity to increase topsoil foraging might be adaptive for phosphorus acquisition in low P soils, while in more arid soil, deep-rooted plants may be adaptive (White and Castillo, 1992). A root trait that may also be important for P efficiency is plasticity, or the ability to sense and respond to localized or temporary changes in P availability like in the case of the group under SSP conditions that sensed the presence of P and started elongating towards it. Similarly, the bean genotypes G19833, G19839 and BAT477, which had been proven to be phosphorus efficient in both the screen house and field studies under various soil conditions (CIAT, 1996; Yan et al. 1995), had more gravitropic sensitivity than the phosphorus inefficient genotypes DOR364 and G2333.

Table 13: Effect of P on the root length of the selected cowpea genotypes and relative response (RCR) in the field (Minjibir).

	cm plant^{-1}				%RCR	
Genotypes	0P	RP	SSP	Means	RP	SSP
IT00K-1148	161	166	166	164	3	3
IT90K-277-2	173	118	284	192	-32	64
IT97K-340-1	161	216	167	181	34	4
IT97K-813-21	206	172	268	215	-16	30
IT97K-819-154	129	65	127	107	-50	-2
IT97K-819-170	114	127	239	160	12	110
IT98D-1399	149	148	253	183	-1	70
IT98K-476-8	392	221	167	260	-44	-57
IT99K-826-119	210	255	222	229	22	6
ALOKA	78	138	254	157	77	228
DANILA	229	220	176	208	-4	-23
IAR-48	221	178	162	187	-19	-27
TN256-87	252	179	181	204	-29	-28
TN28-87	164	319	173	219	95	6
Means	188	180	203	190	-4	8
SE± (G) = 2						
SE± (P) = 2						
SE ± (PXG) = 4						

4.4.2 Effect of P source on specific root length of cowpea genotypes in the field

The specific root length is the root length per unit weight of the root and it is expressed in centimeter per gram (cm g^{-1} root dry weight). The study examined the usefulness of the specific root length (SRL) to explain the P use efficiency by cowpea genotypes. There was significant ($P < 0.01$) difference for the effect of P on the specific root length and mean specific root length varied from 57.2 cm g^{-1} under low P conditions to 81 cm g^{-1} under high P conditions (Table 14). Irrespective of P source , genotype Danila had the highest of 110 cm g^{-1} while the least had 35 cm g^{-1} . The P source had

significant ($P < 0.01$) effect and the trend was SSP > RP > 0P. The P source had significant ($P < 0.01$) among the cowpea genotypes. At 0P, the highest had 79 cm g^{-1} while the lowest had 28 cm g^{-1}. Under RP conditions, the highest which was the same genotype (TN28-87) had 120 cm g^{-1} while the lowest had 24 cm g^{-1} . Under SSP conditions, the highest had 139 cm g^{-1} while the lowest had 52 cm g^{-1} .The genotypes that gave high mean SRL under low P conditions (IT98K-476-8, IAR-48, and TN256-87) was previously to be P use efficient. Those (IT00K-1148, IT90K-277-2, IT97K-340-1, IT97K-813-21, IT97K-819-154, IT98K-476-8, IT99K-826-119, Aloka, Danila) that showed high SRL under SSP conditions were previously observed to be sensitive responders or tolerant responders. For example, Aloka local increased its specific root length from 53 cm g^{-1} under 0P to 106 cm g^{-1} under SSP. This is related to P use efficiency in the sense that the relative increase in specific root length of that genotype was 99% compared with the control without P (Table 14**)**. This result suggestes the application of a certain dose of P to Aloka local to increase its root length relative to its dry weight thereby increasing its above ground biomass. The fineness of a root often expressed as specific root length and roots with high specific root lengths are often found in plants grown under nutrient deficient conditions (Fitter, 1985) but that was not similar in this study probably because of the high response encountered due to SSP.

Table 14: Effect of P source on specific root length of cowpea genotypes and relative cowpea response (RCR) in the field.

	cm g^{-1}				%RCR	
Genotypes	0P	RP	SSP	Means	RP	SSP
TN28-87	79	120	69	89	51	-13
IT97K-819-170	74	106	72	84	43	-4
IT98K-476-8	72	43	79	65	-41	10
DANILA	70	121	139	110	73	99
IAR-48	65	60	65	63	-8	0
IT00K-1148	60	67	101	76	11	68
IT97K-819-154	59	38	103	67	-34	76
IT97K-813-21	54	55	73	61	0	34
TN256-87	54	49	46	50	-9	-16
ALOKA	53	54	106	71	1	99
IT90K-277-2	53	39	114	69	-26	115
IT99K-826-119	46	35	60	47	-23	32
IT98D-1399	39	57	55	50	45	41
IT97K-340-1	28	24	52	35	-15	83
Means	57	62	81	67		
SE± (G) = 3						
SE± (P) = 2						
SE± (PXG) = 6						

SE (P) for the P source means between
SE (G) for the cowpea genotypes
SE (PXG) for the interaction means between the P sources and cowpea genotypes.

4.4.3 Effect of P source on grain yield of cowpea genotypes in the field.

The grain is the most important part of the mature cowpea which provides food protein for the urban and rural poor in West Africa (Alghali, 1991) and a source of cash to farmers. Phosphorus fertilizers generally increase the grain yield of cowpea and this has been shown in this study (Table 15). At Minjibir, there was a significant difference ($P < 0.01$) in the effect of P source on the cowpea genotypes. Irrespective of P source, genotypes IT98D-1399 and IT98K-476-8 had the highest above 2200 kg ha^{-1} compared

with the over all mean of 1116 kg ha^{-1} while the lowest had 114 kg ha^{-1} far below the mean. Cowpea genotypes also vary significantly in their response to various P sources. At 0P, the highest had above 2000 kg ha^{-1} while the lowest had 321 kg ha^{-1}. Under RP application, the highest had above 2700 kg ha^{-1} while the lowest had 121 kg $ha^{-1.}$ Under SSP conditions, the highest had above 2400 kg ha^{-1} while the lowest had 153 kg ha^{-1}. At Toumnia, there was a significant difference ($P < 0.01$) in the effect of P source on the cowpea genotypes. Irrespective of P source, genotypes TN256-87 and IAR-48 had the highest above 1400 kg ha^{-1} compared with the over all mean of 845 kg ha^{-1} while the lowest had 395 kg ha^{-1} far below the mean. Cowpea genotypes also vary significantly in their response to various P sources. At 0P, the highest had 1535 kg ha^{-1} while the lowest had 256 kg ha^{-1}. Under RP application, the highest had 1447 kg ha^{-1} while the lowest had 355 kg $ha^{-1.}$ Under SSP conditions, the highest had 2445 kg ha^{-1} while the lowest had 500 kg ha^{-1}. Fist et al., (1987) made similar observation on pigeon pea and soybean.

Table 15: Effect of P source on the grain yield variability of selected cowpea genotypes in the field

	Minjibir				Toumnia			
Genotypes	0P	RP	SSP	Means	0P	RP	SSP	Means
TN256-87	735	668	830	744	1535	1177	2445	1719
IAR-48	911	1782	1810	1501	1349	1447	1494	1430
TN28-87	658	506	690	618	1128	635	1045	936
IT99K-826-119	596	370	532	499	1057	1020	1643	1240
ALOKA	321	509	417	416	841	831	1183	952
IT97K-819-154	68	121	153	114	740	574	602	639
IT00K-1148	1117	1695	1544	1452	672	627	730	676
DANILA	1278	1494	2420	1731	647	692	734	691
IT97K-340-1	BG	BG	BG	BG	633	1024	534	730
IT97K-813-21	693	1011	1254	986	609	589	558	585
IT98D-1399	2170	1756	2816	2247	517	555	1308	793
IT97K-819-170	460	224	687	457	365	355	909	543
IT98K-476-8	2067	2705	2075	2282	319	419	768	502
IT90K-277-2	1435	1447	1494	1459	256	430	500	395
Means	962	1099	1286	1116	762	741	1032	845
SE±(G)M= 235								
SE±(P)M=110								
SE±(PXG)M=406								
SE±(G)T= 161								
SE±(P)T=95								
SE±(PXG)T=285								

BG = Bad germination
G = Cowpea genotypes; P = Phosphorus rate; GXP = Interaction between cowpea genotypes and P rates.

4.4.4 Effect of P source on relative P use efficiency (RPUE) of cowpea genotypes in the field

The relative P use efficiency (RPUE) is defined as the cowpea grain yield per unit P fertilizer applied compared with the yield from the control without P application: RPUE = (kg grain ha^{-1} in the P fertilizer plot – kg grain in 0P plot)/ kg P ha^{-1} applied as the P fertilizer). There was significant ($P < 0.01$) over all mean difference for P source effect on the RPUE at both locations. The relative P use efficiency varied generally from

–5.5 to 38.1 kg grain kg^{-1} P applied in this study, and the lowest being recorded for the genotype TN28-87 while the highest was for Danila (Table 16). There was also significant differences among ($P < 0.01$) the P sources across the locations and the trend was SSP > RP at both locations. At Minjibir, Irrespective of P source, genotypes Danila and IAR-48 had the highest RPUE and the least had -2.3 as RPUE. It is important to notce that Danila and IAR-48 were observed to be high grain producer in Minjibir. There was significant differences ($P< 0.01$) among the cowpea genotypes in the effect of P sources for RPUE. Under RP, IT98K-476-8 and IAR-48 were recorded as the highest while the lowest was IT98D-1399. Under SSP conditions, the highest were Danila and IAR-48 while the lowest was IT99K-826-119. At Toumnia, Irrespective of P source, genotypes TN256-87 and IT98D-1399 had the highest RPUE and the least had -4.15 as RPUE. It is important to notce that TN256-87 was observed to be high grain producer in Toumnia. There was significant differences ($P< 0.01$) among the cowpea genotypes in the effect of P sources for RPUE. Under RP, IT97K-340-1 was recorded as the highest while the lowest had -5.5 as RPUE. Under SSP conditions, the highest was TN256-87 while the lowest was IT97K-819-154. This result shows the nature of tolerance and response by these cowpea genotypes to their respective localities. The trend may suggest that the local genotype need external phosphorus addition to sustain grain production in low P soil while the improved genotype TN28-87 may not require P on the P deficient soil. Acidic soils with a high pH buffering capacity provide an ideal environment for RP dissolution. Results reported by Bado (1998) indicated that the PUE of the unreactive RP on an acidic soil (pH in H_2O=5) is similar to that of the PUE of water soluble (Triple super phosphate) TSP (Mahaman et al., 1997**)**. In the irrigated system, the PUE of RP was often higher

than the soluble fertilizer TSP (INRAN, 1988) because the RP get solubilized in irrigated soil and the TSP was readly leached. Similarly, the genotype IT98K-476-8 performed well under RP situation at Minjibir while IT97K-340-1 gave higher RPUE at Toumnia probably due to adaptation to the different environments.

Danila gave the highest RPUE of 38 kg grain kg P^{-1} applied as SSP at Minjibir while at Toumnia TN256-87 gave 30 kg grain kg P^{-1} applied as SSP. The data has revealed that RPUE depends on the P source as SSP gave the highest RPUE than RP, the cowpea genotypes, and this compliment the earlier observation by Bationo and Anand Kumar (2002). These observations revealed that a variety such as Danila with high RPUE coefficient would not produce high grain yield under low P conditions. Also, cowpea genotypes identified for high grain yield under low P conditions would not be P use efficient for example IT97K-813-21 or IT98K-476-8. The adaptation to a particular location explained the location specificity of such cowpea genotypes IAR-48, Danila, and IT97K-813-21 for Minjibir and TN256-87, IT97K-819-170, IT99K-826-119, Aloka and IT98K-476-8 for Toumnia. These are site specific data.

Table 16: Effect of P source on relative P use efficiency of the selected cowpea genotypes in the field.

Genotypes	Minjibir			Toumnia		
	RP	SSP	Means	RP	SSP	Means
	kg grain ha^{-1} kg P ha^{-1}					
IT00K-1148	6.4	14.2	10.3	-0.5	1.9	0.7
IT90K-277-2	0.1	2.0	1.05	1.9	8.1	5
IT97K-340-1	BG	BG		4.3	-3.3	0.5
IT97K-813-21	3.5	18.7	11.1	0.0	-1.7	-0.85
IT97K-819-154	0.6	2.8	1.7	-1.8	-4.6	-3.2
IT97K-819-170	-2.6	7.6	2.5	-0.1	18.1	9
IT98D-1399	-4.6	21.5	8.45	0.4	26.4	13.4
IT98K-476-8	7.1	0.3	3.7	1.1	15.0	8.05
IT99K-826-119	-2.5	-2.1	-2.3	-0.4	19.5	9.55
ALOKA	2.1	3.2	2.65	0.0	11.4	5.7
DANILA	2.4	38.1	20.25	0.5	2.9	1.7
IAR-48	9.7	30.0	19.85	1.1	4.8	2.95
TN256-87	-0.7	3.2	1.25	-4.0	30.3	13.15
TN28-87	-1.7	1.1	-0.3	-5.5	-2.8	-4.15
Means	1.5	10.0	5.75	-0.2	9.0	4.4
SE±(G)M= 8.6						
SE±(P)M=4.2						
SE±(PXG)M=12.5						
SE±(G)T= 6.5						
SE±(P)T=3.5						
SE±(PXG)T=9.5						

BG = Bad germination. M: Minjibir and T: Toumnia.
G = Cowpeas, P = Phosphorus source.

4.4.5 Effect of P source on fodder yield of cowpea genotypes in the field.

Fodder of cowpea is very nutritious in rearing livestock in Sahel and Sudan savannas of West Africa. In general most cowpea genotypes increase fodder production in response to P. At Minjibir, there was a significant difference ($P < 0.01$) in the effect of P source on the cowpea genotypes fodder. Irrespective of P source, genotypes IT98D-1399, Danila and IT98K-476-8 had the highest 3090 to 6000 kg ha^{-1} compared with the over all mean of 1819 kg ha^{-1} while the lowest had 462 kg ha^{-1} far below the mean.

Cowpea genotypes also vary significantly in their response to various P sources. At 0P, the highest had above 5500 kg ha^{-1} while the lowest had 333 kg ha^{-1}. Under RP application, the highest had above 6200 kg ha^{-1} while the lowest had 338 kg $ha^{-1.}$ Under SSP conditions, the highest had above 6300 kg ha^{-1} while the lowest had 499 kg ha^{-1}. At Toumnia, there was a significant difference ($P < 0.01$) in the effect of P source on the cowpea genotypes fodder. Irrespective of P source, genotypes IT98K-476-8, IT98D-1399 and Danila had the highest 2488-4560 kg ha^{-1} compared with the over all mean of 1987 kg ha^{-1}. Cowpea genotypes also vary significantly in their response to various P sources. At 0P, the highest had 1500 kg ha^{-1} while the lowest had 250 kg ha^{-1}. Under RP application, the highest had 5106 kg ha^{-1} while the lowest had 555 kg $ha^{-1.}$ Under SSP conditions, the highest had 7881 kg ha^{-1} while the lowest had 1443 kg ha^{-1}. The result indicates that both RP and SSP increase fodder with high increase being with SSP application. It is important to notice that the same genotypes were observed as highest fodder producer in both locationas and two of which were observed to be P use efficient and grain yielder namely IT98K-476-8 and TN256-87. The interaction between P source and the cowpea genotype was significant ($P= 0.05$) at Toumnia but not at Minjibir. IT98K-476-8 gave the highest mean (5550 kg ha^{-1}) at Minjibir under 0P while TN256-87 gave the highest (1500 kg ha^{-1}) at Toumnia under 0P. When P was added, there was an increase in fodder production by IT98K-476-8 from 5550 kg to 6327 kg ha^{-1} at Minjibir and at Toumnia the same cowpea genotype gave 7881 kg ha^{-1} in response to SSP application (Table-17). This was also the same genotypes that came up in the initial screening of 147 cowpea genotypes. IT98K-476-8 and TN256-87 behaved like efficien responders while IAR-48, IT98D-1399, and Danila behaved as inefficient responders.

Similarly, research conducted at Ikenne in the humid zone of Nigeria and Kamboinse in the Sudanian zone of Burkina Faso in West Africa indicated a strong differential response to P by cowpea cultivars (Bationo et al. 2002). The local Kamboinse variety is a fodder type and the application of P resulted in higher fodder yield.

Table 17: Effect of P source on the fodder yield variability of selected cowpea genotypes in the field.

	Minjibir				Toumnia			
Genotypes	0P	RP	SSP	Means	0P	RP	SSP	Means
	kg ha^{-1}							
TN256-87	1055	943	499	832	1500	1332	2220	1684
IT97K-819-154	333	338	569	413	306	555	1887	916
IT97K-819-170	500	522	555	526	917	666	1443	1009
IT00K-1148	943	1554	721	1073	875	1443	2664	1661
IT97K-813-21	1887	1276	666	1276	861	1110	2220	1397
ALOKA	389	499	499	462	833	2109	2442	1795
TN28-87	2054	1443	1110	1536	778	1998	3108	1961
IT98K-476-8	5550	6216	6327	6031	694	5106	7881	4560
IT97K-340-1	BG	BG	BG		667	1554	2553	1591
IAR-48	1776	1776	1498	1683	625	1554	2331	1503
IT98D-1399	3774	2165	3330	3090	583	1554	5328	2488
IT99K-826-119	888	372	1943	1068	583	1443	1776	1267
DANILA	3996	5328	3663	4329	375	5106	5772	3751
IT90K-277-2	1443	1332	1165	1313	250	3441	1998	1896
Means	1891	1832	1734	1819	775	2069	3116	1987
SE±(G)M= 402								
SE±(P)M=153								
SE±(PXG)M=686								
SE±(G)T=357								
SE±(P)T=138								
SE±(PXG)T=657								

G =Cowpea genotypes; P = Phosphorus sourcesSSP, Single Super phosphate (30kg ha^{-1}).
GXP = Cowpea genotypes X P sources interaction.
SE (P) for comparing the means between the P sources
SE (PXG) for comparing the interaction means of the P sources and cowpea genotypes. BG = Bad germination.

4.4.6 Effect of P source on AMF infection rate of cowpea roots in the field.

Mycorrhizal symbiosis has been proposed to explain the P efficiency of crop plants (Koide, 1991). Phosphorus application had significant ($P < 0.05$) influence on AMF such that P suppressed AMF infection in more than 78% of the cowpea genotypes at both Minjibir and Toumnia. (Table 18). However, AMF infection of Danila was rather increased by RP application in both locations (13% and 15% higher than 11% with 0P). IT97K-340-1 gave very high AMF infection rate of 29% at Toumnia under RP compared to the control of 8% while it did not germinate at Minjibir. The genotype IT98K-476-8 was observed to have the largest proportion of its root infected by AMF (21%) at Minjibir, while IT97K-813-21 had the highest AMF infection rate (24%) at Toumnia under 0P conditions showing the tolerance of these genotypes to the respective locations. Heckman and Angle (1987) examined 15 soybean genotypes for colonization by a heterogeneous field population of AMF at two P levels and found that colonization varied significantly with cultivars. Also, Krisna et al. (1985) found that root infection by indigenous AMF differed among 30Pearl millet genotypes. Furthermore, Mercy et al., (1990) found that mycorrhizal colonization in cowpea is host dependent and heritable. Root infection by AMF is accompanied by the development of a network of fine extraradicl hyphae, which increases the absorption rate of slow-diffusing nutrient, mainly P, from the soil to the plant (Jackobsen, 1999). Therefore, AMF might play a critical role in low-input or inorganic systems of Minjibir and Toumnia due to their function in linking plant and soil processes. High infection was an indication of high P uptake in low P soil due to the increase in root hair of the cowpea genotypes. On the other hand, low infection is an indication of low P uptake if P is not applied. The AMF infection was

positively related (r = 0.47) to RPUE in this study. Sanginga et al. (2000) made similar observation. AMF infection is therefore one of the mechanisms that may explain the variability of cowpeas in low P soils as suggested by other workers (Koide, 1991; Sanginga et al. 2000). At Minjibir RP increased the %AMF infection of the genotype IT98K-476-8 by 20%, Aloka by 8% and Danila by 13%. P tolerance was related to the high infection of AMF as seen with the genotype IT97K-813-21 with 17% infection rate under low P at Minjibir compared with 13% under RP condition. Similarly, the genotype IT98K-476-8 was 21% root infected under low P at Minjibir compared with 20% infection rate under RP condition. At Toumnia, IT97K-813-21 was 24% root infected under low P compared with 16% under RP conditions. This explains somehow the machanism behind the P tolerance in which AMF contribute a lot. At Toumnia compared with control RP increased the %AMF infection of IT97K-340-1 by 29%, IT98D-1399 by 23%, IT99K-826-119 by 28%, Aloka (15%), Danila (15%), IT98K-476-8 by 11% (Table 18). These results are in contrast to the reduction of root infection by AMF resulting from addition of rock P in cowpea cv. Pale Green (Islam et al., 1980). The application of RP had increased the AMF infection compared with SSP and the results showed that RP improved the AMF infection of 3 cowpea genotypes (IT98K-476-8, Aloka and Danila) at both locations. This increase could be due to low reactivity of RP (Mahamane et al., 1997). AMF has formerly been shown to improve the utilization of sparingly soluble P of RP of varying origins (Manjunath et al., 1989). Vanlauwe et al., (2000) also had the similar report on mucuna and lablab. Young et al. (1986) studied the effect of RP application and mycorrhizal inoculation on corn grown in two soils, Houli and Wanlaum soils, with available P levels of 6.3 and 60 mg kg soil^{-1}, respectively. They found out that

AMF inoculation increased corn yield significantly in both soils with the effect being more pronounced in soil with low available P. They hypothesized that the fungus produced compounds that dissolved RP. Furthermore, AMF can increase P uptake by host plants (Smith and Read, 1997), which is another criterion that can explain the P use efficiency by cowpea genotypes.

Table 18: Effect of P source on AMF of selected cowpea genotypes in the field.

	Minjibir			Toumnia		
Genotypes	0P	RP	SSP	0P	RP	SSP
	----------%AMF----------					
IT97K-813-21	17	13	3	24	16	10
IT99K-826-119	8	5	8	21	28	12
IAR-48	14	8	5	20	13	12
IT00K-1148	16	12	6	19	10	6
TN256-87	15	8	6	19	15	12
IT97K-819-154	2	1	2	17	11	7
ALOKA	4	8	3	16	15	11
IT90K-277-2	19	12	5	15	11	8
TN28-87	8	7	5	15	6	10
IT98D-1399	20	10	6	14	23	9
IT98K-476-8	21	20	6	13	11	9
DANILA	11	13	3	11	15	4
IT97K-340-1	BG	BG	BG	8	29	9
IT97K-819-170	7	1	3	6	7	10
Means	12	9	5	16	15	9
SE± (G) M = 2						
SE± (P) M = 1						
SE± (PXG) M = 3						
SE± (G) T = 3						
SE± (P) T = 1						
SE± (PXG) T = 5						

M= Minjibir; T= Toumnia; BG = Bad germination
SE (P) for the means between P sources
SE (PXG) for the interaction means between P sources and cowpea genotypes.

4.4.7 Effect of P source on uptake efficiency of cowpea genotypes in the field

Phosphorus uptake efficiency was defined as P uptake per root dry weight by Barrow (1975). P uptake efficiency was derived as mg P in shoot per g root dry weight or simply expressed in percentage (%). At Minjibir, there was a significant difference ($P < 0.01$) in the effect of P source on the cowpea genotypes in P uptake (Table 19). Irrespective of P source, genotypes IT97K-819-154 had the highest of 12% while the lowest had 4%. Cowpea genotypes also varied significantly ($P < 0.01$) in their response to various P sources. At 0P, the highest had 17.3% while the lowest had 4.2%. Under RP application, the highest had 9.7% while the lowest had 4.3%. Under SSP conditions, the highest had 8.5% while the lowest had 3.3%. At Toumnia, there was a significant difference ($P < 0.01$) in the effect of P source on the cowpea genotypes. Irrespective of P source, genotypes IT97K-819-170 had the highest of 10% while the lowest had 3%. Cowpea genotypes also vary significantly ($P < 0.01$) in their response to various P sources. At 0P, the highest had 10.1% while the lowest had 2.1%. Under RP application, the highest had 10.1% while the lowest had 2.4%. Under SSP conditions, the highest had 13.3% while the lowest had 3.0%. As far as P uptake efficiency was concerned in this study, some cowpea genotypes IT97K-819-154, IT98K-476-8 recorded relatively higher values at Minjibir and Aloka, TN28-87 and IT97K-819-154 recorded high P uptake efficiency at Toumnia (Table 19). IT97K-819-154 was observed as grain producer at Toumnia while IT98K-476-8 was observed as dual purpose genotype at both locations. Similarly variation in P uptake efficiency by genotypes of cowpea due to differences in root and root hair length and induced rhizosphere processes might have occurred as shown by Gitte et al., (2003) and reported by others workers in other crops (Barber, 1995;

Horst, 1995; Romer and Schenk, 1998). That suggested that, some of cowpea roots in this study were able to induce transformation and uptake of non labile soil P within the soil volume exploited and this in accordance with findings in other legumes such as pigeonpea (Ae et al., 1990; Subbarao et al., 1997), common bean (Beebe et al., 1997) and recently in cowpea (Gitte et al., 2003). For example Danila had a low P uptake, and IT98K-476-8 had a high P uptake in this study. Gitte et al., 2003; Adelson and Marcelo 2000; had similar experience**.**

Table 19: Effect of P source on P uptake efficiency of cowpea genotypes in the field.

	Minjibir				Toumnia			
Genotypes	0P	RP	SSP	Means	0P	RP	SSP	Means
	----------%P----------							
IT97K-819-170	9.1	9.7	6.1	8	10.1	6.4	13.3	10
IT97K-819-154	17.3	9.3	8.5	12	8.2	5.9	7.7	7
TN28-87	7.8	9.6	5.7	8	7.5	3.0	4.0	5
IT00K-1148	6.4	7.3	5.2	6	6.2	4.5	6.7	6
ALOKA	7.5	7.1	7.5	7	5.5	10.1	6.5	7
TN256-87	4.2	4.7	4.4	4	5.2	8.3	3.5	6
IT98D-1399	4.3	7.0	3.8	5	5.0	6.8	4.1	5
IT90K-277-2	7.1	7.5	5.6	7	3.8	4.8	6.7	5
IT97K-813-21	4.2	5.4	4.4	5	3.3	2.8	4.3	3
IAR-48	5.0	6.8	4.9	6	3.2	4.9	3.0	4
IT98K-476-8	6.2	4.3	3.8	5	2.9	2.4	4.0	3
DANILA	4.8	6.0	3.3	5	2.1	2.8	4.0	3
Means	6.7	6.8	5.1	6	5.2	5.7	5.5	5
SE± (G) M = 0.013								
SE± (P) M =0.6								
SE± (PXG) M =2.3								
SE± (G) T = 0.011								
SE± (P) T =0.5								
SE± (PXG) T =1.9								

SE (G) for comparing the cowpea genotypes. SE (P) for the means between the P sources SE (PXG) for the interaction means between the P sources and cowpea genotypes.