

RESPONSES OF SOME PROMISCUOUS AND NON-PROMISCUOUS SOYBEAN CULTIVARS TO INOCULATION AND PHOSPHORUS APPLICATION

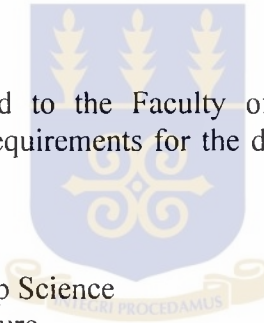
BY



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DEDICATION

Dedicated to Almighty God.





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DECLARATION

I, Samuel Abraham, author of this thesis hereby declare that this report is the result of my own investigation and has not been submitted in this University or any other University for any award. References to other works have been duly cited.



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ABSTRACT

Pot and field studies were carried out at the University of Ghana, Legon, to evaluate the effect of *Bradyrhizobium japonicum* inoculation and five rates of phosphorus application on growth, nodulation and dry matter production of some promiscuous and non-promiscuous soybean cultivars in pots and finally the effect of three rates of phosphorus and inoculation on growth, nodulation, dry matter production and yield of a promiscuous cultivar "Bengbie" in the field.

In the pot experiment, one non-promiscuous cultivar (Davis) and two promiscuous cultivars (Bengbie and Anidaso) were inoculated with *B. japonicum* strain TAL 102 and also received 0, 8.9, 17.9, 26.8 and 35.7mg P/kg soil (equivalent to 0, 20, 40, 60 and 80kg P/ha.). Inoculation generally caused significant increases in nodulation, shoot dry weight, shoot nitrogen (N) and shoot (P), but not root dry weight. Phosphorus application on the average increased nodulation, root and shoot dry weight and shoot N and P.

The non-promiscuous cultivar produced higher nodulation and shoot N than the promiscuous cultivars on inoculation.

Interaction between inoculation and cultivar was significant for nodulation, root dry weight and shoot N while phosphorus and cultivar interaction was significant for shoot dry weight and shoot P.

In the field experiment, one promiscuous cultivar "Bengbie" was inoculated with *B. japonicum* strain TAL 102 and given 0, 30 and 60 kg P/ha. Inoculation in the field increased nodulation, root dry weight, shoot N and shoot P. This indicates that promiscuous cultivars can benefit from inoculation. However, inoculation failed to increase pod number and final grain yield.

Phosphorus application up to 60kg/ha did not significantly increase nodulation, shoot and root dry weight, shoot N and P, 100 - seed weight and final grain yield.

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CHAPTER ONE

INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is a leguminous crop, which has assumed world-wide importance through its industrial and nutritional uses. Its potential for cultivation in Ghana has attracted interest over the years.

The crop has the ability to fix atmospheric nitrogen and become less dependent on soil nitrogen. Fixation of atmospheric nitrogen in the root nodules contributes up to 70% of the total nitrogen uptake by the plant (Weber, 1966).

Soybean production in the tropics is constrained by poor nodulation due to absence of appropriate *Bradyrhizobium spp.* and deficiency of phosphorous, potassium, molybdenum and sulphur in the soil (Singh and Rachie, 1987). Phosphorous appears to be the most limiting nutrient for the growth of legumes in tropical and subtropical regions (Ae *et al.*, 1991). In Ghana the problem of phosphorus deficiency and its attendant effect on low crop yields have long been recognized (Nye, 1952).

Several researchers have reported that inoculation of soybean with *B. japonicum* increased yield (Dadson and Acquaaah, 1984; Mahmoud *et al.*, 1991; Badawy *et al.*, 1992 and Mahmoud and El-far, 1991).

Although bradyrhizobial inoculation technology is simple and extremely cost effective for soybean production legume inoculation is not practised by most African farmers.

A practical alternative to inoculation has been the development of soybean varieties capable of forming effective symbiosis with indigenous cowpea bradyrhizobia (Kueneman *et al.*, 1984).

In Ghana, information on the inoculation of promiscuous soybean genotypes and their response is lacking. For effective comparison between the nodulation of promiscuous soybeans cultivars in our soils, it is important to compare with the non-promiscuous cultivar.

For legumes, P enhances both nodulation and N₂ fixation (Israel, 1987). In this regard there is the need to study the responses of the different cultivars to varying levels of phosphorus.

The objective of this study therefore was to evaluate the effect of *Bradyrhizobium* inoculation and phosphorus application and their combined effect on nodulation, growth and yield of both promiscuous and non-promiscuous soybean cultivars.

CHAPTER TWO

LITERATURE REVIEW

2.1 The effect of bradyrhizobial inoculation on nodulation and nitrogen fixation in soybean

2.1.1 Variability in *Bradyrhizobium* strains

Poor nodulation of soybean by indigenous bradyrhizobia is one of the major constraints to the successful production of soybean in Africa (Singh and Rachie, 1987). Where no soybean crop has been grown before, it is usually necessary to inoculate with an efficient *Bradyrhizobium* strain to maximize yield when fertilizer nitrogen is not applied (Dadson and Acquah, 1984). Significant responses to bradyrhizobial inoculation are observed when the crop is grown in areas where it has not been previously cultivated (Abel and Erdman, 1964; Kang, 1975) and yield increases as high as six-fold have been obtained (Bromfield and Ayanaba, 1980). In some soils where soybean has been grown previously, continued inoculation may still be necessary (Rao *et al.*, 1985) apparently because of poor survival of introduced rhizobia.

A practical alternative to the use of inoculants in developing countries may be the development of cultivars capable of forming an effective symbiosis with the indigenous rhizobia. Through breeding, a number of cultivars which nodulate freely have been released in recent times (Kueneman *et al.*, 1984).

On the other hand, the development of "promiscuous" soybean varieties with unknown nitrogen fixing abilities and rhizobial association may not be a very attractive alternative compared to the conventional inoculation methods when the benefits of the legume/rhizobial symbiosis is to be maximized (Woomer *et al.*, 1992). Consequently, if the available high yielding soybean cultivars are to be grown under tropical conditions of low soil N (Pulver *et al.*, 1992), inoculation will be essential.

Mandimba and Mandibaye (1996) found that inoculation with *B. japonicum* strains TAL 377 and TAL 379 improved nodule number per plant up to 355 and 380% and nodule mass per plant by up to 366 and 182%, respectively, compared to the uninoculated control. Furthermore, inoculation increased shoot N, plant biomass and yield. Inoculation was equivalent to the application of 75 and 65 kg N/ha for TAL 377 and TAL 379 strains respectively.

In Sudan, Mukhtar and Sayda (1987) found that no nodules were produced on uninoculated soybean and inoculation with a mixture of TAL 102, TAL 377 and TAL 379 produced a higher seed yield than applying 120kg N/ha. Olufajo and Adu (1992) also reported high soybean yields in all inoculated treatments and yields were similar to the level obtained with 100kg N/ha application.

Works conducted by Badawy *et al.*, (1992) and Olufajo and Adu (1992) indicated that inoculation of soybean seed with a mixture of bradyrhizobia strains increased nodulation and total plant nitrogen. Several researchers have also found that inoculation of soybean seeds before planting resulted in increases in nodulation, percentage N, plant growth, seed yield and yield components compared to uninoculated control (Mahmoud *et al.*, 1991; Mahmoud and El-far, 1994; Buiyan *et al.*, 1995).

2.1.2 Differential response of soybean cultivars to inoculation.

Differences in responses of soybean cultivars to inoculation with *B. japonicum* have been reported (Cardwell and Vest, 1970; Tawfik *et al.*, 1991). Howle *et al.*, (1987) compared 6 soybean cultivars to inoculation and reported that inoculation produced highest shoot weight in "wright" cultivar of soybean while in "Bragg" it resulted in the highest nodule weight. Such cultivar differences to applied inoculum may depend on the strain of *Bradyrhizobium* used (Israel, 1981).

Rennie and Dubetz (1984) found that "Marple Amber" outyielded "Marple Presto" and "X005" cultivars of soybean when it was inoculated with *B. japonicum*. Olufajo and Adu (1992) also found that among five inoculated cultivars of soybean, TGX 814 - 26D and TGX 888 - 49C had the highest nodule number.

However, Nelson *et al.*, (1978) found no difference between two cultivars of soybean in their response to application of *B. japonicum*. On soils devoid of *B. japonicum* soybean inoculated with different strains of *B. japonicum* showed significant increases in yield, nodule weight and weight of plant (Abel and Erdman, 1964).

Nangju (1980) reported that the soybean cultivar, "Malayan", nodulated quite well with indigenous strains of *Rhizobium* and that inoculation did not significantly improve nodulation, growth and yield. On the other hand, the American cultivars used nodulated poorly, and showed significant increases in growth and yield when inoculated.

Promiscuous soybean cultivars, which are said to nodulate freely in soils have been shown to vary in their ability to form effective symbiotic relationship with indigenous bradyrhizobia in tropical soils (Pulver *et al.*, 1985).

Pulver *et al.*, (1985) screened 400 lines of soybean in Nigeria for promiscuity but only ten formed effective symbiosis at all sites. None of the twenty-five improved cultivars of soybean bred and selected in the USA was capable of nodulating with the indigenous *Bradyrhizobium* strains at any of the test sites.

High yielding soybean cultivars developed at the International Institute of Tropical Agriculture (IITA), Nigeria, and introduced to Ghana have been shown to nodulate freely with indigenous bradyrhizobia. However, most of these cultivars formed few nodules (Mercer-Quarshie, 1992, Djagbletey, 1995). In contrast to the findings of Nangju (1980) and Pulver *et al.*, (1982), Djagbletey (1985) obtained significant increases in the nodulation of two promiscuous cultivars by inoculating with *Bradyrhizobium* and one of the promiscuous cultivar failed to nodulate without inoculation. Promiscuous cultivars may therefore benefit from inoculation (Olufajo and Adu, 1992).

2.1.3. Population of *Bradyrhizobium* strains

When the soil contains effective soybean bradyrhizobia or has produced adequately nodulated soybeans, inoculation may not produce significant increase in yield (Johnson *et al.*, 1965; Caldwell and Vest, 1970; Ham *et al.*, 1971). This lack of response occurred when the soil contained more than 10^3 bradyrhizobia per gram of soil (Weaver and Frederick, 1974; Singleton *et al.*, 1992). However, when the soil contained ineffective bradyrhizobia, application of effective *B. japonicum* in the inoculant produced much greater proportion of nodules even if the population of the effective strains was comparatively low (Robinson, 1969).

Introduced inoculant strains must exhibit both saprophytic and symbiotic superiority, relative to indigenous strains, if they are to maintain yields in the absence of continued inoculation (Fuhrman and Wollum, 1989). A major problem with superior strains however, is that they are not always competitive with ineffective yet inefficient indigenous rhizobia in the soil. Winarno and Lie (1979), observed that inter-strain competition led to inhibition of nodulation and a strain incapable of nodulating a particular cultivar completely suppressed nodulation by an effective strain. Similar observation of inter-strain competition on nitrogen fixation has been reported by Daramola *et al.*, (1994).

2.2 Soil Phosphorus

The phosphorus (P) content of soils is low compared to nitrogen and potassium (Tisdale and Nelson, 1975; Brady, 1990). The total phosphorus content of a soil does not indicate its fertility, what is important is the amount of available phosphorus (Yayock *et al.*, 1989). When soluble sources of phosphorus in fertilizers and manures are added to soil, they are fixed or are changed to unavailable forms and react to become highly insoluble forms (Brady, 1990).

Plants absorb P as either the primary $H_2PO_4^-$ ion or smaller amounts of the secondary HPO_4^{2-} and since the former is more abundant over the range of soils prevailing for most crops, it is usually the principal form absorbed (Russel, 1988; Tisdale and Nelson, 1975).

2.3 Effect of Phosphorus on nodulation and nitrogen fixation

Phosphorus (P) is the most limiting nutrient for the growth of leguminous crops in the tropical and subtropical regions (Ae *et al.*, 1991). Low phosphorus content of between the range 2-6 ppm have been reported for most savannah soils in Ghana (Nye, 1952). The effects of P on legume growth and development is a function of nutritional effects on nodulation (Gates, 1974). Nodules are strong sink for phosphorus and can increase in phosphorus concentration up to 50% (Graham and Rosas, 1979) and dry weight up to 32.8 fold (Israel, 1987).

Cassman *et al.*, (1980) found nodule dry weight of nitrogen fixing soybean to comprise 9% of the total plant dry weight and 61% of root dry weight at the highest rate of phosphorus application. Dadson and Acquaaah (1984) and Assuah (1990) reported that application of phosphorus up to 60kg P/ha increased nodulation in soybean.

P application increased nodulation for both promiscuous and non-promiscuous soybean cultivars (Afuakwa, 1988). Nodulation was more enhanced in the non-promiscuous cultivar.

Increases in nodulation by applying phosphorus to P deficient soils have been reported by several other workers (Singleton *et al.*, 1985; Garside and Fulton, 1986 and Olufajo and Adu, 1992).

2.4 Effect of applied phosphorus on growth and seed yield of soybean

In savannah soils lack of phosphorus has a limiting effect on nodulation and yield (Olufajo and Adu, 1992). Soybean growth is more sensitive to phosphorus when dependent on symbiotic nitrogen (Cassman *et al.*, 1981). Phosphorus supply increased nitrogen and phosphorus uptake (Israel, 1987; Annadurai *et al.*, 1994). Uptake of phosphorus has been found to be similar for both inoculated and uninoculated promiscuous soybean cultivars (Olufajo and Adu, 1992). Deficiency of phosphorus has been found to greatly reduce starch content (Sabbe and Sattin

1995). Pasture legumes failed to grow without phosphorus application and responded to rates between 200 and 800 kg P/ha (Davis, 1991).

The uptake of fertilizer P is more important during early growth when root absorption is limited by relatively small volume (Welch *et al.*, 1949).

Highly significant increases in plant dry weight had been obtained by increasing phosphorus supply to soybean (Israel, 1987).

However, increasing the P fertilizer amount applied did not correspond to increased P uptake (Pongsakul and Jenson 1991).

Improved P nutrition significantly increased dry matter, grain yield, nodule number and weight (Singleton *et al.*, 1995). Cassman *et al.*, (1981) reported significant yield increases up to 620 kg P/ha applied while Pal *et al.*, (1989) obtained significant yield increases in Nigeria with 13.2 to 26.4kg P/ha applied in experiments, which spanned a period of 4 years.

Dadson and Acquah (1984) found that P application increased nodule number, growth, yield and 1000 - grain weight of soybean, however Dickson *et al.*, (1983) could not obtain differences in 1000 - grain weight when P fertilizer was applied at 25 sites. In a four - year trial, Chesney (1973) reported significant linear response in yield of soybean due to phosphorus application in the first two crops and linear and quadratic responses for the subsequent crops.

Response of soybean to phosphorus is site specific (Dickson *et al.*, 1983). Singh and Saxena (1973) reported that at high available phosphorus (24.4kg P/ha), application of 69.6kg P/ha did not significantly improve yield. However, at two sites with lower soil available phosphorus (16.8 and 19.6kg P/ha) application of 17.4kg P/ha significantly improved yield. Dhillon and Sidhu (1992) obtained similar results with groundnuts.

Phosphorus application enhance soybean production, however excess application may have adverse effect on the crop. Demeterio *et al.*, (1992) reported that excess application of phosphorus decreased yield of plant parts, nodule weight and amount of nitrogen fixed. About one nodule was found at the highest rate of phosphorus application of 5.0 mM. Similar findings have been reported by other workers (Fletcher and Kurtz, 1964; Sharpley and Reed, 1982).

2.5 Differential response of soybean cultivars to phosphorus

Cultivars of soybean are known to differ in their response to phosphorus application. Howell (1954) found marked growth differences among four cultivars of soybean in a green-house study as the rate of phosphorus application was increased. Soybean cultivar "Lincoln" was yielding better at the lower phosphorus concentrations of 2-10 ppm. Howell and Bernard (1961) also compared the response of forty-four cultivars of soybean to P nutrition applying different rates of phosphorus. Twenty-three were classified as tolerant, eight as slightly sensitive, five as intermediate and four as very sensitive to phosphorus rates of 50 and 100 ppm.

2.6 Effect of interaction between phosphorus and inoculation on nodulation, growth and seed yield of soybean.

The P content of the soil affect the efficiency of seed inoculation. Both P and inoculation work in the same direction as far as nitrogen fixation is concerned (Dhingrah *et al.*, 1988). In savannah soils where lack of phosphorus fertilization had a limiting effect on nodulation and yield, maximum benefit was derived from biological nitrogen fixation and maximum productivity when phosphorus fertilizer was applied (Olufajo and Adu, 1992).

Olufajo and Adu (1992) and Raychaudhuri *et al.*, (1997) found significant interaction between inoculation and phosphorus on nodule dry weight of soybean at the flowering stage. Similar interaction between inoculation and phosphorus on seed protein of soybean has been reported by Dadson and Acquah (1984).

Apart from soybean, interaction between inoculation and phosphorus has been reported for other legumes. For instance, Giller *et al.*, (1998) found that inoculation together with phosphorus gave an increase in nodulation and nitrogen uptake of beans. In poor soil, Cobbinah *et al.*, (1992) reported that inoculation of *Leucaena leucocephala* with rhizobia and fertilization with P increased shoot N content and an combined application of rhizobia and P fertilizer was as effective as fertilization with both P and N. Similar findings have been reported by Luyindula and Haque (1992) on *Sesbania* and *Leucaena*.

Dhingra *et al.*, (1988) also found that interaction between phosphorus and inoculation on lentil was significant and a combination of *Rhizobium* and 20kg P₂O₅/ha gave yields equivalent to 40kg P₂O₅/ha without *Rhizobium* inoculation.

CHAPTER THREE

MATERIALS AND METHODS

3.0 Two experiments were studied - screen house or pot experiment (experiment 1) and field experiment (experiment 2). In the pot experiment combined effect of inoculation and no inoculation with five rates of phosphorus on two promiscuous and one non-promiscuous soybean cultivars were studied. Based on the results and responses of cultivars in the first experiment treatment combinations were selected for verification in the field.

3.1 Experiment 1: Combined effect of bradyrhizobial inoculation and phosphorus application on nodulation and growth of soybean.

The objective of this pot experiment was to study the response of soybean to various levels of phosphorus with and without inoculation with *B. japonicum* strain TAL 102. The study was conducted at the Sinna's garden, Crop Science Department, University of Ghana, Legon, from 17th January to 28th March, 1997.

3.1.1 Soil Preparation

The soil, which belongs to the Adenta series (Paleustalf), was collected from the University of Ghana farm from a depth of 0 -15cm. Previous crops on the soil were pepper (*Capsicum frutescens*) and okro (*Abelmoschus esculentus*_(L) Moench). Plastic pots of 1200cm³ capacity were used. Three holes were drilled at the base of each pot to facilitate drainage and the base lined with filter paper to prevent loss of soil. Each pot was filled with 2.5kg of air-dried soil, which passed through a 2mm mesh. The soil had the following chemical characteristics: pH (1:1 H₂O) 4.2; organic matter content, 4.5%; total N, 0.57%; available P, 14.08ppm; K, 0.19mg/kg and organic carbon, 2.61%.

3.1.2 Experimental treatment and cultural practices

Seeds of a non-promiscuous soybean cultivar "Davis" and two promiscuous cultivars "Bengbie" and "Anidaso" obtained from the Crop Science Department, Legon were used. Four seeds of each cultivar were sown per pot. Inoculation was carried out by pouring 2ml of a broth inoculum containing 10^8 cells/ml of *B. japonicum* strain TAL 102 per pot after which the seeds were covered with soil. The control pots were not inoculated.

Phosphorus was applied at five rates as potassium dihydrogen phosphate (KH_2PO_4) solution. The rates of P used were 0, 8.9, 17.9, 26.8 and 35.7mg P/kg soil, equivalent to 0, 20, 40, 60, and 80kg P/ha, respectively and which were designated as P₀, P₂₀, P₄₀, P₆₀ and P₈₀. Five hundred (500) ml of potassium dihydrogen phosphate solution containing the appropriate rate of phosphorus was poured on to the soil in the pots to soak them a day before planting.

The treatments were made up of a factorial combination of three cultivars of soybean, five rates of phosphorus and two levels of *Bradyrhizobium* inoculation laid out in a randomized complete block design with four replications.

Pots with less than two seedlings were resown 5 days after planting and those with more than two seedlings were thinned to two seedlings per pot seven days after sowing. The pots were watered daily. At eleven days after planting (DAP) Kocide at the rate of 5g per litre and karate at the rate of 5mls per litre were sprayed against fungal and insect attacks, respectively. Weeds in the pots were controlled by hand-picking.

3.1.3 Data collection (Experiment I)

Plants were harvested at 49 DAP (at flowering stage). At harvesting, plant tops were cut at soil level in the pots, leaving the roots. The soil in the pots were soaked with water and the roots and nodules washed free from soil. The following data were then taken:

(i) Nodulation: All identifiable nodules were carefully removed from the roots and counted. After counting, the nodules were oven-dried at 70°C to constant weight and weight recorded

(ii) Shoot dry weight per plant: The shoots were dried at 70°C to constant dry weight and the weight recorded.

(iii) Root dry weight per plant: The washed roots were dried at 70°C to constant weight and the weight recorded.

(iv) Shoot nitrogen content: The shoot nitrogen content was determined by micro-kjeldahl apparatus (Bhargava *et al.*, 1984) that included concentrated sulphuric acid predigestion to convert ammonia to ammonium. After alkalization of digest ammonia was steam distilled into 2% boric acid and quantified by titration with 0.01N hydrochloric acid. The volume of acid consumed was used to determine the content of the tissue sample.

(v) Shoot phosphorus content: shoot phosphorus content was determined by diacid digestion using nitric acid and perchloric acid (Bhargava *et al.*, 1984)

Based on the results of the pot experiment three levels of P were selected for the field experiment. The rates were 1, 30, and 60kg P/ha.

3.2 Experiment 2: The experiment was carried out on a soil belonging to the Adenta series (Paleustalf). The chemical characteristics of the soil at the beginning of the experiment were: pH (1:1H₂O), 4.7; organic matter, 1.27%; organic carbon, 0.73%; total N, 0.59%; available P, 15.07ppm and K, 0.56mg/kg. The previous crop cultivated was cowpea.

3.2.1 Experimental layout, planting and maintenance

The field was ploughed on 17th April, 1997 and harrowed on 24th April followed by lining and pegging a week later. The soybean cultivar "Bengbie" was used and P was applied at three rates: 0, 30 and 60kg P/ha as triple superphosphate. Potassium was applied at a rate of 20kg K/ha as muriate of potash (KCl) on all plots. The fertilizer was applied by broadcast and later incorporated into the soil with a rake before planting on 20th May, 1997. The seeds were either inoculated with *Bradyrhizobium* or not inoculated. For the inoculated treatments, seeds were coated with peat-based inoculant at a rate of 10g inoculant per 100g of seeds, with 3ml of 40% gum Arabic solution as a sticker. The treatments were made up of a combination of the three rates of phosphorus and inoculation and no inoculation. A randomized complete block design with the six treatments and four replications was employed. Four row plots were used with rows spaced 60cm apart. Thinning was done 17days after planting to 5cm apart within rows to a population of 33,333 plants per hectare. Weeds were controlled by hoeing at 4, 7 and 12 weeks after planting. Supplementary irrigation was done eight weeks after planting and thereafter twice every week with water hose and pipe stand.

3.2.2 Data collection (Experiment II)

Harvesting for nodulation and dry matter determination was done at 52 DAP when the plants were at the flowering stage. Ten plants were taken at random from the two central rows on each plot and the following data were taken in the same manner as in the pot experiment.

- (i) Number of nodules per plant
- (ii) Nodule dry weight per plant
- (iii) Shoot dry weight per plant
- (iv) Root dry weight per plant
- (v) Shoot nitrogen content
- (vi) Shoot phosphorus content

Seed yield at maturity was determined at 112 DAP by harvesting all the plants from an area of 3.6m² from the two central rows of each plot. The harvested plants with pods at 119 DAP were sun-dried for 10 days and threshed. The seeds were sun-dried to about 12% moisture content before weighing.

For 100-seed weight, three lots of 100 seeds were randomly sampled from each plot and weighed and the average recorded.

CHAPTER FOUR

RESULTS

4.1 Experiment 1: Effect of inoculation and phosphorus fertilizer on nodulation, shoot dry weight, shoot N and P content of soybean.

4.1.1 Nodulation

4.1.1.1 Inoculation x cultivar interaction

Application of *Bradyrhizobium* inoculant significantly ($p < 0.01$) increased nodule number in the three cultivars (Table 1). Inoculation resulted in the production of significantly higher ($p < 0.01$) nodule number and dry weight than the control. The non-promiscuous cultivar "Davis" produced significantly higher nodule number and dry weight on inoculation than the promiscuous cultivars "Bengbie" and "Anidaso" which were not different from each other. The difference in nodulation between the cultivars was greatly increased when inoculant was applied compared to when they were not inoculated resulting in significant ($p < 0.01$) interaction between inoculation and cultivar (Table 1). Average nodule number increased from 0.7 to 32.5 on inoculation in "Davis". Similarly the nodule dry weight increased from 7.5mg to 192.5mg after inoculation. The non-promiscuous cultivar "Davis" responded greatest to inoculation in terms of nodule number and dry weight.

Table 1: The effect of inoculation on mean nodule number and nodule dry weight of three soybean cultivars.

Cultivars	Nodule number plant ⁻¹		Mean	Nodule dry wt (mg plant ⁻¹)		Mean
	Uninoc.	inoc.		Uninoc.	inoc.	
Davis	0.7	32.5	16.6	7.5	192.5	100.0
Bengbie	2.2	19.5	10.9	20.5	123.0	71.7
Anidaso	1.2	24.3	12.7	15.5	139.0	77.2
Mean	1.4	25.5	-	14.5	151.5	-
LSD _(0.01) inoc 5.03			LSD _(0.01) inoc 21.34			
LSD _(0.01) inoc x cultivar 8.63			LSD _(0.01) inoc x cultivar 36.96			
C. V. (%) = 22			C. V. (%) = 26			

4.1.1.2 Phosphorus x cultivar interaction

Nodulation of the cultivars, averaged over inoculation, increased with phosphorus application (Table 2). From P₀ - P₆₀ nodule number in "Anidaso" increased from 1.6 to 4.0. The corresponding increases in "Davis" and "Bengbie" were 2.5 to 3.5 and 2.3 to 3.7 respectively. Interaction between phosphorus and cultivar was not significant. Phosphorus application did not lead to significant differences in nodule number among the promiscuous and non-promiscuous soybean cultivars. Phosphorus application (P₂₀ - P₈₀) produced significantly higher (p<0.01) nodule number than the control (P₀).

Table 2: The mean effect of phosphorus on mean nodule number per plant of three soybean cultivars

Cultivar	P₀	P₂₀	P₄₀	P₆₀	P₈₀	Mean
Davis	2.5	3.2	3.4	3.5	3.8	3.3
Bengbie	2.3	2.6	2.8	3.7	2.6	2.8
Anidaso	1.6	2.9	2.7	4.0	3.1	2.9
Mean	2.1	2.9	2.9	3.8	3.2	-
LSD _(0.01) Phosphorus 0.61						
LSD _(0.01) Cultivar N.S.						
LSD _(0.05) Cultivar x Phosphorus N.S.						
C. V. (%) = 22						

Nodule dry weight followed the same pattern as nodule number when phosphorus was applied (Table 3). Application of phosphorus on the average increased nodule dry weight with the optimum being P₆₀. There was no significant interaction between phosphorus and cultivar. Phosphorus application did not cause significant difference among the non-promiscuous and the two promiscuous soybean cultivars in terms of mean nodule dry weight. In the absence of phosphorus fertilizer "Anidaso", a promiscuous cultivar, produced the lowest mean nodule dry weight. However, it was more responsive to phosphorus application, increasing in nodule dry weight by 13 fold over the range of phosphorus application compared to 2 and 3 fold increases in "Davis" and "Bengbie" respectively

Table 3: The effect of phosphorus on mean nodule dry weight of three soybean cultivars (mg plant⁻¹)

Cultivar	P ₀	P ₂₀	P ₄₀	P ₆₀	P ₈₀	Mean
Davis	60.0	95.0	105.0	121.2	108.7	100.0
Bengbie	33.7	61.2	72.5	116.2	75.0	71.7
Anidaso	10.0	67.5	67.5	130.0	112.2	77.2
Mean	34.6	74.6	85.0	122.5	98.3	-
LSD (0.01) Phosphorus 33.74						
LSD (0.05) Cultivar N.S.						
LSD (0.05) cultivar x phosphorus N.S.						
C. V. (%) = 26						

4.1.1.3 Cultivar x inoculation x phosphorus interaction

The cultivar x inoculation x phosphorus interaction was not significant (Figs. 1 & 2). In the absence of inoculation the non-promiscuous cultivar "Davis" showed the least response to P application while "Bengbie" showed the greatest response in terms of nodule number and dry weight.

When inoculant was applied "Anidaso", a promiscuous cultivar, produced the least nodule number and dry weight among the soybean cultivars at P₀. The non-promiscuous cultivar, "Davis", on the other hand produced the greatest number of nodules and highest nodule dry weight with inoculation at P₀.

4.1.2 Shoot dry weight

4.1.2.1 Inoculation x cultivar interaction

Shoot dry matter produced by the three soybean cultivars in response to inoculation is shown in Table 4. The non-promiscuous cultivar "Davis" produced significantly higher ($p < 0.05$) mean shoot dry weight than the two promiscuous cultivars. The

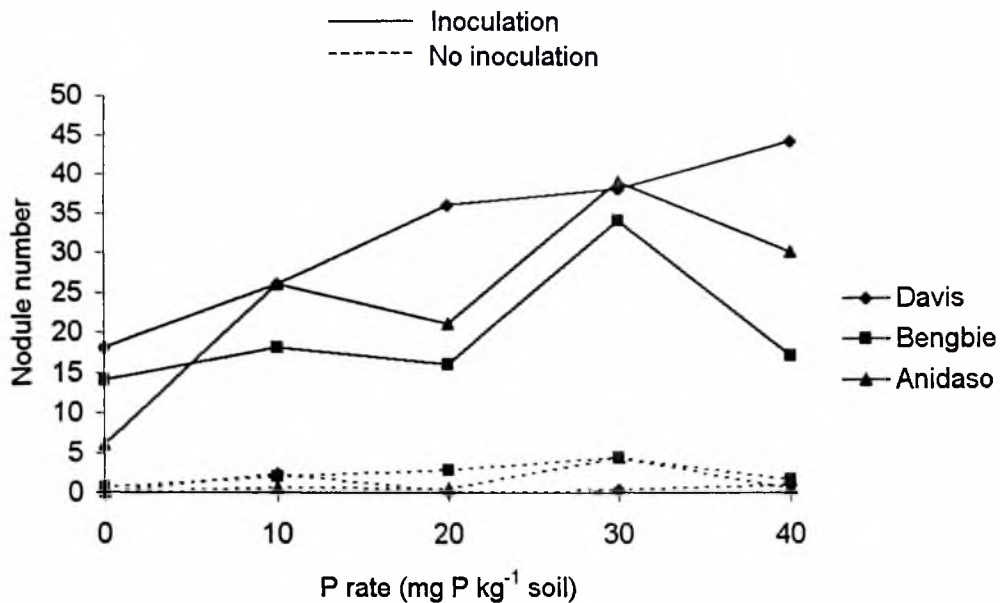


Figure 1: Effect of phosphorus rate and inoculation on nodule number of three soybean cultivars

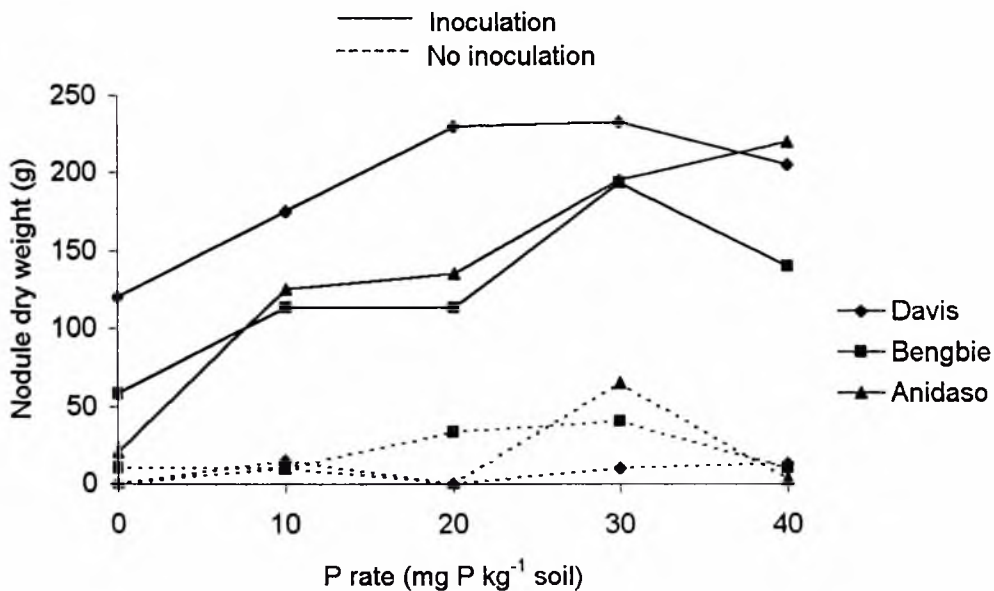


Figure 2: Effect of phosphorus rate and inoculation on nodule dry weight of three soybean cultivars

promiscuous cultivars "Bengbie" and "Anidaso" produced similar amounts of shoot dry weight following inoculation.

Inoculation produced significantly ($p < 0.01$) higher shoot dry weight than the uninoculated control. Interaction between inoculation and cultivar was not significant.

Table 4: The effect of inoculation on mean shoot dry weight of three soybean cultivars (g plant^{-1})

Cultivar	No inoculation	Inoculation	Mean
Davis	2.3	3.2	2.8
Bengbie	2.3	2.6	2.4
Anidaso	2.4	2.6	2.5
Mean	2.3	2.8	-
LSD (0.05) cultivar 0.29 LSD (0.01) inoc. 0.24 LSD (0.05) inoc. x cultivar N.S. C. V. (%) = 30			

4.1.2.2 Phosphorus x cultivar interaction

Table 5 shows the dry matter production of the three soybean cultivars in response to phosphorus application. All cultivars responded to application of phosphorus, with 80kg P /ha producing the highest average shoot dry weight.

Phosphorus application caused significant differences ($p < 0.05$) in shoot dry weight. All the phosphorus rates produced significantly higher ($p < 0.05$) shoot dry weight compared to the control (P_0).

Cultivars responded differently to the various rates of phosphorus application leading to a significant ($P < 0.05$) cultivar x phosphorus interaction. Shoot dry weight ranged from 1.1 g/plant in "Anidaso" without P application to 3.3 g/plant in "Anidaso" when 80kg P/ha was applied.

Table 5: The effect of phosphorus on mean shoot dry weight of three soybean cultivars (g plant⁻¹)

Cultivar	P ₀	P ₂₀	P ₄₀	P ₆₀	P ₈₀	Mean
Davis	2.3	2.7	2.8	2.8	3.3	2.8
Bengbie	1.8	2.3	2.4	2.9	2.6	2.4
Anidaso	1.1	2.2	2.6	3.1	3.3	2.5
Mean	1.8	2.4	2.6	2.9	3.1	-
LSD (0.05) cultivar 0.29						
LSD (0.05) phosphorus 0.38						
LSD (0.05) phosphorus x cultivar 0.66						
C. V. (%) = 30						

4.1.2.3 Cultivar x inoculation x phosphorus interaction

The cultivar x inoculation x phosphorus interaction was not significant (Fig.3). "Anidaso" produced the lowest shoot dry weight when no phosphorus was applied. At P₀ inoculated promiscuous cultivars "Bengbie" and "Anidaso" produced similar shoot dry weights as their respective inoculated control. However, increase in P rates led to an increase in shoot dry weights in both cultivars. The growth performance of the three cultivars are shown in Plates 1,2 and 3.



Plate 1: Effect of *Bradyrhizobium* inoculation and phosphorus on growth performance of "Davis" cultivar of soybean. P₀, P₁, P₂, P₃, and P₄ denote 0,20,40, 60 and 80kg P/ha respectively

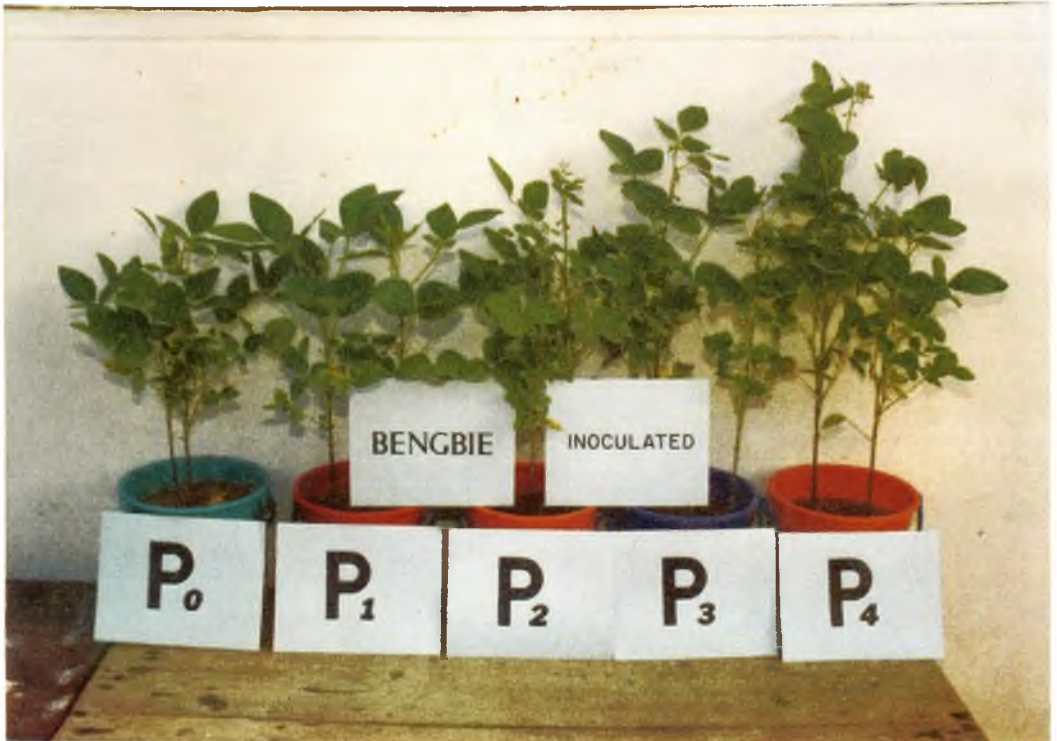


Plate 2: Effect of *Bradyrhizobium* inoculation and phosphorus on growth performance of "Bengbie" cultivar of soybean. P₀, P₁, P₂, P₃, and P₄ denote 0,20,40, 60 and 80kg P/ha respectively



Plate 3: Effect of *Bradyrhizobium* inoculation and phosphorus on growth performance of "Anidaso" cultivar of soybean. P₀, P₁, P₂, P₃, and P₄ denote 0,20,40, 60 and 80kg P/ha respectively

4.1.3 Root dry weight

4.1.3.1 Inoculation x cultivar interaction

The response of root dry weight to inoculation is shown in Table 6. On average the non-promiscuous cultivar "Davis" produced significantly higher ($p < 0.05$) root dry weight than the two promiscuous cultivars "Bengbie" and "Anidaso". The interaction between cultivar and inoculation was not significant.

Table 6: The effect of inoculation on mean root dry weight of three soybean cultivars (g plant^{-1})

Cultivar	No inoculation	Inoculation	Mean
Davis	1.9	2.6	2.3
Bengbie	1.5	1.9	1.7
Anidaso	1.9	1.7	1.8
Mean	1.8	2.1	-
LSD (0.05) cultivar 0.43		C. V. (%) = 21	
LSD (0.05) inoc. x cultivar N.S.		LSD (0.05) inoc. N.S.	

4.1.3.2 Phosphorus x cultivar interaction

On average phosphorus significantly influenced the root dry weight of the soybean cultivars (Table 7). Except for "Bengbie" the three highest rates of phosphorus (P_{40} , P_{60} and P_{80}) produced significantly higher ($p < 0.01$) root dry weight than the control. There was no significant interaction between phosphorus and cultivar. Application of 80kg P/ha increased 3 fold the root dry weight of unfertilized "Anidaso" which happened to give the lowest root dry weight in the control treatments.

Table 7: The effect of phosphorus on mean root dry weight of three soybean cultivars (g plant⁻¹)

Cultivar	P ₀	P ₂₀	P ₄₀	P ₆₀	P ₈₀	Mean
Davis	1.8	2.1	2.4	2.8	2.2	2.3
Bengbie	1.4	1.6	1.8	1.9	1.9	1.7
Anidaso	0.9	1.4	1.7	2.1	2.9	1.8
Mean	1.4	1.7	2.0	2.3	2.3	-
LSD (0.01) Phosphorus 0.55 LSD (0.05) Cultivar x phosphorus N.S.						
LSD (0.05) Cultivar 0.43 C. V. (%) = 21						

4.1.3.3 Cultivar x inoculation x phosphorus interaction

The interaction was not significant (Figure 4). When inoculant was not applied the non-promiscuous cultivar "Davis" and one promiscuous cultivar "Bengbie" did not show any remarkable increase in root dry weight with increase in phosphorus rate. However "Anidaso", a promiscuous cultivar, without inoculation showed the greatest increase in root dry weight in response to phosphorus application.

4.1.4 Shoot nitrogen content

4.1.4.1 Inoculation x cultivar interaction

The interaction was significant ($p < 0.05$) with the non-promiscuous cultivar "Davis" producing higher shoot nitrogen content on inoculation than the promiscuous cultivars "Bengbie" and "Anidaso" which were not different from each other (Table 8). Inoculation on average led to the accumulation of significantly higher ($p < 0.01$) amount of N than the uninoculated control. On average the non-promiscuous cultivar "Davis" accumulated significantly higher ($p < 0.05$) shoot N than the two promiscuous cultivar "Bengbie" and "Anidaso"

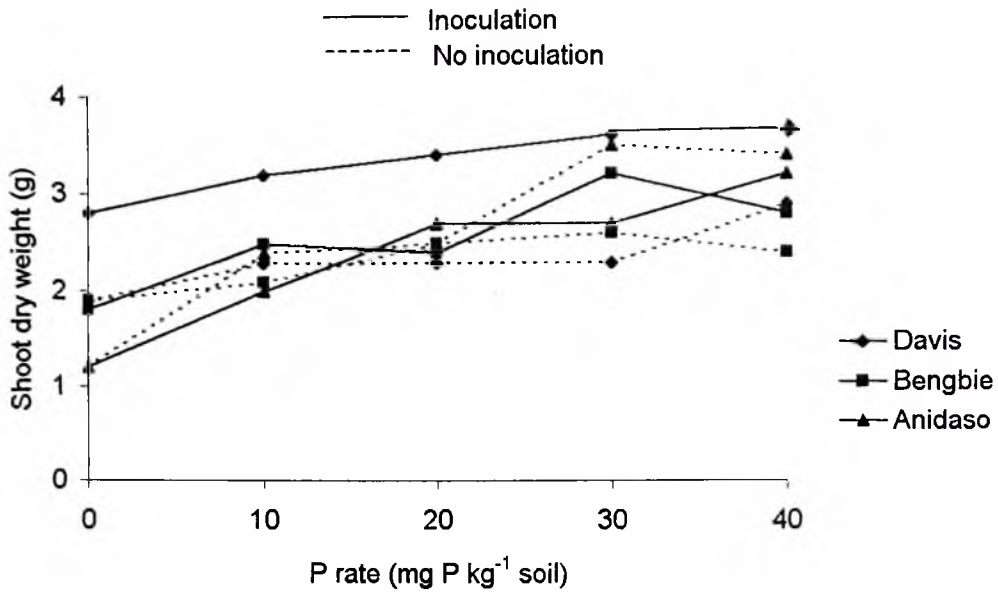


Figure 3: Effect of phosphorus rate and inoculation on shoot dry weight of three soybean cultivars

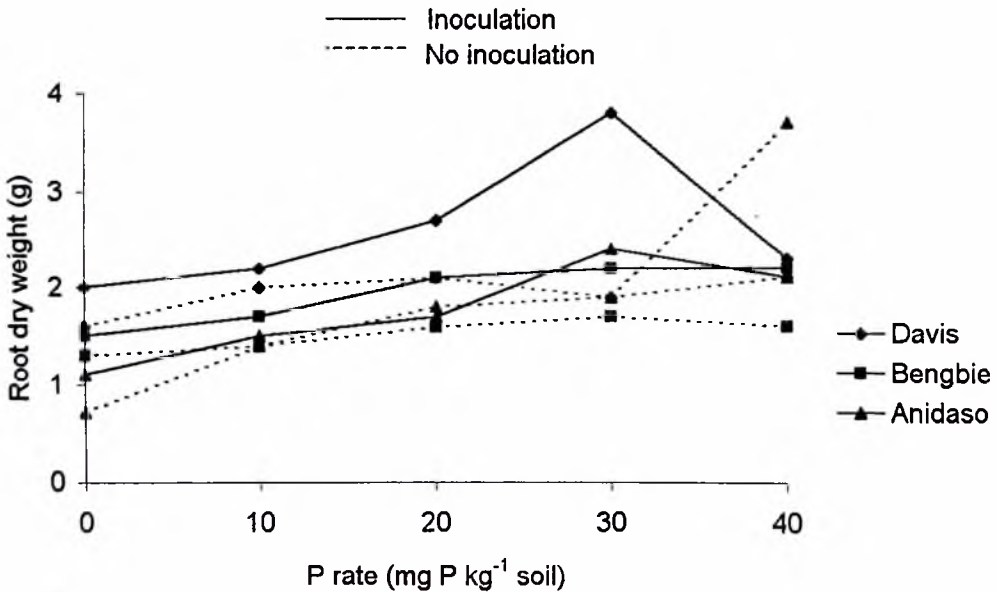


Figure 4: Effect of phosphorus rate and inoculation on root dry weight of three soybean cultivars

Table 8: The effect of inoculation on mean shoot nitrogen content of three soybean cultivars (mg N plant⁻¹)

Cultivar	No inoculation	Inoculation	Mean
Davis	48.2	74.3	61.3
Bengbie	47.7	57.9	52.8
Anidaso	46.8	54.3	50.6
Mean	47.6	62.2	-
LSD (0.01) cultivar 6.52		C. V. (%) = 32	
LSD (0.01) inoculation 5.32			
LSD (0.05) cultivar x inoculation 9.22.			



4.1.4.2 Phosphorus x cultivar interaction

The shoot nitrogen content of the three soybean cultivars in response to phosphorus application is shown in table 9. Shoot nitrogen content was influenced by phosphorus application. Application of phosphorus at all rates produced significantly higher ($p < 0.01$) shoot N than the control. There was no significant interaction between phosphorus and cultivar.

Table 9: The effect of phosphorus rates on shoot nitrogen content of three soybean cultivars (mg N plant⁻¹)

Cultivar	P ₀	P ₂₀	P ₄₀	P ₆₀	P ₈₀	Mean
Davis	48.3	58.0	64.4	65.1	70.6	61.3
Bengbie	38.9	48.5	52.6	65.2	58.8	52.8
Anidaso	22.4	44.5	51.9	65.2	68.9	50.6
Mean	36.5	50.4	56.3	65.2	66.1	-
LSD (0.01) cultivar 8.41						
LSD (0.05) cultivar x phosphorus N.S.				C. V. (%) = 32		

4.1.4.3 Cultivar x inoculation x phosphorus interaction

The interaction was not significant (figure 5). When phosphorus was not applied shoot nitrogen content of uninoculated "Davis" and "Bengbie" was about 2 fold that of "Anidaso" under the same treatment. Uninoculated "Bengbie" and "Anidaso" the promiscuous cultivars accumulated almost the same amount of shoot nitrogen.

4.1.5. Shoot phosphorus content

4.1.5.1 Inoculation x cultivar interaction

Application of inoculant to soybean plants resulted in significantly higher ($p < 0.01$) phosphorus content in "Anidaso" compared to its promiscuous counterpart "Bengbie" and the non-promiscuous "Davis" (Table 10). Inoculation on average produced significantly higher ($p < 0.01$) shoot phosphorus content. Interaction between inoculation and cultivar was not significant

Table 10: The effect of inoculation on shoot phosphorus content of three soybean cultivars (mg P plant^{-1})

Cultivar	No inoculation	Inoculation	Mean
Davis	4.8	7.3	6.1
Bengbie	4.6	5.5	5.5
Anidaso	6.7	8.0	7.4
Mean	5.4	6.9	-
LSD (0.01) cultivar 0.75		LSD (0.05) cultivar x inoc.N.S.	
LSD (0.01) inoculation 0.61		C. V. (%) = 29	

4.1.5.2 Phosphorus x cultivar interaction

The amounts of phosphorus accumulated in the shoots of the three soybean cultivars are shown in table 11. Shoot phosphorus content of "Anidaso" increased by more than four-fold compared to the nearly two-fold increase for "Bengbie" and "Davis" when 80kg P/ha was applied. There was a significant interaction ($p < 0.01$) between

phosphorus and cultivar. On average application of P resulted in significantly higher ($p < 0.01$) shoot phosphorus content than the control (P_0).

Table 11: The effect of phosphorus rates on the shoot phosphorus content of three soybean cultivars (mg P plant⁻¹)

Cultivar	P ₀	P ₂₀	P ₄₀	P ₆₀	P ₈₀	Mean
Davis	4.6	5.6	6.4	6.4	7.2	6.0
Bengbie	3.5	4.6	4.9	5.9	6.3	5.0
Anidaso	2.6	5.8	7.4	10.0	10.9	7.3
Mean	3.6	5.3	6.2	7.4	8.1	-
LSD (0.01) phosphorus 0.96						
LSD (0.01) phosphorus x cultivar 1.67						
C. V. (%) = 29						

4.1.5.3 Cultivar x inoculation x phosphorus interaction

The cultivar x inoculation x phosphorus interaction was not significant (Figure 6). In the absence of inoculation, "Bengbie" and "Davis" accumulated similar amounts of shoot P at different rates of P fertilizer application. The amounts of P accumulated by the two cultivars were less than the shoot P of "Anidaso". At P rates lower than P₄₀, inoculated and uninoculated "Bengbie" accumulated the same amounts of shoot P. Inoculation increased shoot P content in the non-promiscuous cultivar "Davis" more than the promiscuous cultivars "Bengbie" and "Anidaso"

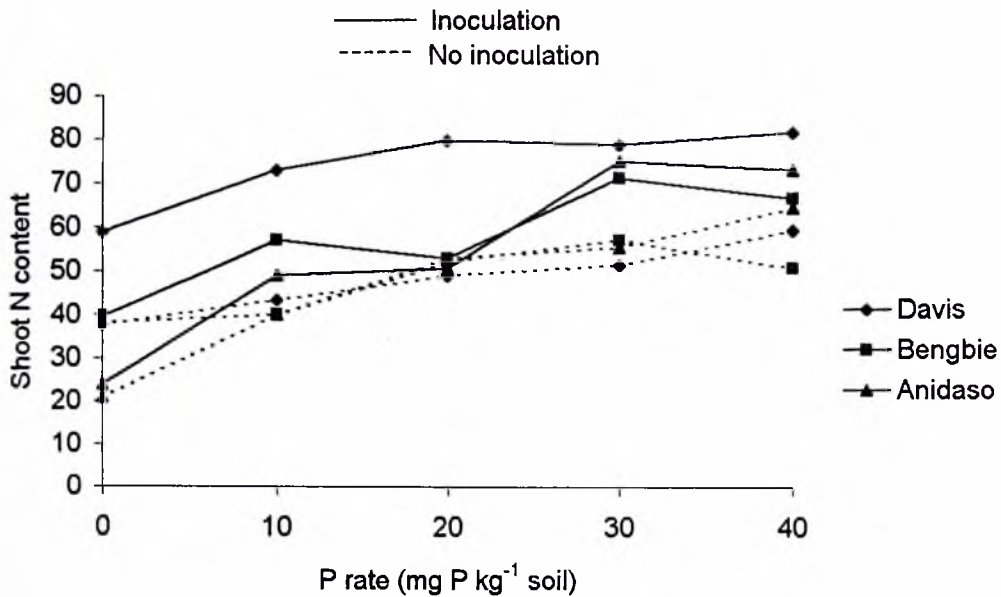


Figure 5: Effect of phosphorus rate and inoculation on shoot N content of three soybean cultivars

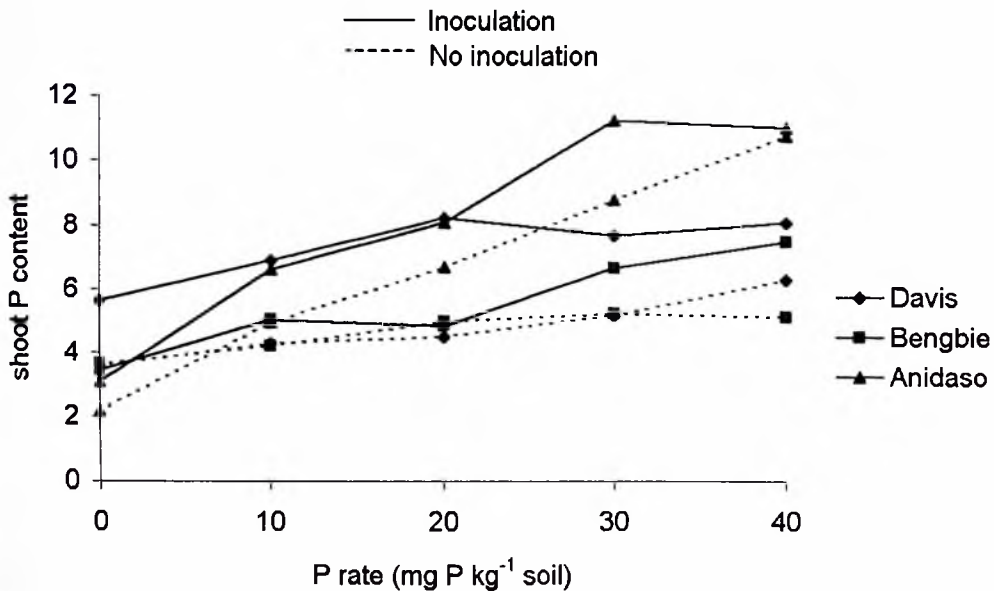


Figure 6: Effect of phosphorus rate and inoculation on shoot P content of three soybean cultivars

4.2 Field experiment

4.2.1 Nodulation

While phosphorus application had no significant effect on nodule number inoculation however resulted in a significant increase ($p < 0.01$) in the number of nodules (Table 12). There was no significant interaction between phosphorus and inoculation.

Table 12: Effect of inoculation and phosphorus application on mean nodule number of "Bengbie" soybean

	Phosphorus rate (kg/ha)			Mean
	0	30	60	
Uninoculated	4.0	5.0	9.0	6.0
Inoculated	33.0	35.0	35.0	34.4
Mean	18.5	20.0	22.0	-
LSD _(0.01) inoculation 3.89				
LSD _(0.05) Phosphorus N.S.				
LSD _(0.05) inoc x phosphorus N.S.				
C. V. (%) = 22				

Nodule dry weight also followed the same trend as nodule number (Table 13). Inoculation resulted in a significant ($p < 0.01$) increase in nodule dry weight. Phosphorus effect and interaction between inoculation and phosphorus were however not significant.



Table 13: Effect of inoculation and phosphorus application on mean nodule dry weight of "Bengbie" soybean (mg plant⁻¹)

	Phosphorus rate (kg/ha)			Mean
	0	30	60	
Uninoculated	41.5	53.8	94.0	63.7
Inoculated	250.5	221.5	257.0	243.0
Mean	146.0	138.7	175.5	-
LSD _(0.01) inoculation 35.25				
LSD _(0.05) Phosphorus N.S.				
LSD _(0.05) inoc x phosphorus N.S.				
C. V. (%) = 26				

4.2.2 Shoot dry weight

The differences found in both phosphorus and inoculation treatments were not significant (Table 14). Their interaction was also not significant.

Table 14: Effect of inoculation and phosphorus application on mean shoot dry weight of "Bengbie" soybean (g plant⁻¹)

	Phosphorus rate (kg/ha)			Mean
	0	30	60	
Uninoculated	3.8	5.8	5.4	5.0
Inoculated	6.3	6.3	6.6	6.4
Mean	5.1	6.1	6.0	-
LSD (0.01) inoculation N.S				
LSD (0.05) phosphorus N.S.				
LSD (0.05) phosphorus x inoc N.S.				
C. V. (%) = 30				

4.2.3 Root dry weight

The influence of inoculation and phosphorus is shown in Table 15. Only inoculation with *Bradyrhizobium* resulted in a significant increase ($p < 0.01$) in root dry weight. Phosphorus effect and phosphorus x inoculation interaction were not significant.

Table 15: Effect of inoculation and phosphorus application on mean root dry weight of "Bengbie" soybean (g plant⁻¹)

	Phosphorus rate (kg/ha)			Mean
	0	30	60	
Uninoculated	0.5	0.7	0.8	0.7
Inoculated	0.8	0.9	0.9	0.9
Mean	0.7	0.8	0.9	-
LSD (0.01) inoculation 0.14				
LSD (0.05) phosphorus N.S.				
LSD (0.05) inoc. x phosphorus N.S.				
C. V. (%) = 21				

4.2.4 Shoot N content

Increase in shoot N content due to application of phosphorus was not significant (Table 16). However, inoculation produced a significant ($p < 0.05$) increase in shoot nitrogen content. Interaction between the two factors was not significant. At Po, the shoot nitrogen content was low in the uninoculated plants but this increased with P application. On average the N content of inoculated plants was not significantly affected by P application.

Table16: The effect of inoculation and phosphorus application on shoot N content of 'Bengbie' (mg plant⁻¹)

	Phosphorus rate (kg/ha)			Mean
	0	30	60	
Uninoculated	83.9	125.7	121.3	110.3
Inoculated	151.1	158.3	168.9	159.8
Mean	117.5	142.0	145.6	-
LSD (0.01) inoculation 35.53				
LSD (0.05) phosphorus N.S.				
LSD (0.05) inoc. x phosphorus N.S.				
C. V. (%) = 32				

4.2.5 Shoot phosphorus content

Across inoculation treatments, phosphorus application did not cause significant increase in shoot phosphorus accumulation (Table 17). However, inoculation produced a significant increase ($p < 0.01$) in shoot phosphorus.

Table 17: The effect of inoculation and phosphorus application on shoot phosphorus content of Bengbie (mg plant⁻¹)

	Phosphorus rate (kg/ha)			Mean
	0	30	60	
Uninoculated	7.23	11.71	13.06	10.66
Inoculated	14.18	14.75	16.68	15.28
Mean	10.71	13.23	14.87	-
LSD (0.01) inoculation 3.26				
LSD (0.05) phosphorus N.S.				
LSD (0.05) inoc. x phosphorus N.S.				
C. V. (%) = 29				



4.2.6 Number of pods per plant

Inoculation and phosphorus application increased the number of pods produced but the increase was not significant (Table 18). Similar number of pods were produced by both inoculated and uninoculated plants. Average pod production though high at the highest P level was not significantly different from the control.

Table 18: The effect of inoculation and phosphorus application on pod number per plant of Bengbie.

	Phosphorus rate (kg/ha)			Mean
	0	30	60	
Uninoculated	31.0	34.0	36.0	34.0
Inoculated	32.0	37.0	39.0	36.0
Mean	32.0	36.0	38.0	-
LSD (0.05) inoculation N.S				
LSD (0.05) phosphorus N.S.				
LSD (0.05) inoc x phosphorus N.S				
C. V. (%) = 24				

4.2.7 100 - seed weight

Application of inoculant and phosphorus did not significantly influence 100 - seed weight (Table 19). Phosphorus x inoculation interaction was also not significant.

Table 19: The effect of inoculation and phosphorus application on 100 - seed weight of Bengbie (g)

	Phosphorus rate (kg/ha)			Mean
	0	30	60	
Uninoculated	9.1	9.0	8.9	9.0
Inoculated	8.8	8.8	8.8	8.8
Mean	9.0	8.9	8.9	-
LSD (0.05) inoculation N.S				
LSD (0.05) phosphorus N.S.				
LSD (0.05) inoc x phosphorus N.S				
C. V. (%) = 5				

4.2.8 Seed yield

Like number of pods per plant, inoculation and phosphorus application did not result in significant increase in seed yield (Table 20). The interaction was also not significant. However, seed yield was increased on the average by about 14% in the inoculated plants. On average seed yield increased by about 34% at the highest level of P application.

Table 20: The effect of inoculation and phosphorus application on seed yield of Bengbie (kg/ha)

	Phosphorus rate (kg/ha)			Mean
	0	30	60	
Uninoculated	691.0	801.0	793.0	762.0
Inoculated	704.0	846.0	1077.0	875.0
Mean	698.0	823.0	935.0	-
LSD (0.05) inoculation N.S				
LSD (0.05) phosphorus N.S.				
LSD (0.05) inoc x phosphorus N.S.				
C. V. (%) = 33				

CHAPTER FIVE

DISCUSSION

5.1 Inoculation effects on cultivar

The effectiveness of the indigenous rhizobia in the soil, its competitive ability, saprophytic competence as well as strain x cultivar interaction will determine whether a soybean cultivar will respond to inoculation or not. In the present study the two promiscuous cultivars and the non-promiscuous cultivar nodulated poorly when no inoculant was applied. Nodules observed on the non-promiscuous cultivar may be due to the occurrence of a low population of *Bradyrhizobium japonicum* in most tropical soils (Pulver *et al.*, 1982). The poor nodulation especially of the promiscuous cultivars when inoculant was not applied may be attributed to the fact that population of indigenous *Bradyrhizobium* capable of nodulating soybeans are generally low in Ghanaian soils (Owiredu and Danso, 1988; Djagbletey, 1995). The latter author estimated 10^1 cells g^{-1} of soil in Kpong (Akuse series) which has a potential for soybean production using soybean as the host. Probably the soil used for this study may have contained less than 10^3 cells per gram of soil (Weaver and Frederick, 1974; Singleton *et al.*, 1992) or promiscuous cultivars vary in their compatibility to indigenous strains (Pulver *et al.*, 1982). Djagbletey (1995) did not obtain a nodule on an uninoculated promiscuous soybean cultivar in Adenta series (Paleustalf).

However the good nodulation obtained by Nangju (1980) and Pulver *et al.*, (1982) on promiscuous soybean cultivars without inoculation in contrast to this study may support the evidence that West African bradyrhizobial populations may vary in number and effectiveness from one location to another and promiscuous soybeans show considerable site - specific nodulation (Pulver *et al.*, 1985).

Nangju (1980), pointed out that promiscuous soybean cultivars can form effective symbiosis and can be grown without seed inoculation with *B. japonicum* in African

soils. In this study however inoculation with the exotic *B. japonicum* strain TAL 102 also caused significant increase in nodulation of the two promiscuous cultivars. Similar observation had been made by Djagbletey (1995) that promiscuous cultivars can respond to inoculation. So-called promiscuous soybeans may have to be inoculated in order to get more nodules. Perhaps the nodulation of promiscuous cultivars in Ghana may have to be studied in more detail. Inoculation also produced significant nodulation in the promiscuous cultivar compared to the two promiscuous cultivars. The non-promiscuous cultivar seem to be more compatible with the exotic *B. japonicum* (Pulver *et al.*, 1982).

The significant increase in nitrogen accumulation by the promiscuous and non-promiscuous cultivars in response to inoculation may be attributed to the significant increase in nodule dry weight. The increase in nodulation through inoculation are in agreement with the results of other workers (Badawy *et al.*, 1992; Mahmoud and El-far, 1994; Buiyan *et al.*, 1995).

The non-promiscuous cultivar produced higher shoot nitrogen, shoot dry weight and root dry weight compared to the two promiscuous cultivars. The superior plant dry weight of the non-promiscuous cultivar may be due to its superior nodulation and nitrogen accumulation since nitrogen promotes vegetative growth.

5.2 Phosphorus effects

The mean nodule number for the non-promiscuous "Davis" was highest at P₈₀ in the first experiment. However, the mean nodule dry weight was highest at P₆₀. P₆₀ seem to be the optimum P rate for nodule number and nodule dry weight. Lowest values for nodulation, shoot and root dry weights were obtained from the promiscuous cultivar "Anidaso" when phosphorus was not applied. However, it gave the highest values at P₆₀ for nodulation and P₈₀ for shoot and root dry weight indicating that the cultivar performs less efficiently at low levels of P and is least tolerant to phosphorus stress. Similar cultivar differences to phosphorus has been made by Howel (1954).

The 13-fold increase in nodule dry weight of the promiscuous "Anidaso" compared to 2 and 3-fold increases respectively, of the non-promiscuous "Davis" and promiscuous "Bengbie" over the range of P application shows that "Anidaso" is more responsive to phosphorus application. It seems there are differences in response to P even among the promiscuous cultivars. The non-promiscuous cultivar seems to be more tolerant to phosphorus application below P₆₀ compared to the promiscuous cultivars in terms of nodulation, shoot and root dry weights.

The significant effect of all rates of phosphorus application P₂₀ and above on nodule number and dry weight, shoot dry weight, shoot N and P content in the pot experiment may indicate that phosphorus deficiency may have inhibited host plant growth and symbiotic nitrogen fixation (Israel, 1987; Sa and Israel, 1995). The greater increase in nodule dry weight per plant (3.5-fold) compared to the shoot mass per plant (1.7-fold) over the range of phosphorus application in the pot experiment showed a greater responsiveness of nodulation than that of host plant growth to improvement in phosphorus nutrition (Cassman *et al.*, 1980; Israel, 1987).

The increase in nodulation caused by phosphorus in the pot experiment agrees with the findings of most workers (Cassman *et al.*, 1980; Dadson and Acquah, 1984; Singleton *et al.*, 1985; Israel, 1987; Afuakwa, 1988; Olufajo and Adu, 1992.) Increase in shoot dry matter in pot experiment due to applied phosphorus may be due to the observation that P promotes vegetative growth (Harper, 1971).

5.3 Response to inoculation and Phosphorus fertilizer in the field

In the fields, inoculation with *Bradyrhizobium* improved nodulation over the uninoculated control and this is consistent with earlier report (Kang, 1975; Mukhtar and Sayda, 1987; Badawy *et al.*, 1992; Mandimba and Mandibaye, 1996). It shows that promiscuous cultivars do benefit from inoculation (Olufajo and Adu 1992).

Nodulation of promiscuous "Bengbie" in the field was about twice higher than in the pot experiment. The field is known to have been cropped with cowpea in the season

prior to planting and the presence of a legume in the cropping system enhances the number of compatible rhizobia in the soil (Weaver *et al.*, 1972). For instance Djabletey (1995) found that the soil in which cowpea was planted as the previous crop contained twice as much soybean bradyrhizobia as two other soils with non-legume as previous crop. This probable influence of legume on bradyrhizobia population may account for the better nodulation in the field.

Phosphorus application seemed to reduce 100 - seed weight though not significantly. Although Bharati *et al.*, (1986) found 100 - seed weight of soybean to decrease with phosphorus application up to 111kg P/ha, there is a substantial evidence that phosphorus increased 100 - seed weight (Assuah, 1990; Mahmoud *et al.*, 1991; Dawood and Abou-Salama, 1994; Mahmoud and El-far, 1994). Increase in grain yield due to applied phosphorus has been demonstrated by several workers (Chesney, 1973; Afuakwa, 1988; Pal *et al.*, 1989). Demooy and Pesek (1966) reported that high rates of phosphorus application enhanced rhizobia activity raised nodule number and weight and increased yield. The field study however did not show a significant increase in dry matter production and yield by applying phosphorus even though with inoculation nodule number and dry weight root weight and shoot N and P were increased.



CHAPTER SIX

CONCLUSIONS

The following conclusions can be drawn from this study:

- Nodulation of field grown promiscuous soybean can be improved by inoculation
- Differences exist between non-promiscuous and promiscuous cultivars of soybean in their response to *Bradyrhizobium* inoculation
- Phosphorus deficiency may markedly reduce host plant growth.
- There is a greater responsiveness of symbiotic nitrogen fixation than growth of host plant to improvement in phosphorus nutrition.
- Cultivars of soybean respond differently to phosphorus application.

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