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PROJECT TITLE:

Factors affecting Symbiotic Nitrogen Fixation and yield of cowpeas in central Alabama and Jamaica.

PROJECT NO: DAN 5053-G-SS-4039-00

INTRODUCTION

Limited availability and increase in the cost of nitrogen fertilizer have severely impaired the productive capabilities of small or limited resource farmers mainly in developing countries. Presently, a principal means of increasing crop production is by increasing the application of nitrogen fertilizer. However, in legume production, the only time when nitrogen application has proven to be beneficial is when used as a starter fertilizer and in small amounts (Eaglesani et al., 1983). Studies have shown that generally the rate of nitrogen-fixation will decrease with an increase in the rate of nitrogen fertilizer application (Miller et al., 1982).

Cowpeas (Vigna unguiculata (L)) are grown widely in the tropics and fix substantial amounts of nitrogen when nodulated effectively. Cowpeas have been shown to fix as much as 84 kg/ha nitrogen per year (Graham and Hubbell, 1975). In addition to being tremendously important as a source of nitrogen for further crop production, cowpeas can be of vital importance in alleviating protein deficiency in the diets of humans and livestock, since it has been proven to be highly nutritious (Molina et al., 1976).

A problem in legume production is that often the role of micronutrients in plant growth is ignored. However, some studies have shown that when present in optimum amounts some of these micronutrients can potentially enhance the growth of legumes (Kapur et al., 1975; Martins et al., 1965; Sallee and Smith, 1969).

Kapur et al., 1975, examined the influences of zinc (Zn) on nitrogen-fixation in soybeans and discovered that application of 5-10 ppm of zinc sulphate to zinc deficient soil at pH 7.1 significantly increased yield and nitrogen-fixation. However, the problem of zinc nutrition is one brought on by toxicity or deficiency in acid soils (Ambler and Brown, 1969; Demeterio, 1972; Smith et al., 1945; White et al., 1979).

Another micronutrient that could possibly be beneficial in legume production is manganese (Mn). Studies on tropical legumes showed that Mn is capable of enhancing Rhizobium-legume relationships (Graham and Hubbell, 1975). While research on cowpeas is limited, several studies on soybeans have supported the idea that Mn could enhance legume production (Ohki, 1976; Sallee and Smith, 1969; Smith et al., 1945; White et al., 1979).

This research was undertaken in an effort to determine the effect of the micronutrients Mn and Zn and of phosphorus (P) on the growth and yield of cowpeas at different levels of pH.

MATERIALS AND METHODS

Phosphate Concentration Trials at Mona

Two experiments were carried out under greenhouse conditions at Mona with the aim of determining the effect of phosphate concentration on the growth and nodulation of the cowpea.

Experiment 1

This experiment was conducted in a soil:sand:coir mixture (1:1:1) in which the initial phosphorus concentration was determined by the ammonium molybdate-amino-napthol sulphonic acid method to be 37-40 μg PO_4 /g soil. Seeds of cowpea variety VITA-3 were soaked and aerated over-night (approximately 16 hours) and two seeds were then sown in the soil:sand:coir mixture in glass bottles previously painted with aluminum paint on the outside to exclude light and to reduce heat absorption. One milliliter of inoculum containing the cowpea rhizobium strain JRCA 4 (present in fields at Botany Department, Mona) was added to each bottle. The population of rhizobium in the inoculum was 10^8 cells/ml.

Experiment 2

Seeds of VITA-3 were similarly soaked and aerated and three seeds were sown in plastic pots filled with vermiculite. Three milliliters of inoculum containing the same rhizobium strain and in the same concentration as in Experiment 1, were added to each pot.

Both experiments involved 4 levels of phosphate:

1. No added phosphate..... .....P_0
2. 25 ppm phosphate added as sodium biphosphate (NaH_2PO_4 $2H_2O$) in distilled water (Experiment 1) or nutrient solution (Experiment 2).....P_1
3. 50 ppm phosphate.....P_2
4. 100 ppm phosphate.....P_3

Plants in experiment 1 were watered with distilled water (P) or with their

respective concentrations of phosphorus in distilled water, whereas plants in experiment 2 were given complete nutrient solutions in which phosphorus concentration was the only variable. The nutrient solution contained all of the macro- and micro-elements necessary for growth and these were added as follows: 200 ppm Calcium added as calcium sulfate ($CaSO_4$ $2H_2O$), 200 ppm potassium added as potassium sulfate (K_2SO_4), 100 ppm magnesium added as magnesium sulfate ($MgSO_4$ $7H_2O$), 5.6 ppm iron added as Ferrous ethylenediaminotetraacetic acid (FeEDTA), 0.064 ppm Copper added as copper chloride ($CuCl_2$ $2H_2O$), 0.325 ppm boron added as Boric acid (H_3BO_3), 0.048 ppm molybdenum added as sodium molybdate (Na_2MoO_4 $2H_2O$), 0.550 ppm manganese added as manganese chloride ($MnCl_2$ $4H_2O$) and 0.065 ppm zinc added as zinc chloride ($ZnCl_2$). Nitrogen was omitted from the nutrient solution so that the only source of nitrogen was from symbiotic nitrogen-fixation.

The experimental design in experiments 1 and 2 was completely randomized and consisted of 25 and 8 replicates respectively (figures 1 and 2). Each treatment received regular bi-weekly applications of the respective solutions. Insects were controlled by spraying the growing plants with Azodrin (4 ml/liter) at regular intervals of eight days using Triton B as sticker - spreader.

Twenty-one days after sowing, 8 plants were randomly reaped from each treatment (P_0, P_1, P_2 and P_3) in experiment 1. Shoot height, dry weight of shoot, number of nodules per plant root and number of trifoliate leaves were measured. Thirty-five days after sowing, the remaining seventeen plants were reaped and the same parameters as above were examined. For experiment 2, reaping was done twenty-eight days after sowing.

FIGURE 1 COMPLETE RANDOMIZED DESIGN (EXPERIMENT I)

P_3	P_2	P_3	P_0	P_2	P_0	P_3	P_2	P_0	P_2	P_3	P_0	P_2	P_3	P_0	P_1	P_3	P_2	P_1	P_3
P_0	P_1	P_0	P_3	P_1	P_3	P_0	P_2	P_1	P_3	P_0	P_1	P_3	P_1	P_2	P_3	P_0	P_1	P_0	P_2
P_1	P_3	P_2	P_1	P_0	P_2	P_1	P_0	P_3	P_2	P_1	P_2	P_0	P_2	P_1	P_0	P_1	P_2	P_3	P_1
P_2	P_1	P_0	P_3	P_2	P_0	P_3	P_2	P_1	P_2	P_0	P_3	P_1	P_3	P_0	P_3	P_2	P_0	P_1	P_0
P_0	P_3	P_1	P_2	P_3	P_1	P_2	P_1	P_0	P_3	P_1	P_2	P_0	P_2	P_1	P_0	P_1	P_3	P_2	P_3

FIGURE 2 COMPLETE RANDOMIZED DESIGN FOR PHOSPHATE TRIAL

EXPERIMENT 2

P_3	P_2	P_1	P_0
P_2	P_0	P_3	P_2
P_1	P_2	P_0	P_3
P_2	P_0	P_3	P_1
P_3	P_1	P_2	P_0
P_0	P_2	P_1	P_3
P_1	P_3	P_0	P_2
P_0	P_1	P_3	P_1

P_0 . . . . . no added P in nutrient solution

P_1 . . . . . 25 p.pm of P in nutrient solution

P_2 . . . . . 50 p.pm of P in nutrient solution

P_3 . . . . . 100 p.pm of P in nutrient solution

RESULTS AND DISCUSSIONS

Experiment 1

The general trend observed when plants were reaped at 21 days was that upon the addition of phosphorus, there was no significant difference between nodules for shoot height and for dry weight of shoot (Tables 1 and 3). Nodulation, however, was stimulated by phosphorus application, increasing by 36.9% over the control on addition of 100 ppm phosphorus to the soil:sand:coir mixture (Table 2), although it was not significantly different.

There were no significant differences between the values obtained for dry weight of shoot and shoot height. At thirty-five days of reaping, there were significant differences between values obtained at 50 and 100 ppm and that of the control, with an increase of 54.7% and 76.4% respectively.

The initial concentration of phosphorus in the soil:sand:coir mixture was between 36-40 μg P/g soil mixture. This phosphorus concentration proved to be enough to promote healthy plant growth as no symptoms of deficiency were noticed in the control plants. Phosphorous application however, while not favorably affecting plant growth in this experiment, affected the nodulation process, directly resulting in an increased number of nodules. This observation is similar to that of other researchers who observed the beneficial effects of phosphorus on nodulation. Saito and Ruschel (1978) observed that phosphorus was essential for increased nodulation. DeMooy and Pesek (1966) concluded that phosphorus (and potassium) were required for maximum nodulation by soybeans. Andrews (1976) stated that phosphorus was required in three phases of the nitrogen-fixation process: bacterial multiplication in the rhizosphere, infection and nodule formation and nitrogen-fixation. Israel (1985) concluded that phosphorus plays a specific role in the symbiotic nitrogen-fixation process in soybeans.

TABLE 1. AVERAGE SHOOT HEIGHT IN EXPERIMENT I

Level of Phosphorus	Yield[1]	Yield[2]
P_0	20.66 ± 1.1[a]	22.49 ± 0.5[b]
P_1	19.84 ± 2.8[a]	23.47 ± 0.5[b]
P_2	20.08 ± 1.8[a]	22.78 ± 0.5[b]
P_3	20.63 ± 2.1[a]	23.62 ± 0.4[b]

- Mean ± S.E. within the same column with the same superscript are not significantly different.

1- Means based on 8 replications at 21 days of reaping.

2- Means based on 17 replications at 35 days after sowing.

TABLE 2. AVERAGE NUMBER OF NODULES PER ROOT IN EXPERIMENT I

Levels of Phosphorus	Yield[1]	Yield[2]
P_0	10.5 ± 1.6[a]	10.6 ± 1.0[b]
P_1	15.5 ± 1.4[a]	14.8 ± 1.5[b]
P_2	11.3 ± 2.3[a]	16.4 ± 1.6[b]
P_3	14.4 ± 2.2[a]	18.7 ± 2.1[b]

- Mean ± S.E. within same column with the same superscript are not significantly different.

1- Means based on 8 replications at 21 days of reaping.

2- Means based on 17 replications at 35 days of reaping.

TABLE 3. AVERAGE DRY WEIGHT OF SHOOT (g) IN EXPERIMENT I

Levels of Phosphorus	Yield [1]	Yield [2]
P_0	0.37 ± 0.02 [a]	0.57 ± 0.01 [b]
P_1	0.37 ± 0.01 [a]	0.54 ± 0.01 [b]
P_2	0.37 ± 0.01 [a]	0.56 ± 0.01 [b]
P_3	0.35 ± 0.01 [a]	0.56 ± 0.01 [b]

- Mean ± S.E. within the same column with same superscript are not significantly different.

1-Means based in 8 replications at 21 days of reaping.

2-Means based on 17 replications at 35 days of reaping.

TABLE 4. AVERAGE DRY WEIGHT OF ROOT (g) IN EXPERIMENT I

Levels of Phosphorus	Yield [1]
P_0	0.18 ± 0.01 [a]
P_1	0.18 ± 0.02 [a]
P_2	0.19 ± 0.01 [a]
P_3	0.18 ± 0.01 [a]

- Mean ± S.E. within columns with same superscript are not significantly different.

1-Means based on 25 observations at 35 days of reaping.

Experiment 2

Shoot height and dry weight, were not significantly affected by the addition of these levels of phosphorus; although at 100 ppm of phosphorus, there was an increase over the control (Tables 5, 6 and Fig. 3, Attachment I).

On the application of 25 ppm phosphorus, the number of nodules increased by 40% and with 50 ppm phosphorus, nodules increased by 120% over that of the control. With addition of 100 ppm phosphorus, the increase over the control was 87.6% (Table 7 and Fig. 3, Attachment II). There were no significant differences between values obtained for shoot weight and shoot height. Number of trifoliate leaves rose by 7.4% when 25 and 50 ppm phosphorus were added and declined when 100 ppm phosphorus was added. However these values were not significantly different as shown in table 8.

This experiment exhibited the beneficial effects of phosphorus on the plant growth and especially on the nodulation process. Israel (1985) found that improving soybean plant phosphorus status from limiting to sufficient resulted in increases in plant dry weight, nitrogen accumulation, nodule number and dry weight, acetylene reduction activity of nodules, whole plant leaf area and photosynthesis rates per unit leaf area. The conclusion was reached by this researcher that the symbiotic nitrogen-fixation process had a greater response to improved phosphorus nutrition, than did overall plant growth. Kang and Nangju (1983) in research with cowpea VITA-3, also found phosphorus application to significantly increase nodulation as well as nodule weight, plant dry weight, nitrogen content and seed yield.

CONCLUSION

Low phosphorus concentration appears to affect the nodulation process of VITA-3 more readily than it does the growth of this legume. Wadisirisuk and

TABLE 5. AVERAGE SHOOT HEIGHT IN EXPERIMENT II

Levels of Phosphorus	Growth [1]
P_0	15.1 ± 0.4 [a]
P_1	15.6 ± 0.5 [a]
P_2	16.5 ± 0.7 [a]
P_3	16.9 ± 0.9 [a]

- Mean ± S.E. within columns with same superscript are not significantly different.

1- Means based on 8 replicates at 28 days after sowing.

TABLE 6. AVERAGE DRY WEIGHT OF SHOOT (g) IN EXPERIMENT II

Levels of Phosphorus	Yield [1]
P_0	17.7 ± 1.4[a]
P_1	22.2 ± 2.2[a]
P_2	25.6 ± 4.4[a]
P_3	25.9 ± 3.1[a]

- Mean ± S.E. within column with same superscript are not significantly different.

1-Means based on 8 replications at 28 days after sowing.

ATTACHMENT I

FIGURE III

DRY WEIGHT OF SHOOT AS AFFECTED BY PHOSPHATE CONCENTRATION (ppm)

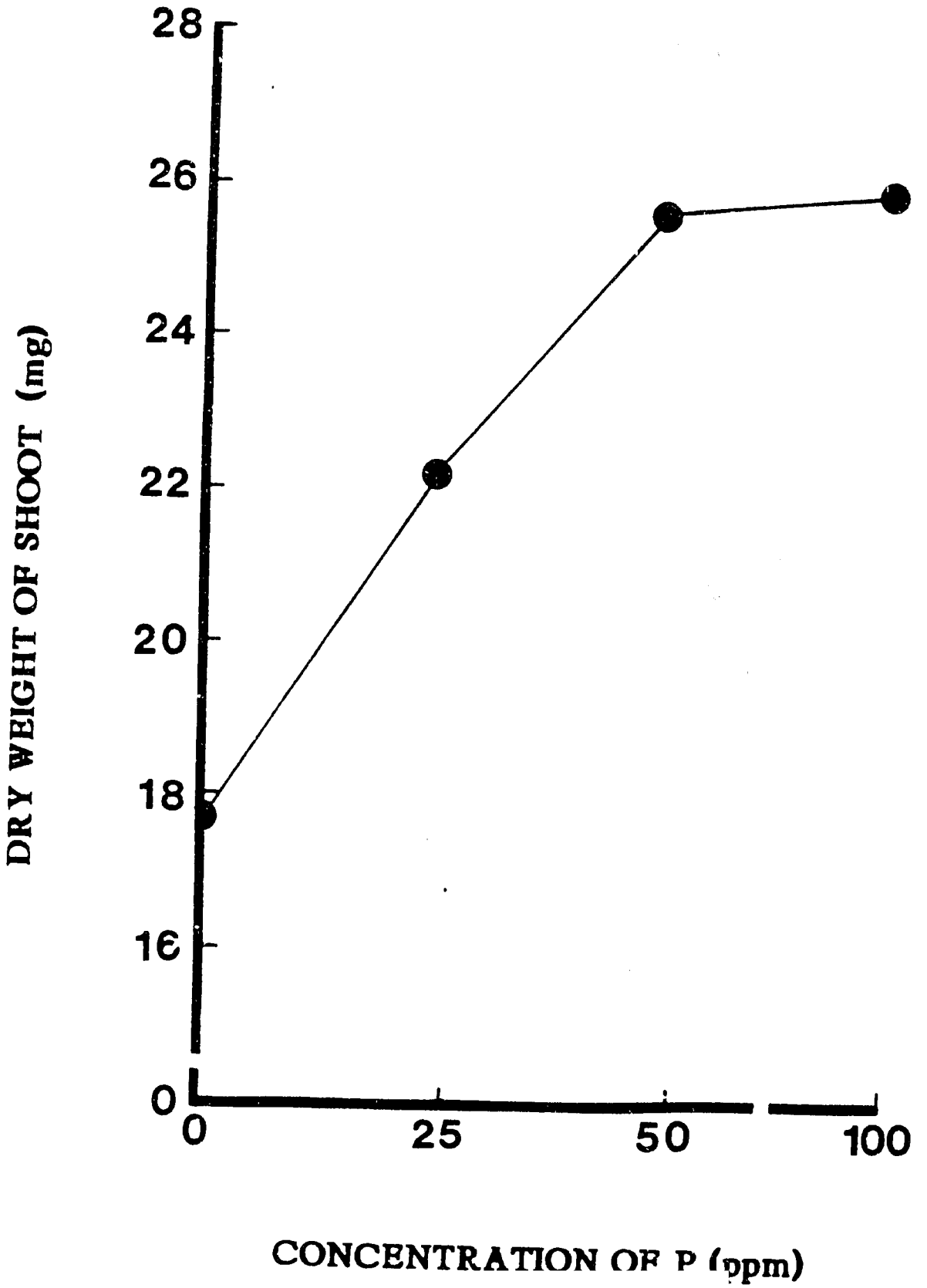


TABLE 7. AVERAGE NUMBER OF NODULES PER ROOT IN EXPERIMENT II

Levels of Phosphorus	Yield[1]
P_0	6.5 ± 1.5^a
P_1	9.1 ± 1.8^b
P_2	14.2 ± 2.5^b
P_3	12.2 ± 1.5^b

- Mean ± S.E. within same column with same superscript are not significantly different.

1-Means based on 8 replications at 28 days after sowing.

TABLE 8. AVERAGE NUMBER OF TRIFOLIATE LEAVES IN EXPERIMENT II

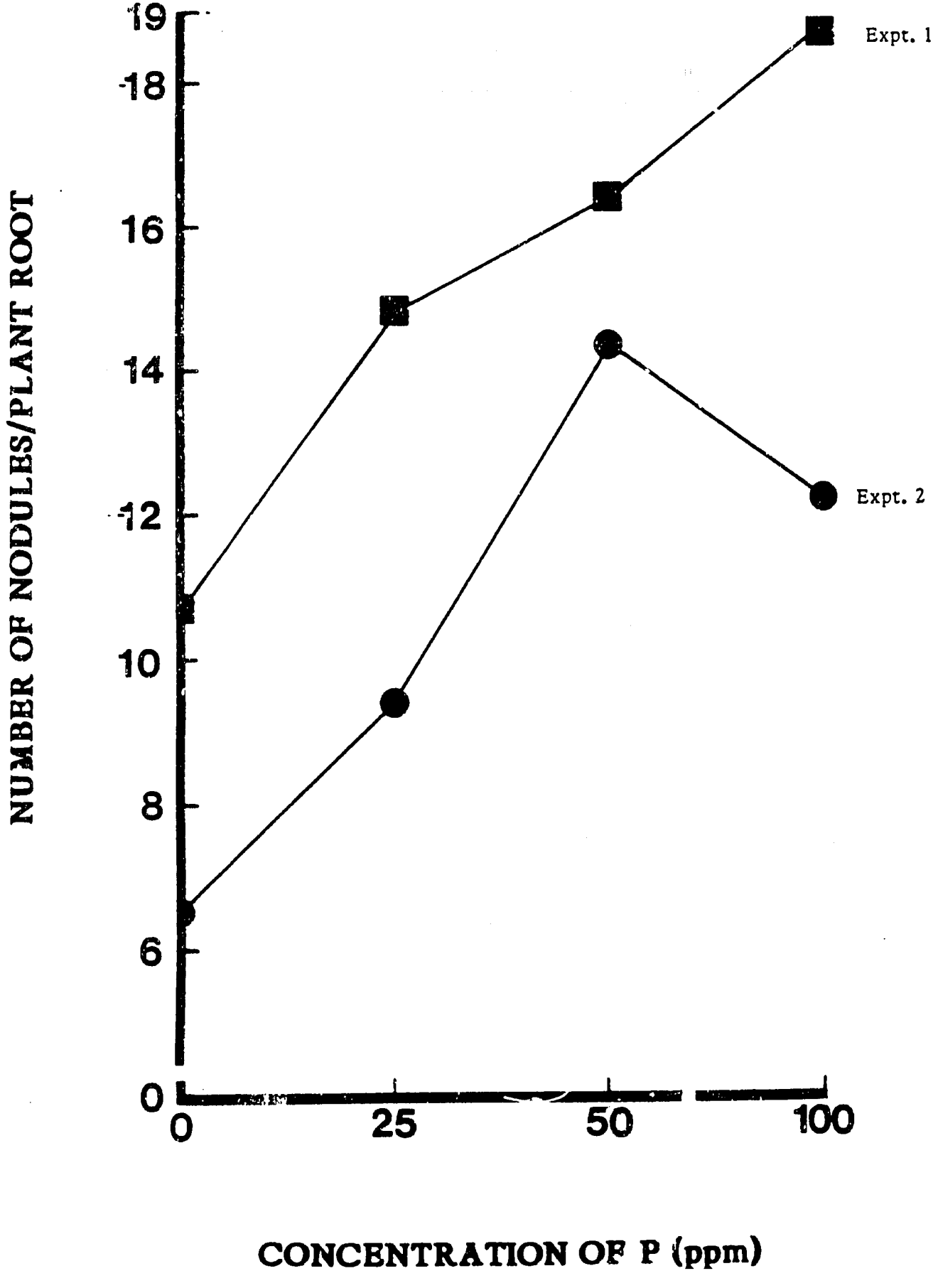
Levels of Phosphorus	Yield[1]
P_0	2.04 ± 0.04^a
P_1	2.19 ± 0.13^a
P_2	2.19 ± 0.13^a
P_3	2.00 ± 0.00^a

- Mean ± S.E. within column with same superscript are not significantly different.

1-Means based on 8 replications at 28 days after sowing.

FIGURE III

THE EFFECT OF P CONC. ON NUMBER OF NODULES/PLANT ROOT



Weaver (1985) considered that there was a direct relationship between the quantity of effective nodule tissue on cowpeas and the quantity of nitrogen, fixed or accumulated. Thus, by increasing P status from limiting to sufficient, not only can the number of nodules formed be increased but also the amount of nitrogen accumulated. Biological nitrogen-fixation is an important trait of cowpeas for economical production of this crop and would thus be enhanced, consequently resulting in a decrease dependence on nitrogen-fertilization of this crop for maximum yield.

MATERIALS AND METHODS

Phosphate, Manganese, Zinc and pH Trials at Mona

Two experiments were carried out between September - December 1984 and February - May 1985 in fields at Botany Department on Maverley loam with the objective of determining the effects of phosphate, manganese and zinc at different pH levels on two cowpea varieties, VITA-3 and LAURA-B.

One hundred and forty-four plots, 2 meters wide and 5 meters long were planted with seeds of VITA-3 (September 1984) and LAURA-B (February 1985) which were previously soaked and inoculated with cowpea-type rhizobium. Seeds of VITA-3 were sown in 6 rows, 40 cm apart and were separated by 35 cm within rows to achieve a population of 90 plants/plot (90,000 plants/hectare). LAURA-B seeds were similarly sown in 6 rows, 40 cm apart but seeds were sown 20 cm apart within the rows to achieve a population of 156 plants/plot (156,000 plants/hectare). Plots were separated by 0.5 meters. Field layout is shown in tables 11 and 12.

The source of phosphate was superphosphate which was applied at the rate of 0, 80 and 160 g/plot (0, 80 and 160 kg/ha). Manganese was applied as Manganese sulphate at the rate of 0, 5, 10 and 20 g/plot (0, 5, 10 and 20

TABLE 9. FIELD LAYOUT (BLOCK II pH 6.9)

PLOT 1

	1	2	3	4
	Zn1	Zn2	Zn3	Zn4
21	5	6	7	8
Mn4	Mn1	Mn2	Mn3	Mn4
22	9	10	11	12
Mn2	Zn2	Zn3	Zn4	Zn1
23	13	14	15	16
Mn1	Mn4	Mn3	Mn2	Mn1
24	17	18	19	20
Mn3	Zn4	Zn3	Zn2	Zn1

No Additional Phosphate

PLOT 2

	25	26	27	28
	Mn1	Mn2	Mn3	Mn4
45	29	30	31	32
Zn4	Zn1	Zn2	Zn3	Zn4
46	33	34	35	36
Zn2	Mn2	Mn3	Mn4	Mn1
47	37	38	39	40
Zn1	Zn4	Zn3	Zn2	Zn1
48	41	42	43	44
Zn3	Mn4	Mn3	Mn2	Mn1

80 Kg. Superphosphate/ha
or 16 Kg. P/ha.
or 80 g. Superphosphate/plot.

PLOT 3

69	49	50	51	52
Mn3	Zn4	Zn3	Zn2	Zn1
70	53	54	55	56
Mn1	Mn4	Mn3	Mn2	Mn1
71	57	58	59	60
Mn2	Zn2	Zn3	Zn4	Zn1
72	61	62	63	64
Mn4	Mn1	Mn2	Mn3	Mn4
	65	66	67	68
	Zn1	Zn2	Zn3	Zn4

160 Kg. Superphosphate/ha.
or 32 Kg. P/ha.
or 160 g. Superphosphate/plot.

TABLE 10. FIELD LAYOUT (BLOCK 1 (pH 6.0))

PLOT 1

73	74	75	76	77	78	79	80
Zn_1	Zn_2	Zn_3	Zn_4	Mn_1	Mn_2	Mn_3	Mn_4
81	82	83	84	85	86	87	88
Mn_2	Mn_4	Mn_1	Mn_3	Zn_2	Zn_4	Zn_1	Zn_3
89	90	91	92	93	94	95	96
Zn_4	Zn_3	Zn_2	Zn_1	Mn_4	Mn_3	Mn_2	Mn_1

PLOT 2

97	98	99	100	101	102	103	104
Mn_1	Mn_2	Mn_3	Mn_4	Zn_1	Zn_2	Zn_3	Zn_4
105	106	107	108	109	110	111	112
Zn_2	Zn_4	Zn_1	Zn_3	Mn_2	Mn_4	Mn_1	Mn_3
113	114	115	116	117	118	119	120
Mn_4	Mn_3	Mn_2	Mn_1	Zn_4	Zn_3	Zn_2	Zn_1

PLOT 3

121	122	123	124
Zn_1	Zn_2	Zn_3	Zn_4
125	126	127	128
Mn_1	Mn_2	Mn_3	Mn_4
129	130	131	132
Zn_2	Zn_4	Zn_1	Zn_3
133	134	135	136
Mn_2	Mn_4	Mn_1	Mn_3
137	138	139	140
Zn_4	Zn_2	Zn_3	Zn_1
141	142	143	144
Mn_4	Mn_3	Mn_1	Mn_2

No Additional Phosphate

70 kg Superphosphate or 16 kg P/ha

160 kg Superphosphate or 32 kg P/ha

kg/ha). Zinc was applied as Zinc chloride at rates of 0, 5, 10 and 20 g/plot (0, 5, 10 and 30 kg/ha). Elemental sulfur at the rate of 50 g/plot (50 kg/ha) was applied to 72 plots to achieve a lowered pH of 6.0 compared to the 72 untreated plots which had pH of 6.9. All the plots received 25 g of potassium chloride (25 kg/ha). All the fertilizers were mixed with sand and broadcast on the soil surface.

The experimental design was split - plot with three replications per treatment. The two pH levels were designated as pH 6.0 and 6.9. For each pH level there were 12 treatment combinations of Manganese (Mn) and Phosphorus (P) or Zinc (Zn) and Phosphorus (P). These treatment combinations are as follows:

1. Control. No applied micronutrient or phosphorus (only residual soil conc.)
2. No applied P (residual soil conc.) but 5 kg Mn or Zn/ha.
3. No applied P (residual soil conc.) but 10 kg Mn or Zn/ha.
4. No applied P (residual soil conc.), but 20 kg Mn or Zn/ha.
5. Recommended amount of P (80 kg superphosphate/ha) but no applied Mn or Zn.
6. Recommended amount of P + 5 kg Mn or Zn/ha.
7. Recommended amount of P + 10 kg Mn or Zn/ha.
8. Recommended amount of P + 20 kg Mn or Zn/ha.
9. Double the recommended amount of P (160 kg superphosphate/ha) but no applied Mn or Zn.
10. Double the recommended amount of P + 5 kg Mn or Zn/ha.
11. Double the recommended amount of P + 10 kg Mn or Zn/ha.
12. Double the recommended amount of P + 20 kg Mn or Zn/ha.

Insect control was maintained by spraying the growing plants with Azodrin (4ml/liter) at regular intervals (8 days). Triton-B was used as the sticker-spreader.

Weed control was manual at the early seedling stage and as the plants matured, foliage cover suppressed weed growth thus omitting the need for further weed control. Irrigation water was supplied by overhead sprinklers after planting and throughout the growing season twice per week.

At maturity, plants were reaped from inner rows and number of pods and seed weight as well as other yield components were determined. Nodule numbers were determined at an earlier stage (35 days for LAURA-B and 42 days for VITA-3).

Description of Cowpea Varieties

Two varieties of the cowpea (*Vigna unguiculata* (L)) were used in the field trials. These varieties were LAURA-B, a local variety and VITA-3, a variety developed by the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria.

VITA-3

VITA-3 is a tropical strain of *Vigna unguiculata* (L). It shows reasonable field tolerance to leafhoppers (*Empoasca dolichi*) and foliage thrips (*Sericothrips occipitalis*). It is an indeterminate, semi-prostrate, moderately daylength sensitive strain. It grows rapidly and vigorously during the early stages and tends towards vininess under poor light or extended daylengths.

The foliage is dark green, leaves are large and subglobose, flowers are purple and the plant branches profusely. The pods of VITA-3 are large (5.6 x 141 mm) averaging about 16 seeds/pod. The seeds are dark red, classified as SOO-R40 eye pattern and color, have a smooth testa and are large-size, class 6, 19 g/100 seeds. Dry seeds contain 29% crude protein, 0.9% oil and 3.5% ash.

LAURA-B

This is a black-eye cultivar. Black-eye peas, distinguished from other cowpeas by their mainly white or cream-colored seeds, account for more than 75 percent of the cowpeas consumed as dried grain in the Caribbean region.

LAURA-B is a determinate strain of medium height tending to form long branches at low plant densities. It matures in about 66-70 days. Seeds are medium-sized (14 g/100 seeds) and cream-colored with black eyes. LAURA-B is resistant to Cowpea Mosaic Virus. The field experiments were conducted in fields on the soil series typifying Maverley Loam in the Botany Department, Mona, Jamaica.

Characteristics of Soil

Maverly Loam is described as a dark brown loam with good structure. At six inches, it changes to brown clay of poor structure which changes gradually to gravelly or sandy parent material at three to four feet. It is derived from sandy and gravelly deposits of the Liguanea Plain, Jamaica, West Indies. The characteristics were compiled from Technical Guide Sheets, Agricultural Chemistry Division, Ministry of Agriculture, Jamaica, as shown in Table 13 (Hewitt 1963).

RESULTS AND DISCUSSIONS

1. Results of Experiment with LAURA-B

The Effect of Phosphorus

At pH 6.0 (50 g elemental sulfur added), addition of phosphorus affected the seed weight and number of pods per plant favorably. Although values were not significant for seed weight, values obtained at 160 kg/ha and 80 kg/ha were higher than the control. The same trend was observed for shoot weight and the number of pods per plant (Tables 10 and 11). The number of nodules formed were negatively affected by phosphorus application, resulting in a significant reduction in the number of nodules with the addition of 80 and 160 g superphosphate per plot. Nodule number declined by 13.7 - 21.6% upon the addition of 80 g superphosphate and by 22.5% when 160 g superphosphate was applied to the plots (Table 12).

TABLE 11. DESCRIPTION OF SOIL, NUTRIENT RATING AND SITE DESCRIPTION

SOIL PROPERTIES		MAVERLEY LOAM
Depth	-	16" - 36"
Reaction (pH)	-	6.7 - 7.3
Moisture Retention (H_2O ft depth)	-	0.75" - 1.00"
Internal Drainage	-	0.20" - 5"/hr.
NUTRIENT RATING		
Organic Matter	-	1.4%
Nitrogen	-	0.04 - 0.08%
Phosphate	-	45-60 ppm P_2O_5
Potassium	-	340 - 420 ppm
SITE DESCRIPTION		
Slope	-	2°
Elevation	-	500 ft.
Erosion	-	Very slight
Exposure	-	Eastern

TABLE 12. AVERAGE SEED WEIGHT (g) PER PLOT OF LAURA-B VARIETY AS AFFECTED BY PHOSPHATE AND MANGANESE AT pH 6.0 AND 6.9.

Treatment (Kg/ha)	pH 6.0 [2]	pH 6.9 [3]
Level of Phosphate		
0	724.50 ± 40.01 [a]	729.17 ± 63.16 [a]
80	787.75 ± 48.30 [a]	681.00 ± 61.96 [a]
160	786.33 ± 45.86 [a]	715.42 ± 45.64 [a]
Level of Manganese		
0	798.22 ± 57.09 [a]	773.78 ± 82.24 [a]
5	796.00 ± 37.43 [a]	740.00 ± 65.97 [a]
10	759.78 ± 55.79 [a]	634.22 ± 49.11 [a]
20	710.78 ± 55.68 [a]	686.11 ± 58.66 [a]

1- Mean ± S.E. within column with same superscript are not significantly different.

2,3 - Means are based on 27 and 50 observations respectively.

TABLE 13. AVERAGE NUMBER OF PODS PER PLANT OF LAURA-B VARIETY AS AFFECTED BY PHOSPHATE AND MANGANESE AT pH 6.0 AND 6.9 [1]

Treatment (Kg/ha)	pH 6.0 [2]	pH 6.9 [3]
Level of Phosphate		
0	11.89 ± 0.46 [a]	12.43 ± 0.81 [a]
80	12.98 ± 0.62 [a]	11.95 ± 0.57 [a]
160	13.13 ± 0.42 [a]	13.93 ± 0.57 [a]
Level of Manganese		
0	13.88 ± 0.58 [a]	13.24 ± 0.98 [a]
5	13.11 ± 1.66 [a]	13.31 ± 0.82 [a]
10	12.66 ± 0.60 [a]	11.88 ± 0.63 [a]
20	12.02 ± 0.59 [a]	12.64 ± 0.75 [a]

1 - Mean ± S.E. within column with same superscript are not significantly different.

2, 3 - Means are based on 27 and 50 observations respectively.

TABLE 14. AVERAGE NUMBER OF NODULES PER PLANT OF LAURA-B AS AFFECTED BY PHOSPHATE AND MANGANESE AT pH 6.0 AND 6.9 [1]

Treatment (Kg/ha)	pH 6.0 [2]	pH 6.9 [3]
Levels of Phosphate		
0	34.33 ± 2.44 [a]	30.58 ± 2.46 [a]
80	26.93 ± 2.23 [b]	36.55 ± 5.49 [a]
160	26.63 ± 1.39 [b]	28.49 ± 2.58 [a]
Levels of Manganese		
0	28.07 ± 2.16 [a]	29.33 ± 3.66 [a]
5	28.66 ± 2.54 [a]	33.23 ± 4.89 [a]
10	32.17 ± 2.94 [a]	30.24 ± 4.18 [a]
20	28.29 ± 2.97 [a]	34.68 ± 5.22 [a]

1 - Mean ± S.E. within column with same superscript are not significantly different.

2, 3 - Means are based on 27 and 50 observations respectively.

At pH 6.9 (no elemental sulfur was added), plots which received no added phosphorus gave the highest seed yield. These tended to decrease when phosphorus was added, although values were not significant. For the number of pods/plant, there were no significant differences among values. However, phosphorus addition stimulated nodulation at this pH, resulting in an increase of 18.7 - 19.5% in the number of nodules at 80 g superphosphate and then a decline at 160 g superphosphate (6.8 - 13.4% over the control).

The favorable effects of phosphorus on seed yield and the number of pods/plant at pH 6.0 may be due to the synergistic effects of sulphur (added to lower the pH) and phosphorus. Kumar and Singh (1980) attributed the yield response in soybeans to be due to the strong synergistic relationship between phosphorus and sulfur in plants. Thus, when phosphorus was added to the soil, there may have been some interaction between the sulfur and the phosphorus, resulting in increases in seed yield and number of pods per plant.

The concentration of phosphorus was obviously sufficient for healthy plant growth as no deficiency symptoms were noticed in control plants. This concentration may have been enough to produce maximum nodulation, thus resulting in no positive response of the symbiotic nitrogen-fixation system to the applied phosphorus.

Nitrogen-fixation in Trifolium subterraneum (L) has been shown to be enhanced by sulphur nutrition (Shock et al., 1984). Similarly Zaroug and Munn (1980) found that sulfur addition increased the number and size of nodules in Clitoria ternatea (L). They concluded that sulfur nutrition enhanced nodulation by increasing the growth and nitrogen demand in plants. Plots treated with sulphur produced plants which were not only visibly healthier, but were considerably higher in seed weight, number of pods and number of nodules than for plots not receiving any sulfur (pH 6.9).

In plots where sulfur was not added (pH 6.9), the effects of phosphorus tended to be negative in respect to seed weight and number of pods. Soil phosphorus concentration ranged between 45 - 60 μg P/g soil, thus addition of phosphorus may have resulted in excess phosphorus concentration which apparently had a more negative effect on the plant itself but which was beneficial to the symbiotic process, whereas seed weight and number of pods/plant were reduced by phosphorus application. Number of nodules increased, probably indicating a greater need of the symbiotic nitrogen-fixation system for phosphorus nutrition. Israel (1985) concluded that phosphorus had a specific role in the nitrogen-fixation process in soybeans.

The Effect of Phosphate (P) and Manganese (Mn)

The soil concentration of manganese (residual) was apparently sufficient for healthy plant growth as no symptoms of manganese deficiency were observed throughout the growing season.

Addition of manganese to the soil generally gave very little if any favorable response over the control plots. The levels of manganese sulfate ($MnSO_4$) did not significantly effect seed weight at both pH 6.0 and pH 6.9 (Table 12). This was also observed for values obtained for number of pods/plant. At pH 6.0 and pH 6.9, the levels of manganese did not significantly affect nodulation, although there were slight increases in values at manganese levels over the control.

Phosphorus, which was added in the form of phosphate at pH 6.0 and 6.9, did not significantly effect the seed weight per plot of Laura-B. This was also observed for the number of pods/plant at both pH 6.0 and 6.9 (Tables 15 and 16 respectively). For the number of nodules/plant at pH 6.0 and 6.9, there was no significant increase with the addition of all three levels of phosphate (Table 17).

TABLE 15. AVERAGE SEED WEIGHT (g) PER PLOT OF LAURA-B VARIETY AS AFFECTED BY PHOSPHATE AND ZINC AT pH 6.0 AND 6.9

Treatment (Kg/ha)	pH 6.0 [2]	pH 6.9[3]
Levels of Phosphate		
0	661.17 ± 45.27 [a]	784.75 ± 60.39 [a]
80	690.00 ± 45.25 [a]	671.83 ± 40.36 [a]
160	781.33 ± 40.63 [a]	708.25 ± 38.26 [a]
Levels of Zinc		
0	654.00 ± 45.93 [a]	705.56 ± 77.15 [a]
5	799.33 ± 49.18 [a]	759.56 ± 58.41 [a]
10	655.56 ± 56.09 [a]	688.89 ± 41.46 [a]
20	734.44 ± 48.38 [a]	732.44 ± 44.96 [a]

1 - Mean ± S.E. within column with same superscript are not significantly different.

2, 3 - Means are based on 27 and 50 observations respectively.

TABLE 16. AVERAGE NUMBER OF PODS PER PLANT OF LAURA-B VARIETY AS AFFECTED BY PHOSPHATE AND ZINC AT pH 6.0 AND 6.9 [1]

Treatment (kg/ha)	pH 6.0 [2]	pH 6.9 [3]
Levels of Phosphate		
0	12.20 ± 0.48 [a]	13.23 ± 0.64 [a]
80	12.46 ± 0.33 [a]	11.91 ± 1.24 [a]
160	12.60 ± 0.34 [a]	12.53 ± 0.55 [a]
Levels of Zinc		
0	11.97 ± 0.36 [a]	13.66 ± 0.91 [a]
5	13.36 ± 0.41 [a]	12.92 ± 0.68 [a]
10	11.99 ± 0.53 [a]	12.46 ± 0.60 [a]
20	12.37 ± 0.29 [a]	11.18 ± 1.48 [a]

1 - Mean ± S.E. within column with same superscript are not significantly different.

2, 3 - Means are based on 27 and 50 observations respectively.

The Effect of Phosphate (P) and (Z) Zinc

Application of zinc (Zn) at the rate of 5 grams of zinc chloride ($ZnCl_2$) per plot at both pH levels 6.0 and 6.9 resulted in greater seed weight, number of pods/plant and number of nodules than when zinc was withheld, although they were not significantly different (Tables 15, 16 and 17 respectively). At pH 6.0 and 6.9, values for seed weight, number of pods/plant and nodules/plant were not significantly different, although there were increases in values. Values for seed weight increased over the control at both pH levels. For number of pods/plant and nodules/plant, values were variable.

The beneficial effects of zinc on yield and nodulation have been observed in other legumes e.g. green gram (Vigna radiata) by Singh and Badhoria (1984), soybeans (Glycine max) Payne et al, (1986) and in cowpeas (Vigna unguiculata) by Laskar and Rhoden (1981), Allen and Dadhwal (1980) and Yadav et al (1984). Zinc has been shown to significantly affect the number of pods per plant and to increase seed yield by 59.7 - 123.3% in cowpea (Ghildiyal et al., 1978). Soil zinc concentration, though not determined in this experiment, was apparently sufficient to allow healthy plant growth. Thus, when Zn was added, favorable effects were observed, but these proved not to be significant as the initial soil Zn concentration was not limiting.

2. Results of VITA-3

The Effect of Phosphorus (P) and Manganese (Mn)

At pH 6.0 (50 g elemental sulfur (S) added to the soil), application of phosphorus significantly decreased seed weight/plot (with phosphate level of 160 being the lowest). The average number of pods/plant were not affected by the addition of extra levels of phosphorus. This is seen in tables 18 and 19

TABLE 17. AVERAGE NUMBER OF NODULES PER PLANT OF LAURA-B VARIETY AS AFFECTED BY PHOSPHATE AND ZINC AT pH 6.0 AND 6.9 [1]

Treatment (kg/ha)	pH 6.0 [2]	pH 6.9 [3]
Levels of Phosphate		
0	37.68 ± 3.09 [a]	30.58 ± 4.27 [a]
80	32.51 ± 3.08 [a]	36.32 ± 3.27 [a]
160	34.26 ± 2.42 [a]	26.49 ± 3.15 [a]
Levels of Zinc		
0	34.66 ± 3.45 [a]	30.68 ± 5.02 [a]
5	37.59 ± 3.09 [a]	30.54 ± 3.92 [a]
10	33.39 ± 2.97 [a]	30.01 ± 2.74 [a]
20	33.63 ± 4.03 [a]	33.29 ± 5.53 [a]

1 - Mean ± S.E. within column with same superscript are not significantly different.

2, 3 - Means are based on 27 and 50 observations respectively.

TABLE 18. AVERAGE SEED WEIGHT (G) PER PLOT OF COWPEA VARIETY VITA-3 AS AFFECTED BY PHOSPHORUS AND MANGANESE AT pH 6.0 AND 6.9 [1]

Treatment (kg/ha)	pH 6.0 [2]	pH 6.9 [3]
Levels of Phosphate		
0	2495.25 ± 151.74 [a]	1808.00 ± 85.99 [a]
80	2092.00 ± 104.99 [b]	1745.08 ± 64.65 [a]
160	1594.33 ± 82.26 [c]	1887.17 ± 75.23 [a]
Levels of Manganese		
0	2105.00 ± 137.54 [a]	1814.00 ± 79.68 [a]
5	2117.23 ± 211.37 [a]	1855.22 ± 107.69 [a]
10	2075.11 ± 187.14 [a]	1779.33 ± 98.99 [a]
20	1944.67 ± 204.32 [a]	1805.11 ± 71.90 [a]

1 - Mean ± S.E. within column with same superscript are not significantly different.

2, 3 - Means are based on 50 and 27 observations respectively.

TABLE 19. THE AVERAGE NUMBER OF PODS PER PLANT AS AFFECTED BY PHOSPHATE AND MANGANESE AT pH 6.0 AND 6.9 FOR COWPEA VAR VITA-3 [1]

Treatment (kg/ha)	pH 6.0 [2]	pH 6.9 [3]
Levels of Phosphate		
P_1	13.0 ± 0.5 a	17.9 ± 0.9 a
P_2	12.7 ± 0.3 a	15.3 ± 0.6 b
P_3	13.2 ± 0.4 a	[illegible].4 ± 0.5 c
Levels of Manganese		
Mn_1	12.8 ± 0.4 a	15.4 ± 0.8 a
Mn_2	13.3 ± 0.7 a	15.2 ± 1.3 a
Mn_3	12.8 ± 0.6 a	15.3 ± 1.3 a
Mn_4	12.9 ± 0.4 a	14.9 ± 1.2 a

1 - Mean ± S.E. within column with same superscript are not significantly different.

2, 3 - Means are based on 50 and 27 observations respectively.

TABLE 20. THE AVERAGE NUMBER OF NODULES PER PLANT AS AFFECTED BY PHOSPHATE AND MANGANESE AT pH 6.0 AND 6.9 FOR COWPEA VAR VITA-3.[1]

Treatment (kg/ha)	pH 6.0 [2]	pH 6.9 [3]
Levels of Phosphate		
P_1	31.4 ± 1.8 [a]	17.7 ± 1.7 [a]
P_2	14.4 ± 1.5 [a]	21.7 ± 2.9 [a]
P_3	23.4 ± 2.0 [a]	16.2 ± 1.3 [a]
Levels of Manganese		
Mn_1	22.2 ± 3.0 [a]	17.6 ± 2.6 [a]
Mn_2	22.1 ± 2.9 [a]	19.7 ± 2.9 [a]
Mn_3	25.8 ± 3.9 [a]	19.1 ± 2.6 [a]
Mn_4	22.[illegible] ± 2.8 [a]	17.6 ± 2.2 [a]

1 - Mean ± S.E. within column with different superscripts are significantly different at $P < 0.01$ and $P < 0.05$ at pH 6.0 and 6.9 respectively.

2, 3 - Means are based on 50 and 27 observations respectively.

respectively.

At pH 6.0, at the 0 g level of phosphorus, the number of nodules/plant increased significantly over that of the 80 g level of phosphorus.

At pH 6.9 (no added sulfur), the control yielded more pods than the other two levels of phosphorus that were added. The number of pods/plant increased by 7.1% and the number of nodules by 18.4% when 80 g phosphorus were added. Increasing phosphorus concentration to 160 g superphosphate/plot tended to cause reduction in pods/plant while the other parameters were unchanged. There were no significant differences in number of nodules/plant (Table 20).

The general trend was for application of manganese at the rate of 5 g/plot to cause slight increases in the seed weight, number of pods/plant and number of nodules at both pH 6.0 and 6.9.

Further additions of manganese (10 g and 20 g $MnSO_4$/plot) resulted in decreases in these parameters.

At pH 6.0, there were no significant differences among the values obtained for seed weight, number of pods/plant and the number of nodules/plant. At pH 6.9, no significant difference existed among seed weight/plot and number of nodules/plant. However, there was a significant decrease in the number of pods/plant at the highest level of Mn (Tables 18, 19, and 20)

11. Effect of Zinc (Zn) and Phosphorus (P)

Zinc addition had no beneficial effect on the seed weight, number of nodules/plant and number of pods/plant (Tables 21, 22, and 23). At pH 6.0, the application of Zn at the various levels did not significantly affect the seed weight/plot, number of pods/plant and the number of nodules/plant. At pH 6.9, the application of Zn did not significantly affect seed weight, number of pods/plant or number of nodules/plant.

At pH 6.0, for all parameters measured, the addition of phosphorus significantly decreased the yield of cowpea var VITA-3. This progressive

TABLE 21. AVERAGE SEED WEIGHT (g) PER PLOT OF COWPEA VARIETY VITA-3 AS AFFECTED BY PHOSPHATE AND ZINC AT pH 6.0 AND 6.9 [1]

Treatment (kg/ha)	pH 6.0 [2]	pH 6.9 [3]
Levels of Phosphate		
0	2369.25 ± 85.35 [a]	1741.00 ± 95.62[a]
80	2076.17 ± 108.40 [b]	1822.83 ± 73.46[a]
160	1702.92 ± 39.54 [c]	1621.00 ± 121.06[a]
Levels of Zinc		
0	2039.44 ± 137.71 [a]	1733.89 ± 125.58[a]
5	2121.78 ± 146.55 [a]	1625.22 ± 85.56[a]
10	1945.22 ± 89.34 [a]	1722.22 ± 108.82[a]
20	2091.33 ± 155.82 [a]	1831.78 ± 139.12[a]

1 - Mean ± S.E. within column with same superscript are not significantly different.

2, 3 - Means are based on 50 and 27 observations respectively.

TABLE 22. THE AVERAGE NUMBER OF PODS PER PLANT AS AFFECTED BY PHOSPHATE AND ZINC AT pH 6.0 AND 6.9 FOR COWPEA VAR VITA-3 [1]

Treatment (kg/ha)	pH 6.0 [2]	pH 6.9 [3]
Levels of Phosphate		
P_1	16.8 ± 0.5	12.6 ± 0.5
P_2	15.5 ± 0.6	13.5 ± 0.6
P_3	12.9 ± 0.4	11.7 ± 0.8
Levels of Zinc		
Zn_1	14.7 ± 0.7	12.8 ± 0.9
Zn_2	15.7 ± 0.9	12.1 ± 0.6
Zn_3	14.4 ± 0.6	12.1 ± 0.7
Zn_4	15.4 ± 1.1	13.5 ± 0.01

1 - Mean ± S.E. within column with same superscript are not not significantly different ($P < 0.05$).

2, 3 - Means are based on 50 and 27 observations respectively.

TABLE 23. THE AVERAGE NUMBER OF NODULES AS AFFECTED BY PHOSPHATE AND ZINC AT pH 6.0 AND 6.9 FOR COWPEA VAR VITA-3 [1]

Treatment (kg/ha)	pH 6.0 [2]	pH 6.9 [3]
Levels of Phosphate		
P_1	34.4 ± 2.3 a	19.8 ± 1.8 a
P_2	16.6 ± 2.2 b	17.4 ± 1.4 a
P_3	25.1 ± 2.2 c	19.9 ± 2.1 a
Levels of Zinc		
Zn_1	24.8 ± 4.0 a	17.1 ± 1.7 a
Zn_2	29.2 ± 4.2 a	16.1 ± 1.7 a
Zn_3	22.1 ± 1.9 a	21.8 ± 2.4 a
Zn_4	25.3 ± 3.7 a	20.9 ± 1.9 a

1 - Mean ± S.E. within column with different superscripts are not significantly different ($P < 0.05$)

2, 3 - Means are based on 50 and 27 observations respectively.

decrease is illustrated in tables 21, 22, and 23. The various levels of phosphorus at pH 6.9 did not significantly affect yield of all parameters measured.

CONCLUSION

The beneficial effects of added Zn and Mn were observed with both varieties of cowpea and at both pH levels. The effects of phosphorus, however, were not clear, differing between the varieties and the pH levels.

Initial soil levels of phosphorus and trace-elements Zn and Mn were adequate as control plants were just as vigorous and yielded as well as plants in plots which were treated. These initial levels of P, Mn and Zn did not allow for any significant differences in seed weight, number of pods and number of nodules/plant upon the application of these elements to the soil.

APPENDICES

TABLE 24. ANALYSIS OF VARIANCE OF SHOOT HEIGHT IN EXPERIMENT I

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	31	178.40969			
Treatments	3	3.96844	1.3228	0.212	P < 0.8870
Error	28	174.44125	6.2300		

TABLE 25. ANALYSIS OF VARIANCE OF SHOOT HEIGHT IN EXPERIMENT I

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	67	285.635			
Treatments	3	15.066	5.022	1.188	P < 0.3214
Error	64	270.568	4.228		

TABLE 26. ANALYSIS OF VARIANCE FOR NUMBER OF NODULES PER ROOT IN EXPERIMENT I

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	31	948.7188			
Treatments	3	139.3438	46.4479	1.807	P < 0.2101
Error	28	809.3750	28.9063		

TABLE 27. ANALYSIS OF VARIANCE FOR NUMBER OF NODULES PER ROOT IN EXPERIMENT I

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	67	3353.059			
Treatments	3	586.706	195.569	4.525	P < 0.0061
Error	64	2766.353	43.224		

TABLE 28. ANALYSIS OF VARIANCE FOR DRY WEIGHT OF SHOOT IN EXPERIMENT I

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	31	0.02907			
Treatments	3	0.00184	0.00061	0.629	P < 0.6026
Error	28	0.02724	0.00097		

TABLE 29. ANALYSIS OF VARIANCE FOR DRY WEIGHT OF SHOOT IN EXPERIMENT I

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	67	0.1341			
Treatment	3	0.0075	0.00250	1.265	P < 0.2941
Error	64	0.1266	0.00198		

TABLE 30. ANALYSIS OF VARIANCE FOR DRY WEIGHT OF ROOT IN EXPERIMENT I

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	67	0.0366			
Treatments	3	0.0010	0.000338	0.607	P < 0.6126
Error	64	0.0356	0.000557		

TABLE 31. ANALYSIS OF VARIANCE FOR DRY WEIGHT OF SHOOT IN EXPERIMENT II

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	31	114.360			
Treatments	3	15.788	5.263	1.495	P < 0.2375
Error	28	98.573	3.520		

TABLE 32. ANALYSIS OF VARIANCE FOR DRY WEIGHT OF SHOOT IN EXPERIMENT II

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	31	2349.965			
Treatments	3	355.163	118.388	1.662	P < 0.1978
Error	28	1994.802	71.243		

TABLE 33. ANALYSIS OF VARIANCE FOR NUMBER OF NODULES PER PLANT ROOT IN EXPERIMENT II

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	31	1062.909			
Treatment	3	281.006	93.669	3.354	P < 0.0329
Error	28	781.903	27.925		

Treatments are significantly different

TABLE 34. ANALYSIS OF VARIANCE FOR NUMBER OF TRIFOLIATE LEAVES IN EXPERIMENT II

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	31	2.2497			
Treatment	3	0.2334	0.07781	1.081	P < 0.3734
Error	28	2.0163	0.07201		

TABLE 35. ANALYSIS OF VARIANCE FOR SEED WEIGHT (g) PER PLOT OF LAURA-B AT pH 6.0

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	828101.86			
Phosphate	2	31303.72	15651.86	0.577	P < 0.5693
Manganese	3	45236.97	15078.99	0.556	P < 0.6494
Phosphate X Manganese	6	100202.94	16700.49	0.615	P < 0.7159
Random Error	24	651358.00	27139.92		

TABLE 36. ANALYSIS OF VARIANCE FOR SEED WEIGHT (g) PER PLOT OF LAURA-B AT pH 6.9

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	1323090.00			
Phosphate	2	14774.39	7387.19	0.163	P < 0.8508
Manganese	3	101446.97	33815.66	0.745	P < 0.5361
Phosphate X Manganese	6	116838.28	19473.05	0.429	P < 0.8524

TABLE 37. ANALYSIS OF VARIANCE FOR NUMBER OF NODULES PER PLANT OF LAURA-B AT pH 6.0

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	2159.02			
Phosphate	2	457.57	228.78	3.784	P < 0.0373
Manganese	3	100.588	33.53	0.555	P < 0.6501
Phosphate X Manganese	6	149.76	24.96	0.413	P < 0.8632
Random Error	24	1451.10	60.46		

TABLE 38. ANALYSIS OF VARIANCE FOR NUMBER OF NODULES PER PLANT OF LAURA-B AT pH 6.9

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	6080.35			
Phosphate	2	419.91	209.96	0.951	P < 0.4005
Manganese	3	169.37	56.46	0.256	P < 0.8565
Phosphate X Manganese	6	192.33	32.05	0.145	P < 0.9883
Random Error	24	5298.74	220.78		

TABLE 39. ANALYSIS OF VARIANCE FOR NUMBER OF NODULES PER PLANT OF LAURA-B AT pH 6.9

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	5710.40			
Phosphate	2	584.57	292.29	1.683	P < 0.2070
Zinc	3	58.14	19.38	0.112	P < 0.9525
Phosphate X Zinc	6	899.98	149.99	0.864	P < 0.5352
Random Error	24	4167.71	173.65		

TABLE 40. ANALYSIS OF VARIANCE FOR NUMBER OF PODS PER PLANT OF LAURA-B AT pH 6.0

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	112.26			
Phosphate	2	10.93	5.465	1.451	P < 0.2541
Manganese	3	5.92	1.973	0.524	P < 0.6701
Phosphate X Manganese	6	5.01	0.835	0.222	P < 0.9659
Random Error	24	90.40	3.767		

TABLE 41. ANALYSIS OF VARIANCE FOR NUMBER OF PODS PER PLANT OF LAURA-B AT pH 6.9

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	198.56			
Phosphate	2	25.44	12.72	2.444	P < 0.1081
Manganese	3	11.97	3.99	0.767	P < 0.5239
Phosphate X Manganese	6	36.27	6.04	1.162	P < 0.3590
Random Error	24	124.89	5.20		

TABLE 42. ANALYSIS OF VARIANCE OF SEED WEIGHT (g) PER PLOT OF LAURA-B AT pH 6.9

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	969446.56			
Phosphate	2	79714.39	39857.19	1.414	P < 0.2626
Zinc	3	25971.00	8657.00	0.307	P < 0.8199
Phosphate X Zinc	6	187390.50	31231.75	1.108	P < 0.3866
Random Error	24	676370.67	28182.11		

TABLE 43. ANALYSIS OF VARIANCE FOR SEED WEIGHT (g) PER PLOT OF LAURA-B AT pH 6.0

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	853089.00			
Phosphate	2	94452.67	47226.33	2.157	P < 0.1376
Zinc	3	132078.56	44026.19	2.011	P < 0.1392
Phosphate X Zinc	6	101124.44	16854.07	0.770	P < 0.6010
Random Error	24	525433.33	21893.06		

TABLE 44. ANALYSIS OF VARIANCE FOR NUMBER OF PODS PER PLANT OF LAURA-B AT pH 6.0

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	59.656			
Phosphate	2	0.494	0.494	0.353	P < 0.7058
Zinc	3	11.425	3.808	2.727	P < 0.0663
Phosphate X Zinc	6	13.731	2.288	1.639	P < 0.1798
Random Error	24	33.513	1.396		

TABLE 45. ANALYSIS OF VARIANCE FOR NUMBER OF PODS PER PLANT OF LAURA-B AT pH 6.9

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	306.01			
Phosphate	2	10.42	5.208	0.667	P < 0.5226
Zinc	3	29.27	9.758	1.249	P < 0.3140
Phosphate X Zinc	6	78.85	13.142	1.683	P < 0.1686
Random Error	24	187.47	7.811		

TABLE 46. ANALYSIS OF VARIANCE FOR NUMBER OF NODULES PER PLANT OF LAURA-B AT pH 6.0

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	3445.43			
Phosphate	2	166.30	83.18	0.655	P < 0.5283
Zinc	3	100.35	35.45	0.264	P < 0.8509
Phosphate X Zinc	6	133.77	22.30	0.176	P < 0.9809
Random Error	24	3045.00	126.88		

TABLE 47

ANALYSIS OF VARIANCE FOR SEED WEIGHT(g)/PLOT FOR VITA-3 AT pH 6.0

Source of Variation	DF	Sum of Squares	Mean sum of Squares	F	P
Total	35	5396040.00			
Phosphate level	2	2676854.06	1338427.03	16.881	P<0.0001
Zinc level	3	161541.56	53847.19	0.679	P<0.5734
Phosphate x zinc	6	654832.61	109138.77	1.377	P<0.2641
Random Error	24	1902810.00	79283.69		

TABLE 48.

ANALYSIS OF VARIANCE FOR SEED WEIGHT(g)/PLOT FOR VITA-3 AT pH 6.9

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	4101230.00			
Phosphate levels	2	247333.56	123666.78	0.842	P<0.4433
Zinc levels	3	192607.67	64202.56	0.437	P<0.7286
Phosphate x zinc	6	134660.00	22443.33	0.153	P<0.9866
Random error	24	3526630.00	146942.75		

TABLE 49

ANALYSIS OF VARIANCE FOR AVERAGE SEED WEIGHT(g)/PLOT FOR VITA-3 at pH 6.0

Source of Variation	DF	Sum of Squares	Mean sum of Squares	F	P
Total	35	10275600.00			
Phosphate	2	4887734.06	2443867.03	11.876	P<0.0003
Manganese	3	169570.08	56523.36	0.275	P<0.8431
Phosphate x Manganese	6	279714.83	46619.14	0.277	P<0.9641
Random error	24	4938580.00	205774.33		

TABLE 50

ANALYSIS OF VARIANCE FOR AVERAGE SEED WEIGHT(g) FOR VITA-3 AT pH 6.9 AS AFFECTED BY PHOSPHORUS

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	2396570.00			
Phosphate	2	121654.17	60827.08	0.749	P<0.4838
Manganese	3	26808.31	8936.10	0.110	P<0.9534
Phosphate x Manganese	6	297754.94	49625.82	0.611	P<0.7194
Random Error	24	1950350.00	81264.72		

TABLE 51

ANALYSIS OF VARIANCE FOR NUMBER OF PODS/PLANT AT pH 6.0

Source of Variance	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	390.77			
Phosphate	2	180.83	90.413	11.172	P<0.0004
Manganese	3	1.34	0.448	0.055	P<0.9824
Phosphate x Manganese	6	14.37	2.395	0.296	P<0.9329
Random Error	24	194.23	8.093		

TABLE 52

ANALYSIS OF VARIANCE FOR NUMBER OF PODS/PLANT AS AFFECTED BY PHOSPHATE AND Mn AT pH 6.9 FOR COWPEA var VITA-3

Variation		Squares	Squares		
Total	35	76.295			
Phosphate	2	1.755	0.878	0.334	P<0.7196
Manganese	3	1.533	0.511	0.194	P<0.8993
Phosphate x Manganese	6	9.877	1.646	0.626	P<0.7080
Random Error	24	63.130	2.630		

TABLE 53

ANALYSIS OF VARIANCE FOR NUMBER OF PODS/PLANT FOR COWPEA var VITA-3 AT pH

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	209.796			
Phosphate levels	2	94.866	47.433	14.122	P<0.0001
Zinc levels	3	9.833	3.278	0.976	P<0.4205
Phosphate x Zinc	6	24.483	4.080	1.215	P<0.3330
Random Error	24	80.614	3.359		

TABLE 54

ANALYSIS OF VARIANCE FOR NUMBER OF PODS/PLANT

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	201.920			
Phosphate	2	21.108	10.554	1.560	P<0.2307
Zinc	3	12.927	4.309	0.637	P<0.5985
Phosphate x Zinc	6	5.529	0.921	0.137	P<0.9901
Random Error	24	162.357	6.765		

TABLE 55

ANALYSIS OF VARIANCE FOR NUMBER OF NODULES FOR COWPEA var VITA-3 AT pH 6.0

Source of Variation	DF	Sum of Squares	Mean sum of Squares	F	P
Total	35	2957.26			
Phosphate	2	1741.07	870.54	21.756	P<0.0001
Manganese	3	89.92	29.97	0.749	P<0.5336
Phosphate x Manganese	6	165.95	27.66	0.691	P<0.6588
Random Error	24	960.32	40.01		

TABLE 56

ANALYSIS OF VARIANCE FOR NUMBER OF NODULES/PLANT

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	1914.26			
Phosphate	2	203.07	101.534	1.712	P<0.2017
Manganese	3	31.60	10.534	0.178	P<0.9105
Phosphate x Manganese	6	256.56	42.760	0.721	P<0.6366
Ramdom Error	24	1423.03	59.293		

TABLE 57

ANALYSIS OF VARIANCE FOR NODULE NUMBER/PLANT FOR PHOSPHATE AND ZINC AT pH 6.0 FOR VITA-3

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	3889.97			
Phosphate	2	1895.00	947.50	16.157	P<0.0001
Zinc	3	227.71	75.90	1.294	P<0.2991
Phosphate x Zinc	6	359.82	59.97	1.023	P<0.4346
Random Error	24	1407.43	58.64		

TABLE 58

ANALYSIS OF VARIANCE FOR NUMBER OF NODULES/PLANT AT pH 6.9 FOR COWPEA var VITA-3

Source of Variation	DF	Sum of Squares	Mean Sum of Squares	F	P
Total	35	1292.05			
Phosphate	2	47.58	23.790	0.830	P<0.4483
Zinc	3	209.50	69.834	2.436	P<0.0894
Phosphate x Zinc	6	346.88	57.813	2.016	P<0.1028
Random Error	24	688.09	28.670		

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