PART TWO: EXPERIMENTAL REPORTS

CHAPTER SIX

EXPERIMENT I

STUDY OF RESPONSES TO PHOSPHORUS AND POSSIBLE PHOSPHORUS-ZINC INTERACTION IN FIELD PEAS AND WHEAT

6.1. Introduction

Phosphorus and nitrogen are the most limiting nutrients in Australian agriculture. Yield response to P fertilisers is usually high; for instance, Smith and Spence (1974) reported increased wheat grain yield with increasing application rate of P fertiliser in the wheat growing areas of southern NSW. Although the response of wheat to P application in Australia is well recognised, little response data is available for peas. Research on P nutrition of most relevance to Australian conditions is that conducted on low fertility soils in India. For example, Naik *et al.* (1991) found increased dry matter and P uptake by pea plants at maturity with increasing application rate of P on a sandy loam soil near Delhi. Similar responses in plant growth, P uptake and yield of peas to increasing application rates of P were observed by Ibrahim (1989) and Dahiya *et al.* (1990). In an experiment conducted to compare the responses of cereals and legume crops and pastures to P in solution culture, Fageria and Baligar (1989) found that the optimum P concentration for maximum growth varied with plant species but was higher for legumes than for cereals.

Zinc is one of the most important micronutrients in wheat nutrition and it has often been studied together with P to investigate P-Zn interaction effects (Wagar *et al.*, 1986; Verma and Minhas, 1987; Webb and Loneragan, 1988 and 1990). Earlier work by Millikan (1940) reported no significant responses in wheat growth and Zn uptake to the application of Zn alone on the Wimmera black soil unless Zn was applied in conjunction with superphosphate. It was concluded that application of superphosphate increased Zn requirement of wheat and would result in Zn deficiency if the soil was low in available Zn. More recent studies have proved that high levels of P increase Zn requirements of the plant (and hence Zn uptake) and that under low Zn fertility Zn deficiency is induced and plant growth reduced, not only in wheat but in other cereals and some legume crops (Sims and Rooney, 1956; Bingham and Garber, 1960; Wagar *et al.,* 1986; Verma and Minhas, 1987). However, a P-Zn interaction in field pea has not yet been established.

The objectives of the experiment reported in this chapter were to investigate responses to P fertiliser and a possible P-Zn interaction in field pea and to compare the response in field pea and wheat.

6.2. Materials and methods

6.2.1. Experimental Design

To study the effects of P and possible P-Zn interaction in peas and wheat, a pot experiment was set up in a temperate glasshouse with the following treatments:

(i) two crops: wheat (*Triticum aestivum* L.) var. Sunco,
peas (*Pisum sativum* L.) var. Dundale.

(ii) P fertiliser application at 0, 10, 20 and 40 kg P/ha.

(iii) Zn fertiliser application at 0 and 5 kg Zn/ha.

The experiment had four replicates and was designed as a factorial completely randomised block design. The mean daily temperature in the glasshouse was 25°C and mean night temperature was 12°C.

Table.6.1. The rates of P, Zn and basal nutrients (kg/ha) applied to each pot. Unless stated otherwise, 2 ml of each solution were added to each pot.

Nutrient	**Rate (kg/ha)**	**Source**
P	0	-
P	10	2 ml of 9.6032 g/250 ml KH_2PO_4
P	20	4 ml of 9.6032 g/250 ml KH_2PO_4
P	40	8 ml of 9.6032 g/250 ml KH_2PO_4
Zn	0	-
Zn	5	0.9203 g/100 ml Zn Cl_2
N	20	25.255 g/250 ml NH_4NO_3
K for P0	126	10.6296 g/50 ml KCl
for P10		9.6032 g/250 ml KH_2PO_4 & 9.5676 g/50 ml KCl
for P20		9.6032 g/250 ml KH_2PO_4 & 8.5056 g/50 ml KCl
for P40		9.6032 g/250 ml KH_2PO_4 & 6.3817 g/50 ml KCl
S	30	23.38 g/250 ml $MgSO_4.7H_2O$
Mg	22.7	23.38 g/250 ml $MgSO_4.7H_2O$
Ca	28.9	50.934 g/250 ml $CaCl_2.2H_2O$
Mo	0/198	0.0885 g/200 ml $Na_2MoO_4.2H_2O$
Mn	1.002	0.6376 g/200 ml $MnCl_2.4H_2O$
Cu	0.2037	0.0966 g/200 ml $CuCl_2.2H_2O$
B	0.498	0.5032 g/200 ml H_3BO_3

6.2.3. Soil

The soil used in this experiment was a grey clay, collected from 'Auscott', at Narrabri, to a depth of 8 cm. This soil has been used for irrigated cotton cropping and its main characteristics are shown in Appendix A. 15 cm diameter pots were filled with the soil, lined with plastic bags, to give 1300 g per pot.

6. 2. 4. Experimental Procedure

P and Zn with the basal nutrients N, K, S, Ca, Mg, Mn, B, Cu and Mo (Table 6.1.) were applied as solutions to the soil surface, allowed to dry and then mixed with the soil by shaking. The pots were inoculated with the **Group E** Rhizobia by mixing the inoculum with the top soil. For both peas and wheat four seeds were sown per pot to a depth of 5 cm.

The pots were watered to 38.5 % (w/w), which approximated field capacity, and were maintained above 75 % field capacity throughout the experiment. After seedling emergence the plants were thinned to two plants per pot.

6.2.5. Plant Measurements

Observations of growth were made throughout the experimental period and plant height measurements were taken every week. These measurements were used to calculate plant growth rate.

Harvesting commenced six weeks from germination after the seeds in the pea pods had hardened and after the heads of wheat plants had emerged. The plant tops were cut close to the soil, care being taken to avoid contamination with the soil. The roots were washed out of the soil and both the roots and tops were dried separately in a force-drought oven (80 °C) overnight. Their dry weights (DW) were recorded; the dry tops were ground and oven - dried for chemical analysis.

6.2.6. Chemical Analysis of Plant Tops

The oven-dried plant tops were ground and then digested by the Sealed Chamber Digest (SCD) method, using perchloric acid and hydrogen peroxide. Samples were then analysed for P and Zn with an Inductively Coupled Plasma Atomic Emission Spectrometer (ICP) using an ARL 3560B ICP Analyser. The ICP program also gave the concentrations of S, K, Ca, Mg, Na, Mn, Fe, Cu, Al, B and Mo.

6.2.7. Data Analysis

The effects of treatments were analysed by analysis of variance (AOV) using the NEVA Program. The results discussed in the following sections were significant at $P < 0.05$ unless stated otherwise.

6.3. Results and Discussion

6.3.1. Visual Observations

Due to problems with germination, especially of pea seeds, some pots had to be transplanted with young seedlings. For wheat only one pot, which received 20 kg P/ha, did not germinate well and this contained one plant instead of two.

For treatments without Zn, pea plants receiving 20 and 40 kg P/ha grew better than those receiving 0 and 10 kg P/ha. When Zn was applied with P, those receiving 10 kg P/ha grew best; those receiving the 0, 20 and 40 kg P/ha of P without Zn grew better than those receiving the same levels of P with Zn. The application of P at 10 kg/ha with Zn gave better growth than when it was applied without Zn; it gave similar growth to the application of P at 20 and 40 kg/ha without Zn.

For wheat, the plants which received P grew better than the controls. The application of P with Zn gave better growth than for the application of P alone at all levels; this is in marked contrast to the response shown by peas Zn. The response to P and Zn increased with the level of P applied.

6.3.2. Growth Measurements

Phosphorus effect

(a) Plant height, growth rate and node number:

Peas

Table 6.2 shows the responses of the two crops to P application in terms of plant height, plant growth rate and the concentrations of some nutrients other than P and Zn in which the responses were significant at $P < 0.05$ and those in which there was a trend ($P<0.1$) for a significant response. There were P application effects on the height of pea plants at week 5 and week 6 after germination and on plant growth rate between weeks 2 and 3, 3 and 4, 4 and 5 and 5 and 6. Application of P increased both plant height and growth rate above the control. However, there was no difference in the effect of P application on plant height among the 10, 20 and 40 kg P/ha rates. Application of P at 20 and 40 kg/ha increased pea plant growth rate compared to the zero application; only in weeks 4 - 5 was the 10 kg/ha growth rate different from zero. Application of P increased node number, but there was no difference between the three application rates (Fig. 6.1).

Table 6.2 . The effect of P application (kg/ha) on pea and wheat plant height (cm), plant growth rate (cm/week) and concentrations of K, Ca, Na, Fe, Mo, Al and B in dry shoot tissues.

	P0	P10	P20	P40	*	P0	P10	P20	P40	*
Pea						**Wheat**				
Plant height (cm)										
wk1	6.35a	7.14a	7.54a	9.23a		14.31a	15.93a	13.55a	14.18a	
wk2	9.14a	10.43a	10.44a	13.12a		16.15a	17.93a	15.01a	16.03a	
wk3	13.25a	15.25a	17.08a	17.80a		18.13a	21.76a	16.44a	19.46a	
wk4	15.93a	21.88a	25.25a	24.47a		20.76ab	24.58c	19.91a	23.76bc	*
wk5	16.80a	28.93b	36.90b	36.75b	**	25.23ab	27.54b	22.41a	25.88ab	_
wk6	25.10a	34.98ab	46.80b	45.91b	*	30.59ab	34.98b	28.03a	29.94ab	_
Plant Growth Rate (cm / week)										
wk1-2	2.79a	3.22a	3.43a	3.37a		1.84a	2.00a	2.52a	3.34a	
wk2-3	3.43a	4.83ab	6.64b	6.81b	_	2.37a	3.87a	2.07a	3.44a	
wk3-4	3.93a	6.63ab	8.18b	8.92b	*	2.61a	2.49a	3.14a	4.30a	
wk4-5	2.90a	7.05b	11.65c	9.99bc	***	2.93a	2.96a	2.50a	2.11a	
wk5-6	5.27a	6.05ab	9.90b	9.16bc	*	5.32ab	6.70b	4.32a	4.68a	_
% K	3.53a	3.59a	3.23b	3.49ab	_	3.36a	4.17b	3.71ab	4.18b	**
% S	0.24ab	0.25ab	0.23a	0.26b	_					
% Ca	3.08a	2.90ab	2.55bc	2.35c	**					
% Na	0.12a	0.12a	0.10b	0.10b	**					
Al (*ug/g*)	0.05a	0.04b	0.04b	0.04b	**					
Fe (*ug/g*)	104.53a	68.39b	96.85ab	99.73ac	_	88.25a	88.94a	92.51a	125.36b	_
B (*ug/g*)						33.43a	30.03b	29.10b	29.55b	*
Mo (*ug/g*)	6.14a	6.01a	7.34a	7.89b	_	2.64a	3.15ab	3.19ab	3.58b	*

Within times treatments followed by the same letter are not different at $P < 0.05$, (Duncan's Multiple Range Test). * is the level of significance of F test: – for $P < 0.1$ (non-significant); * for $P < 0.05$;

** for $P < 0.01$; and *** for $P < 0.001$.

Wheat

As for peas, P application affected wheat plant height late in the growth cycle, that is, during the 4th week after germination (Table 6.2): the overall response was variable between P rates and less than for peas. However, there was no significant response to P application in growth rate of wheat plants as occurred in peas, except for a trend for a significant effect at weeks 5-6. P application increased the number of tillers, but again there was no difference between P rates.

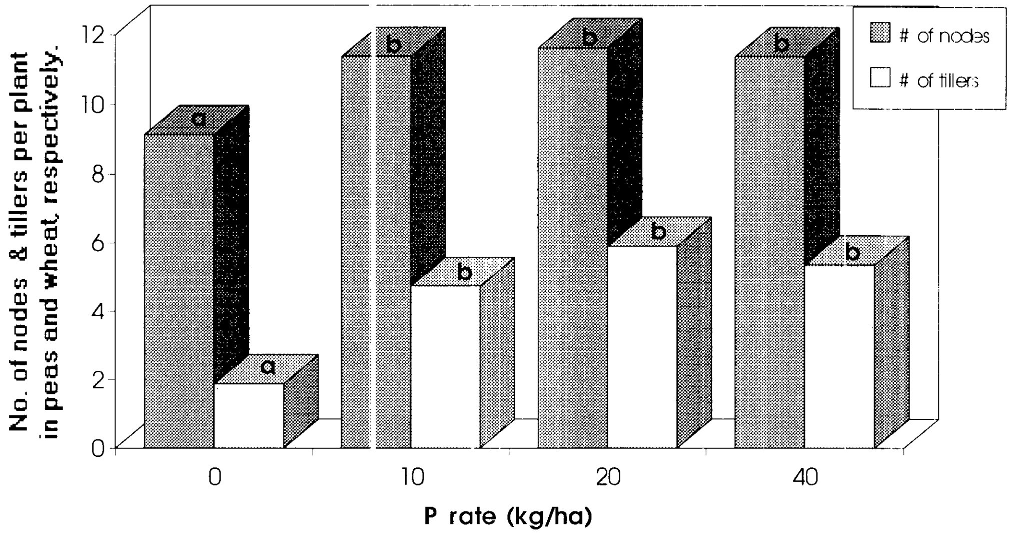


Fig. 6.1. The effect of P application on node number in peas and number of tillers in wheat. Within '# of nodes' and '# of tillers' histograms with same letter are not different ($P \leq 0.05$), Duncans Multiple Range Test.

(b) Dry matter yield:

Peas

P application above 10 kg/ha increased shoot dry matter of peas (Fig. 6.2a). The rates of 20 and 40 kg/ha were not different in their effect on shoot dry weight. For root dry weight, application of P at 10 kg/ha had a positive effect over the control; the higher rates (20 and 40 kg/ha) did not cause further increases in root dry weight above the 10 kg/ha rate (Fig. 6.2b).

Wheat

Application of P at 10 kg/ha increased shoot and root DM compared to zero P (Figs. 6.2a and b). However, there was no difference in response in these parameters to higher rates of P application.

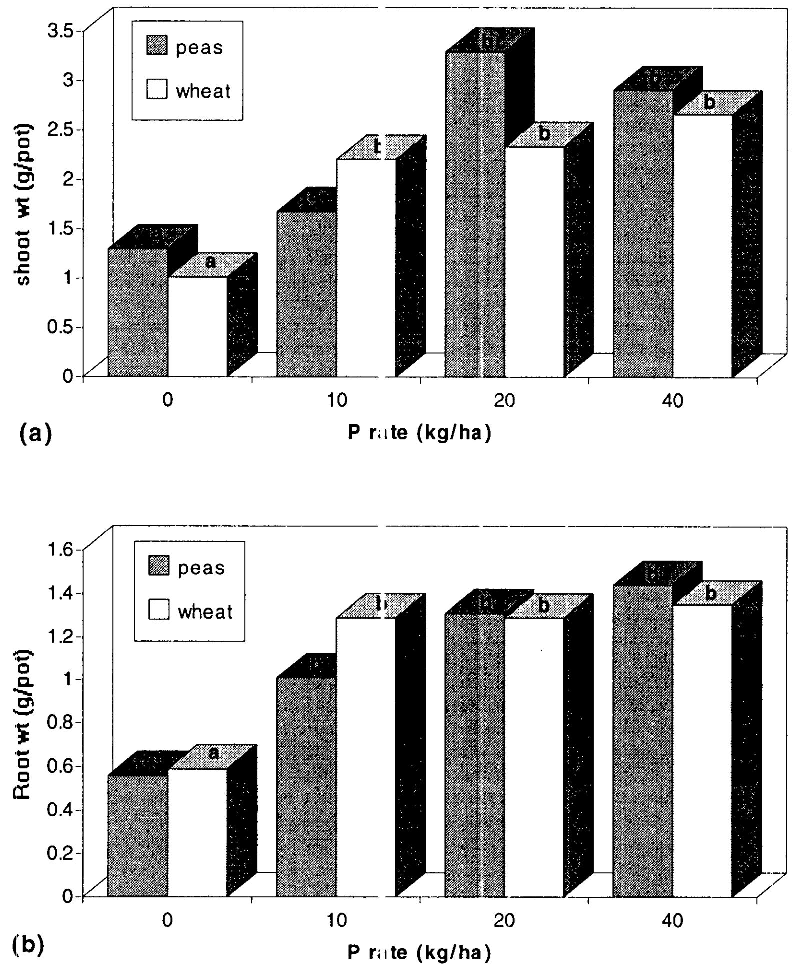


Fig. 6.2. The effect of P application on (a) shoot and (b) root dry matter on peas and wheat. Within species histogram with same letter are not different ($P \leq 0.05$), Duncan's Multiple Range Test.

(c) P and Zn in the plant tissue:

Peas

P application increased both P uptake and concentration (Figs. 6.3a and b). P uptake was increased by the application rates of P above 10 kg/ha; there was no significant difference between the effects of 20 and 40 kg/ha levels of P. However, the P concentration at 40 kg P/ha was greater than for 20 kg P/ha. There was no response in Zn concentration of pea shoots to P application (data not presented). However, the application of 40 kg P/ha increased Zn uptake compared to the other treatments (Fig. 6.4).

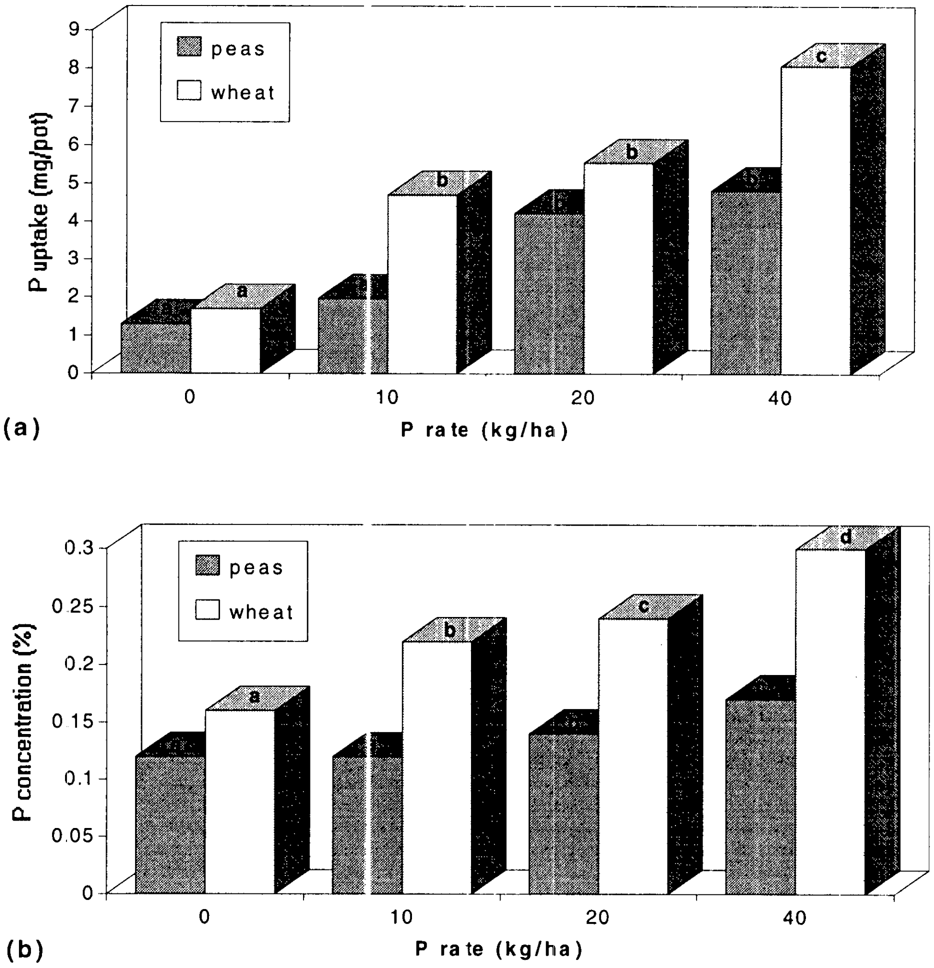


Fig. 6.3. The effect of P application on (a) P uptake and (b) P concentration in the tops of peas and wheat. Within species histogram with same letter are not different ($P \leq 0.05$), Duncan's Multiple Range Test

Wheat

The uptake of P and its concentration in dry shoot material increased with an increase in the rate of P (Figs. 6.3 a and b). There was a progressive increase in P concentration from 0 to 40 kg/ha application rates. The application of P did not affect either the concentration or the content of Zn in wheat (Fig. 6.4).

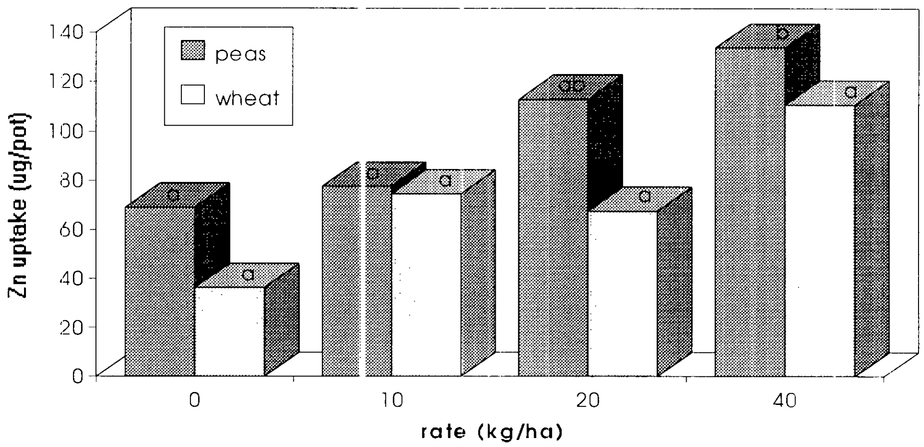


Fig. 6.4. The effect of P application on Zn uptake by peas and wheat. Within species histogram with same letter are not different ($P \leq 0.05$), Duncan's Multiple Range Test.

(d) Other nutrients:

Peas

There was a trend for significant effects ($P < 0.1$) of P application on K, S, Fe and Mo concentrations in shoot dry matter in peas (Table 6.2). The concentrations of K and Fe tended to be depressed by the application of P; those of Ca and Na and Al were strongly depressed, whereas those of S and Mo were slightly increased by P application (Table 6.2).

Wheat

The application of P increased the concentrations of K, Fe and Mo and decreased that of B in the shoot tissue of wheat plants (Table 6.2). There was no effect on the other nutrient conditions.

Zinc effect

(a). Plant growth:

Peas

There was no effect of Zn application on plant height, plant growth rate and on dry weight of root or shoot (data not presented). Nevertheless it greatly increased the number of nodes of pea plants (Fig. 6.5).

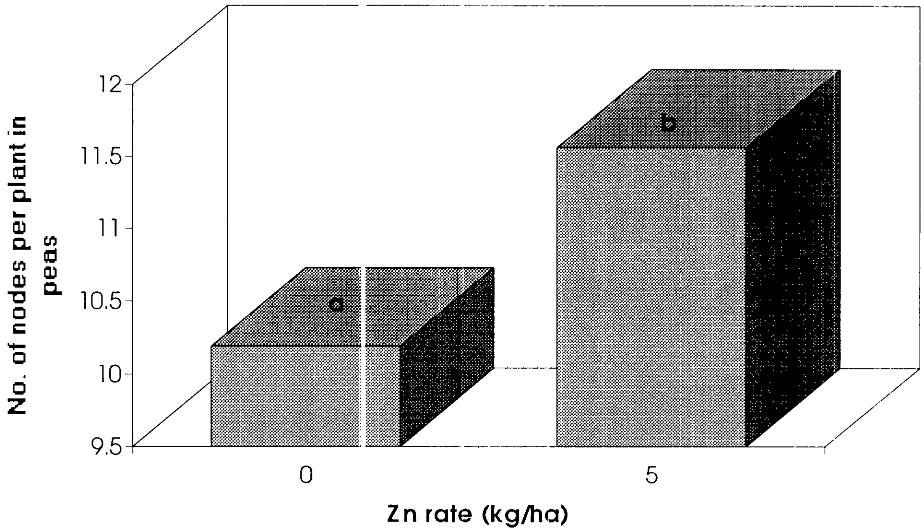


Fig. 6.5. The effect of Zn application on node number of peas. Histograms with same letter are not different ($P \leq 0.05$), Duncan's Multiple Range Test.

Wheat

As for peas, there was no response to the application of Zn by wheat in terms of plant height, growth rate and dry weight of root and shoot materials (data not presented). The number of tillers was also not affected by the application of Zn.

(b) Nutrient concentrations and uptake:

Peas

There were strong responses in Zn concentration and content and the concentration of Fe by peas. The application of Zn at 5 kg/ha doubled the concentration of Zn relative to the control (Fig. 6.6); the concentration of Fe was decreased (Table 6.3). There was a trend ($P < 0.1$) for Zn to decrease concentrations of K, Ca, Na and Al in the pea plant tissue (Table 6.3). No significant effect of Zn application was found on P concentration and content in dry shoot of peas.

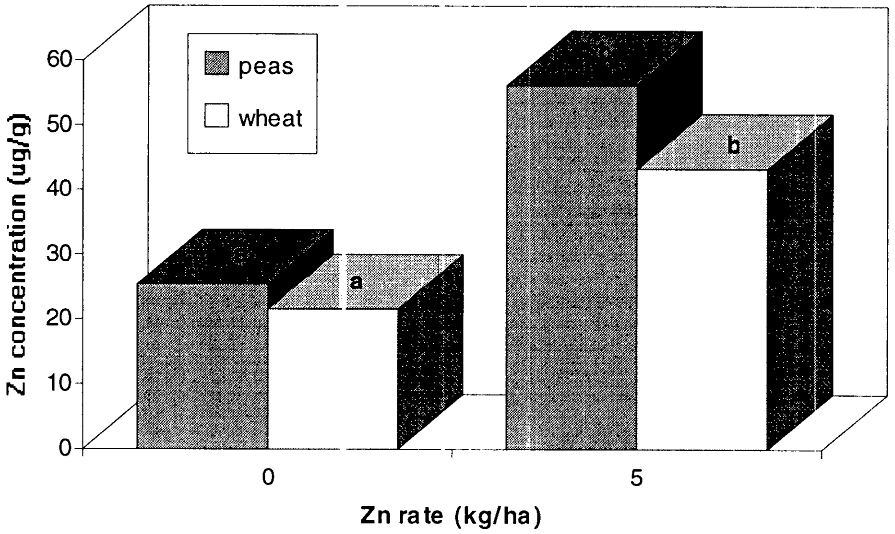


Fig. 6.6. The effect of Zn application on Zn concentration in the tops of peas and wheat. Within species histogram with the same letter are not different (P≤0.05), Duncan's Multiple Range Test.

Table 6.3. The effect of Zn application on pea and wheat plant concentrations of P, Ca, Mg, Na, Mn and Fe in dry shoot tissues.

	Zn0	Zn5	*	Zn0	Zn5	*
	Pea			**Wheat**		
% P				0.24a	0.22a	–
% K	3.55a	3.37a	–			
% Ca	2.85a	2.59a	–	0.55b	0.48a	*
% Mg				0.21b	0.19a	**
% Na	0.11a	0.10a	–	0.07b	0.065a	*
Mn(*ug*/g)	71.71a	72.11a		67.59b	52.42a	***
Fe(*ug*/g)	105.71b	79.04a	*	112.86b	84.67a	*
Al(*ug*/g)	0.06a	0.04a	–			

Treatments followed by the same letter are not different at P < 0.05, Duncan's Multiple Range Test. * is the level of significance of F test: – for P < 0.1 (non-significant); * for P , 0.05; ** for P < 0.01; and *** for P < 0.001. Only parameters significantly affected (P<0.1) are listed.

Wheat

The application of Zn increased the concentration of Zn (Fig. 6.6) and decreased the concentrations of Ca, Mg, Na, Mn and Fe in wheat plant tissue (Table 6.3). There was a trend for Zn to decrease P concentration in the dry shoot tissue (Table 6.3).

Phosphorus and zinc interaction

(a) Plant Growth:

Peas

Generally, the P-Zn interaction effects were smaller and variable compared to the main P and Zn effects. There was a trend for a significant P-Zn interaction on plant height in peas at the first week after germination, a significant interaction in the second week and another trend for a significant interaction in the third week after germination (Table 6.4). There was a significant P-Zn interaction on the growth rate of pea plants only between the first and second weeks after germination (Table 6.4). Pea plants receiving large amounts of P with Zn showed a taller trend than the other treatments. The application of P at 20 and 40 kg/ha without Zn increased root DW over the lower rates whereas when P was applied together with Zn even the lower level of P (10 kg/ha) caused a significant increase in root DW over the control.

Wheat

There was a significant P-Zn interaction on growth rate of wheat plants between the third and fourth weeks and the fifth and sixth weeks (Table 6.4). Wheat plants receiving 40 kg P/ha with Zn had higher growth rates than plants in others treatments during weeks 3-4; the reverse occurred during weeks 5-6. Plant height root and shoot dry matter and the number of tillers were not affected by the P-Zn interaction (data not presented). However, there was a trend for the root to shoot ratio to decrease when P was applied at 40 kg/ha with Zn compared to other treatments (Table 6.4).

(b) Plant Tissue Nutrients:

Peas

There was a strong interaction effect on the concentrations of K, Fe and Cu in shoot dry matter, and a trend for this interaction to affect Al concentration (Table 6.4). Application of P at 20 and 40 kg/ha without Zn increased Fe concentration compared with 10 and zero P levels, but when P was applied with Zn it decreased the concentration of Fe. There was no P and Zn interaction effect on the concentrations of P and Zn or on P content of shoot dry matter of peas (data not presented).

Table 6.4. The P and Zn interaction effect on pea and wheat plant height(cm), plant growth rate (cm/week), root DW, root : shoot ratio and concentrations of P, K, Mn, Fe, Cu, Zn and Al in shoot tissues.

	P0Zn0	P10Zn0	P20Zn0	P40Zn0	P0Zn5	P10Zn5	P20Zn5	P40Zn5	P x Zn
Wheat									
Plant Growth Rate (cm / week)									
wk1-2	1.95a	1.85a	1.99a	3.28a	1.73a	2.15a	3.05a	3.56a	
wk2-3	2.79a	4.86a	0.94a	3.90a	1.95a	2.89a	3.20a	2.98a	
wk3-4	2.78a	2.78a	3.93ab	2.13a	2.45a	2.21a	2.35a	6.48b	*
wk4-5	3.45a	2.13a	2.85a	1.85a	2.41a	3.80a	2.15a	2.38a	
wk5-6	5.08ab	5.40ab	5.36ab	6.11bc	5.57ab	8.00c	3.28a	3.25a	*
root:shoot	0.53ab	0.60ab	0.48ab	0.58ab	0.63b	0.61b	0.64b	0.44a	_
% P	0.16a	0.22bc	0.24bc	0.33e	0.17a	0.21b	0.24c	0.28d	_
Zn (*ug*/g)	22.25ab	15.98a	28.18ab	20.04ab	54.65c	53.00c	27.35ab	38.53bc	_
% Mg	0.20ab	0.22b	0.20ab	0.22b	0.20ab	0.19a	0.20ab	0.18a	_
Mn(*ug*/g)	58.23bc	64.65c	66.10c	81.39d	55. 80b	54.20b	62.00c	37.68a	***
Pea									
Plant height (cm)									
wk1	5.85ab	5.14ab	8.57bc	7.63ab	6.85ab	9.15bc	6.50ab	10.83c	_
wk2	9.38ab	6.28a	11.43abc	10.23abc	8.90ab	14.58ab	9.45ab	16.01c	*
wk3	15.42abc	9.43a	18.63abc	15.57abc	11.08ab	21.08c	15.53abc	20.03bc	_
wk4	17.80a	14.08a	25.70a	23.75a	14.05a	29.68a	24.80a	25.18a	
wk5	16.65a	19.18a	35.58a	33.30a	16.95a	38.68a	38.23a	40.20a	
wk6	27.53a	24.85a	45.85a	41.43a	22.68a	45.10a	47.75a	50.40a	
Growth rate (cm/wk)									
wk1-2	3.53abc	1.01a	3.91abc	2.60abc	2.05ab	5.43c	2.95abc	5.14bc	*
wk2-3	4.68a	3.15a	7.20a	5.35a	2.18a	6.50a	6.08a	8.28a	
wk3-4	4.88a	4.65a	7.08a	8.18a	2.98a	8.60a	9.28a	9.66a	
wk4-5	2.91a	5.10a	9.88a	9.55a	2.90a	9.00a	13.43a	10.43a	
wk5-6	4.82a	5.68a	10.28a	8.13a	5.73a	6.43a	9.53a	10.20a	
roots(g)	0.62ab	0.53a	1.44c	1.29c	0.49a	1.49c	1.18bc	1.60c	*
root:shoot	0.56ab	0.47ab	0.52ab	0.56ab	0.44ab	0.70b	0.39a	0.53ab	_
% K	3.98c	3.77bc	3.11a	3.36ab	3.07a	3.42ab	3.36ab	3.62bc	***
Fe(*ug*/g)	73.30a	73.07a	128.95b	147.50b	135.75b	63.70a	64.75a	51.95a	***
Cu(*ug*/g)	18.95b	8.35a	2.15a	5.30a	0.00a	5.48a	8.00a	6.18a	**
Al(*ug*/g)	0.06b	0.05ab	0.04a	0.04a	0.05ab	0.04a	0.04a	0.04a	_

Treatments followed by the same letter are not different at $P < 0.05$, Duncan's Multiple Range Test. * is the level of significance of F test: -- for $P < 0.1$ (non-significant); * for P , 0.05; ** for $P < 0.01$; and *** for $P < 0.001$. Only parameters which contained some interactions (at least at $P<0.05$) are listed.

Wheat

There was a strong P-Zn interaction effect on the concentration of Mn, the concentration at P at 40 and Zn at 0 kg/ha being over twice that when Zinc was applied at this P rate. There was also a suggestion ($P < 0.1$) of a P-Zn interaction effect on the concentrations of P and Zn in wheat shoot dry matter (Table 6.4).

6.4. Discussion

When the responses of peas and wheat to P and Zn applications are compared it happens that both crops had similar responses to P in terms of root DW and number of nodes for peas and tillers for wheat. However, the responses in shoot DW, P uptake and concentration were significantly different between the two crops: wheat responded to the application of 10 kg P/ha whereas peas only responded to the application of 20 kg P/ha. P concentration in wheat increased progressively from P0 to P40, whereas that for peas only increased above P20. P uptake showed similar differences between the species.

The results obtained in the present study agree with those of Fageria and Baligar (1989) who found that legumes have a larger P requirement for maximum growth than cereals. Thus the difference in response to P application, especially at 10 kg P/ha, between wheat and peas might have been due to the different P requirements of the two crops (Fageria and Baligar, 1989) or to a difference in root absorbing power of the two crops. Wheat, as a monocotyledonous plant, has a better developed root system, (especially root length and rooting density) than dicotyledonous peas and hence has a greater ability to exploit the soil for P than peas (Costin and Williams, 1983; Hamblin and Hamblin, 1985; Gregory, 1988). Therefore, the wheat plants had a greater ability than peas to absorb P and to respond to the low levels of P application.

The P concentrations in both crops were lower than the adequate value for peas and the critical value for wheat (Fageria, 1977; Elliott, 1984 cited by Reuter and Robinson, 1986). Although the published data for peas are incomplete and few are available for Australian conditions, the greater difference between concentrations measured for the P40 treatment and the critical values for pea (0.17 % P compared with 0.4 % for deficient conditions) than for wheat (0.30 % P compared with 0.35 % critical value) suggests that peas suffered from a greater deficiency.

P application increased Zn uptake by peas but not by wheat. An increase in Zn uptake by plants with the application of P is widely recognised (Millikan, 1940; Olsen, 1972; Verma and Minhas, 1987). The difference in response to P application between peas and wheat suggests greater significance of Zn in peas than in wheat.

The application of Zn had no effect on plant height, plant growth rate and dry weight of root and shoot in both crops. It increased node number in peas but did not increase the number of tillers in wheat.

The responses in Zn concentrations to Zn application were essentially the same for both crops. However, the concentration was slightly higher in peas than in wheat. Again, Zn application affected Zn content in peas but not in wheat; Zn uptake by peas increased three fold in response to Zn application.

A P-Zn interaction was found for only some of the growth parameters, such as plant height in peas and growth rate in both crops. The effects of P-Zn interaction were small and variable compared to the main P and Zn effects. No interaction was observed on root and shoot dry weight in either crop, or on node number in peas and number of tillers and root dry weight in wheat. The application of P with Zn increased root DW over the applications of P without Zn and of Zn without P. Without Zn, 20 kg P/ha was needed to produce the equivalent root weight produced by 10 kg P/ha with Zn. Since there was no effect on shoot dry matter, particularly in peas, the effect on root : shoot ratio was only marginal.

There was a suggestion of a P-Zn interaction in P and Zn concentrations in wheat but not in peas. P concentration increased with increased application of P (except with P20Zn0) whether with or without Zn, but was higher when P was applied at 40 kg/ha without Zn than with Zn. This is in agreement with previous findings that under low Zn fertility conditions P was absorbed by the roots and transported to the shoots in large quantities resulting in high P contents (Wagar *et al.*, 1986; Mengel and Kirkby, 1987; Verma and Minhas, 1987; Webb and Loneragan, 1989 and 1990). The high P uptake found when a P-Zn interaction occurred was in most cases correlated with poor shoot growth, high root : shoot ratio and the occurrence of necrotic symptoms (Section 3.3). In the present experiment, there was no significant correlation between P concentration and either shoot DW or root : shoot ratio.

When Zn was applied with P, Zn concentration was higher when P was applied at 0 and 10 kg/ha than at 20 and 40 kg/ha. This was likely to be a dilution effect described by Boawn *et al.* (1954), Christensen and Jackson (1981), Tisdale *et al.* (1985), Summer and Farina (1986) and Mengel and Kirkby (1987). The lack of a significant interaction for P and Zn concentration in peas, as occurred in wheat, may have been due to insufficient P having been applied.

In the light of the relativly insignificant effects of the P/Zn interactions further experimental work will concentrate on the determination of optimum P rates for peas.

CHAPTER SEVEN

EXPERIMENT II

PRELIMINARY EXPERIMENT TO IDENTIFY A SOIL RESPONSIVE TO PHOSPHORUS APPLICATION FOR PEA GROWTH

7.1. Introduction

The study of soil fertility in the restricted sense of the supply of nutrients to plants can be classified into two main practical aspects: (i) the identification of soil nutrients limiting plant growth and (ii) determination of quantities of fertilisers required to eliminate the nutrient deficiencies (Janssen, 1974). Research methods for investigating soil fertility include plant experiments (field and pot trials), plant and soil chemical analysis and microbiological laboratory techniques (Janssen, 1974; Loneragan, 1971 and 1985; Mengel and Kirkby, 1987).

Chemical analysis is quick, accurate and relatively cheap. However, its usefulness depends on adequate knowledge of sampling procedures (Jones *et al.*, 1971) and a knowledge of the relationships between the chemical data and the response of different crops to fertilisers (Loneragan, 1985). Only when such information is available can chemical analysis be used with confidence.

The use of field and pot trials has the merit of using the actual plant to assess fertility status and thus avoid problems with the interpretation of analytical data.

Field trials mimic agricultural practices. They suffer from the disadvantages of the high costs of labour, time, the availability of land and variability in the results which may be caused by environmental factors other than those being investigated. The use of pot trials under controlled glasshouse conditions, generally reduces this variability. Statistical techniques, such as covariate and nearest neighbour analysis, have also been developed to deal with the variability encountered in field trials.

Field and pot trials may show no response to applied fertiliser where the experimental soil is able to adequately supply nutrients to the plants being grown. The waste of resources including a large experiment with a non-responsive soil can be avoided by:

(i) determining the nutrient status of the soil by chemical analysis;

(ii) running a preliminary trial with a limited number of treatments to test the response of the crop to nutrient application.

The objective of the experiment in this chapter was to determine the suitability of a soil to study the P nutrition of field peas. The two qualities of interest were: (i) that the soil should represent Australian soils used for growing peas, and (ii) that such a soil should be responsive to P application.

7.2. Materials and Methods

7.2.1. Soil Chemical Analysis and Soil Choice

The topsoils from four locations were selected:

(i) A sandy loam from a solodic soil, "Trevenna', Armidale,

(ii) A medium clay from a cracking grey clay, 'Auscott', Narrabri,

(iii) A loam from a podzolic soil from the Grafton Road, Armidale,

(vi) A loam from a red-brown earth, Douglas McMaster Field Station, Warialda.

Available P was determined using Colwell's (1965) method of extraction for 16 hours with 0.5M sodium bicarbonate.

The results were as follows:

Soils	**Available P (*u*g/g soil)**
solodic	30.6
grey clay	28.0
podzolic	15.6
red brown earth	13. 8

The grey clay was collected from the same property as the soil type used in experiment I, but due to possible differences in fertiliser history and parent material its available P status (and that of the solodic soil) was much higher. Of the two remaining soils, the red-brown earth from Warialda was selected for the experiment because it was possible to conduct a field experiment at this site in conjunction with the glasshouse study.

7.2.2. Soil Response to P Application

Experiment

The experiment was conducted in the temperate glasshouse (mean daily temperature 25 ^{O}C and mean night temperature 12 ^{O}C) to determine the response of peas grown on the red brown earth to P application. It consisted of four treatments in factorial combination: two levels of P (0 and 60 kg P/ha) and two varieties of field peas (Dundale and Bluey); each treatment was replicated twice. Since the P concentrations in the dry matter of peas measured in experiment I was below the critical levels published in the literature, the rate of P application was increased to 60 kg/ha.

Dundale is an early maturing, high yielding variety from the Dun type group, grown most widely in South Australia; Bluey is a new variety from the blue boiler type, released in 1993 under PVR from Victoria to satisfy the specialist market for premium quality peas for human consumption (Lamb and Poddar, 1994).

The top 10 cm of a red brown earth soil was collected at the Field Station, Warialda. Its chemical composition is shown in Appendix B. The soil was gently broken by hand to less than 5 mm, and 1600 g samples were weighed into 15 cm diameter pots lined with plastic bags. The pots were inoculated with the Group E *Rhizobium* to enhance nodulation and nitrogen fixation. Phosphorus was applied as mono-ammonium phosphate; nitrogen rates were balanced with urea to maintain the same level of applied nitrogen (40 kg N/ha) for each pot. To each pot basal nutrients solutions were added and mixed with the soil at the rates shown in Table 6.1, Chapter 6.

Half of the pots were planted with Dundale seeds and another half with Bluey seeds to a depth of 5 cm. Five seeds were initially sown in each pot; these were thinned to two plants per pot after seedling emergence. The pots were watered to field capacity (w/w) and were maintained at between 100 and 75 % field capacity during the course of the experiment by watering to weight when the pots' water content decreased to 75%.

Visual observations were made of plant growth throughout the experiment; the plants were grown until fully mature. Grain was then harvested and weighed after drying at 80 ^{O}C for 24 hours.

Chemical analysis of seed material and data analysis

After weighing, the dry grain was finely ground for analysis of P, as described for Experiment I. Data on grain yield, P concentration and content were analysed by analysis of variance using the NEVA Program.

7.3. Results

A marked response to P application was observed in plant height and colour of both varieties during vegetative growth. Bluey grew larger than Dundale; the latter showed P deficiency symptoms (thin and stunted bottom leaves) when no P fertiliser was applied. Flowering of both varieties was delayed when no P was applied, although Bluey flowered a week earlier than Dundale.

There was no significant difference in grain yield between the two varieties. The mean grain weight for the two varieties at 0 kg P/ha was 2.77 g with 3.93 g at 60 kg P/ha; this difference was significant at P = 0.07. With greater replication it is likely that the significance of the difference would be increased to below P = 0.05. A large increase in the P concentration of grain was obtained from 60 kg P/ha (Fig. 7.1).

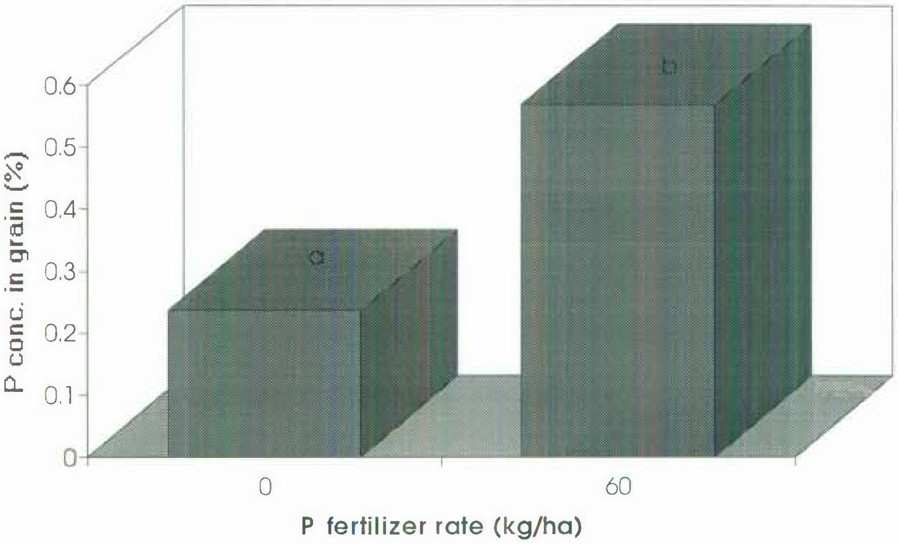


Fig. 7.1. The effect of P fertiliser on P concentration in grain.

7.4. Discussion and Conclusions

With just two replicates, a large increase in P concentration and content of the peas was obtained on adding 60 kg P/ha. Although the increase in grain weight was only significant at P = 0.07, greater replication would most likely have shown a significant effect. It was concluded that the red brown earth was responsive to P application and hence was suitable for the proposed experiment.

The lack of a variety effect on the response of field peas to P application indicates that the two varieties responded similarly to the application of P. Unfortunately, there is no published work on phosphorus nutrition of these two varieties at present with which to compare these results. In a greenhouse experiment Dravid (1990) found that the varieties Pusa-10 and KPSD-5 differed in their response to P application; it is possible that with greater replication of treatments and with more P application rates differences between the two varieties may have been found. However, the primary purpose of the experiment was to determine whether the red-brown earth was responsive to P application and was thus suitable for the main glasshouse and field experiments. The data indicated that at an application of 60 kg P/ha gave an increase in both yield and P uptake and that the soil was suitable for the remaining experiments.

CHAPTER EIGHT

EXPERIMENT III

A GLASSHOUSE EXPERIMENT TO DETERMINE THE OPTIMUM RATE OF P APPLICATION AND CRITICAL TISSUE CONCENTRATION OF P FOR FIELD PEAS (*Pisum sativum* L., var. Bluey)

8.1. Introduction

Peas are adapted to a wide range of soils but best yields can be expected from heavy textured soils, soils not susceptible to surface sealing or waterlogging and from the non-saline soils (Lovett and Lazenby, 1979; Munroe, 1989; Lamb and Poddar, 1992). They are best suited to areas which receive 375 mm of rainfall or more per year. Though peas have some tolerance to drought they require a good supply of water during flowering and pod filling for high yields (Yadav *et al.*, 1990; Andersen and Aremu, 1991). They are very sensitive to frost and high temperature especially during flowering and pod filling (Lovett and Lazenby, 1979; Munroe, 1989; Mahoney, 1991; Lamb and Poddar, 1992). High yields of peas, as well as of other legume crops, can be obtained by choosing the sowing time such that they are not planted too early so as to avoid late frost, but also they are allowed to finish flowering before the week in which the average daily temperature reaches 20°C (Munroe, 1989). Yield and seed quality are adversely reduced by hail after flowering and by the heavy rains on the ripe crop (Munroe, 1989).

Like all the grain legumes, peas require a large external supply of P for satisfactory growth and yield production (Nourse, 1977). However, there is limited information on the optimum P application rates for different soils commonly used for field pea cropping, particularly in Australia.

Munroe (1989) recommended that the P application rate recommended for wheat can also be used for peas, while Lamb and Poddar (1992 and 1994) recommended an application rate of 15 to 20 kg P/ha as a dressing for expected yields of 2.5 to 3 tons/ha. It is probable that peas, like other grain legumes, remove P in large amounts but little information is available on this. Reuter and Robinson (1986) have presented data for peas on critical tissue concentration of nutrients obtained under Canadian, Indian and USA conditions. The very limited information on P nutrition in peas under Australian conditions at present suggests that the critical range of P in the youngest open leaf blade at pre-flowering stage is between 0.25 and 0.3 % (Lamb and Poddar, 1994).

The objectives of the experiment reported in this chapter were (i) to investigate the optimum rate of P fertiliser to obtain 90 % maximum yield production of field peas (*P. sativum* L. var. Bluey) under glasshouse conditions using the red brown earth from Warialda; (ii) to determine the critical concentrations of P in different plant parts at different growth stages for obtaining 90 % maximum yield; (iii) to identify which plant parts at different stages of growth give the best indication of P nutrient status; (vi) to determine P uptake by peas and hence its rate of depletion of soil reserves; and (v) to assess the effect of P application on nitrogen content of pea grain, and hence on crop quality.

8.2. Materials and Methods

8.2.1. Experimental Design

The experiment consisted of seven P fertiliser levels (0, 10, 20, 40, 80, 160 and 320 kg P/ha). Each fertiliser treatment was replicated four times. The experiment was arranged in a randomised block design in a temperate glasshouse.

8.2.2. Choice of Variety

The variety Bluey was selected for the experiment. Since there was no significant difference in the response to P application between the Bluey and Dundale varieties in Experiment II, Bluey was chosen as it is a new variety, released recently to satisfy the specialist market for premium quality blue boiler peas for human consumption (Lamb and Poddar, 1994). Bluey is adapted to medium to low rainfall areas with early to medium sowing dates and is an early to medium season maturing pea. The yields for Bluey are lower than for Dundale and other blue boiler pea varieties, hence market contracts will be required to grow it (Lamb and Poddar, 1994).

8.2.3. Soil Treatment and Sowing

The soil used was the Warialda red-brown earth soil chosen from Experiment II (for soil details, see Appendix B). The soil was weighed into 25 cm diameter pots to a weight of 11 kg; P was applied as mono-calcium phosphate. Basal treatments of 5 kg Zn/ha as $ZnSO_4.7H_2O$ and 15 kg S/ha as gypsum ($CaSO_4.2H_2O$) were applied; the fertilisers were applied on the surface of the soil and mixed to a depth of about 18 cm. The pots were inoculated with Group E *Rhizobium* to enhance nodulation and N fixation. Seeds were sown on 24th July, 1994 in a temperate glasshouse (daily temperature varied between 24 and 29 ^{o}C and night temperature between 12 and 18 ^{o}C) at the rate of 16 per pot, at a depth of 5 cm Pots were watered so that soil moisture content did not fall below 75 % field capacity during the course of the experiment. After seedling emergence pots were thinned to 9 plants per pot.

8 2.4. Sampling and Harvesting

The plants were sampled three times: (i) at 47 days after sowing (DAS), during vegetative growth; (ii) between 68 and 75 DAS, after the opening of the first flowers on individual plants; and (iii) between 92 and 98 DAS, after pod filling and before the first seeds dried. At each time three plant parts were sampled: (i) youngest leaves (YL), open compound leaves at the first node from the top; (ii) the open compound leaves at the third node from the top (TYL); and (iii) the remainder of the shoot, that is , the whole shoot minus YL and TYL. The weight of the YL, TYL and the remainder of the shoot were added together to give the total weight of the whole shoot (WP). At the final harvest, seeds and pods were also collected. At each time three plants were harvested from each pot. Plant material was dried in a force-draught oven at 80 ^{o}C for 24 hours before weighing. Dry weight of all plant samples, the number of pods per plant and of seeds per pod, and the weight of 100 seeds were obtained. Dry weights have been expressed as mean weights per plant for each pot.

8.2.5. Chemical Analysis of Plant Material

The plant samples were ground to pass through a 1 mm sieve. Sub-samples were taken for chemical analysis by the ICP method as described in Section 6. 2. 6. The seed samples from the final harvest were analysed for nitrogen by the Dumas-type continuous flow catalytic combustion method with the evolved gases analysed by mass spectrometry (Carlo Erba NA 1500 preparation system, coupled to an Europa Tracermass 9001). Nutrient contents of the whole plant were computed from the contents and the weights of the YL, TYL and the remainder of the whole shoot.

8.2.6. Data Analysis

The relationships following variables were analysed by regression analysis using the SuperAnova Program, a Macintosh compatible statistical package. In the regressions mean values of treatments have been used.

8.3. Results

8.3.1. Visual Observations

Seedling emergence was first observed at 10 DAS. Two days later, seedlings had emerged in all the pots except those which received 160 and 320 kg P/ha. Very poor seedling emergence in these pots started three weeks after sowing, with the pots fertilised with 160 kg P/ha exhibiting better emergence than those fertilised with 320 kg P/ha. Growth of the plants in the pots treated with 160 kg P/ha varied but, in general, was poor relative to the growth in other treatments apart from 320 kg P/ha. One of the replicates of the 160 kg P/ha treatment survived only up to the first harvest leaving only three replicates. The few plants emerging in pots receiving 320 kg P/ha showed leaf burn and died despite pots being adequately watered.

There was a clear difference between the control (0 kg P/ha) plants and the plants which received P; the former were thin and more yellow Flowering of all plants started during the 9th week after sowing.

8.3.2. Growth Measurements

Shoot dry matter and yield components

Significant correlations were found between P application rates and shoot dry matter at 47 and 92-98 DAS, number of seeds per pod, and weight of 100 seeds at 92-98 DAS (Fig 8.1). Dry matter and yield showed a quadratic relationship with P application rate. There was poor correlation between the P application rate and shoot dry matter at 68-75 DAS ($r^2 = 0.40$) and number of pods per plant at 92-98 DAS ($r^2 = 0.41$).

The quadratic relationships shown in Fig. 8.1 indicate that growth variables increase up to a certain rate of P application and thereafter decline. The regressions were used to estimate 90 % maximum yields and the significant rates of P application to achieve these yields (Table 8.1). These rates were considered to be optimum.

Table 8.1. The optimum application rate of fertiliser P to attain 90 % maximum vegetative and grain yields.

DAS	**Plant part**	**90 % max. yield (g/plant)**	**Optimum rate of P application (kg P/ha)**
47	shoot	0.75	56
68-75	shoot	2.70	57
92-98	shoot	4.26	91
92-98	pods	1.44	74
92-98	seeds	2.52	45

P concentration

Fig. 8. 2 shows that the concentration of P in plant tissues was strongly and positively correlated with the application rate of P. The relationships at 47 DAS are shown as fitted Mitscherlich curves in Fig. 8.2 a-c. Those at 68-75 and 92-98 DAS fitted linear graphs (Figs. 8.2 d and e), except for the plot of P concentration of pods at 92-98 DAS, which best fitted a Mitscherlich type curve (Fig. 8.2 f). P concentrations were always higher in the YL than in either the TYL or the WP.

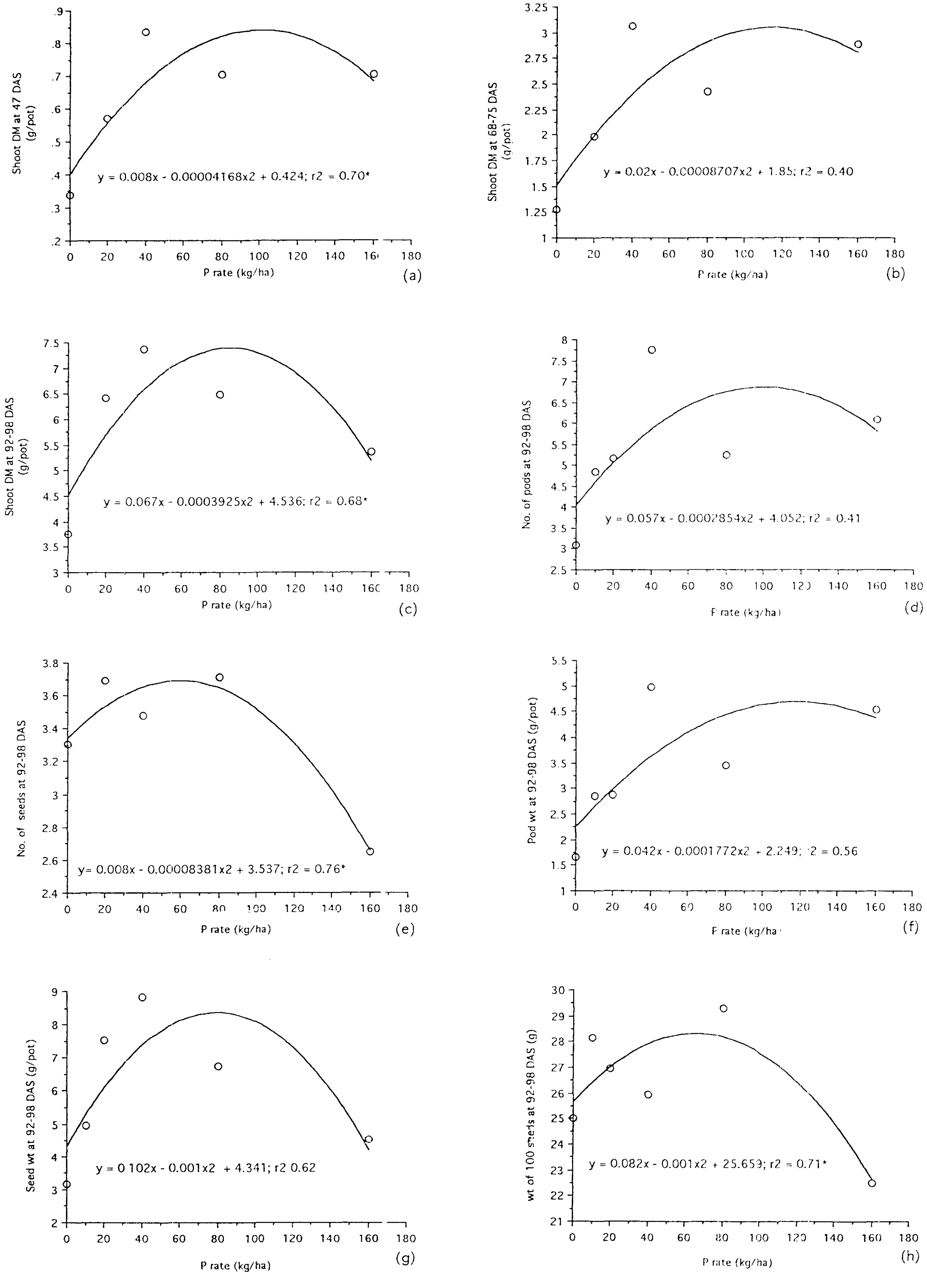


Fig. 8.1. The effect of P application on dry matter and grain yield at different growth stages.

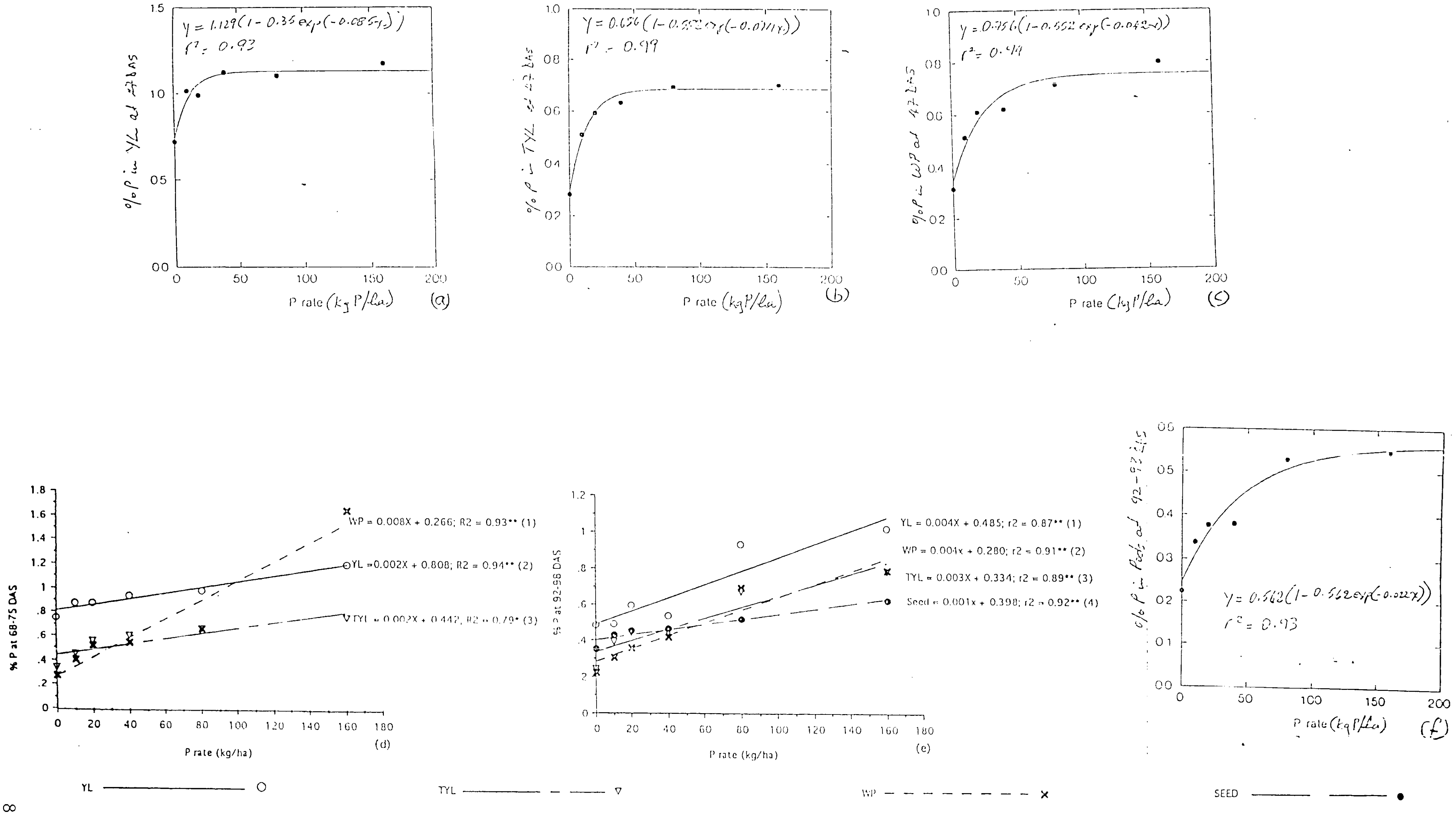


Fig. 8.2. The effect of P application on the concentration of P in various plant parts at different growth stages.

The concentration of P in the YT, TYL and WP decreased with time between the first and final harvests.

Critical P concentration at different growth stages

Tissue concentrations of P were plotted against the corresponding dry matter of YL, TYL and WP at the three different stages of growth, and dry matter of pods and seeds at the final harvest (Fig. 8.3). Six of the eleven plots showed quadratic relationships. Of the remaining five, the plots of P concentration against dry matter weight of YL at 47 and at 92-98 DAS and of TYL at 47 DAS gave a linear graph, (data not shown); while plots of P concentration against dry matter weight of the whole plant at 47 DAS against dry weight of pods at 92-98 DAS gave Mitscherlich type curves (Fig 8.3 a and b).

The quadratic curves (Fig. 8.3 c to j) showed four different response zones: (i) an ascending zone where the accumulation of dry matter increases with P concentration; (ii) a transitional zone where the rate of dry matter accumulation decreases as P concentration increases; (iii) an adequate zone where the dry matter production does not increase with P concentration; and (iv) a toxic zone where the level of P appears to becomes toxic and hence causes a decline in dry matter yield. The Mitscherlich curve lacks the last zone of the quadratic model (toxic zone), but otherwise the first three zones are similar.

With the exception of Fig. 8.3 a and d, all regressions failed to reach $P \leq 0.0a5$.

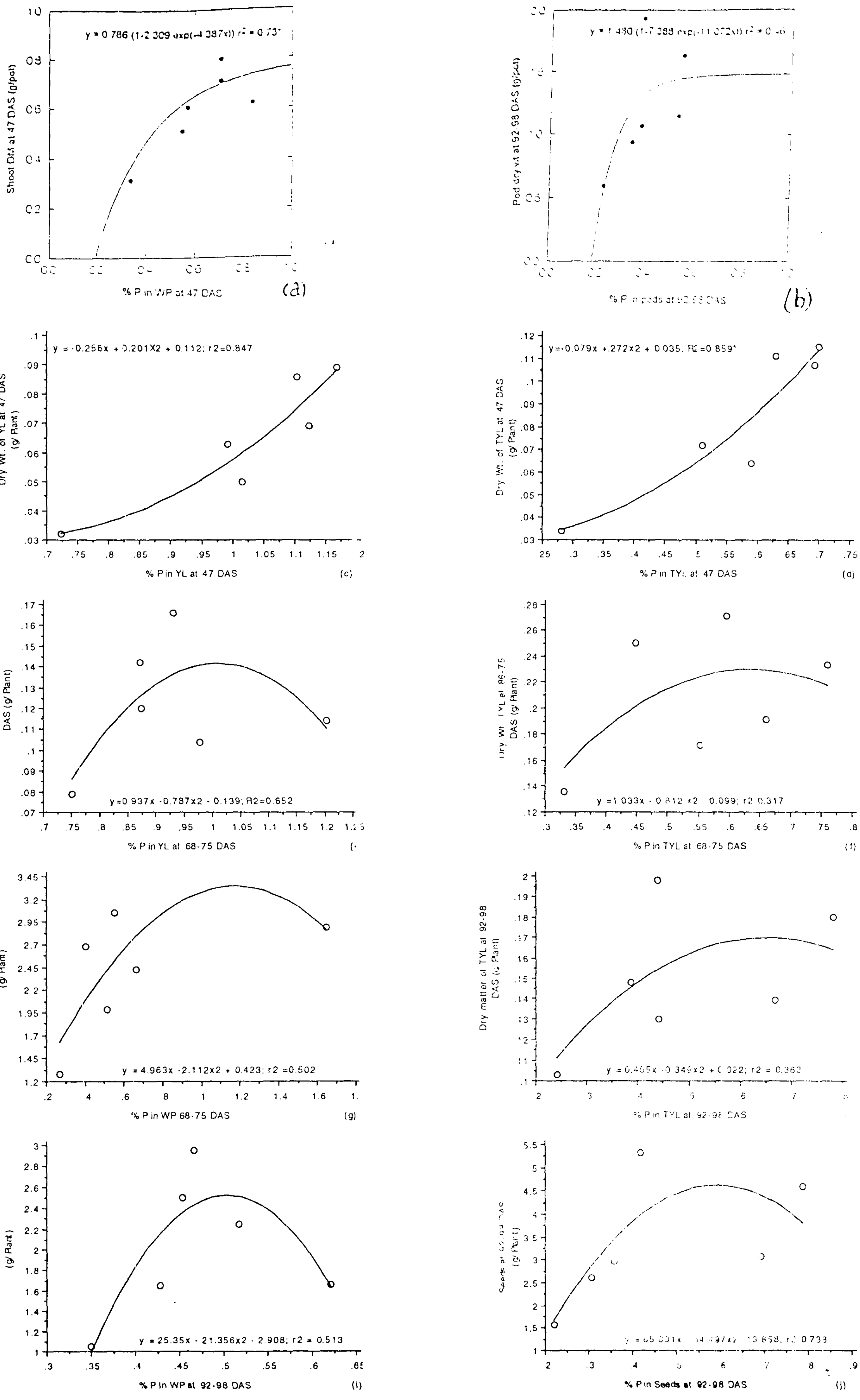


Fig. 8.3. The Mitscherlich (a and b) and quadratic (c - j) relationships between P concentration and plant dry weight at different growth stages.

P concentration and grain yield

The section, *Shoot dry matter and yield components,* was concerned with the relationship between the weight of plant parts and the corresponding P concentration at different stages of growth. Except where peas are grown as green manure crops, grain yield is the most important component of growth. To identify the optimum stage of growth and plant part for sampling, P concentrations should therefore be related to grain yield.

Fig. 8.4 shows the relationships between grain yield and P concentrations in YL, TYL and WP at the three harvesting times. At the first two harvests all relationships were quadratic but, unfortunately, were not significant at $P \leq 0.05$. The only significant relationship was for grain yield and %P in WP at 92-98 DAS. The critical P concentration at 90% maximum yield was 0.39% P.

P uptake

P uptake by the whole plant at the three harvest times are shown in Fig. 8.5. The P application rates at which the maximum P uptakes were obtained were 100 kg P/ha at 47 DAS and 68-75 DAS, and 160 kg P/ha at 92-98 DAS.

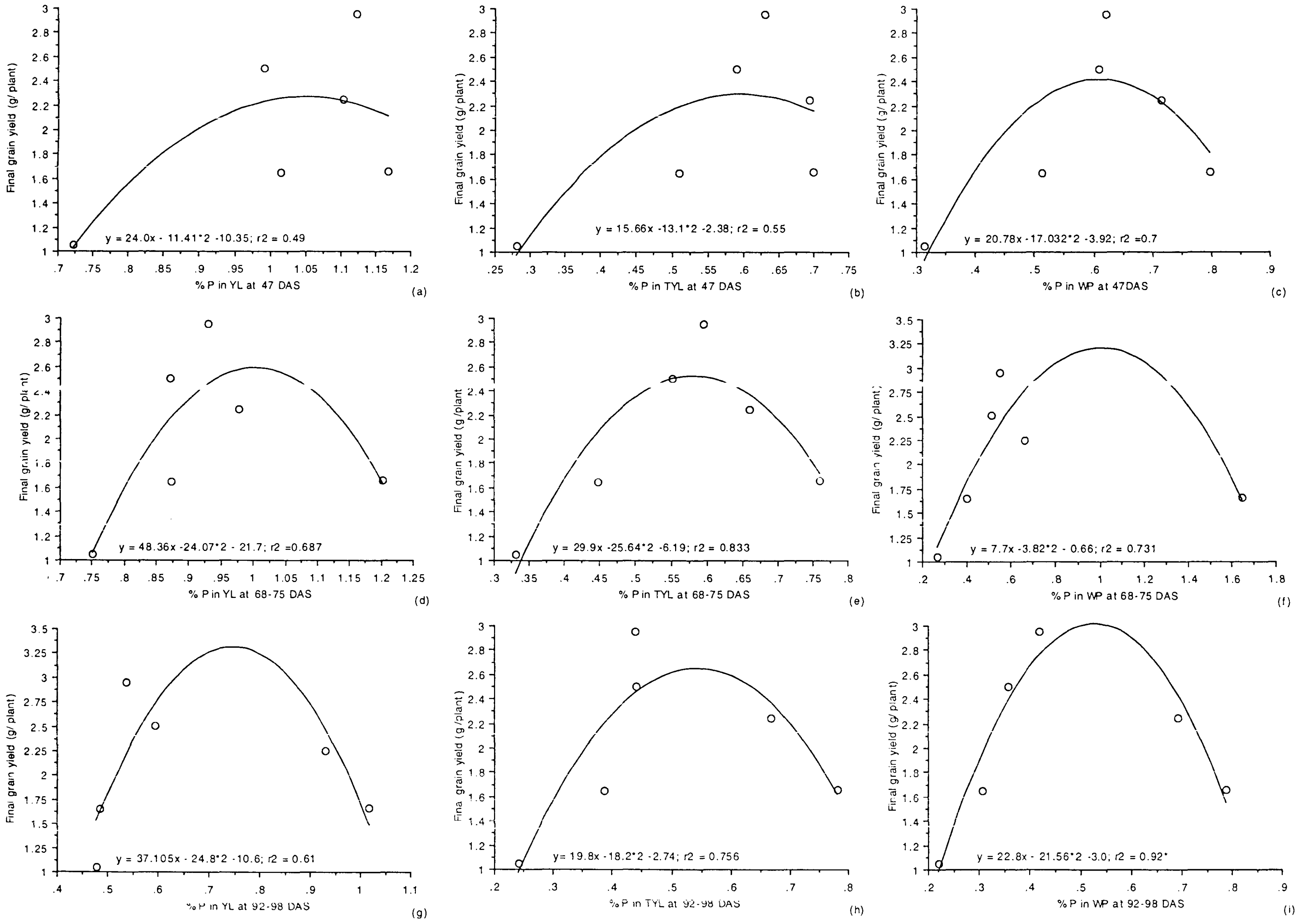


Fig. 8.4. The relationship between P concentration in different plant parts at different growth stages and the grain yield at final harvest.

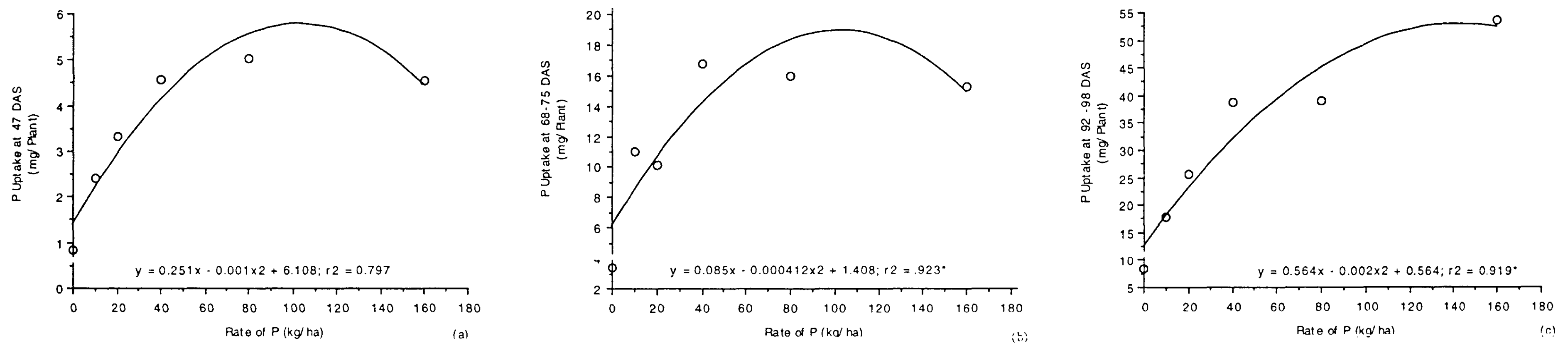


Fig. 8 5. The relationship between P application rate and P uptake by pea.

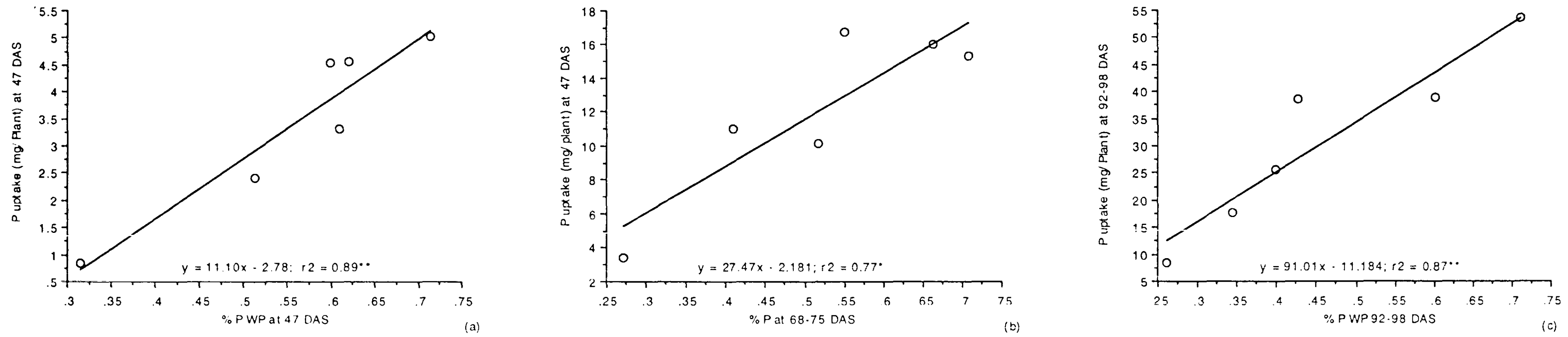


Fig. 8.6. The relationship between P concentration and P uptake by the whole plant

P application and seed nitrogen

The application of P increased the uptake of N by seed (Fig. 8.7). N uptake by seed was greatest at a P application rate of 72 - 78 kg P/ha The maximum N uptake was 270 mg N/pot, which was twice as much as the N uptake at 0 kg P/ha. The application of P at rates above 78 kg P/ha resulted in a decline in N uptake.

The concentration of N in seed varied between 3.0 and 4.2 % N. There was no correlation between N concentration and P application.

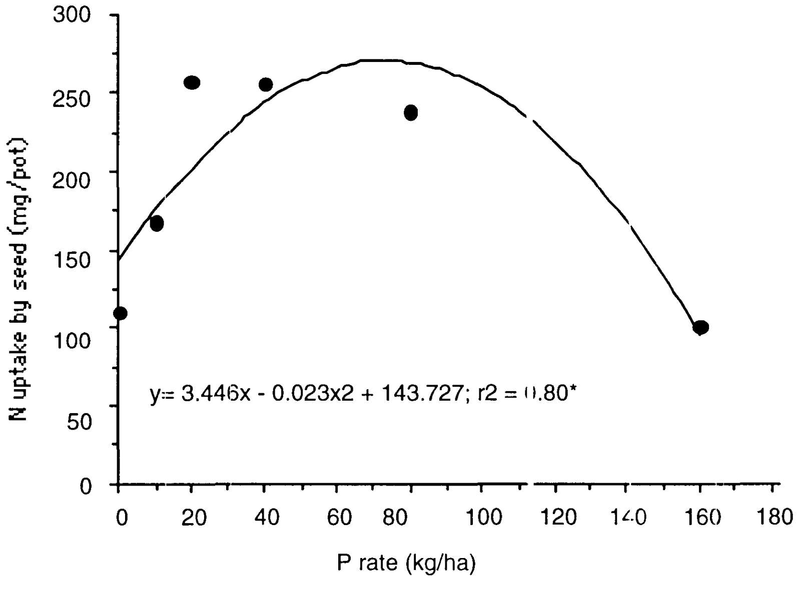


Fig. 8.7. The effect of P application on N uptake by grain at 92-98 DAS

8.4. Discussion

8.4.1. Optimum Rate of P Application for 90 % Maximum Yield

Excessive variability in the response of peas to P application resulted in few significant relationships between P applied and P uptake/dry matter/grain y8ield production.

At 68-75 DAS plant growth was not well correlated with P application rate (Fig. 8.1). This could be due to factors other than P availability affecting pea growth. At this time the plants were at the critical flowering stage, when the demand for water increases and sensitivity to extreme temperatures is greatest (Munroe, 1989 Lamb and Poddar, 1992 and 1994). However, under glasshouse conditions these factors are unlikely to have been limiting. Deficiencies of other nutrients at this particular time seem unlikely. Since flowering overlapped with pod filling, it was difficult to make an accurate count of flower buds and/or flowers to see if there was a possible effect of P on initiation and development of buds and flowers.

8.4.2. P Concentration and Growth

P is one of the nutrients which are readily mobilised in the plant (Bouma, 1976; Marchner, 1985; Smith, 1986). Remobilisation of P from old to young tissues during growth results in the concentration of P being lower in the old leaves than in the younger leaves and the seeds (Spiertz and Ellen, 1976). In the present study, the concentration of P was usually highest in the YL and lowest in the WP.

The linear relationships between P concentration and P application at 68-75 and 92-98 DAS (Fig 8.2 d and e) could either mean that the external supply of P was not enough to raise the concentration of P in the plants to maximum levels or that the higher rates of P application increased the level of P in the plant to toxic levels, resulting in a reduction in accumulation of dry matter and an increase in the ratio of P content to shoot dry matter. Fig. 8.5 suggests a quadratic relationship in which P uptake increases with P application rate to a maximum value. A linear relationship appeared to exist between P uptake and P concentration (Fig. 8.6), with P uptake increasing progressively as P concentration increases. The reduction in shoot dry matter due to high levels of P in the plant was previously observed by Loneragan *et al.* (1979), Christensen and Jackson (1981) and Webb and Loneragan (1988 and 1990). At the highest P application rate of 320 kg P/ha toxicity caused the death of seedlings.

8.4.3. Critical P Concentration for 90 % Maximum Yield

The relationships between P concentration of tissue and growth took the form of a quadratic (Fig. 8.3c - j) or a Mitscherlich curve (Fig. 8.3a and b). Both types of relationship show that as P concentration increased above a certain level, yield increments become smaller. The difference between the quadratic and Mitscherlich curves is that, whereas the Mitscherlich curve shows that yield increments flatten out to zero, in the quadratic relationship yields decrease after plateauing out to zero.

Most of the relationships between P concentration in plant parts and dry weight production was poor ($P > 0.05$) and the data showed extreme variability. Assessing critical values from these data is therefore not possible.

8.4.4. Effect of P Application on N Content and the Crop Quality

The measured concentration of N in seeds (3.0 to 4.2 %) was, according to Lamb and Poddar (1992 and 1994), normal and sufficient for peas . The higher the nitrogen content in the seed the higher the protein content and hence the quality of the legume crop. P is important for development of seeds and accumulation of biochemical substances such as protein. Its importance on seed characters had previously been reported for other varieties of *P. sativum* L. (Shuklu and Kohli, 1991).

P application rate was not significantly related to N concentration in the seed, but the uptake of N by grain showed a quadratic relationship with P application (Fig. 8.7). The increase in N uptake by peas associated with P application has been reported by Rai and Sinha (1986). The relationship between P application and N uptake by grain is similar to that between grain yield and P application (Fig. 8.1). The decreased seed production at the highest rate of P application would explain the decrease in N uptake by seed. An additional factor may be that the supply of photosynthates to the roots for nodule growth and hence N fixation (Jakobsen, 1985), was reduced due to P toxicity.

CHAPTER NINE

EXPERIMENT IV

A comparative study of the optimum rate of P application and critical tissue concentration of P for field peas (*Pisum sativum* L., var. Bluey) between glasshouse and field conditions.

9.1. Introduction

Field experiments are meant to approximate agricultural practices; they constitute the final stage of a sequence of soil fertility studies to test the results of glasshouse experiments and chemical analyses of soil fertility. The results obtained from field trials depend on climatic conditions during the growing season and crop and soil management practices. In Australia temperature and rainfall distribution during the growing season are the most important climatic factors which affect the performance and yields of peas in the field (Munroe, 1989; Lamb and Poddar, 1992 and 1994). Chauhan *et al.* (1992) observed an increase in grain yield of peas var. Apata with irrigation at flowering and at both flowering and pod formation stages. The application of P without irrigation had no significant effect on the grain yield, whereas the application of P with one or two irrigations increased grain yield by 20 - 40 %. These results indicate that rainfall has a marked effect on the response of peas to P fertilisation in field trials, and that responses will vary from year to year according to rainfall during the growth period. Other climatic factors which can affect the results of field experiments on peas are hail and heavy rainfall during flowering and afterwards (Munroe, 1989; Mahoney, 1991; Lamb and Poddar, 1992 and 1994).

The objectives of this experiment were (i) to investigate the optimum rate of P fertiliser to obtain 90 % maximum yield production of field peas (*P. sativum* L. var. Bluey) under field conditions; (ii) to determine the critical concentrations of P in different plant parts at different growth stages for obtaining 90 % maximum yield; (iii) to identify which plant parts at different stages of growth give the best indication of P nutrient status; (iv) to determine P uptake by peas and hence its rate of depletion of soil reserves; (v) to assess the effect of P application on nitrogen content of pea grain, and hence on crop quality under field conditions with irrigation.

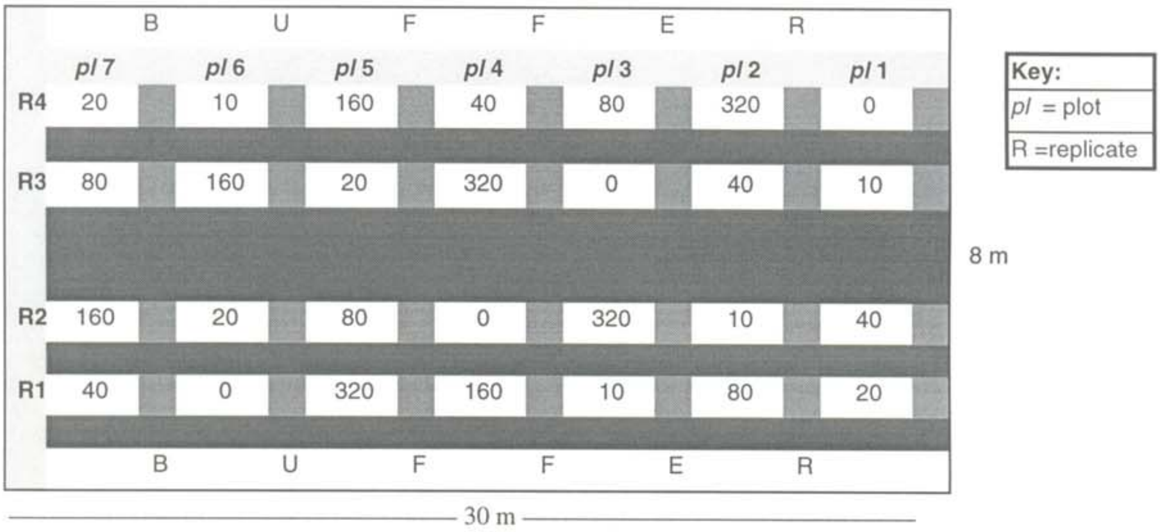
9.2. Materials and Methods

9.2.1. Experiment Design

A field experiment was conducted at the same time as the glasshouse experiment reported in Chapter 8. The treatments in this experiment were the same as those in the glasshouse experiment (Chapter 8) with P applied at rates of 0, 10, 20, 40, 80, 160 and 320 kg P/ha. A basal treatment of sulphur at 15 kg S/ha as gypsum ($CaSO_4.2H_2O$), and of Zn at 5 kg Zn/ha as $ZnSO_4.7H_2O$ was also applied. There were four replicates for each treatment, arranged in randomised complete block design.

9.2.2. The Site

The experiment was conducted on the red-brown earth soil at the Douglas McMaster Field Station, Warialda, located 150° 38' E and 28° 18' S on the northern slopes of New South Wales, Australia. The soil is the red-brown earth used in Experiments II and III and described in Chapters 7 and 8. Details of the soil are given in Appendix B. The site area was 30 m long and 8 m wide, and consisted of four replicates (blocks) and seven plots in each replicate (Fig. 9.1). Each plot was 3 m by 1.3 m; the space interval between the replicates and the plots was 1 m, except between the inner two replicates (R2 and R3) where it was 3 m. Soil samples were collected from 0 - 10 cm from each plot for the determination of available P by the Colwell method (Colwell, 1965) prior to the establishment of the experiment to check for variations between plots (Table 9.1). Nine cores were taken per plot and bulked.



	pl 7	*pl* 6	*pl* 5	*pl* 4	*pl* 3	*pl* 2	*pl* 1
R4	20	10	160	40	80	320	0
R3	80	160	20	320	0	40	10
R2	160	20	80	0	320	10	40
R1	40	0	320	160	10	80	20

Fig. 9.1 Layout of the experimental site. The number in each plot represents the P rate applied.

Table 9.1. Available P (*ug*/g) on individual plots in the experimental area.

Replicate (R)	Plot (pl)	P treatment (kg P/ha)	Available P (*ug/g*)	Replicate (R)	Plot (pl)	P treatment (kg P/ha)	Available P (*ug/g*)
1	1	20	11.5	3	1	10	11.9
	2	80	11.1		2	40	12.3
	3	10	13.9		3	0	12.6
	4	160	13.5		4	320	11.5
	5	320	10.8		5	20	10.6
	6	0	13.0		6	160	9.1
	7	40	13.6		7	80	12.1
2	1	40	11.1	4	1	0	13.1
	2	10	12.8		2	320	13.3
	3	320	15.0		3	80	13.6
	4	0	15.0		4	40	11.8
	5	80	11.8		5	160	13.0
	6	20	9.5		6	10	11.5
	7	160	13.2		7	20	16.7

The climatic data for the area during the growing season from June to November, 1994 are shown in Appendix C.

9.2.3. Sowing

Due to drought during the year of the experiment, sowing was relatively late (June 21, 1994); a normal sowing time would be mid-May for this region. Seeds were banded with the 1.3 m wide Hege plot seeder, which produced six rows per plot. Each plot was sown at 15g seeds per 3 m row. Initially, it was planned to band all the plots with fertilisers using the seeder but due to the difficulty of banding larger quantities using this machine the method was discontinued after banding the first three plots. For the rest of the plots fertiliser was hand broadcast on the rows. Plant growth on the three plots that were banded did not differ from that on plots from the same treatments that received P fertiliser by broadcasting. Two buffer blocks of the same width as the plots were sown on each side of the experimental area at the same rate but without fertilisers (Fig. 1). The plots were irrigated immediately after sowing and fertiliser application to dissolve the fertiliser, using a sprinkler attached to a hosepipe. Irrigations were applied every week during which no rain fell. The depth of wetting was approximately 40 mm which was sufficient to keep the plants alive. Weeds were removed by hand at 78 days after sowing (DAS); prior to this there was no serious weed problem.

9.2.4. Sampling, Harvesting and Plant Analysis

Plants were sampled at the same stages of development as in the glasshouse experiment: (i) at 57 days after sowing (DAS), during vegetative growth; (ii) at 79 DAS, after the opening of the first flowers on individual plants; and (iii) at 107 DAS, after pod filling and before the first seeds dried. Plant parts sampled at each stage were: (i) open compound leaves at the first node from the top or youngest leaves (YL); (ii) the open compound leaves at the third node from the top (TYL); (iii) the remainder of the shoot, that is , the whole shoot minus YL and TYL; and (iv) pods and seeds at 107 DAS. At 57 DAS seven plants were harvested randomly from 1 m^2 areas in each plot and separated into their components; at 79 and 107 DAS, respectively, five and three plants were harvested from the same size of areas and treated likewise. The weight of the YL, TYL and the remainder of the shoot were added together to give the total weight of the whole shoot (WP). Final harvesting was carried out at maturity on November 11, 1994 at 143 DAS. All the plants in a 1 m^2 area per plot were harvested and separated into seeds, pods and whole shoots.

Plant materials were dried at 80°C and weighed. Nutrient concentration was determined by the ICP method described in Section 8. 2. 5. Nitrogen content of seed was analysed from the seeds harvested at 143 DAS.

9.3. Results

9. 3. 1. Visual Observations

Seedling emergence started at 20 DAS. Eight weeks after sowing a difference in colour between the plants as a result of the P treatments was evident. The intensity of the green colour increased with the increase in P application rate. There was no toxicity effect from the highest rates of P as observed in the glasshouse experiment. The first flowers were observed at 70 DAS.

9.3.2. Shoot Dry Matter and Yield Components

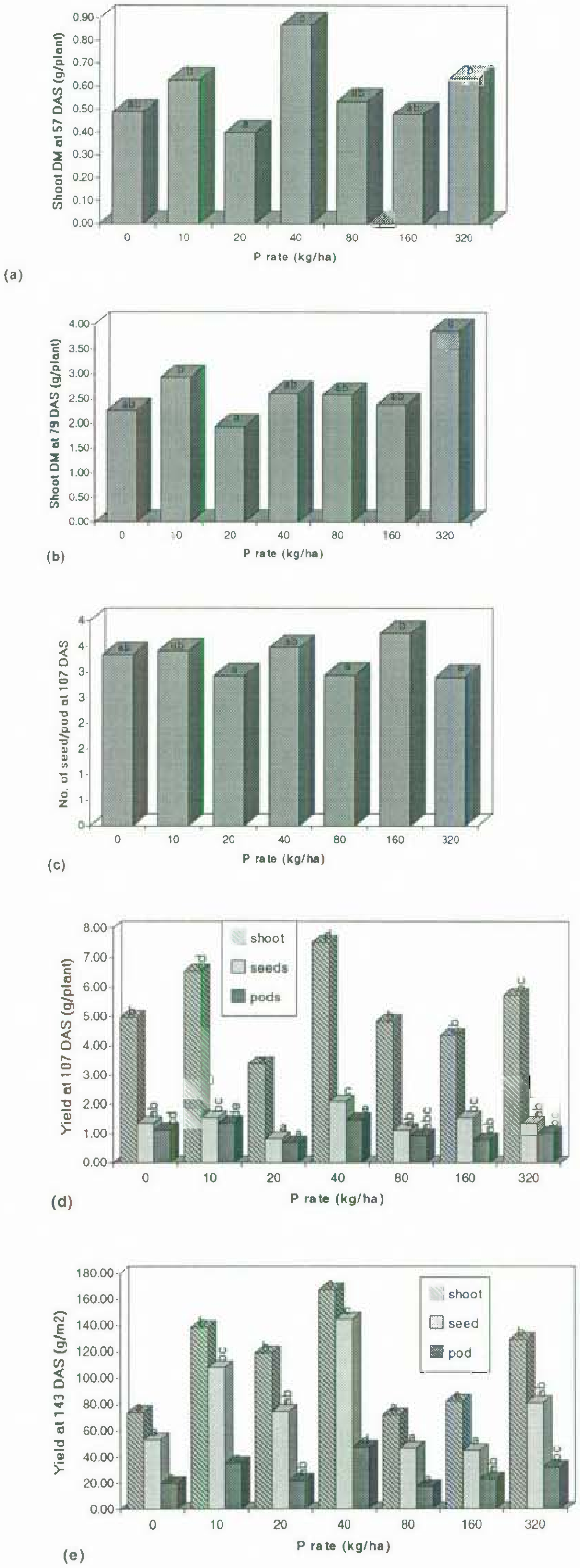


Fig. 9.2. The relationships between the P application rate and yield at (a) 57 DAS , (b) 79 DAS, (c and d)107 DAS and (e)143 DAS . For each plant part means followed by the same letter are not significantly different at P = 0.05

Regression analysis failed to show significant correlation between application rate of P and dry matter of field peas at almost all the sampling times, except for shoot dry matter at 79 DAS, which was linearly correlated with P application rate. However, analysis of variance showed significant effects ($P < 0.05$) of P fertiliser on all dry matter components except for the number of pods per plant at 107 DAS (Fig. 9.2). For harvests at 57, 107 and 143 DAS (Fig. 9.2a, d and e) the highest shoot dry matter was obtained at an application rate of 40 kg P/ha; at 79 DAS (Fig. 9.2b) the highest shoot dry matter was at an application rate of 320 kg P/ha . The responses to P20 were unusual with the yield being depressed at P20 compared to the yield at P10.

Again, regression analysis showed no significant correlation between the application rate of P and the number of pods per plant and of seeds per pod at 107 DAS, dry weight of pods and seeds at 107 and 143 DAS. However, analysis of variance showed a significant effect of P on the weight of seed and pods at 107 and 143 DAS (Fig. 9.2d and e), and the number of seeds per pod at 107 DAS (Fig. 9.2c). There was no effect on number of pods per plant at 107 DAS, and on the weight of 100 seeds at 143 DAS.

9.3.3. P Concentration

There were excellent linear correlations between the concentration of P in plant tissue and the application rate of P at all the sampling times (Fig. 9.3a - d). The level of P in the plant was always much higher in the youngest leaves (YL) at all P rates compared with the third youngest leaves (TYL and whole plant (WP) for the first two harvests. The higher P level was close to double that of the remainder of the plant. The P concentration in the TYL was lower than in the WP at 57 DAS but the reverse was true at 79 and 107 DAS. P concentration at 107 DAS decreased in the order seeds > YL > pods > TYL > WP. At the final harvest, the level of P was highest in the seeds; the pods and the WP had almost the same concentrations, and showed relatively little

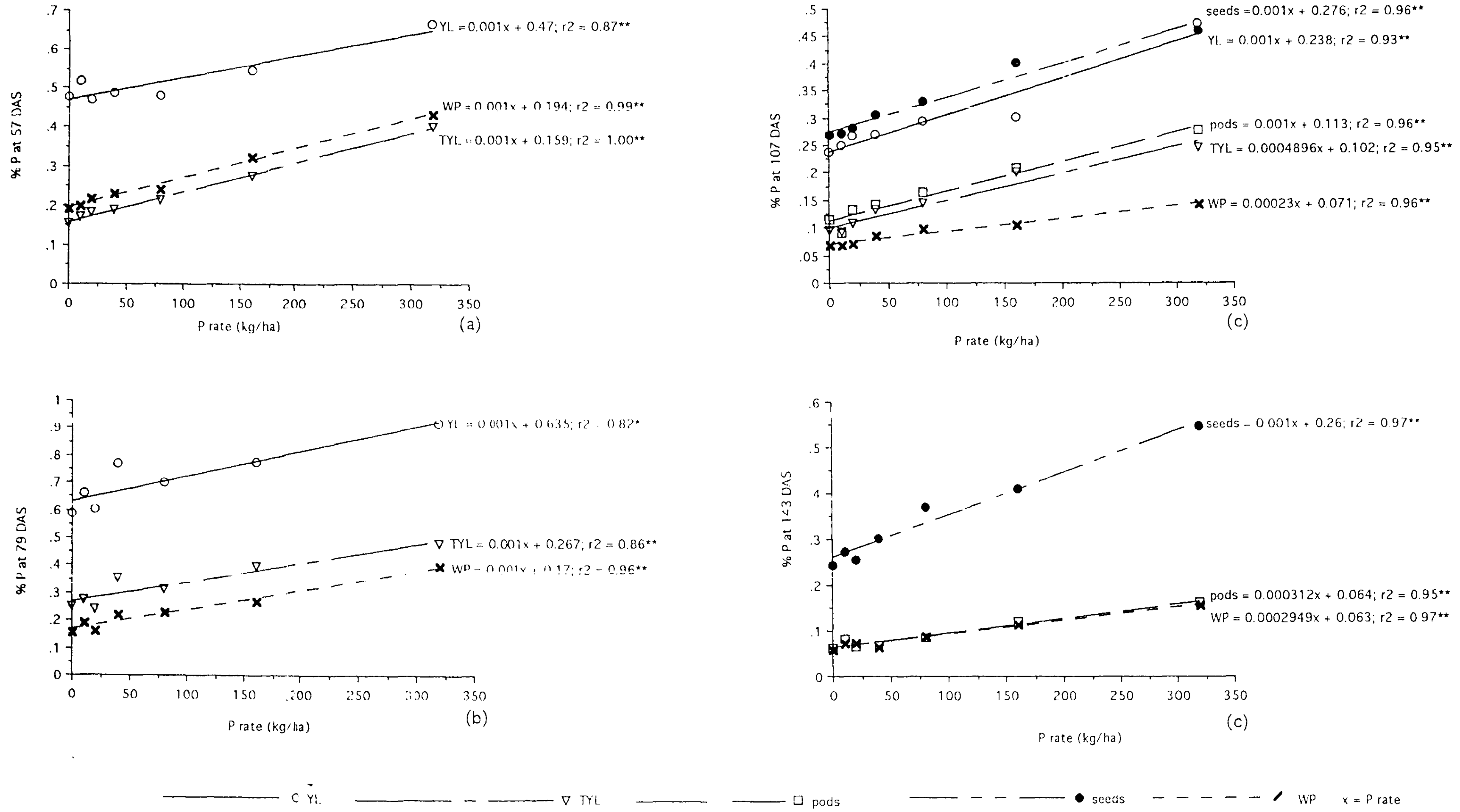


Fig. 9.3. The relationship between P application rate and the concentration of P in various plant parts at different growth stages.

change with P application compared to the seeds. The concentration of P in the YL and TYL increased from the first harvest to the second harvest; and then decreased between the second and third harvests. In the WP, it decreased from 57 DAS to 107 DAS but did not change between 107 and 143 DAS.

9.3.4. P Uptake

The uptake of P by the WP was linearly and positively correlated with the application rate of P at all the sampling times (Fig. 9.4 a-d). An increase in P uptake was observed at every harvest relative to the previous harvest. There was also a strong correlation between the concentration of P in the WP and the P uptake by the whole plant at corresponding growth stages (Fig. 9.5) and between the concentration of P in the YL, TYL and WP and the total P uptake at final harvest (Fig. 9.6). The best predictor of P uptake at final harvest (based on the r^2 data) was %P in YL at 79 DAS. There was no correlation between the concentration of P in the YL, TYL and WP and final dry matter or grain yield.

9.3.5. Seed Nitrogen

The mean nitrogen concentration of seed ranged between 3.4 and 3.9 %. The mean nitrogen uptake by seed was 2.65, 3.06, 2.10, 3.63, 1.71, 2.08 and 2.67 g N/m^2 at application rates of 0, 10, 20, 40, 80, 160 and 320 kg P/ha, respectively. Neither concentration nor uptake of N was correlated with P application or showed a significant effect of P when analysed by analysis of variance.

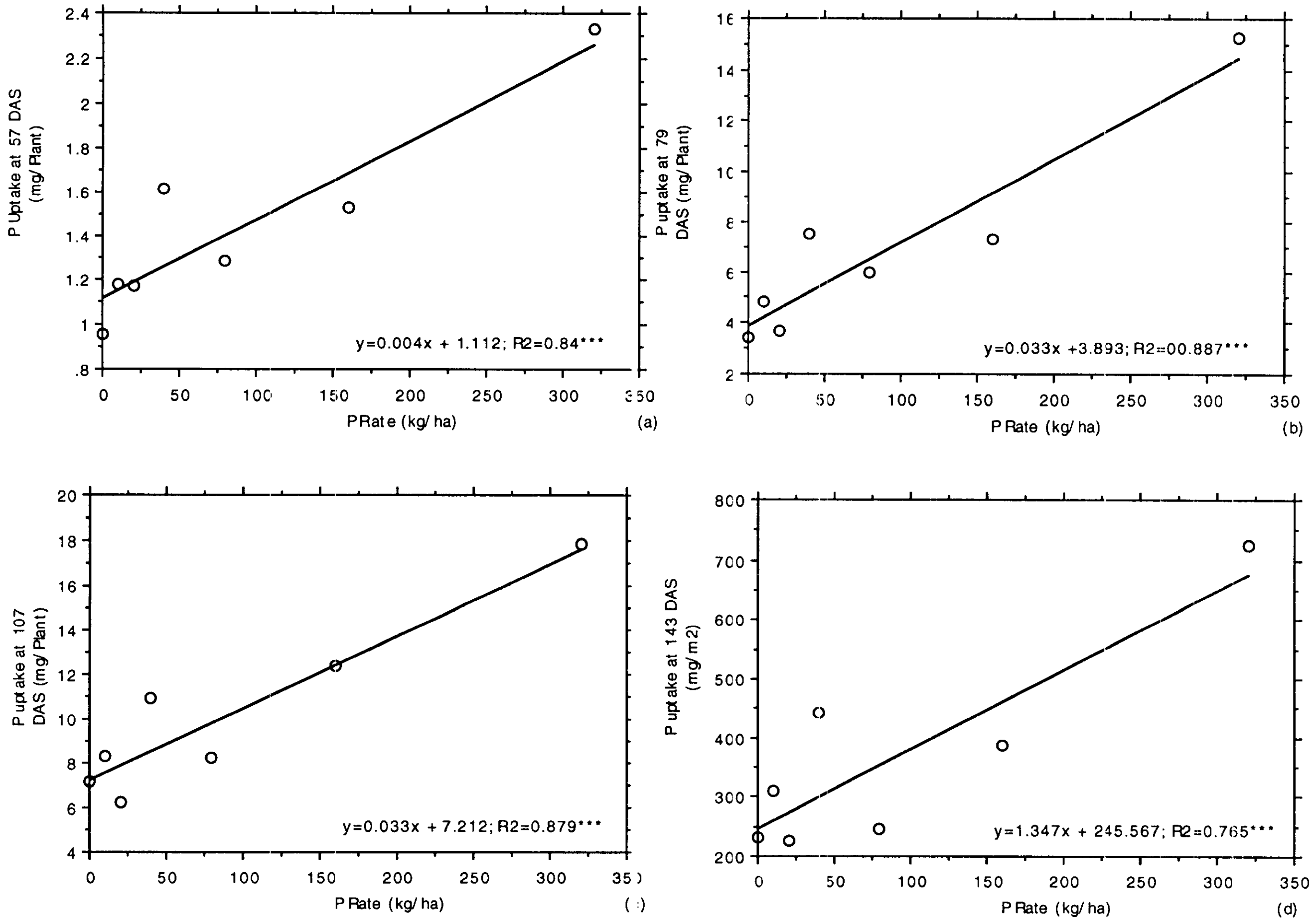


Fig. 9.4. The relationship between the P application rate and the P uptake by the whole plant at different growth stages .

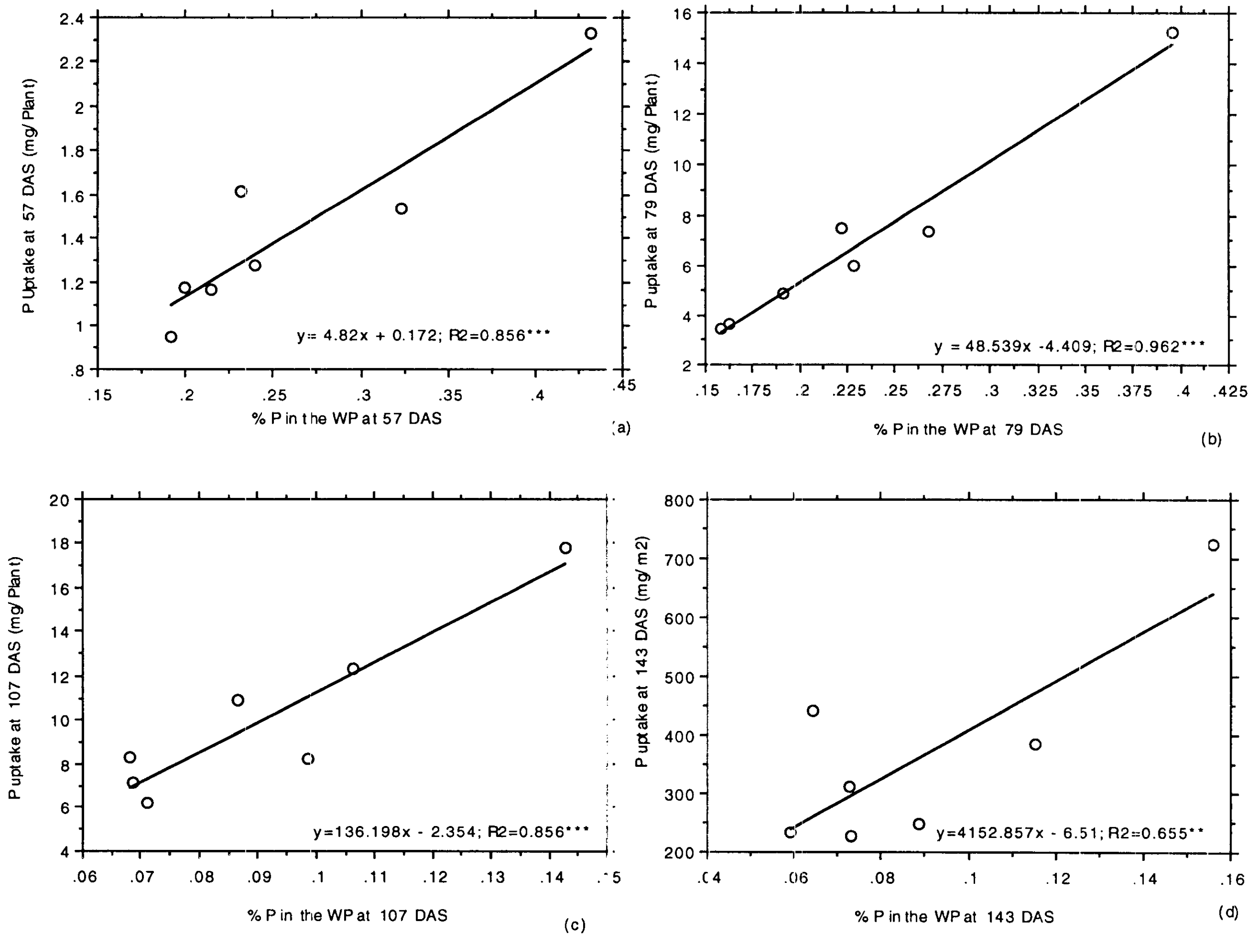


Fig. 9.5. The relationship between the concentration of P and the P uptake by the whole plant at different growth stages .

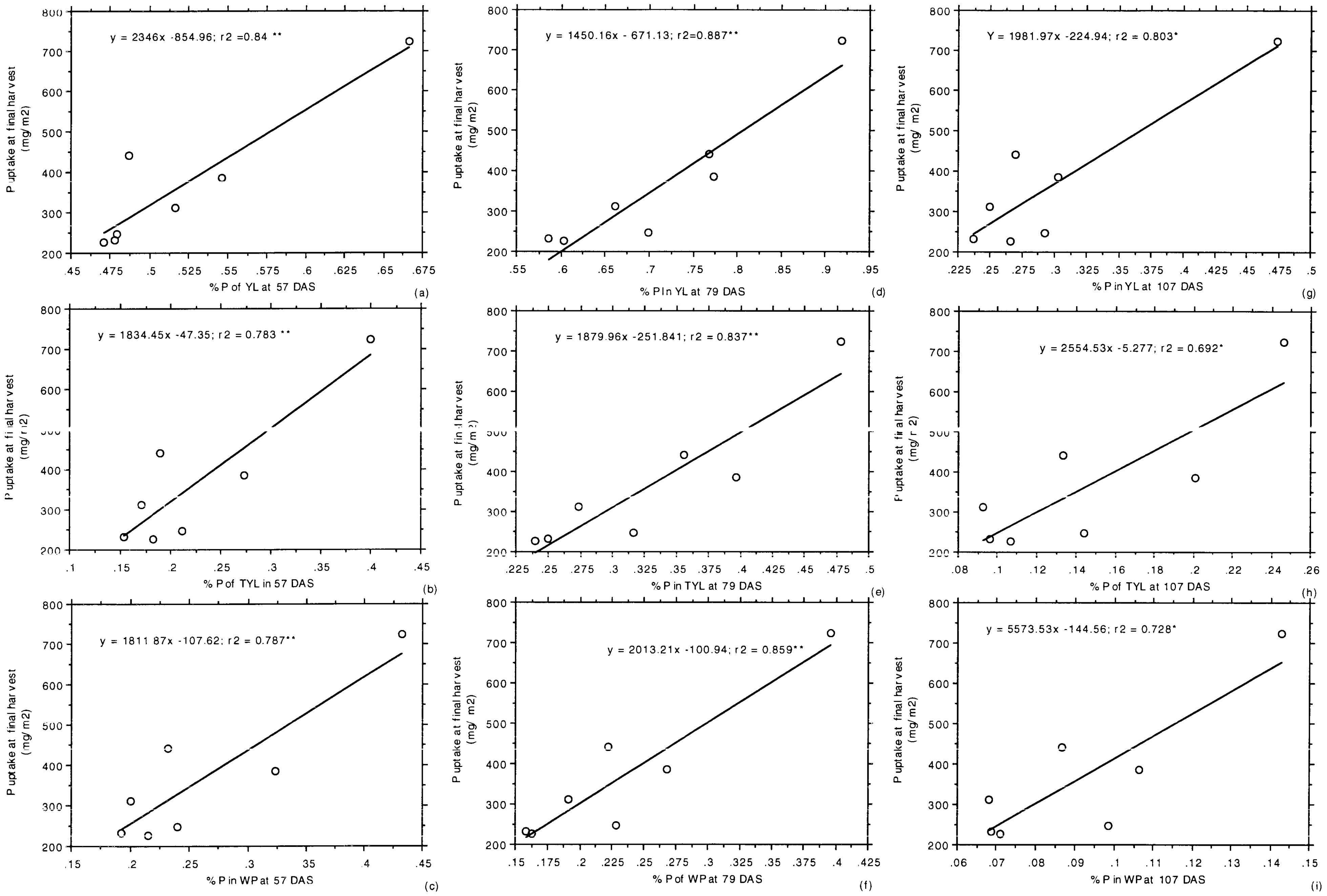


Fig. 9.6. The relationship between P concentration in various plant parts and the final P uptake by the whole plant.

9.4. Discussion

The main similarity between the results of experiment IV and those of experiment III is that the P concentration in the dry tissue of plant materials was linearly related to P application. Other similarities are a response in P uptake to P application and the existence of correlations between total P uptake and P concentration in various plant parts (Figs. 9.5 and 9.6). However, these relationships were linear rather than quadratic as observed in experiment II. The maximum grain yield was 1.45 t/ha and it was produced at a P application rate of 40 kg/ha compared to optimum grain yield of 4.58 t/ha produced at the optimum P application rate of 40 kg P/ha under glasshouse conditions.

In contrast to experiment III, there was no correlation between the P application and N uptake by seed. The weight of dry matter (except for shoot DM at second harvest and weight of 100 seeds at final harvest) exhibited linear relationships rather than the quadratic relationships with applied P as observed in experiment III. In fact, all significant correlations were linear in the field experiment. This form of relationship restricted the estimation of optimum application rate of P to obtain 90 % maximum yield, maximum uptake of P and the critical tissue concentrations of P.

Based on the P40 treatment (maximum grain yield) any plant component (YL, TYL and WP) could be analysed to predict P response since the regressions up to 107 DAS had similar slopes and high r^2. At this yield level the plant P concentrations should be in the ranges listed in Table 9.2.

Table 9.2. %P in plant tissues required for optimal yields (based on data from Fig. 9.3)

DAS	57			79			107				143	
Plant component	YL	TYL	WP	YL	TYL	WP	YL	TYL	WP	S	WP	S
%P	0.51	0.2	0.23	0.68	0.31	0.21	0.28	0.12	0.08	0.32	0.07	0.3

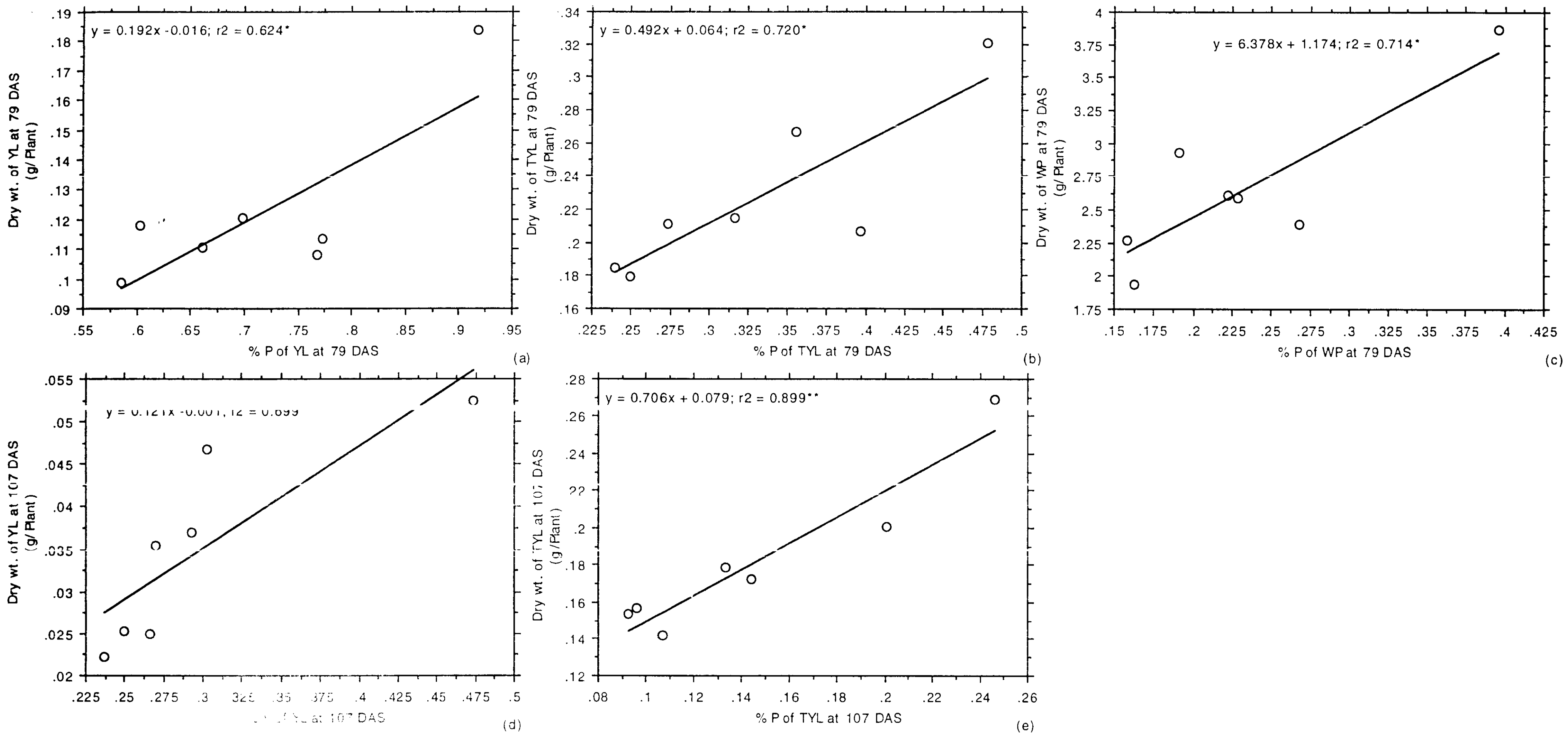


Fig. 9.7. The relationship between P concentration and dry weight of various plant parts at 79 and 107 DAS.

The weight of 100 seeds ranged from 18 to 21 g compared to the range 22 - 29 g found in experiment III and to an average weight of 25 - 30 g reported by Lamb and Poddar (1992 and 1994). Strong correlations existed between the concentration of P in plant tissue and P uptake at final harvest. Whereas in experiment III the strongest correlations were found for leaflets at third node from the top (TYL) at the flowering stage, as reported by Jones *et al.* (1971), in the field experiment the plant part giving the highest correlation varied with the time of sampling.

At high application rates in Experiment III, P seemed to be having a toxic effect on growth as indicated by the quadratic relationships between dry matter and P application and concentration. However, in Experiment IV these relationships were linear (Figs. 9.4 to 9.7). The toxic effects of high P application rates observed in experiment III were absent in the field experiment. Hence, the linear increase in P concentration with an increase in P application rate in the field was not associated with the effects of P toxicity on plant growth. Also, the "P toxicity argument" cannot be sustained since there was no correlation between dry matter and seed yield and the P application.

The continued linear response to P (even at 320 kg P/ha) raises the suspicion that there must have been other factors which interfered with the response of the plants to P application. Response to factors other than the controlled factors is a major limitation of the use field experiments in soil fertility studies (Janssen, 1974).

Drought and high temperature are the major factors which could have affected the response of peas to the P application in the field. Appendix C shows the distribution of rainfall six months prior to and during the period of experiment IV. The total amount of rainfall received from 01/01/94 to 28/11/94 was 346.2 mm with 280 mm of this rain falling in the first six months prior to the experiment and 56.2 mm during the experiment.

The season suffered from a 1 in 2(year drought and although the plants had been lightly irrigated every week of the growing season it is likely that irrigation was not enough to meet the full water requirements of the crop and to improve the availability of the applied P, especially in view of the high temperatures during the growing season (Appendix C). Though there were no records of average daily temperature from the beginning of the growing season until 40 DAS, the records of maximum daily temperature showed fluctuations close to 20°C immediately after the sowing date. These high temperatures would have reduced the effectiveness of irrigation and hence increased the effect drought stress on P availability and plant growth, as discussed in Chapter 2.

Peas, in particular, have a high requirement for water and are very sensitive to extreme temperatures during flowering and pod filling (Munroe, 1989; Chauhan *et al.*, 1992; Lamb and Poddar, 1992 and 1994). During the year of this experiment frost lasted for longer than normal and was still occurring at flowering , resulting in damage to flowers and pods. After flowering, temperatures were above optimal which, in conjunction with moisture stress, would have led to poor responses to P application and lowered grain yield. The effects of temperature and soil moisture were controlled in the glasshouse. Night temperature in the glasshouse ranged from 12 to 14 °C and daily temperature from 24 to 29 °C.

The concentration of P in seed at the highest rate of P application, 320 kg/ha, (0.64 % at 107 DAS and 0.62 % at 143 DAS) exceeded the optimum tissue concentration of P for peas of 0.25 - 0.4 % given by the Plant Tissue Analysis Service (1989). This high level of P in seed might have been an indirect result of high temperature and insufficient soil moisture reducing seed yield. Subsequently, the high P concentration in seed and the low seed yield might explain the negative correlation between the weight of 100 seeds and the application rate of P.

Another factor which could have affected the results of the field experiment was the variability of the site. The plants on the left-hand side of the site (plots 5 to 7) were relatively short, thinner, darker in colour and showed more water stress than those on the right-hand side. This variation in plant growth could not be related to variation in available P within the site (Table 9.1). However, the peculiar response to P20 compared to P10 and P40 might be due to the fact that three out of four replicates of this treatment fell to the left-hand side of the site which showed poor growth, whereas for P10 and P40 only one replicate for each fell to the left-hand side of the site (Fig. 9.1).

It is possible that plants on the left-hand side were being affected by unknown diseases. An alternative explanation is that other soil factors reduced the growth. No usual differences in the soil were found across the site and further investigation of variation in physical and chemical properties of the soil was beyond the scope of the present study.