1987

Residual value of rock phosphate fertilizers

J W. Bowden

Michael D A Bolland

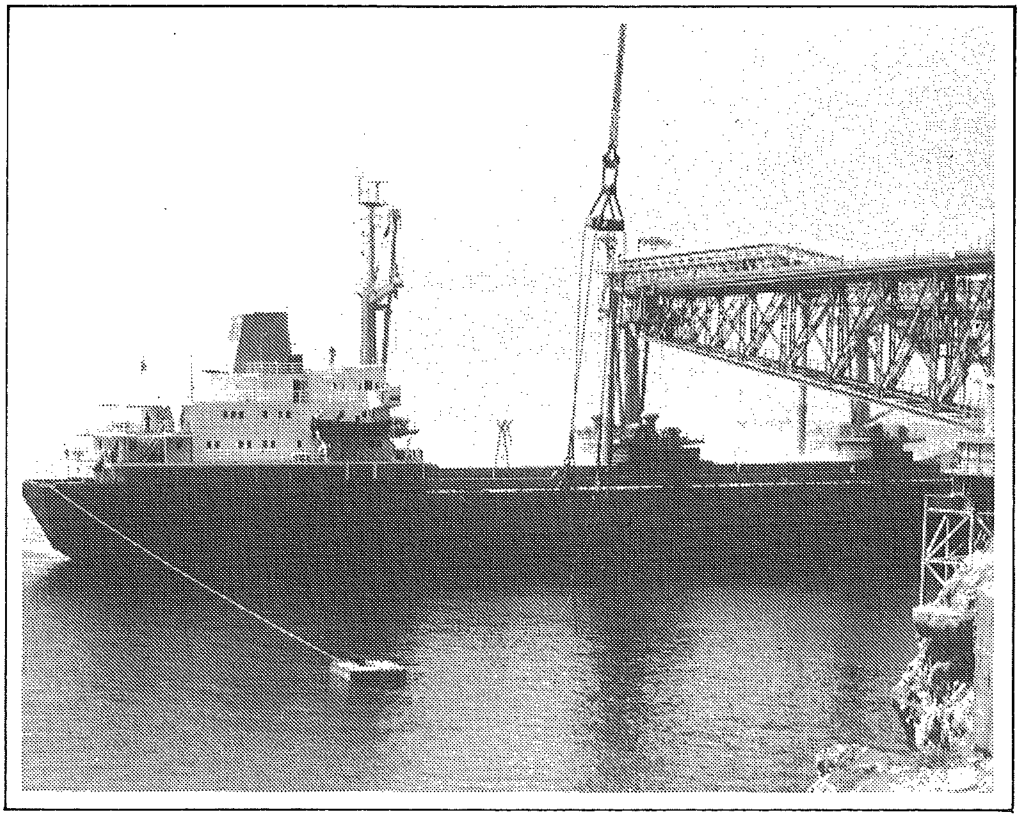
Western Australian
Department of Agriculture

ISSN 0085-8675
Agdex 540

Technical Bulletin

Residual value of rock phosphate fertilizers

No. 75



M.D.A. Bolland and J.W. Bowden

The authors:

M.D.A. Bolland, Research Officer and J.W. Bowden, Principal Research Officer, Division of Plant Research, Department of Agriculture, Western Australia.

Manuscript received, November 1984.

Bolland, M.D.A. (Michael David Anthony), 1946- .
Residual value of rock phosphate fertilizers.

Bibliography.
ISBN 0 7244 8942 8.

1. Phosphatic fertilizers — Western Australia — Evaluation. 2. Phosphate rock — Western Australia — Evaluation. 3. Superphosphates — Western Australia — Evaluation. I. Bowden, J.W. II. Western Australia. Dept. of Agriculture. III. Title. (Series: Technical Bulletin (Western Australia. Dept. of Agriculture); No. 75).

631.8'5'09941

Introduction

The aim of the three experiments was to measure the residual value of three Australian rock phosphates and superphosphate on three soils in south-west Western Australia. The effectiveness of superphosphate was expected to be high initially, followed by a marked decrease in effectiveness in the first few years (Trumble and Donald 1938; Arndt and McIntyre 1963; Mattingly 1971). The residual value of the three rock phosphates was unknown. The initial effectiveness of the rock phosphates was expected to be lower than superphosphate, but the decline in effectiveness with time was expected to be less marked (Arndt and McIntyre 1963; Devine *et al.* 1968). However, rock phosphates vary markedly in physical, chemical and crystallographic properties (Lehr *et al.* 1967) so that the fertilizer effectiveness of rock phosphates for plant growth also varies markedly (Lehr and McClellan 1972; Chien 1981; Hammond 1981).

Regular applications of phosphorus are essential for profitable agriculture in southern Australia (Smith 1983), because of low phosphorus status of the soils (Wild 1958). The development of agriculture in southern Australia was made possible by cheap superphosphate which, before 1974, was applied liberally. The price of superphosphate in Western Australia increased in 1974 from about $14/t to about $50/t. In 1984 it cost about $110/t. Most of the price increase arose from increased royalty payments for Nauruan rock phosphate which occurred shortly after the large price increase for Moroccan rock phosphate in 1973. However, royalties are not payable for Christmas Island rock phosphate. All of Australia's yearly rock phosphate requirements for superphosphate manufacture cannot be supplied from Christmas Island caused partly by problems in loading rock phosphate onto ships. A blend of Nauruan and Christmas Island rock phosphate is used to manufacture superphosphate in Australia. Recently, this blend has included rock phosphate supplies from countries such as Morocco and the United States of America. Christmas Island possesses two types of rock phosphate, apatite (A-grade ore) and calcium aluminium phosphate (C-grade ore, or simply C-ore) (Hoare 1980). The A-grade ore lies underneath the C-ore, and has been mined since the early 1900s to manufacture superphosphate in Australia and New Zealand. The principle minerals in C-ore are crandallite and millisite (Doak *et al.* 1965; White 1971; Gilkes and Palmer 1979). C-ore can not be used to manufacture superphosphate using conventional methods and contains no water soluble or neutral ammonium citrate soluble phosphates (Palmer 1980). Pot trials (Doak *et al.* 1965; Buchan *et al* 1970) have shown C-ore to be very ineffective for promoting plant growth. The maximum effectiveness of C-ore occurs when it is calcined at about 500°C (Doak *et al.* 1965; Palmer *et al.* 1979). The heated (calcined) product, Calciphos (Hoare 1980), contains negligible water soluble phosphates, but more than 70% of the total phosphorus is soluble in neutral ammonium citrate and is described as available phosphorus (Doak *et al.* 1965; Gilkes and Palmer 1979; Palmer *et al.* 1979).

In the mid-1970s, C-ore and Calciphos were potentially cheaper alternative phosphatic fertilizers than superphosphate. However, neither had been used as such, and their short and long-term effectiveness as determined in the field was not known. For it to have been economical in the mid 1970s to develop facilities on Christmas Island to produce Calciphos the paddock applied price of Calciphos needed to be about two-thirds the price of superphosphate (J. Hoare, personal communication). Most of the cost of producing Calciphos is due to the cost of oil required to calcine C-ore. C-ore was potentially much cheaper than Calciphos and, as such, was worth testing as a potential fertilizer.

Only a small proportion of applied phosphorus is used by plants in the year of application. Some of the remaining residual phosphorus may be available to plants in future years (Barrow 1980). For economic comparisons, both the initial and residual effectiveness of fertilizers needs to be considered. The first step in determining whether C-ore or Calciphos could be used as substitutes for superphosphate was to measure their initial and residual effectiveness in the field. The initial effectiveness of these potential fertilizers had been measured in pot experiments (Doak *et al.* 1965; Buchan *et al.* 1970). However, the results of these glasshouse pot experiments were ambiguous and could not be confidently expected in the field. This is because, in the pot, the fertilizer is usually mixed uniformly through the soil which is kept moist at all times by frequent waterings to maintain the soil near field capacity. In pots the roots only grow in fertilized soil. These conditions maximize the effectiveness of rock phosphates (Khasawneh and Doll 1978).

Conditions in the field differ from those in pots in several aspects. In south-western Australia cereal crops are grown in rotation with ley pastures (usually subterranean clover-based). Fertilizers applied to the surface are only mixed through the soil as a result of subsequent cultivations for cereal cropping. There is no extensive mixing of soil and fertilizer under pasture although natural processess do slowly incorporate fertilizer into the soil. It would take many years to achieve a homogenous mix of fertilizer through the surface soil. During the growing season the surface horizons of soils in south-western Australia frequently dry out between rains, which is likely to reduce the dissolution and effectiveness of rock phosphates. Another difference between glasshouse pot and field experiments is that, in the pot, the fertilizer is only in contact with a small mass of soil whereas in the field, it may be affected by a much greater soil mass. This is likely to increase dissolution of rock phosphates and allow the diffusion of phosphorus through a greater volume of the soil. Also, field climatic conditions are often unfavourable to plant growth whereas growing conditions are optimised in a glasshouse.

The short term effectiveness of Calciphos has been measured in the field (Mason and Cox 1969; Muller 1970; Lipsett and Williams 1970), but results were contradictory and inconclusive. Muller concluded that Calciphos was initially 90% as effective as superphosphate, but the other reports suggested that Calciphos was only about 33% as effective.

We measured the residual value of C-ore, Calciphos and superphosphate in several field experiments, three of which are reported here. These three experiments add to data already reported for different management systems, soil type and superphosphate histories. One experiment was on newly cleared texture contrast (duplex) soil at Gibson for a permanent subterranean clover pasture. The other two experiments were on old land which had received about 500 kg/ha superphosphate over five years (Newdegate) or seven years (Wongan Hills) before the start of the experiments, and involved a clover pasture-cereal cropping management system. Previous results were for lateritic soils for permanent clover pasture (Bolland and Bowden 1982, 1984; Bolland *et al.* 1984) and continuous cropping with wheat (Bolland 1985). In the Gibson experiment, the residual value of apatite rock phosphate, which comes from the Duchess deposit in north-western Queensland (QRP), was also determined. This is a very large deposit which represents Australia's assured future source of apatite rock phosphate (Abbott 1983). Little is known about the initial and residual effectiveness of these apatites when they are used as direct application fertilizers. At present, it is uneconomic to mine and transport Queensland apatite to the superphosphate manufacturers at the coast around Australia. Moreover, Australian superphosphate manufacturers are only equipped to grind the relatively soft rock phosphates such as from Christmas and Nauru Islands the U.S.A. and Mexico. The rock phosphate from Queensland contains chert which wears out current grinding equipment more rapidly than soft rocks so, to use this apatite, alternative grinding equipment would be required.

Materials and methods

The C-ore and Calciphos were donated as fine powders by the British Phosphate Commission. The Calciphos was calcined on Christmas Island. Superphosphate was purchased from CSBP and Farmers Ltd., Perth, Western Australia. The QRP as a fine powder was donated by Broken Hill South Pty. Ltd., Melbourne, Victoria, and is a sample of the unbeneficiated or 'direct shipping grade' ore from the Duchess deposit (Abbott 1983).

Some chemical and physical properties of the phosphatic fertilizers used are listed in table 1.

The locations of the experiments are shown in figure 1. Some climatic data, the previous history of each site and some properties of the surface soil, are listed in table 2.

The experiments at Newdegate and Wongan Hills started in 1976 and at Gibson in 1977. All were terminated, after sampling, in 1983. The Newdegate and Wongan Hills

The experimental design is each case was a split plot, randomised block, with three replications. The phosphatic fertilizers were the main plots, and levels and frequency of application of fertilizer phosphorus the subplots. At Gibson, different amounts of each experiments involved a pasture — cropping management system on old land with a superphosphate history of five and seven years respectively. The third experiment at Gibson was on newly cleared duplex (texture contrast) soil for a permanent subterranean clover pasture.

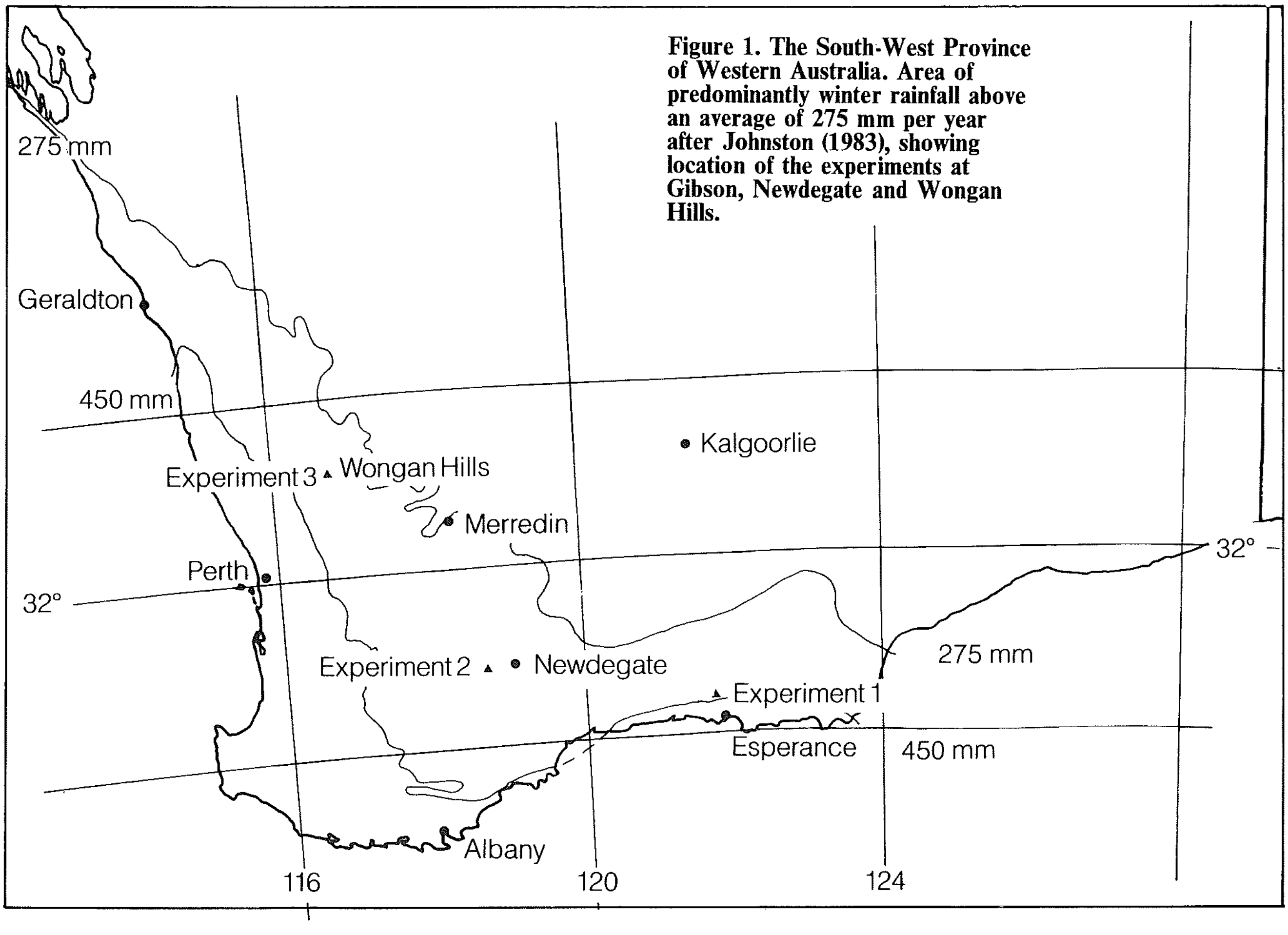


Figure 1. The South-West Province of Western Australia. Area of predominantly winter rainfall above an average of 275 mm per year after Johnston (1983), showing location of the experiments at Gibson, Newdegate and Wongan Hills.

Table 1. Some chemical and physical properties of phosphatic fertilizers

		C-ore %	Calciphos %	QRP %	Superphosphate %
Moisture		2.6	1.2	0.9	nm[D]
Total phosphorus		10.9	13.4	14.1	9.6
Water-soluble phosphorus[A]		0.1	0.1	0.1	7.4
Citrate-soluble phosphorus[B]		0.1	6.5	1.8	1.2
Acid-soluble phosphorus[A]		10.7	6.9	12.2	1.0
Aluminium		11.8	11.1	0.9	nm
Iron		7.7	6.6	0.8	nm
Calcium		9.4	17.6	31.2	nm
Particle size [C]:					
BSI sieve No.	Aperture (mm)				
> 52	> 0.295	8.2	5.0	3.8	E
52-100	0.295-0.152	14.0	25.0	7.5	
100-200	0.152-0.076	8.6	29.0	19.5	
200-300	0.076-0.053	1.7	9.0	10.5	
<300	<0.053	67.6	34.0	58.7	

[A] Measured by standard A.O.A.C. (1975) procedures. [B] In neutral ammonium citrate (A.O.A.C. 1975). [C] By wet sieving. [D] nm, not measured. [E] Granulated 0.5-2.0 mm

Table 2. Location; rainfall, length of growing season; previous history of each experimental site, soil description and phosphorus status of the < 2 mm fraction of the top 10 cm of soil at each site determined for soil samples collected before the commencement of the experiments

Experiment	1	2	3
		Location and climate (see figure 1)	
Location	Gibson	Newdegate	Wongan Hills
Property	Esperance Downs Research Station	P. Clarke	Wongan Hills Research Station
Average rainfall (mm/a)	484	393	348
Average length of growing season (months)*	6.5	5.5	4.5
		History of each site before commencement of experiments	
	New land 1977	New land 1971	New land 1969
			1969 cropped (11†)
			970 cropped (11)
		1971 cropped (12)	1971 pasture (7)
		1972 cropped (12)	1972 pasture (8)
		1973 pasture (7)	1973 cropped (0)
		1974 cropped (7)	1974 pasture (10)
		1975 cropped (7)	1975 pasture (0)
Total P applied before commencement of experiments (kg/ha)	0	45	47
		Soil	
Soil type	Grey sand and gravel over gravel	Gravelly sand over massive gravel	Sandy loam
Soil classification (Northcote 1979)	Dy 5.82	KS-Uc 4.11	Gn 2.21
		Phosphorus status of the < 2 mm fraction of top 10 cm of soil before commencement of experiments	
Total P (μg/g)	96	130	146
Bicarbonate-extractable P (μg/g)(Colwell 1963)	2	4	6
Buffer capacity (μg/g) (Ozanne and Shaw 1967)	1	9	2

* From : precipitation (mm)/evaporation (mm) x 0.7 = 0.54 (from Prescott's formula $P/E^{0.7} = 0.54$, where P is effective rainfall, E is evaporation from a free water surface, both in mm per month).

† Values in parenthesis are the amounts of P (kg/ha) applied as superphosphate

Table 3. **Amount of phosphorus applied as each fertilizer in the first year (1977) at Gibson.**

C-ore	Phosphorus applied (kg P/ha)* Calciphos	QRP	Superphosphate
157	143	182	56
314	286	364	112
470	428	546	168
627	571	728	224

* The experiment included control treatments to which no phosphorus was applied for the duration of the experiment.

phosphatic fertilizer were applied only in 1977 (year 1) (table 3). In the other two experiments, different amounts of each fertilizer were applied once only in 1976 (year 1), applied at the same level every year (i.e. applied annually), and applied every second year i.e. in 1976, 1978, 1980 and 1982 (years 1, 3, 5 and 7 respectively) (table 4).

The phosphatic fertilizers were applied to the soil surface (top-dressed) using a 12-row, disc drill on plots 2.1 m wide and 50 m long. The following nutrients were top-dressed at the commencement of the experiments (April-May): 10 kg/ha copper sulphate (27% Cu); 2 kg/ha zinc oxide (80% Zn); 0.2 kg/ha molybdenum trioxide (67% Mo); 100 kg/ha potassium chloride (50% K) and 100 kg/ha gypsum (18% S); and in April-May of successive years, 100 kg/ha potassium chloride and 100 kg/ha gypsum.

At Gibson, three levels of superphosphate were top-dressed across all subplots in April-May each year, using a new section of the subplots. The yields, measured for the different phosphatic fertilizers applied in year 1 only (1977) were compared with the yields measured from the superphosphate treatments applied across all subplots in the current year (relative effectiveness)(Eik *et al.* 1961; Barrow and Campbell 1972).

Apart from the first year (1976) in the experiments at Newdegate and Wongan Hills, a single rate of superphosphate was top-dressed across all subplots in April-May each year, using a new section of the subplots each year, and at levels sufficient to determine the maximum yield for each year (up to 300 kg P/ha).

At Gibson, subterranean clover (*Trifolium subterraneum* cv. Daliak) was sown on all plots in May 1977 using inoculated and lime pelleted seed, at a seeding rate of about 100 kg/ha. A disc drill was used with the discs about 1.5 cm in the soil.

The experiments at Newdegate and Wongan Hills were sown to subterranean clover cv. Geraldton in 1976, and the resultant pasture used in 1976 and 1977 to determine the effectiveness of the the fertilizers. Subsequently, crops of either wheat (*Triticum aestivum* cv. Madden) or barley (*Hordeum vulgare* cv. Clipper), were grown each year to determine the effectiveness of fertilizer applied phosphorus. Before sowing, weed control was achieved by cultivating along the plots with a tyned implement. In addition, herbicides were used as required. The cereals were sown at 55 kg/ha. Nitrogen as either urea or ammonium nitrate was top-dressed across all plots at about 60 kg N/ha three weeks after emergence of the crop.

The pastures were grazed with three to four dry adult sheep/ha until four to six weeks before yield measurements were taken in spring. Sheep were then returned to the plots until all the dried herbage had been grazed off during summer.

Pasture yield was determined in August-September using a rising plate meter similar to that described by Earle and McGowen (1979). The meter was calibrated by cutting the pasture to ground level using pasture shears. These samples were then dried at 70°C in a forced draught oven and weighed.

Vegetative yields of cereals were determined by cutting all top growth within random quadrats at ground level. Grain yields were measured using small-plot harvesting machines, or by collecting seed heads from random quadrats and threshing out the grain.

Each January-February, soil samples from the top 10 cm were collected from all treatments for determination of bicarbonate-extractable soil phosphorus (Colwell 1963).

Table 4. Amount of phosphorus applied as each fertilizer for experiments at Newdegate and Wongan Hills commencing in 1976.

	Applied P (kg/ha)						
	Year						
	1	2	3	4	5	6	7
	Newdegate						
C-ore	36	15	38	33	38	36	36
	73	51	76	49	76	76	77
	36	0	38	0	38	0	36
	73	0	76	0	76	0	73
	73	0	0	0	0	0	0
	220	0	0	0	0	0	0
	367	0	0	0	0	0	0
	734	0	0	0	0	0	0
	1 707	0	0	0	0	0	0
Calciphos	38	18	48	30	20	38	38
	70	70	72	59	40	70	70
	38	0	48	0	40	0	38
	70	0	72	0	71	0	70
	38	0	0	0	0	0	0
	140	0	0	0	0	0	0
	210	0	0	0	0	0	0
	420	0	0	0	0	0	0
	770	0	0	0	0	0	0
Superphosphate	14	13	14	18	15	14	14
	27	25	28	27	30	27	27
	14	0	14	0	18	0	14
	27	0	28	0	35	0	27
	51	0	0	0	0	0	0
	86	0	0	0	0	0	0
	171	0	0	0	0	0	0
	342	0	0	0	0	0	0
	428	0	0	0	0	0	0
	Wongan Hills						
C-ore	13	11	13	13	12	12	13
	26	22	25	27	24	24	26
	39	0	38	0	36	0	39
	64	0	63	0	48	0	64
	26	0	0	0	0	0	0
	52	0	0	0	0	0	0
	129	0	0	0	0	0	0
	193	0	0	0	0	0	0
	380	0	0	0	0	0	0
Calciphos	7	6	8	6	8	7	7
	15	14	14	11	16	15	15
	19	0	16	0	16	0	19
	38	0	36	0	32	0	38
	19	0	0	0	0	0	0
	57	0	0	0	0	0	0
	88	0	0	0	0	0	0
	263	0	0	0	0	0	0
	440	0	0	0	0	0	0
Superphosphate	6	6	5	6	7	7	6
	8	8	8	8	8	11	8
	13	0	12	0	14	0	13
	18	0	18	0	17	0	18
	13	0	0	0	0	0	0
	28	0	0	0	0	0	0
	55	0	0	0	0	0	0
	110	0	0	0	0	0	0
	240	0	0	0	0	0	0

* Both experiments included control treatments to which no fertilizer phosphorus was applied for the duration of the experiments.

Analysis of data

Effectiveness

In all experiments, the effectiveness of the phosphatic fertilizers was calculated each year using the initial slope of the following relationships: bicarbonate-soluble phosphorus extracted from the soil and the amount of total phosphorus applied (E_{BP}); yield (expressed as a percentage of the maximum yield) and the amount of total phosphorus applied (E). The initial slope of these relationships was calculated using nil and the first two levels of phosphorus applied, which were located in the linear part of each relationship. The initial slopes were calculated for each fertilizer every year using each replicate and method of application (i.e. for fertilizer treatments applied in year 1 only, annually, or in year 1 and re-applied in years 3, 5 and 7). At Gibson, herbage yields of subterranean clover were used to calculate E values. At Newdegate and Wongan Hills, yields of whole tops or grain (see legend to figure 5) of barley and wheat, respectively, were used to calculate E values.

Relative effectiveness (experiment 1 only)

At Gibson, different rates of superphosphate were applied across all the subplots each year, using a new section of the plot. The effectiveness of the phosphatic fertilizer treatments which were all applied in year 1 only (1977) were calculated relative to superphosphate applied across all the subplots in the current year (relative effectiveness (Eik *et al.* 1961; Barrow and Campbell 1972; Bolland *et al.* 1984)). For each phosphatic fertilizer, the slope of the relationship between herbage yield of subterranean clover and amount of phosphorus applied for the year 1 only treatments was divided by the initial slope of the relationship between yield and the amount of phosphorus applied measured for the cross strips of superphosphate which were applied in the current year (see Bolland *et al.* 1984 for more details). Relative effectiveness was determined in experiment 1 for each phosphatic fertilizer each year using each replicate and level of application.

Statistical analysis

No statistical analysis could be undertaken on the slope or relative effectiveness data because these variables are not normally distributed (Barrow and Campbell 1972).

Results

Bicarbonate-extractable-soil phosphorus

Although very large amounts of C-ore were applied, particularly in the Newdegate experiment (table 4), the bicarbonate-extractable phosphorus (BC) measured from the soil samples was very low (figure 2), and similar to the values determined for soil samples collected from the control treatments. The arrows in figure 2 show the BC values determined from the controls in year 2. For the experiments at Newdegate and Wongan Hills, the BC values determined for superphosphate decreased in a similar fashion for all rates of application (figure 2). The BC values for the experiment at Gibson were only measured in 1978 (year 2) and 1983 (year 7). The change in the BC values between these years was not marked for any of the fertilizers (figure 2).

Effectiveness calculated using bicarbonate-extractable soil phosphorus

The effectiveness of C-ore calculated using BC data was always very low (figure 3 and table 5) and remained about constant for six years. The effectiveness of Calciphos was between 2 to 3 times that of C-ore. It remained about constant through time for the Newdegate experiment, and decreased uniformly by about 50% over the six years for the experiment at Wongan Hills (figure 3). At Newdegate, the effectiveness of superphosphate decreased by about 70% from year 2 (1977) to year 3 and decreased by a further 10% in subsequent years (figure 3). At Wongan Hills, it decreased more uniformly by about 70% over six years. At Gibson, only year 2 (1978) and year 7 data are available (table 5). The effectiveness of C-ore trebled in the six years, but was still extremely low. The effectiveness of Calciphos and QRP were low and were the same in 1978 and 1983 (table 5). The effectiveness of superphosphate decreased by about 50% in the seven years of the experiment (table 5).

Table 5. Effectiveness of the phosphatic fertilizers calculated for the Gibson experiment using bicarbonate-soluble phosphorus extracted from the < 2 mm fraction of the top 10 cm of soil, using soil samples collected in January-February in years 2 and 7

	C-ore	Calciphos	QRP	Superphosphate
Year 2 (1978)	0.003	0.07	0.02	0.25
Year 7 (1983)	0.010	0.08	0.03	0.11

At Newdegate and Wongan Hills, the effectiveness of all fertilizers calculated using BC data was similar irrespective of whether the fertilizers were applied in year 1 only, annually, or in years 1, 3, 5 and 7. The mean of all the data was used to derive figure 3.

Yield data

Yield results for experiments 1 and 2 are shown in figures 4 and 6, respectively. Yield data were limited by the relatively dry seasons and, at Wongan Hills, by the low response of the pasture or cereal crops to the phosphorus applications. In such a low response situation it was difficult to measure the relative value of the fertilizers.

Effectiveness calculated from yield data

The effectiveness of the fertilizers was calculated using percentage of the maximum yield measured each year. This percentage of the maximum yield was used to reduce the variation resulting from different seasonal and management conditions (Bolland amd Bowden 1982, 1984). The greatest (maximum) yield was measured each year from the cross strips to which superphosphate had been topdressed across all subplots in April-May of the current year (for rates of superphosphate applied, see legend to figure 5).

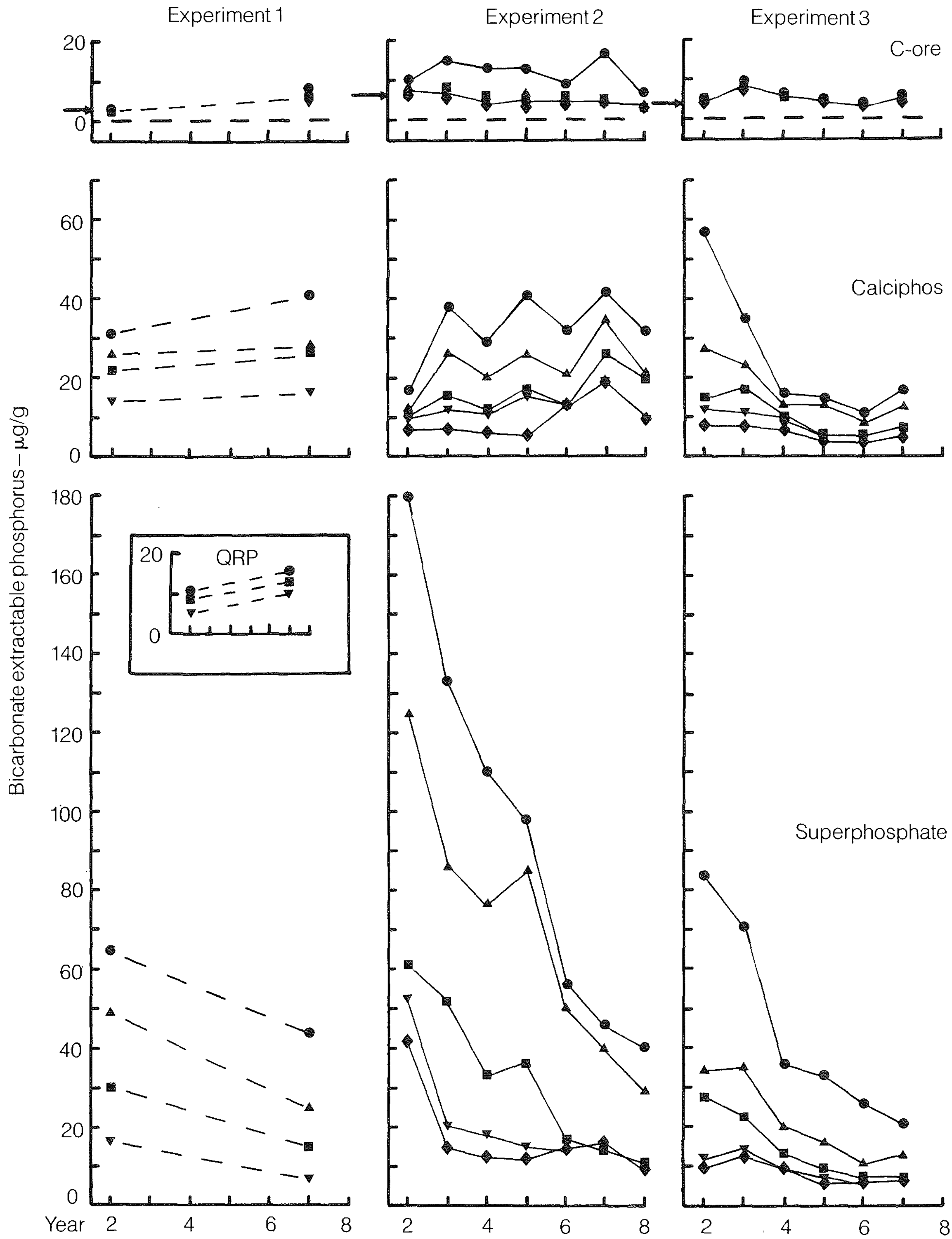


Figure 2. Bicarbonate-soluble phosphorus extracted from the top 10 cm of the < 2 mm fraction of soil for those phosphatic fertilizer treatments applied in year 1. The soil samples were collected January-February each year for experiments at Newdegate and Wongan Hills, and in years 2 and 7 at Gibson. Levels of applied P (kg/ha): Experiment 1, C-ore, ▼157, ■314, ▲470, ●627; Calciphos, ▼143, ■286, ▲428, ●571; QRP, ▼182, ■364, ▲546, ●728; Superphosphate, ▼56, ■112, ▲168, ●224; Experiment 2, C-ore, ◆73, ▼220, ■367, ▲734, ●1707; Calciphos, ◆38, ▼140, ■210, ▲420, ●770; Superphosphate, ◆51, ▼86, ■171, ▲342, ●428; Experiment 3, C-ore, ◆26, ▼52, ■129, ▲193, ●380; Calciphos, ◆19, ▼57, ■88, ▲263, ●440; Superphosphate, ◆13, ▼28, ■55, ▲110, ●240

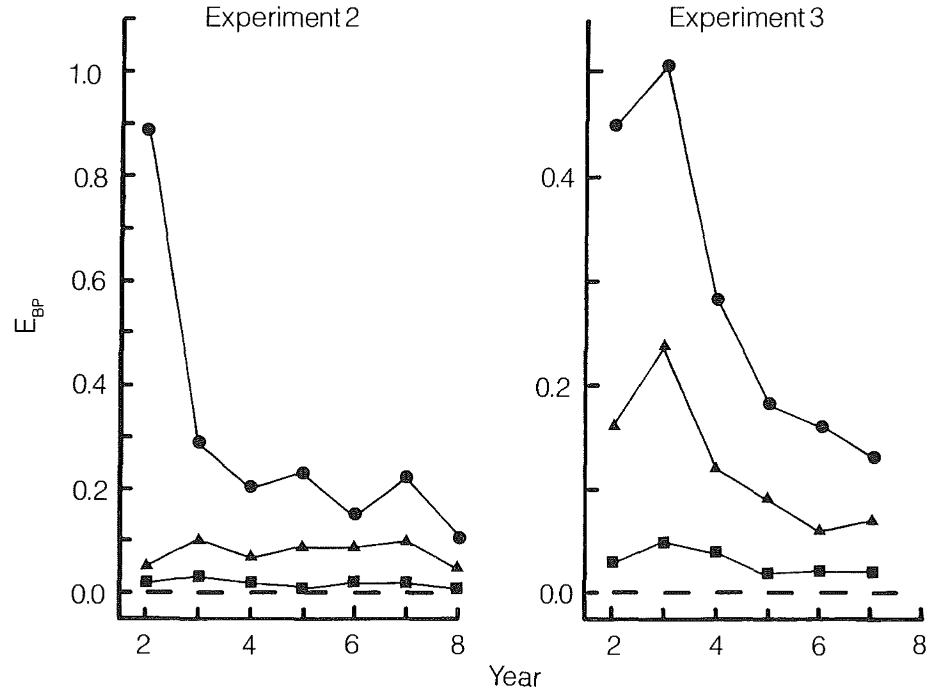


Figure 3. Effectiveness of the phosphatic fertilizers for experiments at Newdegate and Wongan Hills calculated from the initial slope of the relationship between bicarbonate-soluble phosphorus extracted from the < 2 mm fraction of the top 10 cm of soil (E_{BP}) and the amount of total phosphorus applied. The soil samples were collected every January-February. Note that the scales of the y axes are different. In each case ■ C-ore, ▲ Calciphos, ● superphosphate.

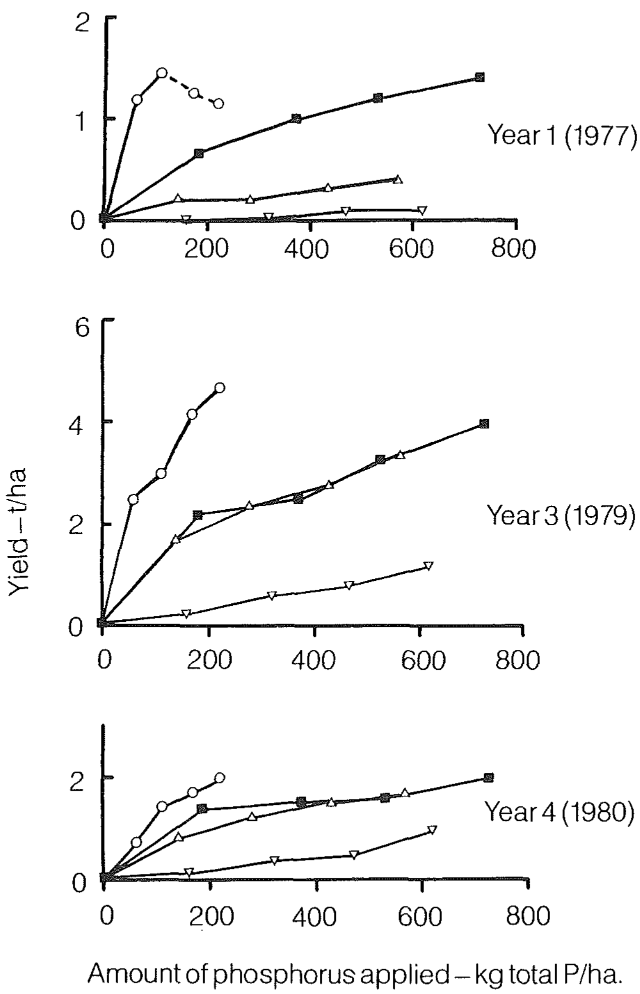


Figure 4(a) Subterranean clover herbage yields at Gibson. Note the decline in yield from superphosphate in 1977 because of toxicity.

■ QRP
Δ Calciphos.
∇ C-ore
° Superphosphate

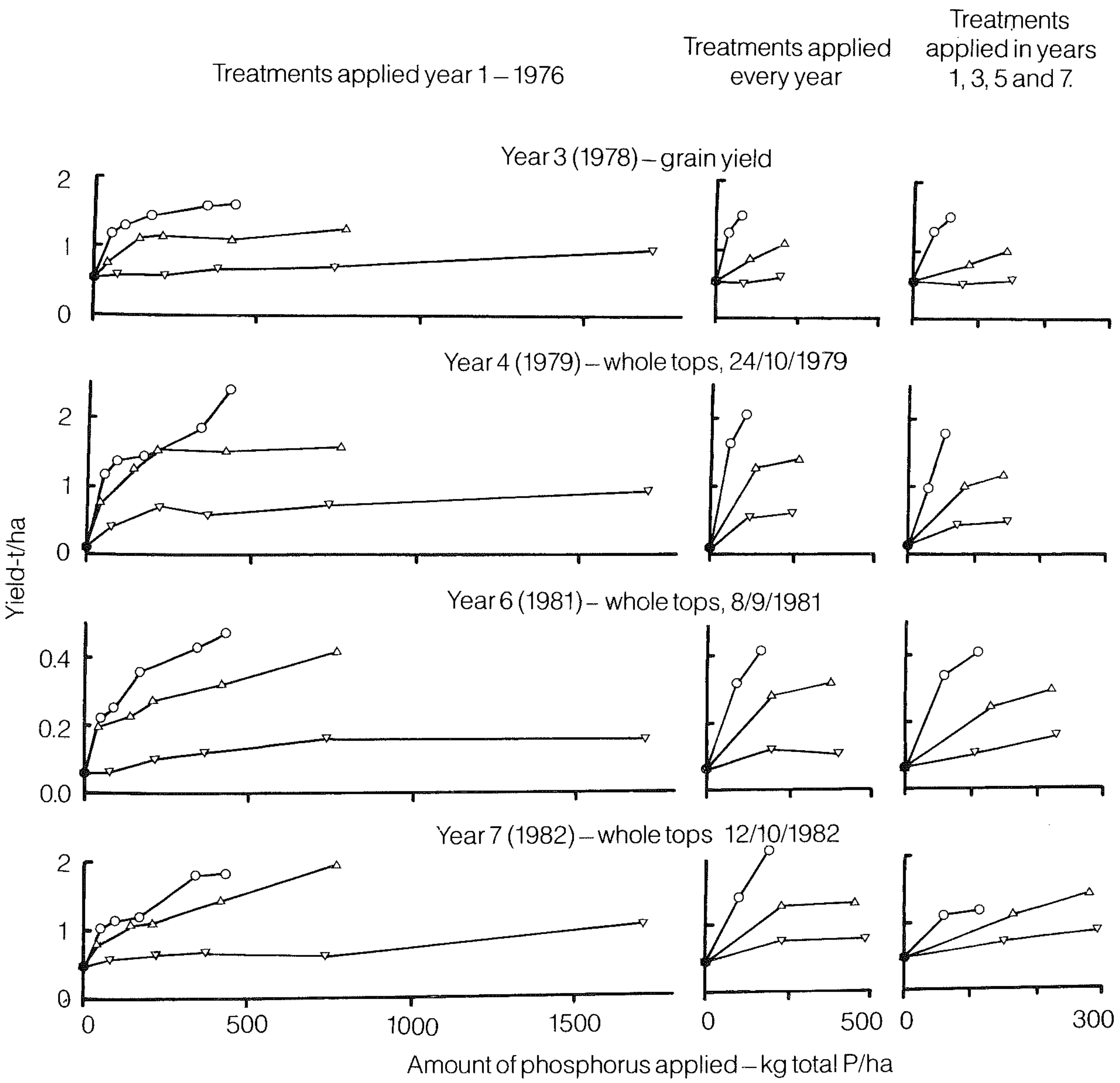


Figure 4(b) Cereal grain and herbage yields at Newdegate. QRP was not used. △ Calciphos, ▽ C-ore, ○ superphosphate.

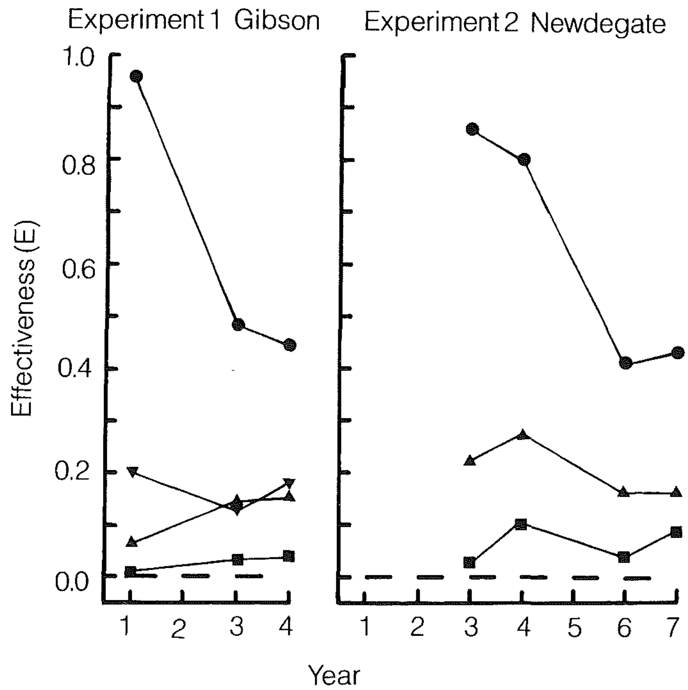


Figure 5. Effectiveness (E) of the phosphatic fertilizers for different years calculated using plant yield for the experiments at Gibson and Newdegate. The E values were calculated from the initial slope of the relationship between percentage of the greatest (maximum) yield and the amount of total phosphorus applied, using nil and the first two levels of phosphorus applied. At Gibson, herbage yields of subterranean clover were used. At Newdegate, barley grain yields were used in year 3 (1978), and whole tops in years 4, 6 and 7. Maximum yields (kg/ha) measured from the superphosphate cross strip applied in the current year were (1) Gibson : year 1, 1500; year 3, 6300; year 4, 2800; (2) Newdegate 2 : year 3, 1700; year 4, 3000; year 6, 800; year 7, 3000. In each case ■C-ore, ▲Calciphos, ▼QRP and ●superphosphate.

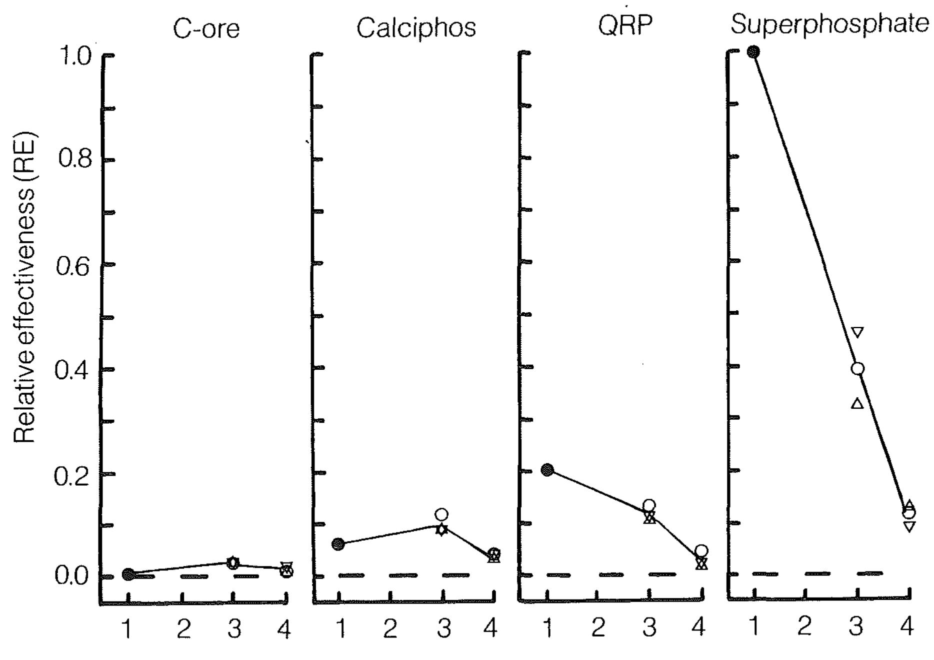


Figure 6. Effectiveness of the phosphatic fertilizers relative to superphosphate applied in the current year (relative effectiveness or RE) in years 1, 3 and 4 calculated for the Gibson experiment. RE was calculated for the relationship between yield and phosphorus applied by dividing the slope for the subplots by the initial slope for the superphosphate cross plots applied in the current year (see text and Bolland *et al.* 1984). In each case, RE calculated using the following levels of phosphorus applied to the subplots in year 1: nil and the first two levels of application (○); the first, second and third levels of application (△); the second, third and fourth level of application (▽).

Using plant yield, superphosphate was by far the most effective phosphatic fertilizer for all years in the Gibson and Newdegate experiments (figures 5 and 6). The effectiveness of superphoshate declined through time, but was always much higher than for the rock phosphates. The effectiveness of superphosphate decreased by about 50% between years 1 and 4 at Gibson, and by about the same amount between years 3 and 7 at Newdegate (figure 5). At Gibson and Newdegate, C-ore and Calciphos were respectively between about 3-10%, and 10-20% as effective as superphosphate applied in the first year. At Wongan Hills, year 7 results (calculated using grain yields of wheat) showed that as C-ore and Calciphos were respectively 10% and 50% as effective as superphosphate. The values were 0.05, 0.21 and 0.51 for C-ore, Calciphos and superphosphate, respectively.

Relative effectiveness is probably the best method of comparing fertilizer effectiveness (Eik *et al.* 1961; Barrow and Campbell 1972; Bolland *et al.* 1984), and was used to calculate the effectiveness of the fertilizers in experiment 1 at Gibson. It was possible to calculate relative effectiveness in this experiment, because more than one rate of superphosphate was applied across the treatments each year. The relative effectiveness of superphosphate at Gibson decreased by 90% from year 1 to year 4 (figure 6). The relative effectiveness of the rock phosphate fertilizers, particularly C-ore, was very low and remained low for the duration of the experiment (figure 6). Relative to freshly applied superphosphate, C-ore and Calciphos were about 1.5% and 10% as effective, respectively. QRP was initially about 20% as effective as freshly applied superphosphate, but its effectiveness decreased through time. By year 4 it was about 5% as effective as freshly applied superphosphate.

For the Gibson experiment, the superior effectiveness of superphosphate compared to the rock phosphates is shown in figure 7. Compared with the relatively large amounts of phosphorus applied as rock phosphate in year 1, the addition of only very small amounts of superphosphate in years 3 and 4 markedly increased pasture yield. None of the rock phosphates produced the same maximum yield as currently applied superphosphate. This confirms the results from other field experiments (Bolland 1985; Bolland and Bowden 1982, 1984; Bolland *et al.* 1984).

For the experiments at Newdegate and Wongan Hills, the effectiveness of each fertilizer calculated from plant yield was similar for all treatments applied either in year 1 only, annually, or in years 1, 3, 5 and 7. The mean of all these data are shown in figure 5.

Discussion

The main finding is that, at the locations tested, C-ore and Calciphos are unlikely to be economical alternative phosphatic fertilizers for superphosphate. Superphosphate was initially the most effective fertilizer and remained the most effective for the duration of the three experiments (up to seven years). C-ore and Calciphos were respectively about 5% and 12% as effective as superphosphate applied in the first year. On this basis it would not be economical to develop the C-ore deposits on Christmas Island since C-ore and Calciphos would need to be 5% and 12% the price of superphosphate applied in the paddock. Our evidence suggests that, despite applying large amounts of C-ore or Calciphos, neither can support the same yield as much smaller amounts of freshly applied superphosphate (figures 4 and 7). It would be uneconomic for farmers to apply the very large amounts of C-ore and Calciphos required to give near maximum yields. The effectiveness of granulated rock phosphates is usually extremely poor so both are applied as fine powders, which are difficult to handle and spread. The effectiveness of rock phosphates is maximized when they are finely ground (Khasawneh and Doll 1978).

In contrast, granulated superphosphate is highly effective and convenient to use. Other plant nutrients are present, or can be incorporated into the granules and applied in the one operation. This is very difficult to do with the fine rock phosphate powders.

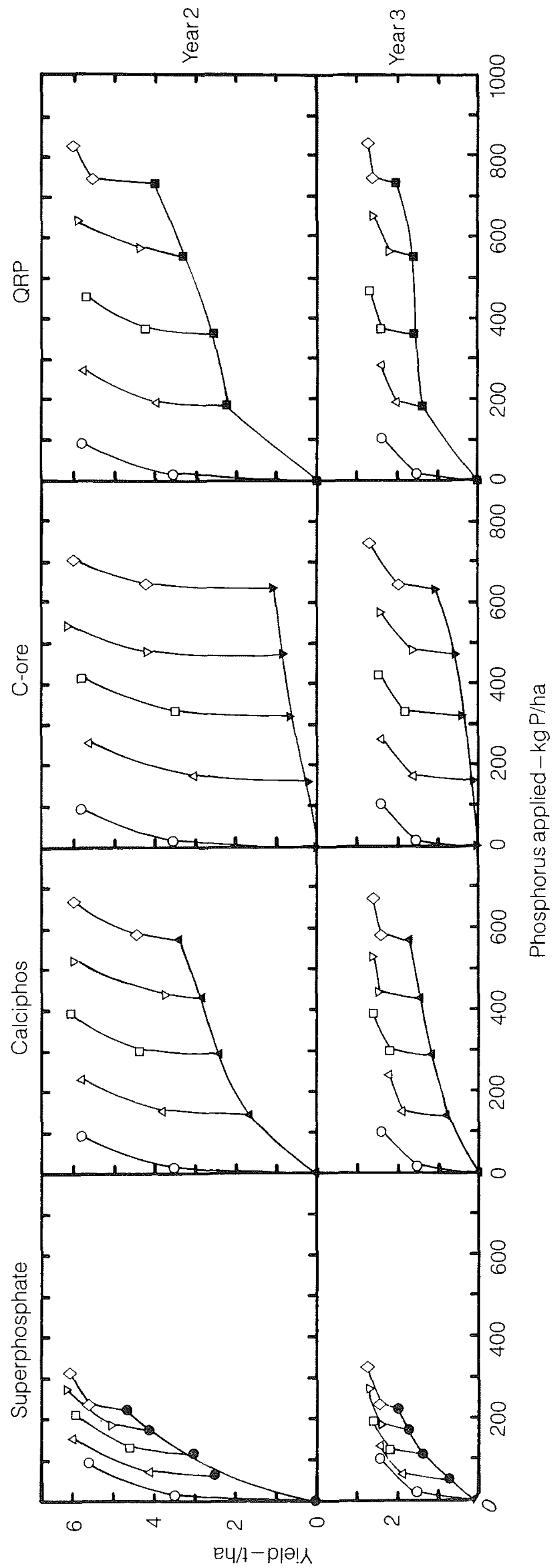


Figure 7. Yield of pasture compared with amount of phosphorus applied in years 3 and 4 for Gibson experiment. In each case, fertilizer applied to subplots in year 1: ▼C-ore, ▲Calciphos, ■QRP, and ●superphosphate. ○, △, □, ▽, ◇, cross plots of superphosphate applied in the current year.

At Gibson, Duchess rock phosphate, also a fine powder, was only about 14% as effective as freshly applied superphosphate. As with C-ore and Calciphos, it is unlikely to be an economic alternative phosphatic fertilizer to superphosphate, and is unable to support the same yield as much smaller amounts of freshly applied superphosphate (figure 7).

The results confirm and enlarge upon data already reported for the rock phosphates and superphosphate on newly cleared lateritic gravel soils in south-west Western Australia for various management systems involving permanent subterranean clover pasture (Bolland and Bowden 1982, 1984; Bolland *et al* 1984) and continuous cropping with wheat (Bolland 1985). The effectiveness of the fertilizers calculated using bicarbonate-soluble soil phosphorous and yield tended to be higher for the two experiments with a superphosphate history (Newdegate and Wongan Hills). The reason for this is not known. Qualitatively, the changes in effectivenes of the fertilizers through time in these three experiments and previously published data are similar. Quantitatively, however, the results are specific to site and management practice and not readily transferred to other sites and management strategies — a major problem with most field experiments.

Slow release (i.e., slowly dissolving) rock phosphate fertilizers, may have a role for poorly buffered deep sandy soils in > 400 mm/a rainfall areas (e.g. Wright 1975). Phosphorus from superphosphate rapidly leaches down the profile of some deep sandy soils (Hingston 1959; Ozanne *et al.* 1961; Alston and Chin 1974; Clarke 1974). Rock phosphates may maintain the supply of phosphorus near the surface of these soils and so near the roots of shallow rooted annual plants.

Acknowledgments

Technical assistance was provided by Messrs M.J. Baker and R.J. Lunt. The Newdegate experiment was on the property of Mr P. Clarke. Determination of bicarbonate-extractable soil phosphorus, and the data for table 1, was provided by the Government Chemical Laboratories of Western Australia. Financial support was provided by the Wheat Industries Research Council of Australia. Associate Professor R.J. Gilkes made helpful comments on an earlier manuscript. The manuscript was typed by the Word Processing Centre and the graphics and design was done by Mr L.T. Webb and Ms F. Roberts of the Information Branch, Western Australian Department of Agriculture, South Perth.

References

Abbott, C.A. (1983). Australian phosphorus : availability and economic perspectives. In, 'Phosphorus in Australia'. Eds. A.B. Costin and C.H. Williams. Ch. 2, pp. 43-69. Australian National University : Canberra, Australia.

Alston, A.M. and Chin, K.W. (1974). Rock phosphate and superphosphate as sources of phosphorus for subterranean clover on an acid sandy soil. *Australian Journal of Experimental Agriculture and Animal Husbandry.* **14** : 358-361.

A.O.A.C. (1975). "Official Methods of Analysis". 12 Edition, Section 2.037 (Association of Official Agricultural Chemists : Washington, D.C.).

Arndt, W. and McIntyre, G.A. (1963). The initial and residual effects of superphosphate and rock phosphate for sorghum on a lateritic red earth. *Australian Journal of Agricultural Research.* **14** : 785-795.

Barrow, N.J. (1980). Evaluation and utilization of residual phosphorus in soils. In, 'The Role of Phosphorus in Agriculture.' (Eds. F.E. Khasawneh, E.C. Sample and E.J. Kamprath). Ch. 13, pp. 333-59. (American Society of Agronomy: Madison, Wisconsin, United States of America).

Barrow, N.J. and Campbell, N.A. (1972). Methods of measuring residual value of fertilizers. *Australian Journal of Experimental Agriculture and Animal Husbandry.* **12** : 502-510.

Bolland, M.D.A. (1985). The residual value for wheat of phosphorus from Calciphos, Queensland rock phosphate and triple superphosphate on a lateritic soil in south-western Australia. *Australian Journal of Experimental Agriculture.* **25** : 198-208.

Bolland, M.D.A. and Bowden, J.W. (1982). Long-term availability of phosphorus from calcined rock phosphate compared with superphosphate. *Australian Journal of Agricultural Research.* **33** : 1061-1071.

Bolland, M.D.A. and Bowden, J.W. (1984). The initial and residual value for subterranean clover of phosphorus from Crandallite rock phosphates, apatite rock phosphates and superphosphate. *Fertilizer Research.* **5** : 295-307.

Bolland, M.D.A., Bowden, J.W., D'Antuono, M.F. and Gilkes, R.J. (1984). The current and residual value of superphosphate, Christmas Island C-grade ore, and Calciphos as fertilizers for subterranean clover pasture. *Fertilizer Research.* **5** : 335-354.

Buchan, J.A.J., Muller, F.B., Rogers, J., Seager, R.H. and Yong, T.A. (1970). Agronomic use of calcined Christmas Island iron/aluminium phosphate. II. Pot trials. *New Zealand Journal of Agricultural Research.* **13** : 465-480.

Chien, S.H. (1981). Direct application of phosphate rocks in some tropical soils of South America: A status report. In, *Proceedings of the International Conference on Phosphorus and Potassium in the Tropics.* Eds. E. Puspharajah and H.A. Hamid Sharifuddin. pp. 509-529. Malaysian Society of Soil Science, Kuala Lumpur, Malaysia.

Clarke, A.L. (1974). The retention of phosphate fertilizers in leached soil and their nutritive value to pasture. *Proceedings of the XII International Grasslands Congress,* Moscow.

Colwell, J.D. (1963). The estimation of phosphorus fertilizer requirements of wheat in southern New South Wales by soil analysis. *Australian Journal of Experimental Agriculture and Animal Husbandry.* **3** : 190-197.

Devine, J.R., Gunary, D. and Larsen, S. (1968). Availability of phosphate as affected by duration of fertilizer contact with soil. *Journal of Agricultural Science.* **71** : 359-364.

Doak, B.W., Callaher, P.J., Evans, L. and Muller, F.B. (1965). Low temperature calcination of C-grade phosphate from Christmas Island. *New Zealand Journal of Agricultural Research.* **8** : 15-29.

Earle, D.F. and McGowan, A.A. (1979). Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry.* **19** : 337-43.

Eik, K., Webb, J.R., Black, C.A., Smith, C.M. and Pesek, J.T. (1961). Evaluation of residual effects of phosphate fertilization by laboratory and plant-response methods. *Soil Science Society of America Proceedings.* **25** : 21-24.

Gilkes, R.J. and Palmer, B. (1979). Calcined Christmas Island rock phosphate fertilizers : mineralogical properties, reversion and assessment by chemical extraction. *Australian Journal of Soil Research.* **17** : 467-481.

Hammond, L.L. (1981). Agronomic measurements of phosphate rock effectiveness. Seminar on Phosphate Rock for Direct Application. pp. 147-173. Special Publications IFDC-SI, International Fertilizer Development Centre (IFDC), Muscle Shoals, Alabama.

Hingston, F.J. (1959). The loss of applied phosphorus and sulphur from soils under pasture in Western Australia. *Journal of the Australian Institute of Agricultural Science.* **25** : 209-213.

Hoare, J. (1980). Phosphate raw materials and fertilizers. II. A case history of marginal raw materials. In, *The Role of Phosphorus in Agriculture.* Eds. F.E. Khasawneh, E.C. Sample and E.J. Kamprath. Ch. 4, pp. 121-128. American Society of Agronomy : Madison, Wisc. U.S.A.

Johnston, D.A.W. (1983) ed. Wheat in Western Australia, Western Australian Department of Agriculture, Bulletin No. 4076.

Khasawneh, F.E. and Doll, E.C. (1978). The use of phosphate rock for direct application to soils. *Advances in Agronomy.* **30** : 159-206.

Lehr, J.R. and McClellan, G.H. (1972). A revised laboratory reactivity scale of evaluating phosphate rocks for direct application. Bulletin Y-43, Tennessee Valley Authority, Muscle Shoals, Alabama.

Lehr, J.R., McClellan, G.H., Smith, J.P. and Fraizer, A.W. (1967). Characterisation of apatites in commerical phosphate rock. *Proceedings of the International Colloquium on Solid Inorganic Phosphates.* **12** : 29-35.

Lipsett, J. and Williams, C.H. (1970). Evaluation of Christmas Island C-grade phosphate as a fertilizer on some soils in southern New South Wales. *Australian Journal of Experimental Agriculture and Animal Husbandry.* **10** : 783-789.

Mattingly, G.E.G. (1971). Residual value of phosphate fertilizer on neutral and calcareous ground. In, *Residual value of applied nutrients.* pp. 1-9. Technical Bulletin, Ministry of Agriculture, Fisheries and Food, HMSO, London.

Mason, M.G. and Cox, W.J. (1969). Calcined rock phosphate as a fertilizer for pasture and cereal production in Western Australia. *Australian Journal of Experimental Agriculture and Animal Husbandry.* **9** : 99-104.

Northcote, K.H. (1979). 'A Factual Key for the Recognition of Australian Soils'. 4th Edn. (Rellim Technical Publications : Glenside, South Australia).

Ozanne, P.G. and Shaw, T.C. (1967). Phosphate sorption by soils as a measure of the phosphate requirement for pasture growth. *Australian Journal of Agricultural Research.* **18** : 601-612.

Ozanne, P.G., Kirton, D.J. and Shaw, T.C. (1961). The loss of phosphorus from sandy soils. *Australian Journal of Agricultural Research.* **12** : 409-423.

Palmer, B. (1980). A chemical, mineralogical and biological evaluation of calcined Christmas Island C-grade rock phosphate. Ph.D. Thesis, University of Western Australia, Perth.

Palmer, B., Bolland, M.D.A. and Gilkes, R.J. (1979). A re-evaluation of the effectiveness of calcined Christmas Island C-grade rock phosphate. *Australian Journal of Experimental Agriculture and Animal Husbandry.* **19** : 605-10.

Smith, A.N. (1983). Australian dependence on phosphorus. In, *Phosphorus in Australia.* Eds. A.B. Costin and C.H. Williams. Ch. 3, pp. 75-91. Australian National University : Canberra, Australia.

Trumble, H.C. and Donald, C.M. (1938). The relation of phosphate to the development of seeded pasture on a podzolised sand. CSIR, (Australia), Bulletin 116, Melbourne.

White, M.S. (1971). Calcination of Christmas Island phosphates. *New Zealand Journal of Science.* **14** : 971-992.

Wild, A. (1958). The phosphate content of Australian soils. *Australian Journal of Agricultural Research.* **9** : 183-204.

Wright, D.N. (1975). Calcined Christmas Island C-grade rock phosphate as a fertilizer. *Australian Journal of Experimental Agriculture and Animal Husbandry.* **15** : 419-423.

53672/4/87-1 100-L/4267 WILLIAM BENBOW, Acting Government Printer, Western Australia