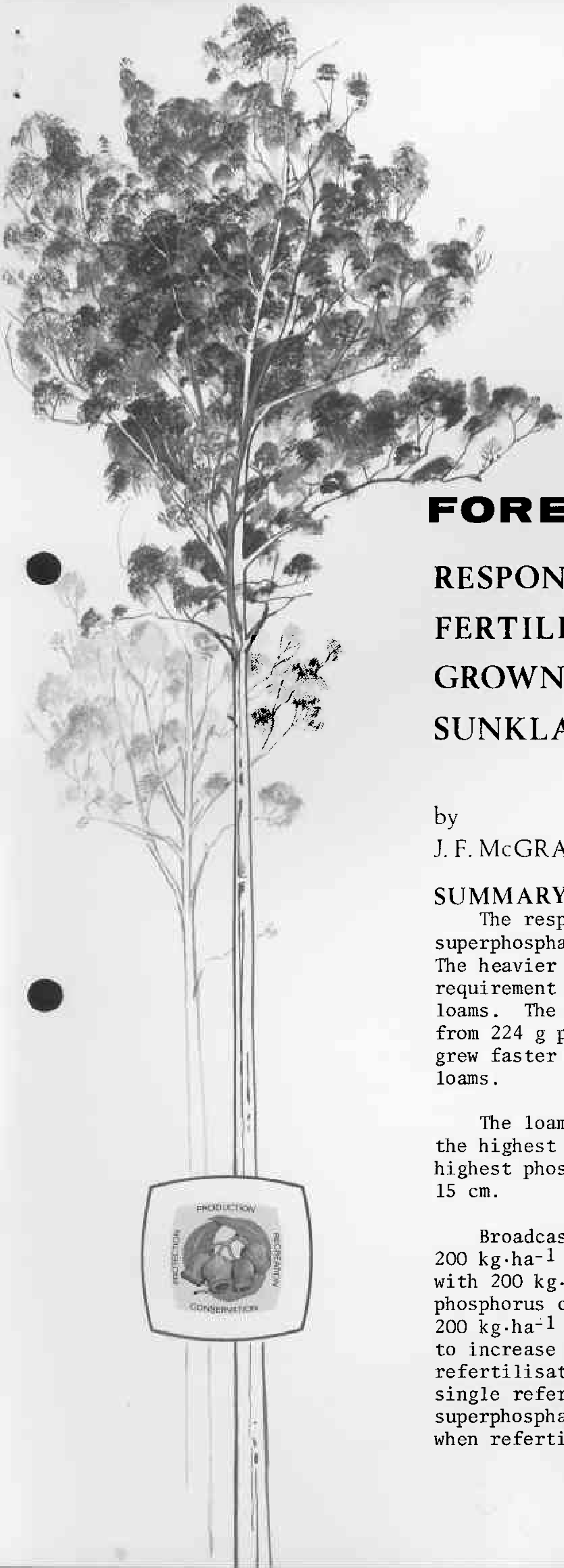

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RESPONSE TO PHOSPHORUS FERTILISATION OF *Pinus radiata* GROWN ON THE DONNYBROOK SUNKLAND

by
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SUMMARY

The response shown by *Pinus radiata* D.Don to superphosphate applied at planting depended on soil type. The heavier loamy sands had a higher phosphate requirement for optimum growth than the lighter sandy loams. The optimum superphosphate application ranged from 224 g per tree to 448 g per tree. *Pinus radiata* grew faster on the heavier loamy sands than on the sandy loams.

The loam soil on which *P. radiata* grew fastest had the highest available phosphate content, and the highest phosphate adsorption capacity in the surface 15 cm.

Broadcast refertilisation of 3-year-old trees with 200 $kg \cdot ha^{-1}$ superphosphate, and of 4-year-old trees with 200 $kg \cdot ha^{-1}$ rock phosphate increased foliar phosphorus concentrations. A single application of 200 $kg \cdot ha^{-1}$ superphosphate to 4-year-old trees failed to increase phosphorus concentrations. The double refertilisation increased tree growth more than the single refertilisation did. It appears that rates of superphosphate greater than 200 $kg \cdot ha^{-1}$ are necessary when refertilising *P. radiata* on the Sunkland.

INTRODUCTION

The soil types classified as suitable for the establishment of Pinus radiata D.Don on the Donnybrook Sunkland are mainly slightly acidic yellow and grey sandy loams which become heavier textured with increased depth. These soils are described by Smith (1951) as Mungite sands and sandy loams.

The poor fertility of the Sunkland soils necessitates fertilisation at planting and at regular intervals thereafter. The importance of early high growth rates on the final production of wood is well documented. Waring (1974) found that delaying fertilisation of P. radiata until the fourth year after planting resulted in wood production which was only half that produced by trees fertilised at planting. A shortage of millable timber in Western Australia makes rapid growth rates highly desirable in order to provide the maximum quantity of timber in the shortest possible time.

In a review of fertilisers used in silviculture Bengtson (1977) states that water-soluble phosphatic fertilisers such as ordinary superphosphate and concentrated (triple) superphosphate are more effective sources of phosphate for pine establishment than the less soluble ground rock phosphate and calcined rock phosphate. Superphosphate was used in this trial as it is a soluble phosphatic fertiliser.

The aims of the trial were:
(1) to determine the phosphate response curves for P. radiata grown on four different Sunkland soil types;

(2) to determine the optimum initial rate of superphosphate required on each of these sites and to test the refertilisation requirements necessary for continued high growth rates.

METHOD

The trial was located on four plots of different soil types on the Sunkland. The soil characteristics of the sites are as follows:

Site 1 Light yellow and light grey sandy loam, becoming heavier textured with increased depth, surface pH 6.0.

Site 2 Surface varies from grey to brown to yellow loamy sand, heavier textured with increased depth, surface pH 5.6.

Site 3 Coarse yellow sand overlying a ferruginous gravel at approximately 75-80 cm, surface pH 6.3.

Site 4 Coarse light grey sand over lateritic gravel. The depth to the gravel varies from 20 to 80 cm, but at some locations within the plot the depth of sand is greater than 1 m, surface pH 5.9.

The plots were cleared and burnt in 1970, and double ploughed and mounded in 1971. Plots were established in August-September 1971 with one-year-old P. radiata seedlings spaced at 2.7 m between mounds and 2.1 m on mounds.

Superphosphate was applied at five different rates: 56, 112, 224, 448, 896 g per tree. In addition, each tree received an application of 28 g of "Minorels", a commercial minor element mix containing; Calcium 5.0%, Copper 1.0%, Zinc 0.7%, Manganese 2.25%, Magnesium 3.3%, Iron 3.5%, Molybdenum 0.04%, Boron 0.1%, Aluminium 1.0%.

Treatments were arranged in a 5 x 5 Latin square on all sites. Plot sizes vary but are approximately 0.02 ha each. Each measurement plot is surrounded by a two-row buffer zone. Refertilisation and silvicultural procedures carried out since establishment are shown in Table 1.

Height of all trees was measured on all sites in August 1972 and November 1974, of all trees on Sites 1 and 2 in July 1973 and of all trees on Sites 3 and 4 in August 1973. Plot top height was measured in March 1976. Top height for the 1972, 1973, 1974 data was calculated by using the mean of the three tallest trees per plot. Diameter at breast height over bark was measured in March 1976 and March 1977.

Foliar samples were taken annually in early autumn (March) from 1973 onwards. The samples were analysed for phosphorus and various other nutrients. Unfortunately, replicates were bulked by treatment in 1975, 1976 and 1977 so no statistical analysis of these results was possible after 1974.

TABLE 1

Fertiliser and silvicultural treatments subsequent to initial establishment

Plot	Fertiliser	Rate (kg.ha-1)	Application date	Foliar sprays	Rate* (per cent)	Application date	Pruning details
Site 1	Super-phosphate	200	26.8.75	Zn Mn Cu	5 5 0.2	22.11.74	All plots were low pruned (2.1 m) in August 1975
Site 2	Super-phosphate	200	26.8.75	Zn Mn Cu	2.5 2.5 0.1	17.11.75	
Site 3	Super-phosphate	200	16.1.74	Zn	(1) 2.5 (2) 5	(1) 3.12.73	
	Rock phosphate	200	7.10.75	Mn	2.5 5	(2) 14.11.74	
	Urea	200	7.10.75	Cu	0.2		
Site 4	Super-phosphate	200	16.1.74	Zn	(1) 2.5 (2) 5	(1) 3.12.74	
	Rock phosphate	200	7.10.75	Mn	2.5 5	(2) 14.11.74	
	Urea	200	7.10.75	Cu	0.2		

* per cent weight for weight of the appropriate sulphate in aqueous solution

(1) First fertiliser treatment subsequent to initial establishment
(2) Second fertiliser treatment subsequent to initial establishment

Four random soil profiles were sampled on each site in 1977. The profiles were divided into three "horizons": 0-15 cm; 16-30 cm; 31-45cm. Total and available phosphorus were determined for each profile and phosphate adsorption isotherms were determined for two profiles on each site.

Total phosphorus was taken as the phosphorus extracted from the soil by boiling it for 4 hours in HCl. Available phosphorus was determined using the modified Bray extraction procedure described by Arnold (1947). Phosphate adsorption isotherms were determined using the method of Ozanne and Shaw (1967). Phosphorus concentration in the extract solutions was measured colorimetrically using the method of Murphy and Riley (1962).

RESULTS

Average plot top height increased significantly ($p < 0.01$) with increased rate of superphosphate on Sites 1, 2 and 3 in all years (Fig. 1). There were no responses to increased rates of superphosphate on Site 4 in 1972 and 1973 and only a very small response was evident in the 1974 and 1976 top height data. There were no significant increases in tree top height where fertiliser applications were above 224 g per tree on Sites 1 and 3 or above 448 g per tree on Site 2.

When plotted basal area measurements (Fig. 2) gave growth response curves similar to those for top height. The differences between sites and fertiliser treatments were magnified by the basal area data, indicating that basal area is more sensitive to growth conditions than is top height.

Figures 1 and 2 show that growth varied between the four sites (significant at $p < 0.01$). The best growth occurred on the yellow-grey sandy loam on Site 2 and the worst on the coarse light grey sand on Site 4. Height and diameter growth on Sites 1 and 3 ranged between those on Sites 2 and 4. From the increment data presented in Table 2 it appears that after refertilisation in 1974 and 1975 differences between annual growth increments on the four sites were reduced.

TABLE 2

Annual growth increments as a percentage of the Site 2 increment

Year	Site 2	Site 1	Site 3	Site 4
*1972-73	100	65	70	64
1973-74	100	85	73	62
1974-76	100	97	95	74
**1976-77	100	104	98	109

*1972-73, 1973-74, 1974-76 data from top height increments

**1976-77 data from basal area increments

The total and available phosphorus levels were very low for all the soils (Table 4). Site 2 has the highest available phosphorus content in the surface horizon. Both the sandy soil types (Sites 3 and 4) have significantly ($p < 0.01$) lower total and available phosphorus levels than the finer-textured clay soils on Sites 1 and 2. The phosphate adsorption isotherms (Fig. 3) show that the soil on Site 2 has a higher adsorption capacity than those on the other sites. On Sites 1, 3 and 4 the phosphate adsorption capacity decreases as depth increases which indicates that the organic matter in the surface horizon of the profile is important in determining the phosphate retention ability of these soils. In contrast with the other three sites the phosphate adsorption capacity on Site 2 increased with increasing depth.

The 1973 and 1974 foliar phosphorus concentrations increased significantly ($p < 0.05$) with increased initial phosphate application at all sites. This trend continued throughout the trial (Table 3).

The phosphorus concentrations in 1973 were low on all sites, even on the plots with the highest rates of application. The highest phosphorus concentrations in 1973 were on Site 4, the plot where growth was slowest: throughout the trial Site 4 showed the slowest growth and the highest phosphorus concentrations. This indicates that phosphorus is not the limiting nutrient on this site; growth factors other than phosphorus probably limit growth. Of the other three sites the fastest growing plot (Site 2) had the highest foliar phosphorus concentrations.

Refertilisation on Sites 3 and 4 in 1974 (superphosphate) and 1975 (rock phosphate) was reflected in the increased phosphorus concentrations in the 1975 and 1976 analyses. Refertilisation of Sites 1 and 2 in 1975 seemed to increase the phosphorus concentrations of the treatments that received the higher initial rates of phosphate. The effects of refertilisation on phosphorus concentrations were transitory, as two years after refertilisation the foliar phosphorus concentrations were the same as before refertilisation. The double refertilisation on Sites 3 and 4 prolonged the increase in phosphorus concentrations. Three years after refertilisation the phosphorus concentrations were slightly higher than before refertilisation, but were below the adequate concentration.

DISCUSSION

Top height and basal area data show typical phosphorus growth responses to increased rates of phosphate. Without the addition of phosphorus *P. radiata* does not grow on the Sunkland soils (F.H. McKinnell, personal communication). In view of the low levels of total and available phosphorus in these soils (Table 4), and the known high nutrient requirement of *P. radiata*, this result is not surprising.

The optimum initial application rate of superphosphate indicated by the top height and basal area growth curves is 224 g per tree on Sites 1 and 3 and 448 g per tree on Site 2. These predicted optimum rates may not be accurate because of the great

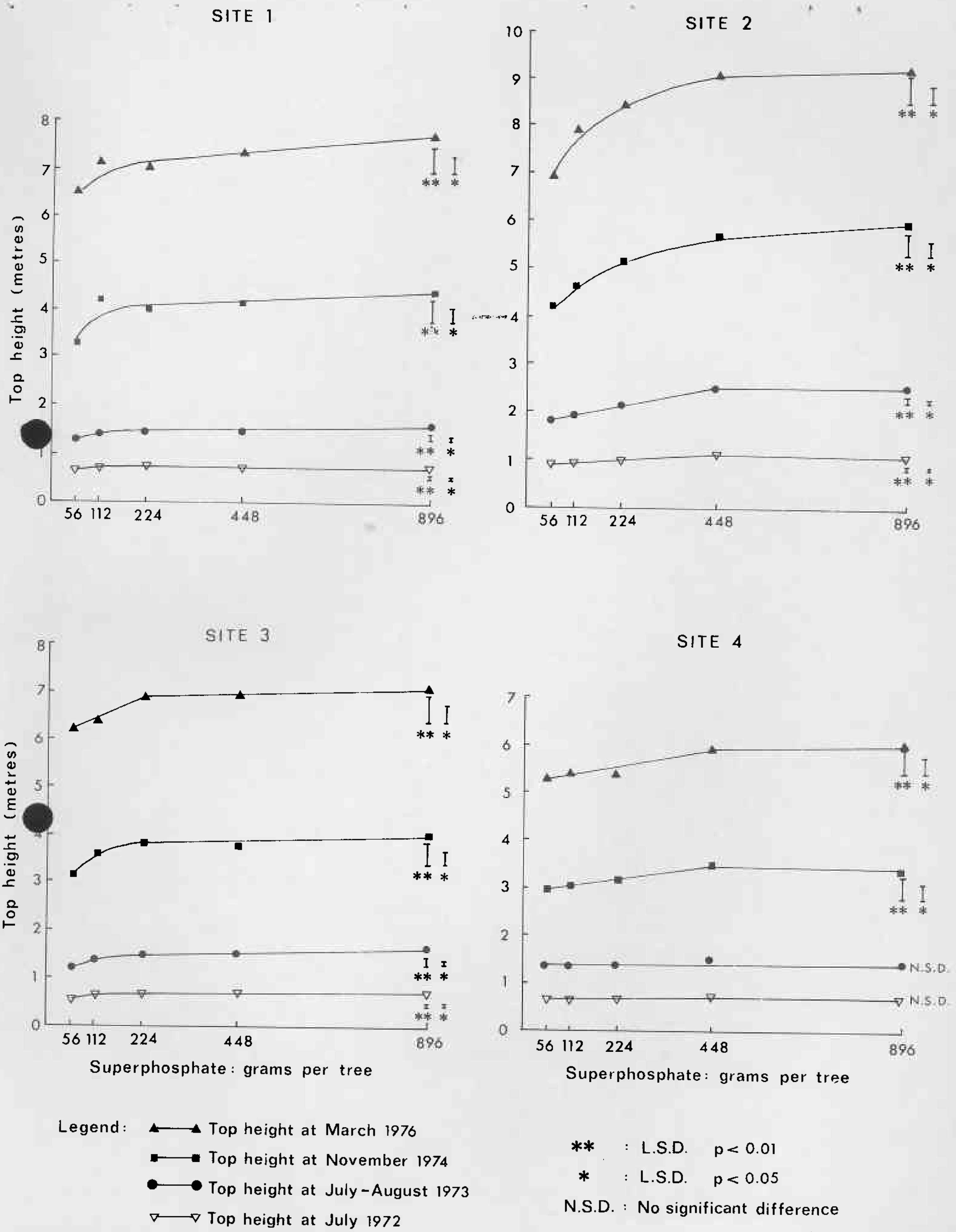

FIGURE 1: Mean plot top height (1972-1976) plotted against initial superphosphate rate on 4 different Sunkland sites.

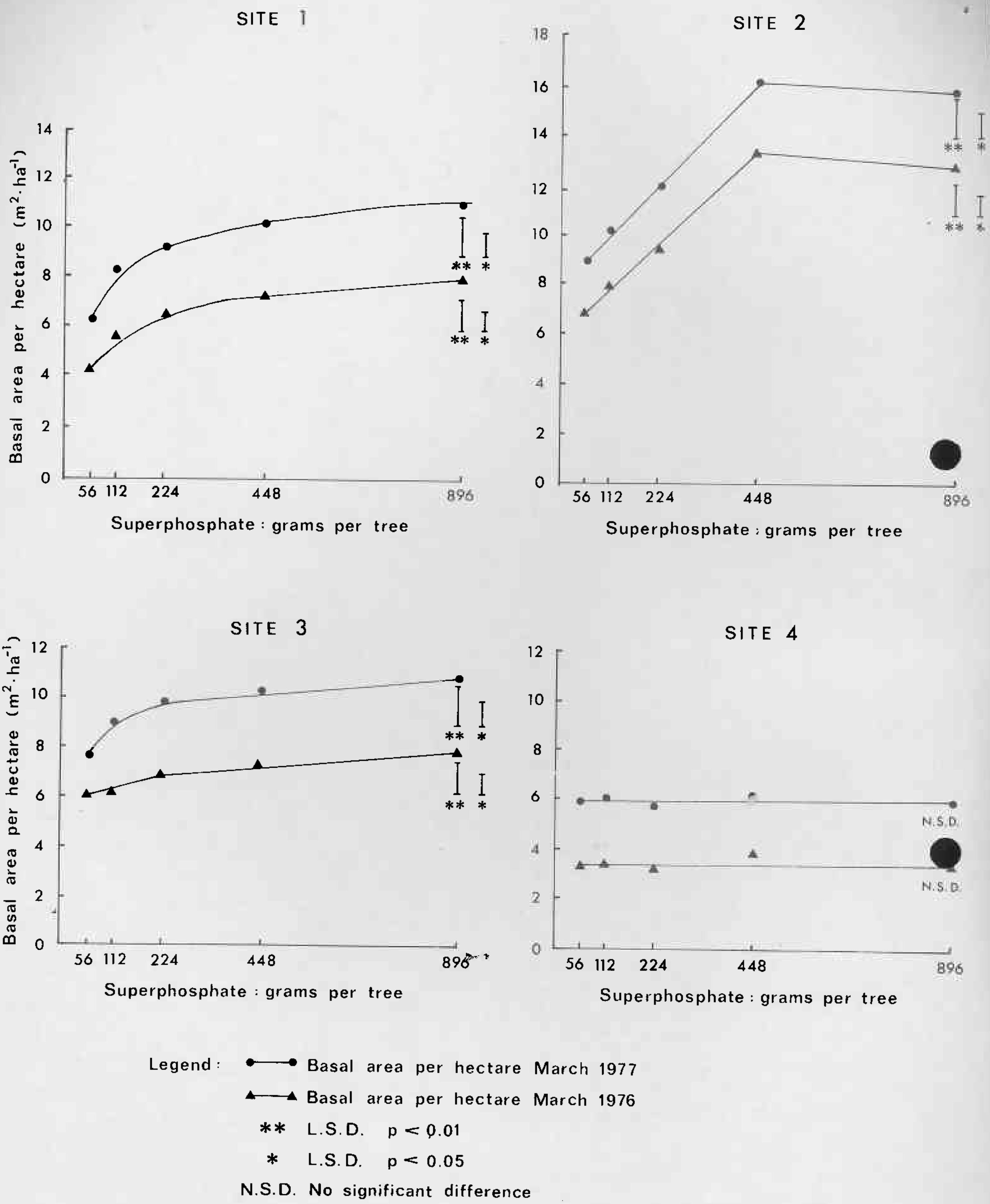

FIGURE 2: Mean plot basal areas (1976-1977) plotted against initial superphosphate rate on 4 different Sunkland sites.

TABLE 3

Mean foliage phosphorus concentrations (per cent dry weight)

Plot	Year	Superphosphate Rate (grams per tree) 56	112	224	448	896	Annual Mean
Site 1	1973	0.068	0.059	0.081	0.062	0.063	0.067
	1974	0.090	0.104	0.098	0.134	0.116	0.108
	1975	NS	NS	NS	NS	NS	NS
	1976	0.108	0.123	0.124	0.126	0.143	0.125
	1977	0.090	0.098	0.111	0.101	0.138	0.108
Site 2	1973	0.054	0.063	0.080	0.065	0.082	0.069
	1974	0.085	0.108	0.135	0.171	0.164	0.133
	1975	0.131	0.150	0.141	0.112	0.142	0.135
	1976	0.100	0.111	0.112	0.141	0.167	0.126
	1977	0.074	0.083	0.085	0.097	0.139	0.096
Site 3	1973	0.052	0.055	0.057	0.067	0.060	0.058
	1974	0.071	0.094	0.104	0.112	0.110	0.098
	1975	NS	NS	NS	NS	NS	NS
	1976	0.151	0.136	0.156	0.174	0.138	0.151
	1977	0.104	0.110	0.120	0.114	0.110	0.112
Site 4	1973	0.072	0.079	0.078	0.100	0.110	0.088
	1974	0.091	0.100	0.122	0.115	0.124	0.110
	1975	0.128	0.129	0.131	0.135	0.151	0.135
	1976	0.146	0.135	0.195	0.193	0.216	0.177
	1977	0.133	0.116	0.119	0.146	0.131	0.129
Treatment mean		0.097	0.103	0.114	0.114	0.128	

1973 L.S.D. $p < 0.01 = 0.014$
L.S.D. $p < 0.05 = 0.009$

1974 L.S.D. $p < 0.01 = 0.025$
L.S.D. $p < 0.05 = 0.016$

NS = not sampled

TABLE 4

Mean HCl extractable phosphorus and mean available phosphorus concentrations

Depth (cm)	Site 1 HCl extracted phosphorus (ppm)	Site 1 Available phosphorus (ppm)	Site 2 HCl extracted phosphorus (ppm)	Site 2 Available phosphorus (ppm)	Site 3 HCl extracted phosphorus (ppm)	Site 3 Available phosphorus (ppm)	Site 4 HCl extracted phosphorus (ppm)	Site 4 Available phosphorus (ppm)
0-15	16.20	1.50	14.35	2.07	7.53	0.001	9.20	0.52
15-30	7.83	0.001	6.05	0.001	3.73	0.18	4.73	0.001
30-45	6.88	0.001	8.00	0.001	3.63	0.001	5.30	0.001

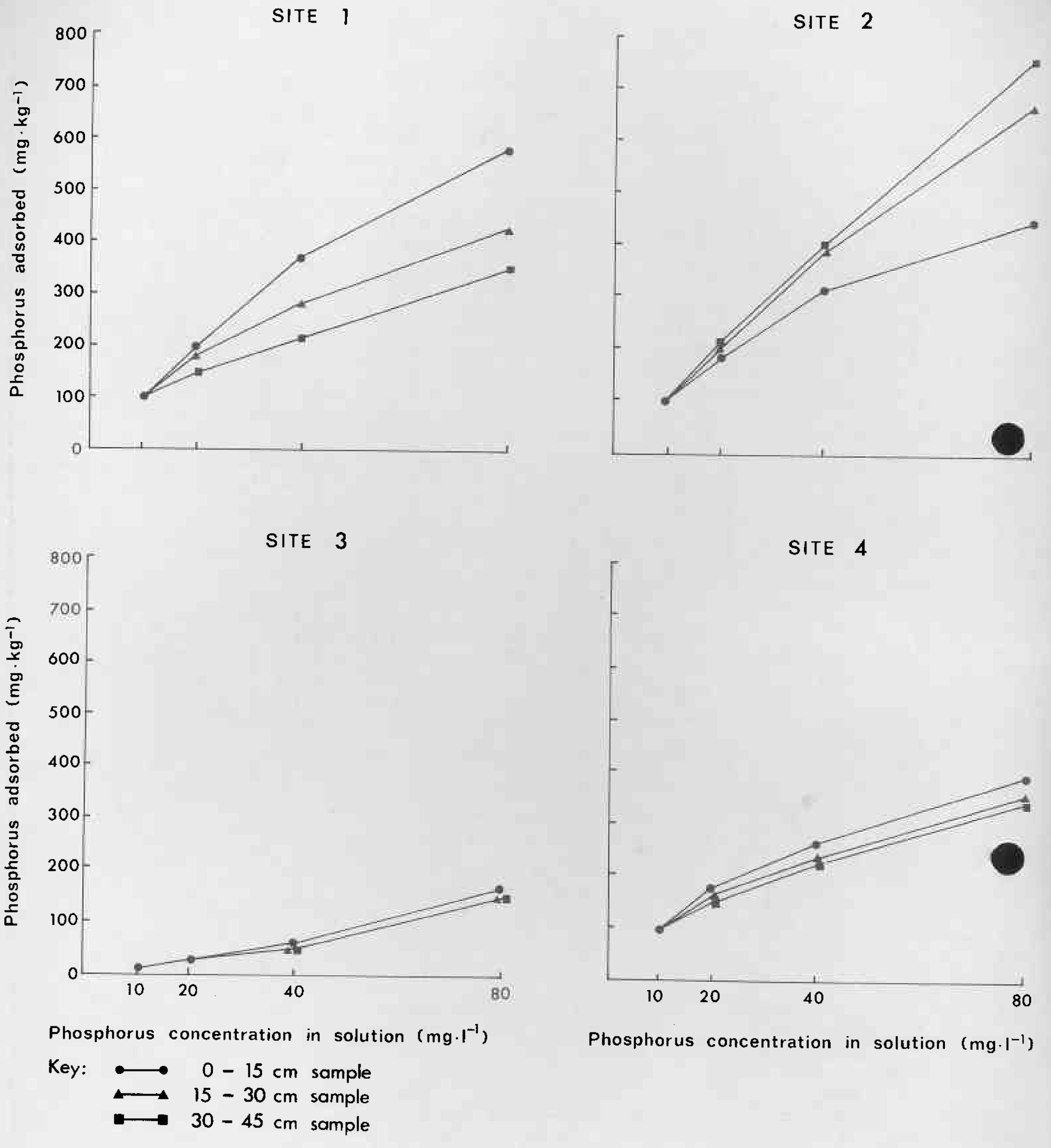

FIGURE 3: Phosphate adsorption isotherms: mean phosphorus adsorption ($mg \cdot kg^{-1}$) at 3 different profile positions plotted against phosphorus concentration ($mg \cdot l^{-1}$).

difference between the initial superphosphate rates. The rate of phosphate necessary to produce maximum growth depends to some extent on the supply of other nutrients available to the trees. The plateau in the growth curves is reached when phosphorus is no longer the limiting growth factor; if other growth factors are found to be limiting and can be remedied then the phosphorus requirement may change.

The higher superphosphate application necessary to produce maximum growth on Site 2 is probably due to the higher adsorption capacity of this soil (Fig. 3). The better initial growth on Site 2 relative to the other three sites could be due to a better supply of nutrients in this soil.

The slow growth and lack of a phosphorus response to applications above 56 g per tree on Site 4 indicate that the plateau stage of the response curve has been reached and that phosphorus is not limiting growth. This conclusion is supported by the comparatively high foliar phosphorus concentrations and by the increase in phosphorus concentrations with increased superphosphate application which are not accompanied by an increase in height or diameter growth.

The poor response to phosphorus fertilisation on Site 4 could be due to a high leaching loss because of the low phosphorus adsorption capacity of the soil. However, this is unlikely because Site 3 has a similar low adsorption capacity but responds to phosphate applications. Growth on Site 4 is probably limited by either water availability or another nutrient deficiency. Until the factors limiting the growth of *P. radiata* on this soil type are defined and remedied, planting and fertilising would be uneconomic.

The initial growth advantage obtained by the higher phosphate applications was maintained for the duration of the trial. Not only do the height and diameter growth reflect initial fertiliser applications after six years, but the foliar phosphorus concentrations also remain higher on the plots initially fertilised with high rates of superphosphate.

Refertilisation increased phosphorus concentrations in the foliage and increased growth on the poorer sites as shown by the increase in increment as a percentage of the Site 2 increment (Table 2). Refertilisation with superphosphate at the rate of 200 $kg \cdot ha^{-1}$ in 1975 had no significant effect on foliar phosphorus concentrations. This lack of response may be either, because of an immobilisation of phosphate by adsorption, or, because the phosphorus concentrations of the trees were below the sufficiency level of 0.17% (Raupach *et al.*, 1969), in which case any adsorbed phosphorus would be used for increasing growth rather than increasing the foliar phosphorus concentrations.

The double refertilisation on Sites 3 and 4 (Table 1) increased growth relative to Sites 1 and 2 which received only one refertilisation (Table 2). The increased growth rates on Sites 3 and 4 are probably due to the higher phosphorus concentrations, but by autumn 1977 the foliar phosphorus levels had dropped towards the critical level of 0.12%. It appears that the single superphosphate application of 200 $kg \cdot ha^{-1}$ on Sites 1 and 2 is inadequate to sustain the phosphorus requirements of *P. radiata* and a higher rate of refertilisation is probably necessary.

The short duration of the response to refertilisation on all sites indicates that either the quantities of fertiliser applied are inadequate or the applied fertiliser is not being used efficiently. Inefficient utilisation of fertiliser could be due to nutrient imbalance or deficiency that has not yet been defined or may be due to poor function of the mycorrhizae on these sites. Work is continuing on the definition of nutrient requirements of *P. radiata* on these soil types.

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