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Phosphate sources for pasture production on summer-dry soils in eastern New Zealand

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Abstract In the period 1988–96, staff of Ravensdown Fertiliser Co-operative Ltd undertook a series of pastoral trials with the primary purpose of examining the performance of commercially and locally available fertiliser products containing various forms of phosphorus (P) and sulphur (S). Treatments included Superphosphate (SSP), Longlife Super, two partially acidulated phosphate rocks (PAPRs), and North Carolina reactive phosphate rock (NCPR), all containing where required additional sulphur (as elemental S, So). These were applied annually for 6 years to supply the current requirements for P and S at each site. The sites were predominantly in eastern New Zealand. This paper covers 12 pastoral sites representing the summer-dry Pallic soils (yellow-grey earths and their intergrades to yellow-brown earths). In mowing trials, 10 sites responded significantly in dry matter production to the commercial fertilisers; the remaining two sites had high initial Olsen P values or did not last 6 years. Superphosphate, Longlife Super, and the PAPR products Hyphos Supreme and Phospar/So produced significantly more dry matter than the control in all years, as did NCPR/So from year 2. Superphosphate gave the highest mean dry matter in all years, producing significantly more dry matter than NCPR/So in all years, Longlife Super in year 4, and the PAPR treatments in years 2–4. By year 5, the Longlife Super and PAPR treatments had reached 80–90% and the NCPR/So 60–70% of the relative effectiveness of SSP. There was some variation in the relative performance of individual fertiliser treatments with each site, however the causes could not be clearly isolated due to the interaction of climate on P and/or S plant availability. Results suggest NCPR/So treatments were not suitable for these soils, due to their inability to release P quickly, and the high requirement for S on these soils. Longlife Super and PAPR treatments performed well but only on some sites. Currently they are not cost effective compared with SSP. Rainfall, in particular summer rainfall, was considered the most important driver of the treatments in releasing P (and S) on these soils.

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INTRODUCTION

Slow release phosphorus (P) fertilisers were the focus of much laboratory and field work in the early 1980s in New Zealand by the Ministry of Agriculture and Fisheries (MAF), Massey University, and the New Zealand Fertiliser Manufacturers' Research Association (NZFMRA), (Braithwaite 1983; Gregg et al. 1983; Rajan 1983). These lower cost, higher P content products were seen as a way of reducing farm costs at a time when farm incomes had declined, and conventional P fertiliser prices had risen. Initial field work on seven pastoral sites had shown that some reactive phosphate rocks (RPR) of a fine particle size could act effectively as P fertilisers (Rajan et al. 1983). In response to this, MAF initiated a National Series of trials on the form of P, involving 19 sites throughout New Zealand. These compared a range of RPR, partially acidulated and fully acidulated P products, some at different P rates. The principal objectives of this work were to delineate the soil and climatic conditions suitable for the direct application of RPR as a maintenance P fertiliser for pasture, and to provide some screening of the performance of a range of RPR-based products relative to water-soluble P fertilisers (Quin et al. 1985). This work showed RPRs became as agronomically effective as fully acidulated products (such as superphosphate (SSP)) after 4–6 years of continuous use (Smith et al. 1990; Sinclair et al. 1990; Edmeades et al. 1991). The conditions most suitable for RPR dissolution were suggested as soil pH < 6.0 and annual rainfall > 800 mm. Partially acidulated phosphate rocks (PAPRs) became more quickly available than RPR, generally after 1–3 years of continuous use.

At the time this work was nearing completion, Ravensdown Fertiliser Co-op Ltd was looking at the commercial position of fertilisers containing slower release forms of P. North Carolina RPR was readily available nationally, as was Longlife Super (a cogranulated SSP/RPR). A phosphoric acid PAPR, Hyphos, and its sulphur (S) derivatives were being locally produced for the Lower North Island market, and an imported phosphoric acid PAPR, Phospar, was available in the South Island. Ravensdown had two concerns relating to the applicability of the MAF National Series data to the above regions. Firstly, there was a lack of data on the yellow-grey earths (YGE) and their intergrades with yellow-brown earths (YBE), particularly those at the summer-dry end of the spectrum (at the time the significant portion of these fell within the Ravensdown sales territory). Although MAF had five sites within this category, three ran for only 3 years and one of the two sites at Winchmore Research Station was irrigated. Secondly, in the MAF National Series, P form was the focus and so S content in the product was eliminated as a variable. However, commercial products contain S and the agronomic importance of S also needs to be considered when comparing alternative products to SSP as pastoral fertilisers.

To answer some of these queries, Ravensdown Fertiliser Co-operative Ltd instigated its own series of trials. The primary objective of these trials was to examine the performance of commercially available products containing various forms of P and S as pastoral fertilisers on summer-dry soils. A secondary objective was to commercially test the validity of the MAF computerised fertiliser advisory scheme (CFAS), at the time the accepted method for calculating the P and S requirements of pasture. This paper largely confines itself to the first objective with dry matter (DM) production rather than the change in soil test levels being the main indicator used to compare the performance of the various commercial fertilisers.

MATERIALS AND METHODS

Trials were initially established on 14 sites in 1988; one of these sites was re-established in 1990, when two new trials also commenced. This paper concentrates on 12 of the final 16 sites, those considered to meet the objective of summer dryness involving YGE and YGE/YBE, now termed Pallic and Brown soils (Hewitt 1992).

Of these 12 sites, 10 sites ran for 6 years and two for 3 or 4 years (one had tile drain damage problems, one was accidentally topdressed). Eleven of these sites ran from 1988–94 and one site from 1990–96. Site and initial soil test details are given in Table 1. Sites were chosen to be responsive to P, to have a soil pH < 6.0 and to not have been topdressed for a year (or longer where elemental S (So) had previously been used). All sites had low anion storage capacity (ASC), 13–35% (Table 1). Sites were typical of the farm or district and consisted of flat or gently sloping sites that could be easily managed, in paddocks grazed by sheep and cattle. Pasture consisted of permanent grass and clover, although one site, because of its rainfall pattern, acted as a short-term pasture. Depending on the dryness of the site, legumes consisted of white clover, with some red, subterranean, and suckling clovers. Grass composition ranged from perennial ryegrass to a higher proportion of sweet vernal, Yorkshire fog, and browntop on the drier (and lower P fertility) sites.

All trials were replicated four times, in randomised blocks with a plot size of 10 m^2 (4×2.5 m). All trials were treated in the same manner under a mowing regime. Plot boundaries were trimmed and this herbage removed. From the remaining area two passes with a mower were taken for DM determination. The remaining pasture was trimmed and returned to the plots, resulting in approximately 40% of the clippings being returned to simulate grazing. Trials were regularly cut depending on the DM accumulated, taking care not to allow excessive growth, although on one or two occasions in wet periods this could not be avoided. On average, trials were cut five to seven times a year, although S7 averaged almost 10 cuts/year. On sites S3 and S5 only three cuts were taken in years 2 and 1, respectively. Some cover was left in summer, and an autumn cut was taken to coincide with soil and herbage testing. All sites were fenced from grazing and, where necessary, from rabbits.

Treatments were applied annually in spring in conjunction with any remedial basal fertiliser required. This was based on autumn soil and herbage

Table 1 Site details.

Name	District	Soil group[1]	Rainfall (mm)	Site conditions	pH[2]	Initial site soil test: Olsen P[2] (µg/ml)	SO_4–S[2] (µg/ml)	ASC[3] (%)
N1 Waipukurau	Hawkes Bay	YGE (Pallic)	550–750	Flat, summer dry	5.7	8	9	22
N2 Masterton	Wairarapa	YGE/YBE (Pallic)	900–1000	Easy hill, slightly summer dry	5.9	7	4	23
N4 Halcombe	Manawatu	YGE (Pallic)	850–950	Flat, summer dry	5.7	11	3	27
S3 Wairau[4]	Marlborough	YGE (Pallic)	600–800	Terrace, summer/autumn dry	5.6	4	3	25
S4 Seddon	Marlborough	YGE (Pallic)	550–750	Easy hill, summer/autumn dry	5.6	5	4.5	23
S5 Cheviot	North Canterbury	YGE (Pallic)	650–800	Flat, summer dry	5.7	7	2	17
S6 Loburn	Canterbury	YGE/YBE (Brown)	750–850	Downland, summer dry	6.0	7	4	13
S7 Montalto	Mid Canterbury	YGE/YBE (Brown)	800–1000	Flat, slightly summer dry	5.8	18	4	26
S7a Westerfield	Mid Canterbury	YGE (Pallic)	450–550	Flat, very summer/autumn dry	5.9	7	9	28
S8 Geraldine	South Canterbury	YGE (Pallic)	550–600	Undulating, summer dry	5.8	8	5	35
S8a Fairlie	South Canterbury	YGE (Pallic)	550–600	Undulating, summer/autumn dry	5.8	8	5	21
S9 Balclutha	South Otago	YGE (Pallic)	600–700	Undulating, adequate summer moisture	5.8	9	6	17

[1]Soil group, New Zealand genetic classification and (approximate equivalent according to New Zealand soil classification system (Hewitt 1992)). YGE, yellow-grey earth; YBE, yellow-brown earth.
[2]pH, 1:2.5 in water; Olsen P, 0.5*M* $NaHCO_3$ extractable at pH 8.5; SO_4–S, 0.02*M* $Ca(H_2PO_4)_2$.
[3]ASC, anion storage capacity, 1:5 soil:1000 µg/ml P solution at pH 4.65.
[4]This trial commenced in 1990 and ran until 1996, the others commenced 1988.

results. Full details of this and other practices are given in a full report (Craighead 1997). Remedial fertiliser included applying magnesium (5–20 kg Mg/ha) on several sites, particularly towards the end of the trial, boron (0.45–1.5 kg B/ha) one to two times on some sites (one site received 1.5 kg/ha, four times), and molybdenum (20–40 g Mo/ha) once on four sites and twice on one site. Two sites also received a single dressing of copper (0.5 kg Cu/ha). Some nitrogen (10 kg N/ha), was applied to all except one site in year 6 and some sites also received 10–20 kg N/ha in year 5. All sites had medium to high reserves of potassium (K) (Cornforth & Sinclair 1984), so initially little K fertiliser was required. However, some sites did initially receive 10 kg K/ha in spring, increasing up to 30 kg K/ha in latter years on most sites. From year 4 (year 2 on site S4), 15 kg K/ha was applied after each harvest to reflect accumulative clipping losses, unless little herbage was removed at that harvest.

All trials were in drought-prone areas and therefore susceptible to insect damage, mainly from grass grub (also porina on North Island sites, and Argentine stem weevil at site S7a). Diazinon (Gesapon 20G, Syngenta Group Co.) was applied as required, and following damage the whole trial was lightly topdressed with a ryegrass and white clover mix. One site, S7a was direct drilled in the autumn of year 3 when plant losses became significant.

Treatments common to all sites were SSP, Longlife Super, and North Carolina RPR (NCPR), all with S added where necessary. For the PAPR treatment, Hyphos S or Hyphos Supreme were used on the North Island sites and Phospar with added fine So on the South Island sites (except for site S9 which received Rockphos S). This was because farmers only had access to these PAPR products in their district. Other regionally available PAPR products were also used on some sites but are not included in this paper. Typical analysis and product descriptions are given in Table 2.

Phosphorus and S requirements were calculated by using the Ravensdown Fertiliser Recommendation programme (Fertrec), a company version of the MAF CFAS programme (Cornforth & Sinclair 1984) widely used by advisers at the time. In the latter years additional S was used, based on new information on the S model, a change in the way sulphate S results were expressed by the laboratory and consideration for the delayed release of coarser fractions of So (Boswell & Swanney 1988; Boswell & Friesen 1993; C. Boswell pers. comm.). The programme gave a "maintenance" and "current" requirement for P and S based on soil type, aspect, stock type, and stocking rate. Maintenance is the requirement to give 90–95% relative yield, while current requirement also considered the existing soil test results. Soil (0–7.5 cm samples) was analysed annually for Olsen P and sulphate S by Soil Fertility Service, Ruakura, Hamilton. The recommendation was duplicated each year: one based on a general site soil test result, and the other on the mean of all the individual plot results. In most years, sites received current requirements (in year 2 all sites received a compromise between current and maintenance, in year 6 application rates were increased where soil test results had not substantially increased). Initially, as all except one site were considered P and S responsive, current requirement was greater than maintenance requirements. The P provided by a fertiliser was based on the useful plant P in the product, a value which took into account the reactivity of the P rock blend used to make the product and the degree of acidulation of the product (Table 2). For SSP this was defined as the 2% citric acid solubility (csp) plus the difference between the total P (TP) and the csp × a %; 100% was used for the RPR component and 20% for the non-reactive PR component in the P rock blend. For NCPR, useful P was defined as 98% of the TP as it was for the PAPRs as they were based entirely on NCPR. The useful P of Longlife Super fell intermediate between these as two-thirds of the product fell under the SSP criteria and one-third under the NCPR criteria. Superphosphate and Longlife Super values altered each year as the PR blend used in their manufacture changed, otherwise annual variation in useful P reflects variations in TP.

The amount of fertiliser product used was based on the amount of P required; at each site each year, all fertiliser treatments received the same amount of useful P. If the product did not then provide sufficient S, it was substituted with a similar product

Table 2 Product descriptions. NCPR, North Carolina reactive phosphate rock; RPR, reactive phosphate rock.

Product	Description	Total P	Useful P[2]	Range of analysis[1] wsp (%)[3]	S (%)	S form[4]
Superphosphate	Fully acidulated P rock (0.60AR) using sulphuric acid. Mixed with molten So as Maxi S Super if required (e.g., to make S Super), average to moderately granulated	8.8–9.0	8.4–8.6	7.9–8.4	11.0–11.8	SO_4 plus So if required
Longlife Super	70/30 Super/NCPR, slightly over acidulated Super with RPR added ex den pre granulation, weaker granule than Super	9.9–10.6	9.7–10.0	4.6–5.4	6.1–8.6	SO_4, plus So if required
Hyphos S	Partially acidulated NCPR (0.30AR) using phosphoric acid and molten el. S	14.9	14.8	4.6	8.5	10% SO_4 + 90% So
Hyphos Supreme	Added during manufacture, moderately granulated	13.8–14.1	13.7–13.9	4.5–5.7	12–14.1	SO_4 + >90% So
Phospar (+So)[5]	Imported partially acidulated NCPR (0.30AR) using phosphoric acid, hard granule, low fines	17.3–17.5	17.2	7.5–7.7	<1.0	So added
RPR (+So)	NCPR as received, 95% < 0.5 mm 95% < 0.5 mm	13.1–13.2	13.0	0.1	<1.0	So added

[1]Product analysis varied each year, particularly for SSP and Longlife Super with rock blend and manufacturing conditions.
[2]Useful P, useful plant P varied with P rock blend used, particularly RPR component, see text for full explanation.
[3]wsp, water soluble P.
[4]Screened So, 99% < 1 mm, 75% < 0.5 mm, 29% < 0.25 mm. Molten So all products < 1 mm, finest Hyphos S (63% < 0.5 mm), coarsest Hyphos Supreme (29% < 0.5 mm), Maxi S Super (av 55% < 0.5 mm).
[5]Rockphos S (0-11-0-10) used instead of Phospar at S9, a weakly acidulated NCPR (0.15AR) using sulphuric acid (useful P 10.8, wsp 0.6–1.3%, 55% of S as So).

containing additional S as So, or additional screened So was added. This meant SSP was substituted by Sulphur Super (0-8-0-19), Hyphos S by Hyphos Supreme and Longlife Super had So added. From year 4, all intergrade soils received at least half their S as So as suggested in the Fertrec model comments section, and because sulphate S soil test values remained low (results not given). Details of typical stocking rates, maintenance P and S requirements and the range of P and S rates applied are given in Table 3.

Trials were managed by a Ravensdown field officer in the district in which the trial was undertaken, and these people are listed in the acknowledgments. Over the trial period personnel changed.

Statistical analysis was carried out by repeated measure analysis of variance at Otago University and by using Minitab (Minitab Corporation, USA) and expressed as least significant difference (Saville 1990).

RESULTS AND DISCUSSION

Dry matter production

Mean DM/year on all sites and average annual, and September–May (termed summer) rainfall are given in Table 4. Production varied on each site, but can be loosely placed into high (N2, N4, S7, S9), moderate (N1, S5, S6, S8), and low (S3, S4, S7a, S8a) categories. Sites in the high category generally have the highest mean annual (>800 mm) and summer rainfall (>580 mm) but there are

Table 3 Soil type and stocking rates as inputs into maintenance fertiliser rate and the range of actual phosphate and sulphur applied over the 6 years.

Site	Soil type	Stocking rate (su/ha)	Maintenance fertiliser[1] (per ha)	Actual fertiliser applied[2] (per ha)
N1 Waipukurau	Matapiro–Crownthorpe	11–12	Initially 9 kg P, 9 kg S Later 11–12 kg P, 10–15 kg S	11–15 kg P, 3–18 kg S
N2 Masterton	Atua	10–11	12 kg P, 15 kg S	13–27 kg P, 10–28 kg S
N4 Halcombe	Halcombe–Raumai	16	Initially 14 kg P, 19–21 kg S (S later reduced slightly)	9.5–17 kg P, 15–25 kg S
S3 Wairau	Wither	12	Initially 12–14 kg P, 19–20 kg S (S later increased slightly)	17–25 kg P, 20–28 kg S
S4 Seddon	Wither	9	9 kg P, 12 kg S (S later lifted to 14 kg S)	11.5–16 kg P, 11–20 kg S
S5 Cheviot	Domett	15	Initially 13 kg P, 15 kg S Later 18 kg P, 21 kg S	18–25 kg P, 14–28 kg S
S6 Loburn	Okuku	10	13 kg P, 15–17 kg S	17.5–30 kg P, 16–27 kg S
S7 Montalto	Kakahu	14–15	19–20 kg P, 21–23 kg S	14–20 kg P, 10–22 kg S
S7a Westerfield	Lismore	9–11	8–11 kg P, 14 kg S	9–15 kg P, 5–18 kg S
S8 Geraldine	Opuha	12	12 kg P, 10–15 kg S (S later lifted to 17–22 kg S)	16–25 kg P, 10–25 kg S
S8a Fairlie	Claremont	10	11 kg P, 9 kg S	14–18 kg P, 8–10 kg S
S9 Balclutha	Te Houka	16	18–20 kg P, 14–17 kg S	17.5–30 kg P, 6–15 kg S

[1]Maintenance fertiliser calculated from Ministry of Agriculture and Fisheries (MAF), computerised fertiliser advisory scheme (CFAS) model (Cornforth & Sinclair 1984) with slight adjustments where necessary for model improvements and site knowledge during the trials.

[2]Actual fertiliser applied is the range over the trial duration, based on the model's current requirement and varied each season based on the site and mean plot soil test results. Where model indicated S:P ratio required was high, some So was used irrespective of treatment.

Table 4 Mean dry matter production (kg/ha) for different phosphorus/sulphur fertilisers and rainfall (mm) over 6 years. PAPR, partly acidulated phosphate rocks; NCPR, North Carolina reactive phosphate rock.

Sites:	N1	N2	N4[1]	S3	S4[2]	S5	S6	S7	S7a	S8	S8a[1]	S9
Control	6125 *c*[3]	7325 *c*	8140 *b*	2660 *b*	3835 *c*	5050 *c*	5440 *c*	8365 *a*	3060 *d*	4340 *c*	3775 *a*	7490 *c*
Superphosphate/S	7080 *a*	9420 *a*	8625 *a*	4760 *a*	5350 *a*	6550 *a*	6895 *a*	8810 *a*	3825 *a*	5655 *a*	4185 *a*	9320 *a*
Longlife Super/S	6485 *b*	8715 *b*	8540 *a*	4795 *a*	5085 *a*	6110 *b*	6750 *a*	8805 *a*	3600 *ab*	5810 *a*	4095 *a*	8705 *b*
PAPR/S[4]	6545 *b*	8740 *b*	8540 *a*	4360 *a*	4655 *b*	6325 *ab*	6375 *ab*	8940 *a*	3500 *bc*	5510 *a*	4130 *a*	9055 *ab*[4]
NCPR/S	6375 *bc*	8770 *b*	8550 *a*	4515 *a*	4785 *b*	6145 *b*	6135 *b*	8465 *a*	3300 *cd*	5065 *b*	3935 *a*	8690 *b*
$LSD_{5\%}$	235	590	300	510	435	335	595	630	260	435	440	380
Annual rainfall	545	955	900	660	625	735	805	830	450	805	565	565
Sep–May rainfall	365	580	595	415	425	520	590	620	335	630	415	410

[1] N4 mean of 3 years data, S8a mean of 4 years data only.
[2] S4 data 1990–96, all others 1988–94.
[3] Within-sites treatments with no letters in common differ significantly from each other, $P < 0.05$.
[4] PAPR—North Island sites—Hyphos S/Hyphos Supreme, South Island sites—Phospar/S (Rockphos S used on S9).

exceptions; S8 under-performed while S9 performed above expectations. Similarly, the lowest producing sites have the lowest rainfall (<660 mm annual and <425 mm summer rainfall). N1 performed reasonably well despite a low rainfall. Other climatic factors probably account for these variations; spring growth would commence earlier at the warmer northern sites (e.g., N1) compared with southern sites extending the growing season and hastening oxidation of So (Boswell & Friesen 1993). Site S9 has the longest daylight hours; it also receives 30–50% more rain days (New Zealand Meteorological Service monthly rainfall observations, 1988–96), and much lower evapotranspiration than the Marlborough and Canterbury sites where hot dry north-west winds are common in summer. Site S8 is in the foothills (265 m altitude), where summer winds are often cooler, reducing DM production.

When all site DM data is combined (Table 5), production is as follows: year 6 > year 5 > year 3 > year 4 > or = year 2 > year 1. Here the relationship between DM production and rainfall is much clearer, in particular that with summer rainfall (Control DM: $r = 0.98$ versus summer rainfall; 0.71 versus annual rainfall). Fertiliser treatments showed a similar improved relationship with summer rainfall, e.g., SSP: $r = 0.98$ and 0.67; NCPR/So: $r = 0.98$ and 0.69, respectively. Hence rainfall, particularly summer rainfall, is considered the main limitation on production on the soil groups examined here. This explains why overall production is quite low compared with the MAF National Series trials (Smith et al. 1990).

Fertiliser treatments

All sites, with the exception of S7 and S8a, responded significantly to P and S fertiliser ($P < 0.05$, Table 4), with a slight response on these two sites (Phospar $P < 0.1$ on S7; SSP $P < 0.1$ on S8a). The greatest response was on the Marlborough sites, S3 and S4. On the 10 responsive sites, SSP, Longlife Super, and PAPR treatments significantly increased DM on all sites, and NCPR/So did so on eight sites. The relative merits of the individual treatments are ranked at 3 and 6 years in Tables 6 and 7, respectively. After 3 years, SSP had significantly increased production at all 10 sites ($P < 0.05$), and on nine of these it was the best performer. In contrast, the other three treatments produced significantly more growth at only five or six of the sites. On the nine responsive sites that ran for 6 years, SSP ranked first on seven and second on the other two. Generally, the order followed SSP > Longlife Super > PAPR > NCPR. Overall, SSP produced significantly more

DM ($P < 0.05$) than all other treatments on two sites (N1 and N2), and NCPR/So on eight sites.

On an annual basis, when all site data is combined (Table 5), SSP, Longlife Super, and PAPR treatments produced significantly more than the nil fertiliser control in all years, as did NCPR/So from year 2 ($P < 0.05$). Superphosphate outyielded NCPR/So in all years, PAPR treatments in years 2–4, and Longlife Super in year 4. Longlife Super outyielded NCPR/So in years 1 and 5, but did not differ significantly from PAPR treatments in any year.

The mean DM response to fertiliser over all sites is given in Fig. 1. Responsiveness generally increased with time from almost 10% in year 1 peaking in the fifth year at 35–40%. Similar responses were noted on some sites in the MAF National Series (Smith et al. 1990). The poorer response in year 6 could reflect the control responding to spring N fertiliser in a wetter year and more N fixation by resident clovers. Gillingham et al. (1998) found N a more economic option than P (and S) on steeper sunny (dry) facing country.

Table 5 Summary of yearly dry matter (kg/ha) by treatment[1], (12 sites years 1–3, 11 sites year 4, 10 sites years 5–6) and mean rainfall (mm). PAPR, partly acidulated phosphate rocks; NCPR, North Carolina reactive phosphate rock.

	Year 1[2] 1988/89	Year 2 1989/90	Year 3 1990/91	Year 4 1991/92	Year 5 1992/93	Year 6 1993/94
Control	4990 *c*[3]	5165 *c*	5530 *c*	5120 *c*	5665 *c*	6045 *c*
Superphosphate/S	5520 *a*	6130 *a*	6735 *a*	6500 *a*	7795 *a*	7890 *a*
Longlife Super/S	5370 *a*	5835 *ab*	6475 *ab*	6080 *b*	7535 *a*	7775 *ab*
PAPR/S	5295 *ab*	5780 *b*	6380 *b*	6180 *b*	7425 *ab*	7520 *ab*
NCPR/S	5120 *bc*	5690 *b*	6285 *b*	5945 *b*	7120 *b*	7335 *b*
$LSD_{5\%}$	245	300	325	280	380	470
Annual rainfall	629	727	669	699	696	803
Sep–May rainfall	423	443	497	445	551	585

[1]Each analysis treated the sites as blocks in a randomised block analysis of variance.
[2]Site S4, year 1 1990/91, year 6 1995/96.
[3]Within-years treatments with no letters in common differ significantly from each other, $P < 0.05$.

Table 6 Ranking in first 3 years of those producing significantly more dry matter (DM) than the control, $P < 0.05$ unless otherwise stated. PAPR, partly acidulated phosphate rocks; NCPR, North Carolina reactive phosphate rock.

	Superphosphate	Longlife Super/S	PAPR/S	NCPR/S
N1	1	–	–	–
N2	1	–	–	2[1]
N4	1	3	4	2
S3	1	2	4	3
S4	1	2	3	4
S5	1	–	3	2
S6	1	2[1]	–	–
S7	–	–	–	–
S7a	1[1]	–	–	–
S8	2	1	3	–
S8a	–	–	–	–
S9	1	3	–	2

[1]$0.05 < P < 0.10$.

Table 7 Ranking over 6 years of those producing significantly more dry matter (DM) than the control, $P < 0.05$ unless otherwise stated. PAPR, partly acidulated phosphate rocks; NCPR, North Carolina reactive phosphate rock.

	Superphosphate	Longlife Super/S	PAPR/S	NCPR/S
N1	1	3	2	4[1]
N2	1	4	3	2
S3	2	1	4	3
S4	1	2	4	3
S5	1	4	2	3
S6	1	2	3	4
S7	–	–	1[1]	–
S7a	1	2	3	–
S8	2	1	3	4
S9	1	2	–	3

[1]$0.05 < P < 0.10$.

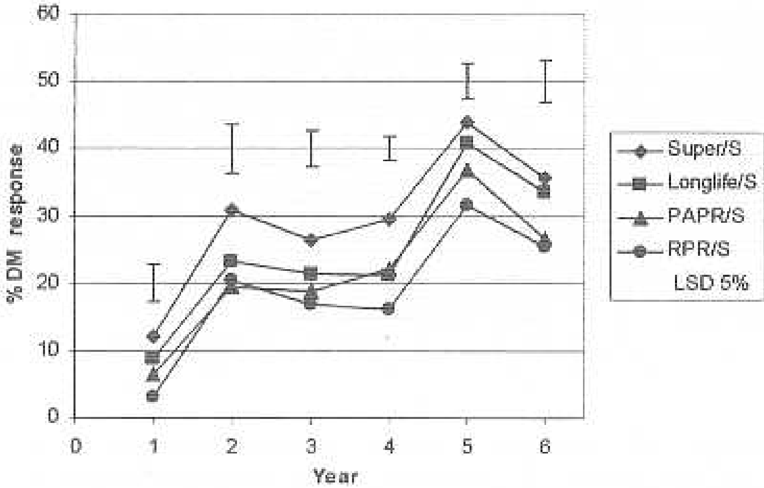

Fig. 1 Percent dry matter response over nil fertiliser in each year to various phosphate and sulphur products, 1988/89–1993/94. Data mean of 12 sites years 1–3, 11 sites year 4, 10 sites years 5–6, S4 data 1990/91–1995/96. PAPR/S Hyphos in North Island, Phospar in South Island bar S9 (Rockphos S). PAPR, partly acidulated phosphate rocks; RPR, reactive phosphate rock.

The performance of different treatments is compared with the best performing fertiliser, SSP, and expressed as relative agronomic effectiveness (RAE) in Fig. 2 (Chien et al. 1990). Since ratios such as the RAE are relatively unstable quantities, the data were averaged over the sites for each year before calculating the RAE for each fertiliser and year, hence no $LSD_{5\%}$ are given. The results show a gradual improvement in performance of all treatments relative to SSP with time. However, no treatment reaches the performance of SSP after 6 years, Longlife Super, and PAPR reaching 80–90%, and NCPR 70% RAE.

As the fairest comparisons amongst fertiliser treatments are made by using the combined site data (Sinclair & Johnstone 1995), the following individual fertiliser comments are largely made on this basis.

RPR

NCPR/So did not produce significantly more DM than the control until the second year. This lack of early response is probably due to the poor initial release of P and So; approx. 30% of P and at least this amount of So is expected to release within a year (Boswell & Swanney 1988; Edmeades et al. 1991). From a P perspective this is in agreement with Sinclair et al. (1990) who found Sechura RPR was ineffective in the first and generally second year, and Condron & Goh (1997) who found a similar effect on P uptake from using NCPR on a Brown soil.

What is less clear is why, relative to SSP, NCPR/So only slightly improved from year 3. From a P perspective, Edmeades et al. (1991) and Rajan et al. (1991) considered the time lag associated with RPR use (to reach > 90% RAE) was 4–6 years, when residual P contributions from previous dressings were considered. Particle size of RPR may also have some influence; "as received" Sechura RPR was two-thirds as effective as finer (0.075–0.15 mm size) on four sites in the National Series (Perrott et al. 1996). North Carolina PR is slightly (but not significantly) less effective than Sechura PR (Sinclair et al. 1998). From a S perspective, a minimum of 85% of residual So would have been available within 3 years on South Island sites and 99% on the warmer North Island sites (Boswell & Swanney 1988; Craighead 1997). In the intermediate term, the screened So used with NCPR is not as effective as that in wet mix Sulphur Supers which generally contain finer So (Boswell & Friesen 1993; M. Craighead unpubl. data).

While the effectiveness of RPR/So blends may be improved by cogranulating the two ingredients to form a Biosuper, Lee et al. (1987) and Rajan (1987) have shown these products to be more effective with lower reactivity P rocks compared with NCPR.

It is difficult to compare the performance of RPR with that in the National Series as they were largely on wetter sites (rainfall 700–1800 mm, Edmeades et al. 1991) in the presence of adequate S. While all sites met their criteria for RPR use of low pH and low ASC, only five had > 800 mm rainfall. Of these, one was not responsive to fertiliser; on three sites, SSP still outperformed NCPR/So, and may have on the remaining site (S8a) had it lasted 6 years. This data suggests that for RPR/So to replace SSP the rainfall criteria for RPR of > 800 mm may be optimistic. The only dryland YGE site in the National Series which lasted 6 years was the Winchmore dryland site, where Sinclair et al. (1990) concluded

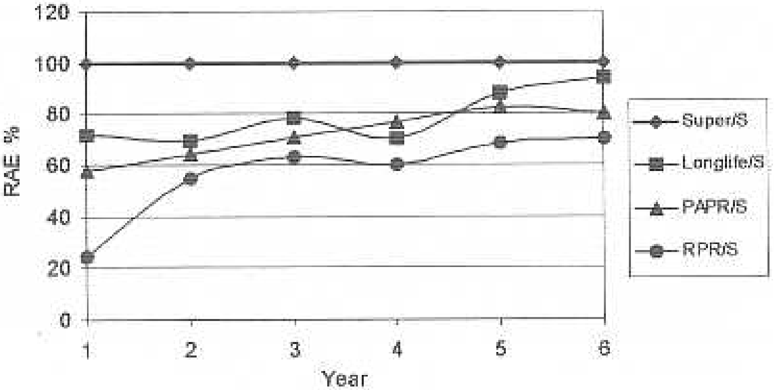

Fig. 2 Relative agronomic effectiveness (RAE = (fertiliser – control) – (super-control) × 100) of products compared with Superphosphate (where RAE = 100), 12 sites in years 1–3, 11 sites in year 4, 10 sites in years 5–6. PAPR, partly acidulated phosphate rocks; RPR, reactive phosphate rock.

Sechura RPR was almost totally ineffective. Site S7a on the same soil type, and N1 were the only two sites where there was no significant DM response to RPR/So, indicating annual and summer rainfall must be > 550 mm and > 400 mm, respectively for RPR/So to be partially effective.

Comparisons with the Australian RPR trial series are also difficult as many of their sites had different pasture species, much warmer climates, and greater rainfall extremes, and so no single environmental feature adequately predicted performance. They generally found RPR was only effective after 4 years providing annual rainfall was > 700 mm (or > 850 mm in the shorter term (Sale et al. 1997)). Sulphur interactions also need to be considered as half their sites were S responsive by this time (Simpson 1997). In our trials of the 10 responsive sites, five would have met their rainfall criteria. Although on all five sites RPR/So gave a DM response, on only one was the response comparable to that of SSP.

While sufficient moisture for RPR and So dissolution remains the most likely limitation to the effectiveness of NCPR/So on YGEs and YGE/YBEs, it must also be recognised that these soil groups are highly responsive to S, requiring S:P ratios greater than 1.0 (Sinclair et al. 1985). This affects the economics of using RPR/S products: Edmeades et al. (1991) calculated the breakeven time for RPR versus SSP increased from 3–7 years to 6–15 years where S was required.

Longlife Super and phosphoric acid PAPR treatments

Both treatments performed intermediate between the SSP and NCPR treatments. Although there was little between the two, Longlife Super performed slightly better in comparison with NCPR/So in year 1, and in year 5, the most responsive year. This may be a reflection, certainly initially, of its higher water soluble P (wsp) and S. Longlife Super contains sulphate S, so comparisons with SSP are more likely to reflect P solubility. Results suggest Longlife Super acted as a mix of its constituent materials, i.e., as a 70% Super, 30% RPR mix, and while it performed well on several sites, e.g., S3, S8, this was not consistent with rainfall. Condron & Goh (1997) found on a wetter Brown soil, a higher rate of Longlife Super, of equal wsp, performed better than SSP, indicating the RPR component was contributing to plant P requirements. Ledgard et al. (1992) achieved similar results on six North Island sites (of medium-high ASC). Longlife Super was not used in the National Series, but a 50/50 blend of SSP/NCPR was slightly inferior to SSP on five sites (Ledgard et al. 1992). They concluded that as there is no chemical reaction between the two components, Longlife Super acts differently from SSP, and therefore the soil and climatic criteria of pH and rainfall applicable to RPR use should also apply to Longlife Super. Of the four responsive sites that met the > 800 mm rainfall criteria, Longlife Super was as effective as SSP on all except N2, the highest producing site.

It is difficult to make comparisons between the PAPR products because few were compared at the same sites. The Hyphos products performed consistently on the North Island sites, even N1, the driest site. The higher average rainfall and warmer temperatures at North Island sites leading to faster dissolution of the residual P and So (Boswell & Friesen 1993), and the finer So in Hyphos products probably account for its better performance compared with Phospar on South Island sites; this despite Phospar having a higher wsp. Phospar performs more comparably with Hyphos if data from the three most drought prone sites is ignored, (S3, S4, and S7a).

On these sites the performance of Phospar may also reflect the hardness of the granule as the product was dried after manufacture. This may have delayed the release of P each spring, explaining its seasonal and annual variability on some sites (Craighead 1997).

Rockphos S, a weakly acidulated sulphuric acid PAPR of low wsp, performed similarly to other PAPR products at S9. It was also used on North Island sites, but performed more variably (Craighead 1997). Based on its P solubility it would be expected to perform intermediate between the other PAPRs and NCPR/So, although any improvements may reflect that 45% of its S is as sulphate S. Rajan et al. (1994) considered SSP/RPR cogranulated products and sulphuric acid NC PAPRs generally inferior to phosphoric acid PAPR of similar wsp, due to calcium sulphate coatings impeding P dissolution. In Australia, a sulphuric acid PAPR performed well compared with Triple Super on only four out of 22 sites, all on temperate grassland under 670–1080 mm rainfall (Lewis et al. 1997). While the MAF National Series showed PAPRs in a good light (Quin et al. 1985; Smith et al. 1990), the PAPRs used in this study had a lower wsp, and S effects cannot be isolated. Stephen (1986) and Friesen et al. (1987) suggest So inclusion in PAPR to be useful, but not as beneficial as it is to RPR, or to PAPRs made from less reactive rocks than NCPR.

Overall, results suggest Longlife Super and some PAPR products can be reasonably effective on these soils, but not as effective as SSP, particularly on drier sites. Both are currently out of favour with farmers and advisers as there is no cost saving over SSP. This is a reflection of the cost of phosphoric acid for PAPR manufacture, and the necessity to add S. Poor granule strength is also an issue with Longlife Super and this may cause handling and spreading problems.

Superphosphate

Superphosphate performed consistently well on all responsive sites in all years, a reflection of its ability not only to provide soluble P, but also to provide soluble S. Hence, it was often the best treatment in spring following fertiliser application and going into the dry summer. Individual treatments performed as well as SSP on only some sites. On the remaining four sites in the full study not reported here, sometimes treatments also performed as well as or better than SSP (Craighead 1997), as they did on some sites in the National Series (Smith et al. 1990); however all these sites were warmer and much wetter. It is also important to recognise in comparisons with the National Series, that SSP quality has been consistently better (higher wsp and 2% citric acid-solubilities (csp)) since the National Series was undertaken. In the National Series the mean of the local SSP used was 9.1% TP, 7.6% csp, 6.7% wsp (Smith et al. 1990) compared with that used in these trials, 8.9% TP, 8.5% csp, 8.2% wsp (Craighead 1997), a reflection of changes in, and finer grinding of the phosphate rock blend used in the manufacture of SSP.

CONCLUSIONS

Superphosphate treatments (SSP or Sulphur Super) grew more dry matter than slower release P and S treatments on 12 YGE or YGE/YBE intergrade soils, predominantly in eastern New Zealand. Partially acidulated and RPR treatments were still not as effective as SSP after 6 years. This work demonstrates that on pasture prone to summer dryness fertilisers should contain soluble P and at least some soluble S, indicating that SSP or Sulphur Supers are still the best fertiliser products for this environment.

Partially acidulated P products, Longlife Super, Hyphos, and Phospar, with variable amounts of soluble S or So can sometimes be quite effective after 2–3 years of use if climatic conditions suit. However, they may not be as cost effective as SSP.

NCPR/So treatments containing slow release P and S were not very effective on these soils compared with SSP. For these treatments to be partially effective, annual rainfall certainly needs to be > 550 mm and summer (September–May) rainfall > 400 mm. However, even on sites with > 800 mm rainfall NCPR/So treatments were generally not as good as SSP.

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