New Zealand Journal of Agricultural Research, 2000, Vol. 43: 1–6
0028–8233/00/4301–0001 $7.00/0

The agronomic effectiveness of lime-reverted and dicalcic superphosphates: A review

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Abstract Results from 10 field trials that compared the agronomic effectiveness of water-soluble phosphate (WSP) fertilisers with reverted or dicalcic superphosphates (DCP) are reviewed. The 51 observed relative responses ranged from +20% to −10%, with a mean response of 0.2%. Nineteen (38%) were positive and 22 (62%) negative. A total of 17 were statistically significant ($P \leq 0.05$), either negative (8) or positive (9). The 51 observed responses were normally distributed about zero, consistent with the hypothesis that these products have no effect on plant growth over and above the effect of WSP and that the range in the observed responses simply reflected the underlying biological variation. There was evidence in one trial that DCP may be more effective than WSP in situations where significant phosphorus (P) is lost through leaching. On an acid soil, DCP was superior to WSP because of the free lime present in the former product. It is concluded that DCP have no effects on plant production over and above that which can be achieved by applying lime and WSP separately. It follows that the interaction of the two components that results in the process of reversion and the formation of less soluble DCP confers no advantage relative to the use of WSP.

Keywords fertiliser; phosphate; lime; reverted superphosphate; P deficiency; soil acidity

A99047
Received 17 September 1999; accepted 17 December 1999

INTRODUCTION

Lime-reverted superphosphate and lime:superphosphate mixtures have been manufactured and sold in New Zealand for many years. Such products contain no free acid and were originally developed to enable superphosphate fertilisers to be sown in contact with seed. Their popularity has extended beyond this use, and it is now claimed in company literature that, relative to water-soluble phosphate (WSP) fertilisers, they have other beneficial effects. Such claims are based on theoretically plausible mechanisms.

1. These products contain predominantly dicalcium phosphate (DCP) ($CaHPO_4$), rather than the more soluble monocalcium phosphate (MCP) ($Ca(H_2PO_4)_2$) present in WSP fertilisers. It is claimed that DCP is utilised more efficiently because it better matches the plant's demand for phosphorus (P).
2. The dissolution of DCP produces alkali and thus less fertiliser P is "fixed" by reaction with active soil Fe and Al oxides and less P is adsorbed onto the surface of soil minerals. This also results in a more efficient source of P for plant growth.

$$Ca\,HPO_4 + H_2O \leftrightarrow Ca^{2+} + H_2PO_4^- + OH^-$$

This liming effect is further enhanced by the presence of free lime in these products.

These two mechanisms result from the two components, lime and WSP, interacting and forming DCP which is said to have effects on plant growth over and above that which can be achieved by applying each component separately.

This paper reviews New Zealand data, both published and unpublished, from field trials which have compared the effects of DCP fertilisers with WSP fertilisers in order to test these claims.

DESCRIPTION OF DATA

A database of field trial records was established. Trials were included only if the treatments were replicated and randomised and actual yield data (either dry matter or green mass) were available. This excluded trials in which treatment effects were assessed visually. The trials also had to include a treatment with a WSP fertiliser (typically either superphosphate or ibex) and a treatment with either lime-reverted superphosphate (typically made by added 15% ground limestone to the "green" superphosphate) or lime:superphosphate mixtures (typically made by wet mixing ground limestone and superphosphate 50:50 by weight). Trials of less than 1 year's duration were not included and trials with serpentine-reverted superphosphate were also not included.

Records from 10 trials met the above criteria and, with the exception of one trial on brassicas (turnips), all were on pastures (Table 1).

The source of WSP used was superphosphate with one exception (Trial 9), in which ibex (mono calcium phosphate) was used. Four trials compared WSP with a 50:50 lime:superphosphate mixture (Trials 2, 3, 4, 7) although this product was specifically referred to as dicalcic superphosphate in only three of these trials. For the sake of simplicity, the latter term will be used to describe all instances where 50:50 lime:superphosphate was used. Reverted superphosphate was used in six trials. Analyses of the products, where available, were recorded.

While all the trials compared soluble P with either reverted or dicalcic superphosphate, only four (Trials 3, 7, 8, 9) included a control (no P fertiliser) and only four (Trials 3, 4, 7, 10) were designed to balance the liming effect of the reverted or dicalcic product.

All products were compared on the basis of an equal weight of P applied except for Trial 10, in which the products were compared on a basis of equal weight of product. Two trials examined possible residual effects, one using dicalcic (Trial 4) and the other reverted superphosphate (Trial 10).

One trial requires special explanation. Crouchley (1979) reported a summary of the results from five trials on the East Coast of the North Island, New Zealand, that examined the effectiveness of dicalcic superphosphate. The treatment effects on pasture production were reported for the five trials combined. Files of the individual trials could not be located, and these trials are recorded as one trial (Trial 7).

In total, and taking into account all the combinations of P rates and lime treatments, there were 51 trial years comparing WSP with DCP.

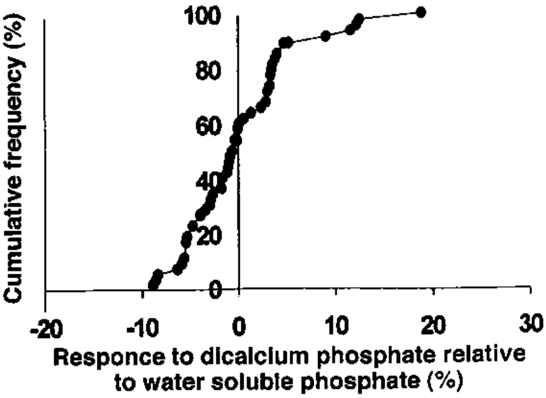

Fig. 1 Cumulative distribution function of plant responses to fertilisers containing dicalcium phosphate (DCP) relative to water soluble phosphate (WSP) fertilisers for all trials.

RESULTS AND DISCUSSION

Responses in plant yield to DCP, expressed as a percentage relative to the yield obtained with WSP, for all 51 trial years are shown in Fig. 1 in the form of a cumulative distribution curve. This approach allows the data to be seen as one experiment of 51 treatment replications. It is assumed that the observed responses for each trial year are independent.

The observed relative responses fall within the range +20% to −10%, with a mean response of +0.2%. Of the 51 responses, 19 (38%) were positive and 22 (62%) negative. A total of 17 were statistically significant ($P \leq 0.05$), either negative (8) or positive (9). This suggests that this population of 51 observations is normally distributed about zero, consistent with the hypothesis that these products have no effect over and above the effect of soluble P. In other words, the observed responses simply reflect the underlying biological variation.

Before this hypothesis can be accepted, the alternative hypotheses, that reverted and dicalcic superphosphates have beneficial effects on plant yields relative to soluble P sometimes (38%), but not others (62%), must be considered.

Negative responses to DCP, relative to WSP, could arise if they were compared on a weight-of-product basis. Because dicalcic and reverted superphosphates have a lower P content, such a basis for comparison would favour WSP products. This was the case in one trial (10) that contributed

Table 1 Summary of field trials. Results of Trials 1, 2, 5, 6, and 10 held by Fertiliser Information Services Ltd (FIS), Hamilton, New Zealand. Soil Group nomenclature follows Hewitt (1993).

Trial	Location	Soil Group	pH	P status	Replicates	Treatments	Parameters measured	Duration (years)	Reference
1	Northland	Gley	–	–	3	6	continuous mowing pasture green yield	3	FIS
2	Waikato	Organic	4.8	Truog 6	4	6	continuous mowing pasture DM	2	FIS
3	Manawatu	Pallic	5.5	Water 7	5	6	continuous mowing pasture DM	1	MacKay et al. (1980)
4	East Coast	Pallic	5.4	Olsen 5	6	4	continuous mowing pasture DM	17	Morton et al. (1998)
5	Manawatu	Pallic	–	–	3	6	continuous mowing pasture green yield	1	FIS
6	Manawatu	Pallic	–	–	3	6	continuous mowing pasture green yield	1	FIS
7	East Coast	Pallic	5.3-5.6	very low	unknown	6	occasional mowing pasture DM	1	Crouchley (1979)
8	Canterbury	Pallic	5.9	Olsen 16	6	5	turnips, DM	1	Hayward & Scott (1993)
9	West Coast	Podzol	5.8	Olsen 10	3	6	continuous mowing pasture DM	2.5	Morton & Quin (1980)
10	Otago	Pallic	–	–	3	6	continuous mowing pasture DM	4	FIS

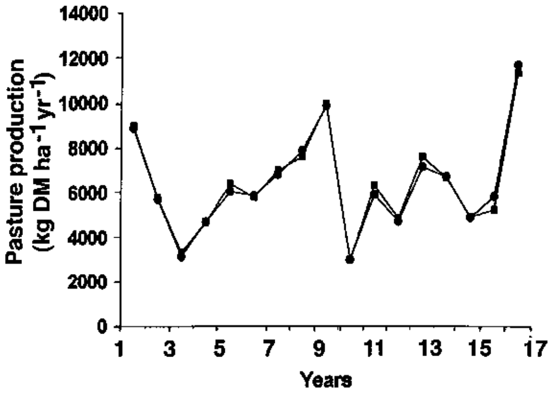

Fig. 2 Effect of superphosphate plus lime (squares) and dicalcic superphosphate (circles) on pasture production (Morton et al. 1998).

8 of the 22 negative observed responses in Fig. 1. That these negative differences persisted, even when excessively high rates of P were applied, and especially during the residual period after 3 years of these high rates, supports the view that they were due to biological variation.

Similarly, negative responses may arise if the reversion process goes too far and some of the P becomes unavailable for plant uptake.

One trial (4) ran for 17 years. The site was P responsive (Fig. 2) (Morton et al. 1998) and the trial was balanced with respect to total lime and P inputs. (dicalcic superphosphate (50:50, 400 kg ha^{-1} yr^{-1}) and low lime (200 kg ha^{-1} yr^{-1}) plus P (20 kg P ha^{-1} yr^{-1})). From Year 8 the fertiliser inputs ceased, allowing the residual effects of the treatments to be examined.

These 17 treatment differences ranged between +11.7% and −5.8%. Seven were positive (1 statistically significant, $P \leq 0.05$) and 10 negative (2 statistically significant, $P \leq 0.05$). It is unlikely that the availability of P in dicalcic superphosphate obtained from the same source could vary from year to year and thus give rise to the observed positive and negative responses. Therefore, it must be concluded that over-reversion of dicalcic is an unlikely explanation for the observed pattern of responses.

In the absence of any other plausible reason, it is suggested that the observed negative responses in Fig. 1 are expressions of the biological variability present in this type of experimental work. In a series of 12 pasture trials which ran for 6 years, coefficients of variation for pasture production for individual trial-years ranged between 4% and 15% (Sinclair et al. 1994), sufficiently large to explain the range in the observed negative responses in Fig. 1.

Positive responses to DCP may arise as a consequence of mechanisms 1 and 2 (above). In addition, they could result from a direct liming effect of the free lime contained in these products, which has nothing to do with the interaction of the components. This latter possibility arises if the trial is conducted on an acid soil and the lime component of the reverted or dicalcic superphosphate is not balanced with a similar input of lime with the WSP.

This direct liming effect is the likely reason for the responses recorded on an organic soil (Trial 2). In this experiment the application of 50:50 lime:superphosphate significantly increased pasture growth in three observations (+9.1%, +12.3%, +12.6%) relative to WSP alone. Given the rate of P application and the known chemical composition of the products, it can be calculated that the equivalent of about 425 kg ha^{-1} limestone was applied in the dicalcic mix. This was not balanced by applying a similar rate of lime to the control (WSP), in this case superphosphate. Thus, it is likely that this result is a real effect due to the liming value of the product when applied to a very acid soil (pH 4.8). Such a result is not evidence that mechanisms 1 and 2 are operating.

Reverted superphosphate had a significant effect on pasture production over superphosphate alone, on a West Coast podzol (Trial 9) in the second year of application. This soil had a low phosphate retention (PR = 1). It is plausible that, under a combination of high rainfall and low PR, significant leaching of P occurred, and that DCP was superior to WSP due to its lower solubility. This trial provides evidence of mechanism 1.

The trial (8) with the largest apparent response (+18%) was on turnips. This result was not statistically significant, which in itself is not evidence of the absence of a real effect. However, this effect occurred in only one of two trials. It is likely, therefore, that this observed response is a further expression of biological variation, unless a reasonable argument is advanced for a site-specific effect of reverted superphosphate.

Thus, all the large positive responses (>4%) in Fig. 1 can best be understood as either statistically random events (Trial 8, 19%; Trial 4, 11.7%), or an unbalanced liming effect (Trial 2, 9.1%, 12.3%, 12.6%) or due to a unique combination of circumstances (Trial 9, 4.1%, 5.3%). A large

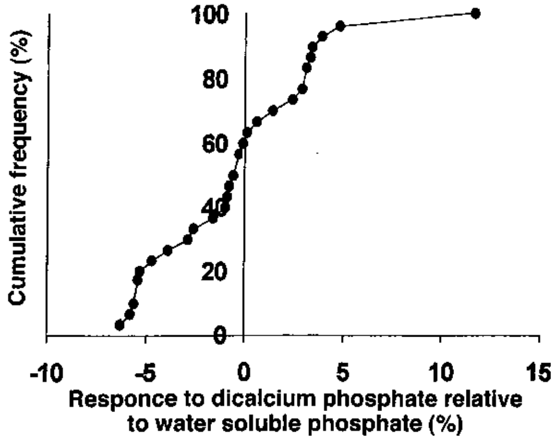

Fig. 3 Cumulative distribution function of plant responses to fertilisers containing dicalcium phosphate (DCP) relative to water soluble phosphate (WSP) fertilisers for a subset of trials balanced with respect to lime inputs.

proportion of the negative responses result from comparing the products on a weight basis (Trial 10). With the exception of the special result obtained in the West Coast trial, none of these individual trial results provides strong evidence for the existence of mechanisms 1 or 2.

As indicated above, four trials were balanced with respect to the liming effect of the free lime. Furthermore, all these sites were known and proven to be P responsive. They are, therefore, an unambiguous test of the question "Are fertilisers which contain DCP more effective than WSP as sources of plant available P?" Expressed differently, "Do mechanisms 1 and 2 operate to the extent that they have practical effects on plant growth?"

The apparent responses for this subset are shown in Fig. 3. They ranged from +11.7% to –6.3 %, with 12 positive and 18 negative. They are approximately normally distributed around a median response of –0.3%. This distribution of responses is consistent with a conclusion that reverted and dicalcic P have no effect on plant growth relative to soluble P. This is strong evidence that mechanisms 1 and 2 do not operate, or, if they do, their effect is too small to be of practical benefit.

Three of these trials were on the same soil group (Pallic) and compared dicalcic superphosphate with superphosphate. The other trial was on a gleyed soil in Northland, New Zealand (Trial 1) and compared reverted superphosphate and superphosphate. It ran for 3 years and included 3 treatments, all with and without lime. It was carefully designed such that the amount of lime applied to the lime treatments was equal to that which was applied over 3 years in the reverted superphosphate (viz 630 kg ha^{-1}). Because of its uniqueness it deserves special consideration. The overall results are given in Table 2.

The percentage differences in production in this trial between reverted superphosphate and superphosphate, for each year, were –4.7%, 3.4%, and 3.9% without lime, and –1.6%, 4.8%, and 3.1% with lime. Thus, although there was evidence that reverted superphosphate was superior to superphosphate on some occasions, it was never superior to superphosphate when the same amount of lime was also applied separately.

Collectively, the evidence suggests that fertilisers containing DCP are not more effective than WSP fertiliser. The exception to this general conclusion may occur on soils where leaching of P is a significant source of P loss, in which case a more insoluble form of P may be superior. However, this would need further substantiation and such situations are rare in New Zealand.

Table 2 Effect of superphosphate, lime, and reverted superphosphate on pasture production (kg green herbage ha^{-1}, mean of 3 years).

Phosphate fertiliser applied (kg P $ha^{-1}yr^{-1}$)	Lime applied (kg ha^{-1} 3 yr^{-1})	Annual yield (kg green herbage ha^{-1})
No fertiliser	no lime	52 000
No fertiliser	630	54 600
Superphosphate; 17 kg P ha^{-1}	no lime	56 400
Superphosphate; 17 kg P ha^{-1}	630	58 400
50% super: 50% lime[a]; 17 kg P ha^{-1}	630 with P fertiliser	56 500
50% super: 50% lime[a]; 17 kg P ha^{-1}	630 with P fertiliser plus 630 lime	59 400

[a]Superphosphate:lime was prepared as a wet mix.

This conclusion is in general agreement with other studies. In earlier work in New Zealand, Lynch (1951) reported that lime-reverted superphosphate was less effective or similar to superphosphate based on observational trials (85) on pasture and trials on wheat and brassicas. In most of these trials the products were compared on an equal weight basis and the possible liming effect of the reverted superphosphate was not balanced. Lynch (1951) noted that the performance of these products was similar on soils regarded as lime-responsive. Cooke (1956) summarised a large body of trial data in the United Kingdom and concluded that, except on very acid soils (as in Trial 2) DCP was no better than WSP on a range of crops when compared on an equivalent rate of P applied basis. Mattingly & Penny (1968) found that dicalcic P was slightly better than soluble P on ryegrass on an acid soil but slightly inferior to soluble P on barley grown on a soil with pH 6.5. Once again these results are consistent with the general conclusion.

CONCLUSIONS

The results reviewed here are consistent with the conclusion that reverted and dicalcic superphosphates, products that contain predominantly DCP, have no effects on plant production over and above that which can be achieved by applying lime and WSP separately. It follows, therefore, that the interaction of the two components that results during the process of reversion and the formation of less soluble DCP confers no advantage relative to the use of WSP. There may be an exception to this rule in soils where significant P is lost through leaching. This is not a common occurrence in New Zealand soils.

These results contradict the contention that DCP is generally superior to WSP because it is either less soluble or less likely to be "fixed" or otherwise more efficiently utilised by plants. It follows that if the two components of these types of products can be purchased and applied separately at less cost, which is generally the case in New Zealand, then this would be a more cost-effective strategy.

These results also highlight the value of having access to large amounts of trial data and examining the responses in terms of their distribution. Results from a single trial are of limited value especially when the magnitude of the possible responses is similar to the background biological variation, a point stressed by Johnstone & Sinclair (1991) in their discussion on experimental design of field trials.

ACKNOWLEDGMENTS

This project was funded by Ravensdown Fertiliser Co-operative Ltd.

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