Pasture yield response to different sulphur fertiliser strategies and its application to modelling

D.M. WHEELER and B.S. THORROLD
AgResearch, Ruakura Research Centre, Private Bag 3123, Hamilton

Abstract

A database of sulphur (S) fertiliser trials was analysed to determine the effect of different fertiliser application times, frequencies and forms on S response. Yields were about 6% higher when S was applied in spring than autumn on high-leaching sites (free-draining, high-permeable soils with high rainfall), and about 4% higher when S was applied in autumn on South Island soils. Pasture yield was about 6% higher when S was applied as a split application than as a single annual application, with the advantage to split applications also tending to be higher on high-leaching soils. The application of S had a small residual affect on S soil test after one year, the size of the residual being dependent on fertiliser rate and season of application. In contrast, a once-only application of S could increase yield above that in the control treatment for at least 3 years after S was applied such that the response in the second and third years was about 0.5 and 0.25 times that in the first year. The residual effect on yield, the effect of applying different fertiliser rates, and previous fertiliser history have been incorporated into decision support software for calculating fertiliser S responses by calculating an effective fertiliser rate using an exponential weighted moving average. However, a standard response curve for determining the relationship between relative yield and effective fertiliser rate had to be used, as a site specific curve could not be predicted from data in the S database.

Keywords: fertiliser, model, pasture yield, sulphur

Introduction

The available soil tests for sulphur (S) indicate the degree of the potential pasture response obtainable by making S non-limiting. Neither the soil test nor the earlier mass balance model of Cornforth & Sinclair (1984) can be used to predict the response to varying S fertiliser inputs or strategies such as split dressings, triennial applications or the use of elemental S fertilisers. The inclusion of these factors in an econometric model for S fertiliser requires the relationship between S fertiliser inputs and pasture yield to be described.

A database of all S trials conducted by AgResearch, and a predecessor, MAF, has been established (Table 1). The database was used to examine the effect of fertiliser S rate, form and application strategies on the response to S. This paper reports the results of this database analysis.

Table 1 Percentage of trials in a given category for those trials with yield data in the North and South Island.

Variable and category	North Island[1]	South Island[2]
Time		
1950–1959	2	3
1960–1979	64	59
1970–1979	15	23
1980–1989	19	14
Region		
Northern	21	14
Central	31	40
Western	28	4
Eastern	20	34
Southern	-	7
Topography		
flat	56	39
rolling	35	27
hilly	8	11
irrigated	-	23
Pasture type		
improved pasture	83	62
unimproved pasture	14	8
tussock–virgin	-	8
lucerne	3	18
Farm		
dairy	24	2
sheep–beef	75	92
Trial cut type		
grazing	6	3
mowing	94	97
Trial cut frequency		
continuous	40	24
occasional	60	76

[1] there were 512 trials in the North Island of which 324 had yield data.
[2] there were 611 trials in the South Island of which 360 had yield data.

Methods

Pasture trials were selected from the database where comparisons could be made between single annual applications applied in either the spring or the autumn, between a single annual application and split applications or triennial applications, and between elemental S and sulphate S. For each trial, data was extracted from the S database and the comparison was made at the same average annual rate of S applied.

The residual effect of S fertiliser on pasture yield was defined as the response to S fertiliser in the second and third years after S was applied on treatments where S was applied once every 3 years (triennial, once only). Trials in which the response was increasing over time (without the addition of fertiliser) were omitted.

Results

Effect of different application times and frequencies

The relative responses to S applied in spring or autumn, and S applied as a split or triennial applications compared to S applied annually, are shown in Tables 2, 3 and 4.

Spring vs. autumn

Sites that showed an advantage to spring application tended to be on high-leaching soils (free-draining high-permeable soils with sufficiently high rainfall to allow water movement through the soil, for example, many of the pumice soils and some sand soils) which had an average annual ratio of 1.06 (Table 2). On these sites, spring-applied sulphate gave higher yields than autumn applications (ratio > 1) in summer and autumn, while autumn applications gave higher yields in winter. Sites that showed an advantage to autumn application (ratio < 1) tended to be in the South Island. Even where one time of application was superior, substantial responses to S occurred at both application times (Table 2).

Spring application of sulphate–elemental S mixes was superior to autumn application, but all trials were on high-leaching soils. There was a small advantage to autumn application of elemental S.

Single vs. multiple applications

On average, multiple applications of sulphate-S within a year gave a higher response than a single annual application (Table 3). Similar to spring applications, the advantage to multiple applications tended to be higher on high-leaching soils. In all but one trial, the annual S rate was 35 kg/ha or greater. This meant that on most sites, 80% or more of the estimated annual S requirement could be met with one of the split applications. At lower rates there may be an advantage to annual applications if split applications apply insufficient S initially to S-deficient pastures.

Table 2 Mean (with range in parentheses) for three forms of S of the ratio of the yield when S was applied in spring to the yield when S was applied in autumn for the treatments applied at the same annual rate. A ratio > 1 indicates that yield was greater when S fertiliser was applied in spring than autumn. The annual response to S when S was applied in autumn is also shown.

	N	Ratio					Annual response to
		Summer	Autumn	Winter	Spring	Annual	autumn applications (%)[1]
sulphate	17	1.04 (0.86–1.40)	1.02 (0.86–1.24)	0.90 (0.71–1.26)	0.99 (0.83–1.14)	1.01 (0.86–1.15)	21 (-3–56)
YBPS	7	1.17 (1.02–1.28)	1.08 (0.95–1.20)	0.85 (0.71–1.03)	0.99 (0.93–1.09)	1.06 (0.98–1.15)	23 (-3–56)
Rest of North Island	4	0.93 (0.86–1.04)	1.04 (0.86–1.24)	0.86 (0.76–0.90)	1.03 (0.98–1.14)	0.99 (0.90–1.12)	8 (4–11)
South Island	6	0.97 (0.86–1.05)	0.95 (0.89–1.04)	0.97 (0.84–1.26)	0.97 (0.83–1.02)	0.96 (0.86–1.01)	28 (9–33)
sulphate mix	3[2]	1.16 (1.11–1.23)	1.12 (1.05–1.16)	0.87 (0.66–1.02)	1.03 (0.94–1.09)	1.08 (1.01–1.13)	46 (29–68)
elemental S	8[3]	1.03 (0.89–1.45)	0.97 (0.89–1.05)	1.00 (0.89–1.15)	0.94 (0.91–1.01)	0.96 (0.87–1.02)	12 (-2–26)

1 annual response to spring–applied S can be calculated as annual ratio * annual response to autumn–applied S.
2 sulphate–elemental S mix containing 55% sulphate, all trials on free-draining high-permeable soils.
3 two trials on free-draining high-permeable soils.

Table 3 Mean (with range in parentheses) of the ratio of the yield when sulphate was applied once annually to the yield when sulphate was applied as multiple applications within a year for the treatments applied at the same total annual rate. A ratio >1 indicates that yield was greater when S was applied as multiple applications within a year. The response to annual application of S is also shown. All trials were on improved pasture.

Group	N	Summer	Autumn	Winter	Spring	Annual	Yield response to annual applications (%)
Overall	21 [1]	1.06 (0.86–1.28)	1.05 (0.64–1.16)	1.17 (0.95–1.97)	1.05 (0.91–1.20)	1.06 (0.84–1.18)	42 (-2–168)
YBPS	9	1.07 (1.05–1.13)	1.10 (1.00–1.22)	1.10 (1.01–1.22)	1.06 (1.00–1.12)	1.09 (1.01–1.11)	25 (2–68)
Organic	2	1.25 (1.23–1.28)	1.14 (1.11–1.16)	1.59 (1.20–1.97)	1.07 (1.04–1.09)	1.17 (1.15–1.18)	165 (162–168)
South Island	9 [2]	1.01 (0.86–1.04)	0.92 (0.64-1.02)	1.02 (1.02-1.04)	1.05 (0.91-1.20)	1.03 (0.84-1.14)	34 (-2 – 76)

[1] N=17 (autumn), 15 (winter)
[2] N=5 (autumn), 3 (winter)

Annual vs. triennial applications
Comparisons between three annual and one triennial (3 times the annual rate applied in Year 1) application were generally done in the South Island on a limited range of soils (Table 4). The only North Island trial had a small response to S. Triennial applications of sulphate gave a higher yield than the annual application in year 1 (ratio > 1) but lower yields in years 2 and 3 (ratio < 1). In three trials where two rates of S was used, the advantage to annual applications tended to be greater at lower S rates. In contrast, triennial applications of elemental S gave a higher yield than annual applications (ratio > 1) in all years. The particle size of the elemental S used had no effect on the advantage of triennial applications.

Table 4 Mean (with range in parentheses) of the ratio of the yield when S was applied once annually to the yield when S was applied every 3 years for the treatments applied at the same average annual rate. A ratio >1 indicates that yield was greater when S was applied triennially than annually. The annual response to S is also shown.

Fertiliser type	N	Year 1	Year 2	Year 3	Year 4	Yield response to annual applications (%)
sulphate	8 [1]	1.03 (0.95–1.13)	0.98 (0.97–1.11)	0.96 (0.92–1.01)	1.05 (0.96–1.23)	26 (6–42)
elemental S	4 [2]	1.06 (0.99–1.14)	1.06 (0.98–1.07)	1.01 (0.9–1.02)	1.05 (1.00–1.07)	17 (9–23)

[1] one North Island trial.
[2] all South Island trials.

Table 5 Pasture response (as a fraction) in years 2 and 3 as estimated from the pasture response in year 1 (resp1, as a fraction) when S is applied once only. Standard errors are shown in parentheses.

Year	Response	R^2	N
1	resp1		
2	0.515 * resp1 – 0.0057 (0.0402) (0.0068)	0.93	15
3	0.263 * resp1 + 0.0066 (0.115) (0.0109)	0.63	5

Residual effects
Knowing the length of time that a single application of S fertiliser affects yield and soil test levels is important for modelling responses. Results from annual vs. triennial and annual vs. once-only applications of sulphate showed that a single application of S fertiliser increases yield for at least 3 years (Table 5). There were no trials on high-leaching soils where residuals could be determined. However, applying the model (see next section) indicated that the residual for high-leaching soils was similar to that of other soils. One year after S was applied, the sulphate-S soil test was still higher in the S treatments than the no-S treatments, with the difference dependent on the rate of S fertiliser and the time of application (Table 6). By 2 years after S was applied, fertiliser S had no effect on sulphate-S test.

Watkinson & Kear (1996) have shown that sulphate application has no short-term effect on soil organic S test levels.

Calculating the effective S fertiliser rate

The results in Table 5 indicate that when S is applied only once, the response in the second and third years was about half and a quarter of that in the first year. If a near-linear relationship between relative yield and S rate is assumed, then the yield in the second year (when no S was applied) is equivalent to the yield at about half the fertiliser rate applied in the first year. Thus the residual effect of S on yield can be modelled by using a exponentially weighted moving average function to calculate an effective fertiliser rate. This approach allows estimation of the effect of previous fertiliser S applications on yield, and predicts the responses to biennial and triennial applications over time.

Elemental S was incorporated using the S oxidation model of Ghani *et al.* (1995), assuming that the amount of elemental S oxidised in one year had the same fertiliser value as that amount of sulphate fertiliser applied in the same year.

The effective S rate was calculated for all the trials with yield data in the S database, and the relationship between relative yield and the effective fertiliser rate determined. This includes both sulphate and elemental S response trials. The exponentially weighted moving average provided a better relationship with relative yield than using annual applied S rates (sulphate) or oxidised S (elemental S). However, on many sites there was still considerable year-to-year variation in pasture response. From the relationship between effective fertiliser rate and relative yield, the knot (effective fertiliser rate at which maximum relative yield first occurs) and the slope (response per kg S) were estimated. The knot and slope where then statistically linked with site and trial information held on the database. The relationships fitted were generally unstable, indicating that the information held on the database was not strongly correlated with either the S rate required for maximum yield, or the slope of the S response curve. Thus site-specific response curves could not be developed.

Discussion

Care is needed in interpreting the results of fertiliser strategies shown:

- The trials for many of the comparisons occurred on a small range of soils and regions, and the results could thus be biased. For example, triennial applications may give lower residual effects on soils with high-leaching characteristics than the results in Table 4 (South Island soils) suggest.
- Time of application is considered only by season. The responses to S addition may be influenced by the timing of climatic conditions conducive to growth or S losses relative to time of application. For example, April application of sulphate in a warm, dryland environment may coincide with growth better than an October application. The advantage to spring applications of sulphate on the high-leaching soils probably reflects higher leaching loss of S over winter on these soils.
- The effect of multiple vs. annual S applications may depend on the rate of S applied. Split applications are most likely to be an advantage when loss rates are high as long as adequate S is applied in the first application to remove immediate deficiency. Annual applications are likely to be superior only when insufficient S is applied initially to deficient pastures.

These results reinforce the need for advisors to use local knowledge and basic principles of plant growth and fertiliser behaviour when considering S fertiliser strategies.

The residual effect of S on yield implies that when S fertiliser is applied, it can affect yield for 2–3 years after that S is applied. The corollary is that in a given year, the response to S is due to the S applied in that year plus S applied in previous years. In the trials where residual effects could be measured (mainly in the South Island), this residual effect was not sufficient to maintain yield at optimum levels 1 year after application of fertiliser. However, on trials with marginal S status, the residual effect may be able to maintain yield at optimum levels for more than 1 year. The residual effect of yield is probably owing to factors other than increased plant availability of S in the soil, as the residual effect on soil test values was seen for only 1 year (Table 6), whereas the effect on yield was seen for 2–3 years (Table 5). The residual effect on yield could be due to storage and subsequent slow release of S in the soil (e.g., in the organic component) which is not reflected in the soil test, changes in the efficiency of S cycling, or changes to other factors such as pasture composition or N cycling (owing to S increasing clover growth).

The residual effect, and thus the effect of different fertiliser rates, have been incorporated into decision support software for calculating S responses using the exponentially weighted moving average function. As a site-specific response curve could not be estimated, a response curve is calculated from relative yield when no S is applied (as predicted by the organic S test) and an average rate constant. As S is a cheap nutrient, the rate constant that in most cases overestimates S requirements was used to ensure adequate S supply.

Table 6 Relationship between residual soil S test and rate of sulphate applied (kg ha^{-1}) for spring and autumn applications. Standard errors are shown in parentheses.

Season	Regression equation	R^2	N
Autumn	residual = 0.018 * rate + 1.53 (0.007) (0.609)	0.29	12
Spring	residual = 0.101 * rate – 0.96 (0.022) (1.16)	0.38	34
Spring (adj)[1]	residual = 0.126 * rate –1.18 (0.020) (1.01)	0.59	29

[1] 5 data points were omitted owing to no residual effects despite high rates of S applied.

As S availability and responsiveness is influenced by climate (plant growth rates, leaching losses, rainfall), individual site climate factors may need to be included in future models.

REFERENCES

Ghani, A.; Watkinson, J.H.; Upsdell, M.P. 1995. Modelling the oxidation of elemental sulphur in New Zealand pastoral soils. pp. 159–169. *In* Fertilizer Requirements of Grazed Pasture and Field Crops: Macro- and Micro-Nutrients. Eds. L.D. Currie and P. Lonanathan. Occasional Report No 8. Fertilizer and Lime Research Centre, Massey University, Palmerston North.

Cornforth, I.S.; Sinclair, A.G. 1984. Fertiliser and Lime Recommendations for pasture and Crops in New Zealand. Second Revised Edition. Wellington, New Zealand, MAF.

Watkinson, J.H.; Kear, M.J. 1996. Sulfate and mineralisable organic sulfur in pastoral soils of New Zealand. II. A soil test for mineralisable organic sulfur. *Australian journal of soil research 34*: 405–412.

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