DEVELOPMENTS IN THE MANAGEMENT OF SOIL FERTILITY AND PASTURE NUTRITION OVER THE LAST 20 YEARS

Dr D C Edmeades

Managing Director, agKnowledge Ltd, PO Box 9147, Hamilton 3240
doug.edmeades@agknowledge.co.nz

Introduction

The theme of this conference is: 'Gains from the Past – Goals for the Future'. This paper applies these two questions to the subset of soil science; soil fertility and pasture nutrition. Specifically this paper reviews the research conducted over the period 1990 to the present by soil scientists in MAF Research Division and subsequently AgResearch Ltd.

To understand the research that was undertaken over this period it is first necessary to appreciate the problems that were apparent at the time. All farm subsidies were removed in 1985, including those on fertiliser. Fertilisers were the largest item of discretionary expenditure on most farms and hence many farmers could not afford to apply fertilisers and were asking what the likely consequences would be in terms of farm production and economics. At this time the nutrient models upon which fertiliser advice was based were static, steady state, maintenance models (Cornforth and Sinclair 1982). Dynamic nutrient models were required so that fertiliser advice could be based on long-term economic outcomes.

Reactive phosphate rocks (RPRs) were also introduced. They were, in the mid 1980s, about 30% cheaper per unit of total P and were claimed to be as effective as soluble P fertilisers such as superphosphate. Farmers were seeking technical advice about these products.

Also, beginning in the 1980s, questions were being raised about the veracity and hence value of soil testing. There was a view that soil tests were too variable to be of use or had not been properly calibrated to be of practical value. There was a need to define the production functions relating pasture production to soil nutrient levels.

For these reasons several long-term research and development projects were commenced by scientists in the Soils and Fertiliser Group of the Research Division of MAF, which became AgResearch Ltd in 1992 (for a more detailed account of the approach that was adopted see Edmeades 1995).

Data-base

MAF Research Division and it predecessors were very well equipped to set-up and conduct fertiliser field-trials, particularly on pasture, all over New Zealand. Collectively this information was an invaluable resource and hence a data-base was established, capturing in a structured format, details from 1300 phosphate (P) trials, 780 potassium (K) trials and 1100 sulphur (S) trials (for further details of the data-base see Edmeades et. al. 2006).

Dynamic Nutrient Models

Metherell et. al. (1995, 1999) developed a conceptual dynamic P model and used the information from the data-base to paramatise, and then test this model. Further verification has been presented by Roberts et. al. (1995). Similarly dynamic models were developed for S (Thorrold and Woodward 1995) and K, although the later was not formally published. These models, together with an economic lime model (Edmeades et. al. 1985, Sinclair 1995) and an RPR dissolution model (see later) were incorporated into a piece of software initially called OUTLOOK (Marshall 1995).

The primary motivation for developing OUTLOOK was as an expert system to examine the economic outcomes of different fertiliser strategies on a given farm. However nutrient inputs and outputs were essential features of these dynamic nutrient models and hence OUTLOOK also produced nutrient budgets for any given scenario.

Since the mid 1990s increasing pressure was applied to farmers to use nutrient budgets as a means of managing nutrient losses for the farm. Thus, the nutrient budget functions of OUTLOOK were separated from the econometric modeling functions and developed further as a stand-alone software package OVERSEER. Further development of OVERSEER has continued but the econometric model (referred to as the PKSLime Econometric Model) has remained unchanged. Metherell (1999) provides examples of its application for examining the economics of fertiliser use.

Reactive Phosphate Rocks

To provide farmers with technical information about RPRs a national series of 19 field trials was commenced in 1982. These trials compared the agronomic effectiveness of Sechura RPR with soluble P, applied as triple superphosphate (TSP) over 5 rates. Most of these trials ran for 6 years. A description of the trials and the annual pasture production data from all these trials was summarized by Smith et. al. (1990). In an initial summary of the data Sinclair et. al. (1990) concluded that it took about 6 years for Sechura RPR to equal the agronomic performance of soluble P. These results were however confounded by the fact that Sechura RPR contains molybdenum (Mo) and that this may have inflated the effectiveness of Sechura PRP on some sites (Sinclair et. al. 1990 a, b).

Edmeades et al (1991) using the agronomic data, and allowing for the Mo effect, together with a newly developed RPR dissolution model, concluded that average dissolution rate of Sechura RPR was about 30% and that the ‘lag-effect’ of Sechura RPR, relative to soluble P, was about 4-6 year, depending on the site characteristics. It was clear that Sechura RPR, accepted at the time as the most reactive phosphate rock, was not equivalent to soluble P. A set of practical recommendations for the use of RPR by farmers was then developed (Edmeades et. al. 1991).

At their peak RPRs, either applied alone or as mixtures, made up about 30% of the New Zealand fertiliser market. As the results of the research summarized above became public sales declined. Today the use of RPR is confined to the small organic farming market.

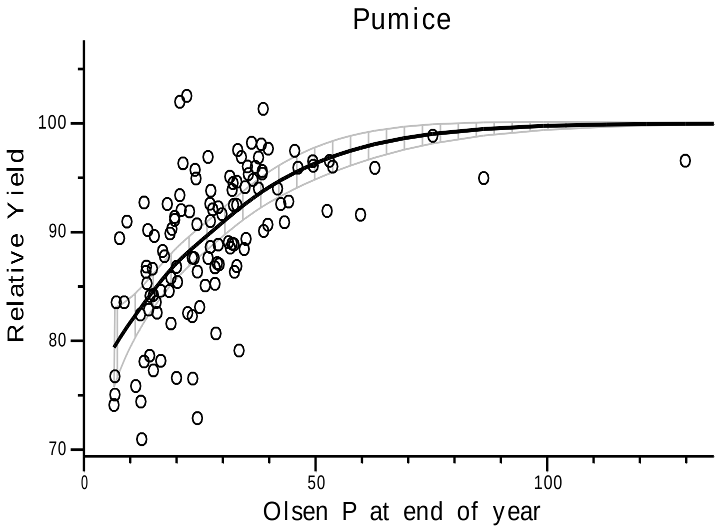
Nutrient Production Functions

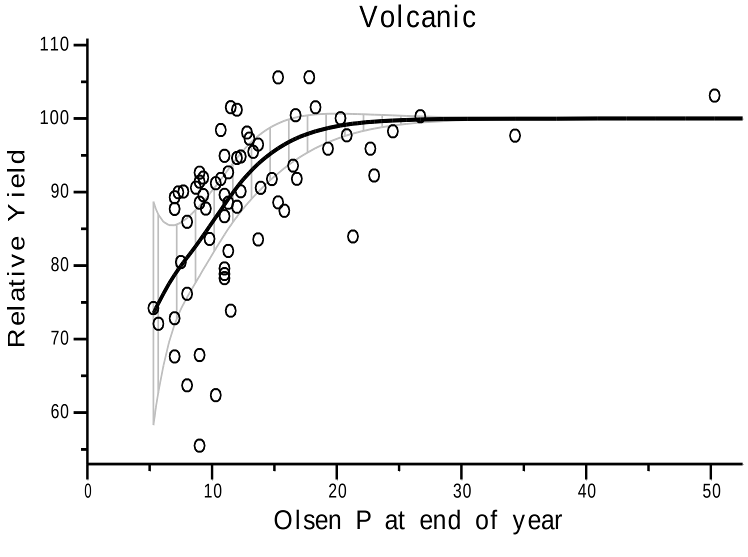
In order to define the relationships between pasture production and available soil nutrient concentration of P, K or S, several technical issues need to be confronted. Traditionally the results from pasture fertiliser trials were plotted with the yield (or relative yield) on the y-axis and the rate of fertiliser or nutrient applied on the x-axis. This made little sense because the state factor determining pasture yield is not the rate of nutrient applied but the nutrient status of the soil. Nevertheless this approach was justified at that time because in multiple year trials the soil nutrient level for any given rate of nutrient application changed over time but the rate of application was constant. This problem was logically solved by modeling the changes in soil nutrient levels over time for any given rate of nutrient application.

The other problem was; which mathematical model best fitted these diminishing returns relationships? The Mitscherlich function was favored but the problem was never resolved. The solution was to use Bayesian statistics to determine the most probable relationship (and the 95% confidence interval), between the soil nutrient concentration and pasture relative yield. This approach makes no mathematical assumptions about the shape of the pasture-soil nutrient relationship.

Phosphorous

This approach has been applied to the set of rates of P pasture trials in the data-base (Edmeades et. al. 2006). The production functions relating relative pasture production and soil P (Olsen P) for the three major soil groups in New Zealand are shown in Figure 1. The grey scale bands represent the 95% confidence internal.





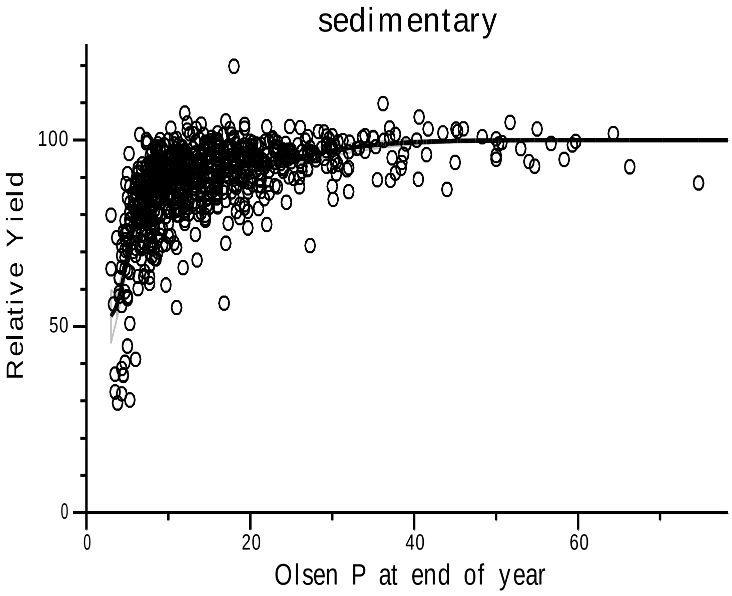


Figure 1: The relationships between relative pasture production and Olsen P for the three major soil groups in New Zealand (from Edmeades et. al. 1996)

From this information the critical Olsen P level and 95% confidence interval were determined (Table 1).

Table 1. The critical levels for Olsen P required to achieve 97% maximum pasture production for the various soil groups in New Zealand. (from Edmeades et. al. 1996)

Soil Group	**Critical Level and Confidence Interval (95%)**
Pumice	50 (43-61)
Volcanic	32(27-38)
Peat	40 (35-45)
Sedimentary	30 (26-32)
Recent	25(20-30)
Podzols	25 (22-30)
Sands	12 (10-15)

It is realistic to suggest that considerable progress has been made in defining the pasture-Olsen P relationship and hence refining the interpretation of the Olsen P test.

Sulphur

It had been known for a long time that there are two pools of plant available S in soils; the readily plant available sulphate S pool and the much larger pool of organic S that is mineralized and becomes plant available over-time. There was no soil test for this fraction of potentially plant available S. In the steady-state S models developed by Cornforth and Sinclair (1982) pasture age was used as a proxy for this pool of available S.

Watkinson (1996b) developed and calibrated (Figure 2) a soil test for organic S and showed that it was logically related to the pasture age (Watkinson et al 1991). The method was based on the measuring the organic S extracted from the soil using potassium phosphate – the same reagent used to extract sulphate S from soils. The organic S was the difference between the total S extracted minus the sulphate S. Watkinson referred to this S as extractable organic S (EOS). Importantly, he showed that EOS was directly related to total soil S. Most laboratories have found it easier and cheaper to measure total S rather than EOS and thus the potentially available organic S (EOS) is now reported as either organic S (EOS) or total organic S.

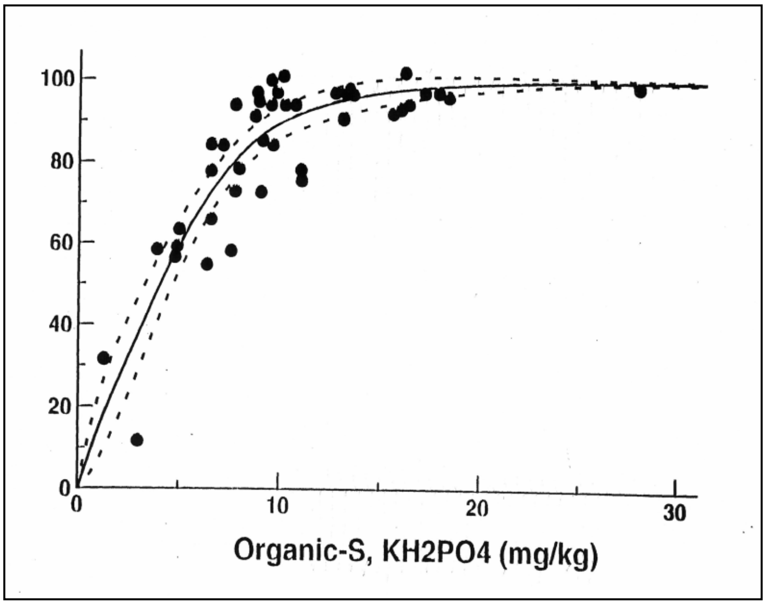


Figure 2. The relationship between relative pasture production (y axis) and organic S extractable in potassium phosphate solution (from Watkinson and Kear 1996b).

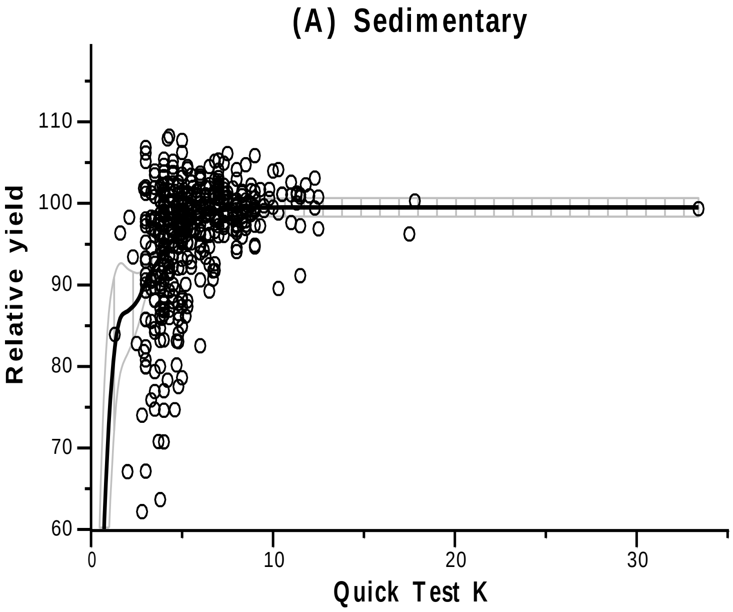
Watkinson (1996a) showed that there was an equilibrium between sulphate S and organic S. However sulphate S concentration are temporally variable due to additions of sulphate in fertiliser and dung & urine, and removals, due to leaching events. For this reason the equilibrium conditions rarely apply. Because it represents the largest and most important pool of available S and is not subject to temporal variability, organic S is a more useful guide for determining the long-term (year to years) soil S status.

The critical level for optimal pasture production for both organic S and sulphate is the same (10-12) – not surprising given the equilibrium between these 2 pools. However the interpretation of the organic S test requires special understanding.

If the organic S is above the critical range there will be sufficient sulphate S mineralized from the pool of organic S over the year to meet the pasture S requirements. However there are some soils, in particular soils formed under low rainfall, which will never accumulate sufficient organic S to reach the critical level, irrespective of how much S is applied (Edmeades et al 2005). In these situations the organic S test will always be less than 10-12 meaning that fertiliser S will always be required to meet the annual S requirement.

Potassium

Defining the production functions for K presented other technical problems. First the relationship between relative pasture production and soil K (Quick Test K, QTK) are flat, particularly over the important critical range between QTK 4 to 10. There is also a lot of uncontrolled variability (Figure 3). A different approach was required to give practical meaning to this data.



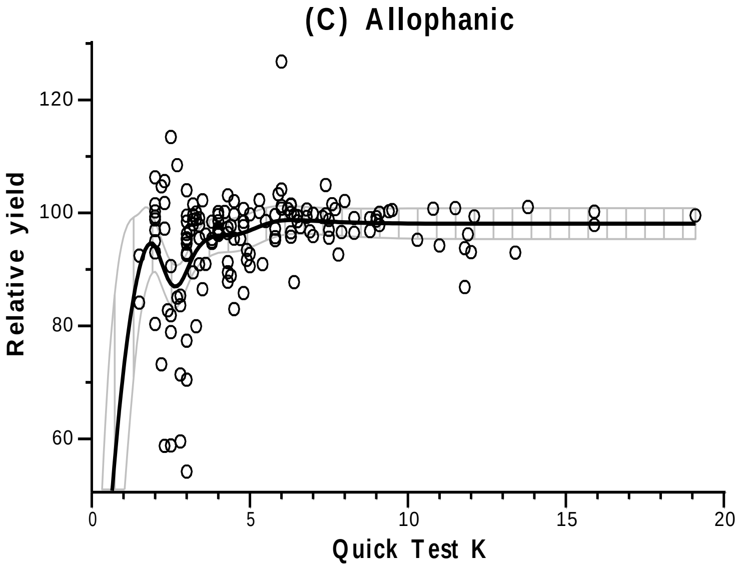


Figure 3. The relationships between pasture relative yield and soil K (Quick Test K) for sedimentary soils and Allophanic soils. (from Edmeades et. al. 2010)

One of the features of Bayesian statistics is that it makes it possible to quantify the probability of getting a response to fertiliser K for any given QTK level. The results are shown in Figure 4.

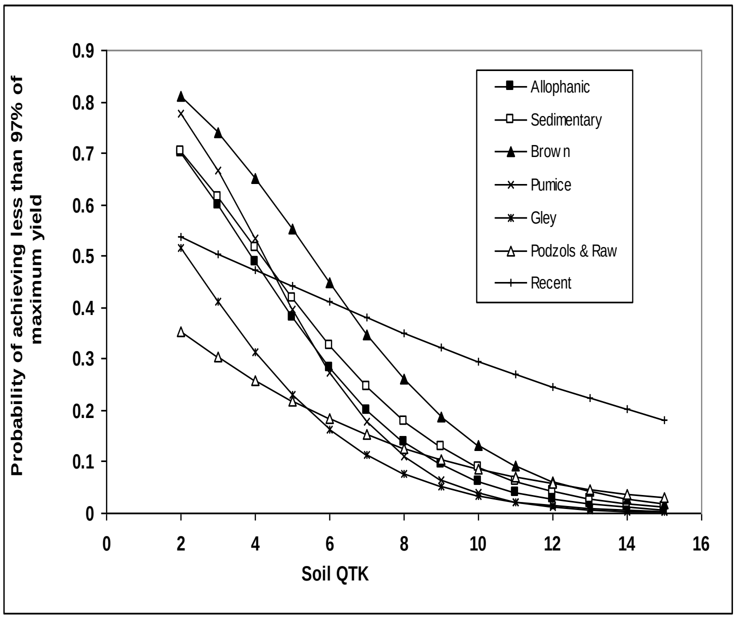


Figure 4: The relationship between soil K (Quick test K, QTK) and the probability of pasture response to fertiliser K. (from Edmeades et.al. 2010).

As the QTK increases the probability of a response to fertiliser K decreases. The relationships are very similar for all soil groups except for the recent soils. For most soils the probability is low (< 10%) for QTK levels of > 10 suggesting that pasture K responses are not likely if the QTK is >10. In practice, the economics of using fertiliser K needs to be considered and allowing for this a critical range of between 7-10 is appropriate for most soils, accepting the normal variability associated with measuring QTK.

The other feature of the production functions is the significant number of trials indicating very little response to fertiliser K even though the QTK is low (<5). The traditional explanation for this was that such soils had significant amounts of Reserve K, which is not measured by the QTK test. However, there was one set of data on the data-base in which both QTK and Reserve K (TBK, which measures QTK plus Reserve K) were measured. There was little difference in the respective production functions (Figure 5) suggesting that Reserve K does not contribute anything to predicting K responses. Edmeades et. al. (2010) suggested other explanations for this feature in the data.

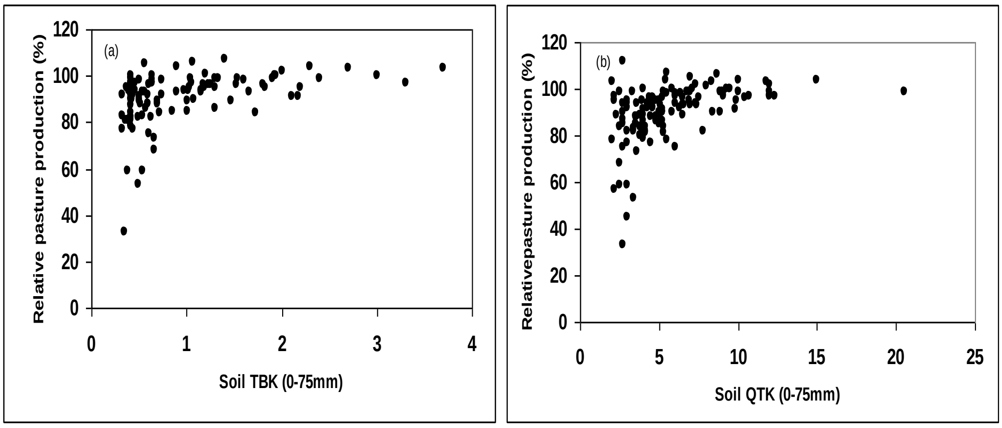


Figure 5. The rleationships between relative pasture production and a) Reserve K (TBK) and soil Quick Test K (QTK). (from Edmeades et. al. 2010)

Future Research

Refining the Pasture Production Functions

The impulse of many soil scientists confronted with the fact that most soil tests can only account for about 40-50% of the variability in predicting crop or pasture production is to develop a new soil test. The results and analysis of reported by Sinclair et al (1997) suggests that this is futile.

They analyzed the sources of variability in 46 data-sets from 17 long-term trials measuring the effects of rates of P on pasture production. They found that most of the variation in the pasture production-Olsen P relationships arose from within years on a given site and between years on a given site. Their conclusion was that, "…even a 'perfect' test, measured with the utmost precision, may be unable to account for more than a small fraction of the variability in response to fertiliser."

Edmeades et al (2006) have developed these ideas further by explicitly identify all the possible sources of variation in the production functions and concluded that, " progress to refining and understanding the nature of production functions will depend on further understanding of how plants acquire soil P rather than trying to find a new soil test for available P." It follows that future research needs to examine plant root architecture and soil moisture and their effects and interactions on the plant's ability to acquire soil P.

Updating the Econometric Models

The data on the data-base has now been reviewed, analyzed and summarized in a series of review paper (Edmeades 2005 (S), 2006 (P) and 2010 (K)) together with reviews on the pasture requirements for calcium (Ca) (Edmeades and Perrrott 2004), magnesium (Mg) (Edmeades 2004) and sodium (Na) (Edmeades and O'Connor 2003). This information collectively represents the end-point of over 50 years of pasture-fertiliser research.

It is suggested that this information should be used to upgrade the dynamic nutrients models that are the frame-work of OVERSEER and the PKSLime econometric models.

Acknowledgements

I acknowledge the efforts all of the scientists who were part of the Soils and Fertiliser Group (AgResearch) over the period of time from 1990 to the present. Much was achieved.

References

Cornforth, I. S.; Sinclair, A.G. 1982. Fertiliser Recommendations for pasture and crops in New Zealand. Ministry of Agriculture and Fisheries, Wellington New Zealand February 1982.

Edmeades, D. C.; Pringle, R.M.; Mansell, G.P.; Shannon P.W.; Ritchie, J. and Stewart, K. M. 1985. Effects of lime on pasture production on soils in the North Island of New Zealand 5. Description of a lime recommendations scheme. New Zealand Journal of Experimental Research, 13: 47-58.

Edmeades, D. C. Watkinson, J. H.; Perrott, K. W.; Sinclair, A. G.; Ledgard, S. F.; Rajan, S. S. S.; Brown, M.W.; Roberts A, H, C.; Thorrold, B.; O'Connor M.B.; Floate, M. J. S.; Risk, W. N and Morton, J. D. 1991. Comparing the agronomic performance of soluble and slow release phosphate fertilisers. Proceedings of the New Zealand Grasslands Association. 53: 181-190.

Edmeades, D. C. 1995. Modelling Nutrient Requirements – AgResearch's Approach. In: Fertiliser Requirements of Grazed Pasture and Field Crops. (Eds L. D. Currie and P Loganathan). Occasional Report No 8. Fertiliser and Lime Research Center, Massey University, Palmerston North, New Zealand. 9-11p.

Edmeades, D. C. and O'Connor, M.B. 2003. Sodium requirements for temperate pastures in New Zealand: a review. New Zealand Journal of Agricultural Research, 46: 37-47.

Edmeades, D.C. 2004. The magnesium requirements of pastures in New Zealand: a review. New Zealand Journal of Agricultural Research, 47: 363-380.

Edmeades, D. C. and Perrott, K.W. 2004. The calcium requirements of pastures in New Zealand: a review. New Zealand Journal of Agricultural Research, 47: 11-21.

Edmeades, D. C.; Thorrold, B.T. and Roberts, A.H.C. 2005. The diagnosis and correction of sulfur deficiency and the management of sulfur requirements in New Zealand pastures: a review. Australian Journal of Experimental Agriculture, 45: 1205-1223.

Edmeades, D. C.; Metherell, A. K.; Waller, J.D.; Roberts, A.H.C. and Morton, J. D. 2006. Defining the relationships between pasture production and soil P and the development of a dynamic P model for New Zealand pastures: a review of recent developments. New Zealand Journal of Agricultural Research, 49: 207-222.

Edmeades, D.C.; Morton, J. D.; Waller, J. E.; Metherell, A.K.; Roberts, A. H. C. and Carey, P. 2010. The diagnosis and correction of potassium deficiency in New Zealand pastoral soils: a review. New Zealand Journal of Agricultural Research, 53: 151-173.

Marshall, P.R. 1995. An Introduction to Outlook: Software for Evaluation of Phosphate Fertiliser Strategies. In: Fertiliser Requirements of Grazed Pasture and Field Crops. (Eds L. D. Currie and P Loganathan). Occasional Report No 8. Fertiliser and Lime Research Center, Massey University, Palmerston North, New Zealand. 40-45p.

Metherell, A. K.; McCall, G.G. and Woodward, S. J. R. 1995. Outlook™: A Phosphorous Fertiliser Decision Support Model for Grazed Pastures. In: Fertiliser Requirements of Grazed Pasture and Field Crops. (Eds L. D. Currie and P Loganathan). Occasional Report No 8. Fertiliser and Lime Research Center, Massey University, Palmerston North, New Zealand. 24-39p.

Metherell, A. K. 1999.

Roberts, A. H. C.; Morton, J.D. and Metherell, A. K. 1995. Comparison of 'Outlook' Model Predictions with Trends in Olsen P Measured on Farms. In: Fertiliser Requirements of Grazed Pasture and Field Crops. (Eds L. D. Currie and P Loganathan). Occasional Report No 8. Fertiliser and Lime Research Center, Massey University, Palmerston North, New Zealand. 54-79 p.

Sinclair, A.G.; Dyson, C. B. and Shannon, P. W. 1990a. The long-term effectiveness of reactive phosphate rock as a phosphate fertiliser for New Zealand pastures. Proceedings of the New Zealand Grasslands Association. 51: 101-104.

Sinclair, A. G.; Shannon, P. W. and Risk, W. H. 1990b. Sechura Phosphate Rock supplies plant-available molybdenum for pastures. New Zealand Journal of Agricultural Research. 33: 499-502.

Sinclair, A.G. 1995. Modelling Soil Acidification in Pastoral Farming. In: Fertiliser Requirements of Grazed Pasture and Field Crops. (Eds L. D. Currie and P Loganathan). Occasional Report No 8. Fertiliser and Lime Research Center, Massey University, Palmerston North, New Zealand. 198-205p.

Sinclair, A. G.; Johnston, P. D.; Smith, L. C.; Roberts, A. H. C.; O'Connor, M. B. and Morton, J. D. 1997. Relationship between pasture dry matter yield and soil Olsen P from a series of long-term field trials. New Zealand Journal of Agricultural Research, 40: 559-567.

Smith, L.C.; Johnstone, P. D.; Sinclair, A. G.; Shannon, P. W.; O'Connor, M. B.; Percival, N.; Roberts, A .H. C.; Smith, R. G.; Mansell, G.; Morton, J. D.; Nguyen, L.; Dyson, C. B. and Risk, W. H. Final Report on the MAF 'National Series' Forms of Phospahe Fertiliser Trials. Par 1: Description of the Trials and Annual Herbage Dry Matter Production. Ministry of Agriculture and Fisheries, Neww Zealand December 1990.

Thorrold, B. and Woodward, S. 1995. A Dynamical Model for Suphur Fertiliser Use on Pastures. In: Fertiliser Requirements of Grazed Pasture and Field Crops. (Eds L. D. Currie and P Loganathan). Occasional Report No 8. Fertiliser and Lime Research Center, Massey University, Palmerston North, New Zealand. 150-158 p.

Watkinson, J. H.; Perrott, K. W. and Thorrold, B. S. 1991. Relationship between the MAF Pasture Development Index and Extractable Organic S. In: Soil and Plant Testing for Nutrient Deficiencies and Toxicities. (Eds. R. E. White and L. D Currie). Occasional Report No 5. Fertiliser and Lime Research Center, Massey University, Palmerston North, New Zealand. 66-71p.

Watkinson, J. H. and Kear, M.J. 1996 a. Sulphate and mineralisable organic sulfur in pastoral soils of New Zealand. I. A quasi equilibrium between sulphate and mineralsable organic S. Australian Journal of Soil Research, 34: 385-403.

Watkinson, J. H. and Kear, M.J. 1996 b. Sulphate 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.