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Nutrient reserves in Southland soils

C.C. BOSWELL[1], W.H. RISK[2], R.P. LITTLEJOHN[1], B. SWANNEY[1], G.M. GRAY[2], and L.C. SMITH[2]
[1]*AgResearch Invermay Agricultural Centre, Private Bag, Mosgiel*
[2]*AgResearch Woodlands Research Station, Private Bag, Invercargill*

Abstract

The major plant nutrients in soils were measured from 53 Southland sites arranged along 4 transects which extended inland from the southern coast and one which extended westwards from Papatowai on the east coast to Manapouri in the west. Soil samples were taken from 8 depths: O-75.75-150, 150-225, 225-300, 300-450, 450-600, 600-750, and 750-900 mm, at each site. In zonal soils, sulphate accumulated deeper in the soil profile and declined logarithmically with distance from the southern coast. In recent soils there was little accumulation in the profile. Rainfall sulphur is the most likely source of the reserves. Magnesium accumulated deep in the profile of inland soils in western transects, suggesting that serpentine rock parent material was its source. Generally, available phosphorus, calcium, potassium, total nitrogen and organic carbon concentrations were greatest in the surface layer of soil and declined with soil depth. However, very high phosphate reserves were present deep in the profile at a few specific inland sites. Short-term sustainable agricultural systems could involve the utilisation of at least some of these reserves. This would require the encouragement of deeper-rooting of plants than currently occurs under pastoral systems.

Keywords magnesium, nutrient reserves, phosphorus, Southland, sulphate, sustainable agriculture, transects

Introduction

Sustainable agricultural systems imply continued production over long periods of time without depleting natural resources such as the reserves of nutrients in soils. Alternative sustainable systems may differ radically from existing production systems because they may involve better utilisation of nutrient reserves, and, where reserves are large, may involve short-term *mining* of them. However, in soils with limited reserves mining of them is not consistent with sustainability. A major challenge in modem agriculture is to use soil nutrient reserves in sustainable agricultural production systems; essentially this involves tapping into reserves and recycling them effectively. The first requirement is to know what the nutrient reserve status of soils is before any sustainable system is planned. The concentration of nutrients in the surface 75 mm of soil is taken as a convenient index of the immediate nutrient status. Long-term reserves can be assessed only by examining the whole soil profile.

An earlier report of large reserves of subsoil sulphate from a few Southland sites on yellow-brown earth soils suggested a relationship between sulphate reserves and rainfall (Risk & Boswell 1988). A survey of sulphur input in rainfall across Southland was conducted at the same sites as are reported in this paper. It showed that inputs of sulphur in rain were strongly associated with the logarithm of distance from the south coast (Boswell *et* al. 1993). Soil sulphate reserves were therefore similarly analysed in association with distance from the south coast.

A broad account of the levels of most other available nutrients distributed in the A and B horizons of soils throughout New Zealand is available from single-factor maps (New Zealand Soil Bureau 1962). However, the maps have limitations for planning sustainable *systems* because they usually involve the upper horizons of the soil profile and the nutrient levels are a mean range of values representative of relatively broad soil group mapping units.

Methods

The locations of the soil sites along five transects are shown in Figure 1. Sites were on developed pastures which generally received regular fertiliser applications. In Transect 3 soil samples were taken from both older terraces (*zonal* soils = 3a) and from adjacent recent soils (recent soils = 3b). Ten to 15 cores (diameter 25 mm) were taken to the following depths at each site : O-75, 75-150, 150-225, 225-300, 300-450, 450-600, 600-750, 750-900 mm. Samples were dried overnight at 35°C, ground to pass a 2 mm sieve, and analysed by standard MAF quick test analysis (Blackmore *et al.* 1972; Sinclair & Enright 1982). Analyses included exchangeable cations calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), extracted in 1N ammonium acetate; sulphate sulphur (S) extracted by calcium dihydrogen

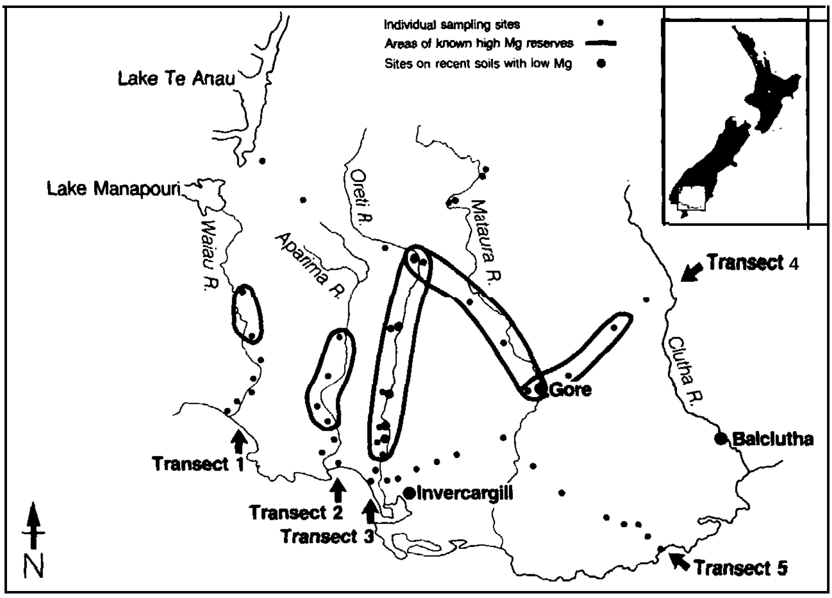

Figure 1 **Map of Southland** showing **location** of soil **sampling sites, and zones** of bigh soil **exchangeable** magnesium **reserves.**

phosphate at pH 4.0; available phosphorus (P) 1/2 hour Olsen extracted by 0.5M sodium bicarbonate; organic carbon (C) and total nitrogen (N).

The dependence of sulphate concentration on soil depth and distance from the coast for each transect was investigated by multiple regression, fitting the equation

$\log(SO_4) = a + b \times \text{depth} + c \times \log(\text{dist}) + d \times \text{depth} \times \log(\text{dist})$ ....equation 1

where dist is the distance from the south coast. The logarithms of sulphate concentration and distance are taken to linearise the relationship. A high value of b indicates that close to the coast sulphate concentration increases rapidly down the soil profile, while a large negative value of c indicates that the surface concentration of sulphatedecreases rapidly with distance from the south coast. The interaction between soil depth and distance from the coast is incorporated into the model by the parameter d; a large negative value of d indicates that sulphate concentrations at depth decrease along the transect more rapidly than in surface soils. If they were not significant, the parameters d followed by band/or c. were dropped from the model. In each transect the coastal site, which in most cases was a sand occupying an unrepresentative narrow coastal strip, was not included in the regression analysis.

Results and discussion

Quantitatively the greatest reserves were of sulphate followed by magnesium and, in isolated locations, phosphorus. Highest reserves occurred where the nutrients accumulated at depth in the soil profile. With the other nutrients and usually with phosphorus, reserves were limited and were greater in the surface layers of the soil than at depth.

Subsoil sulphate reserves varied between transects, and between recent soils and zonal soils on Transect 3. The parameter estimates for fitting Equation 1 to the sulphate data are given in Table 1. For Transect 1 there was little variation in sulphate concentration with depth or distance from the coast. In Transects 2, 3a, 4 and 5, parameters indicate large sulphate reserves below 450 mm near the coast, decreasing to modest levels by 100 km inland. In Transect 3b on recent soils, sulphate concentration did not vary substantially with depth, but it declined in the more inland sites relative to those nearer the coast. Figure 2 summarises the differences between mean soil sulphate concentrations in the 450-900 mm depth in recent soil and zonal soils (Transects 3b and 3a respectively). Where sulphate concentrations were greatest the total profile reserves of sulphate-S are estimated to be 930 kg/ha. The accumulationof reserves below 450 mm is beneath the normal rooting depth of summermoist temperate pasture plants (Risk & Boswell 1988).

Regression analyses of mean soil sulphate at 450-900 mm depth on annual S input per hectare in rainfall (Boswell et *al.* 1993) were significant on all transects (Figure 3). This indicates that long term accumulation of rainfall sulphate is a moreimportant source of the subsoil sulphate reserves than fertiliser sulphate inputs over the last 100 years.

Areas with high subsoil reserves of Mg in this survey are shown in Figure 1. In contrast to sulphate, the major contributor to soil Mg is the parent material. Magnesium reserves at 450-900 mm were highest at Lumsden (Figure 1), near the serpentine rocks at the end of the Red Mountain ultrabasic rocks. Reserves declined from 614 ppm southwards down the Oreti River (Transect 3) at a rate of about 12 ppm/km, and south-eastwards to Gore along the Mataura River system at a rate of about 4 ppm/km. In addition there are small areas with moderate reserves (347 ppm Mg 450-950 mm) about Blackmount on the Waiau River (Transect 1). from Fairfax to Wreys Bush (263-149 ppm Mg) on Transect 2, and from Gore north east to Tapsnui (133-242 ppm Mg) on Transect 4. At the Lumsden site Mg reserves were about 3800 kg of exchangeable Mg/ha.

The association of high reserves with the river systems is in general agreement with the New Zealand Soil Bureau map of Mg reserves.

Table 1 Parameter estimates (and standard errors bracketed) for fitting equation (1) to log (soil SO_4) concentration for each transect (NS = not significant)

Transect	a	b	e	d
1	2.9 (0.11)	NS	NS	NS
2	2.30 (0.39)	0.0056 (0.0010)	-0.10 (0.13)	-0.00078 (0.00033)
3a	2.63 (0.38)	0.0069 (0.0010)	-0.20 (0.11)	-0.00143 (0.00026)
3b	2.85 (0.35)	-0.0006 (0.0003)	-0.24 (0.09)	NS
4	3.10 (0.48)	0.0060 (0.0012)	-0.26 (0.13)	-0.00069 (0.00033)
5	2.62 (0.27)	0.0056 (0.0007)	-0.09 (0.06)	-0.00106 (0.00021)

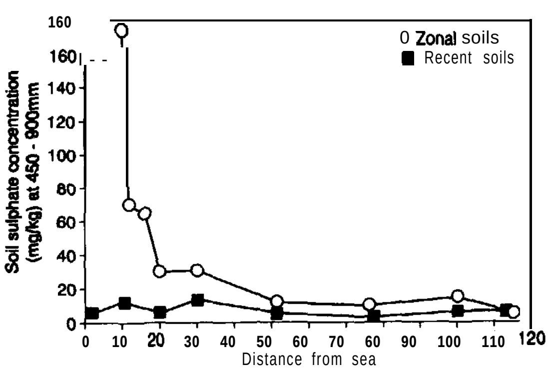

Figure 2 Relationship between mean soil sulphate concentrations (450-900mm depth) and distance from the coast in zonal and recent soils (Transect 3).

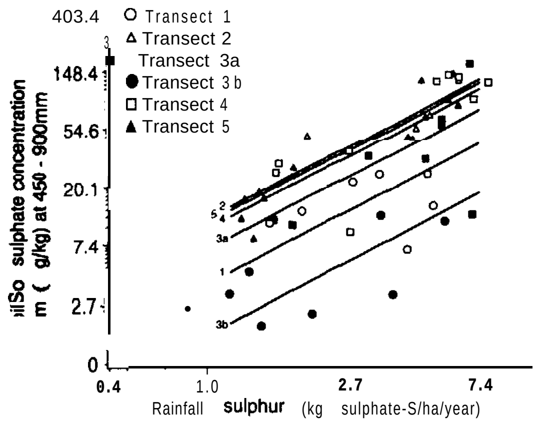

Figure 3 Relationship between annual sulphate S input in rainfall and soil sulphate reserves 450-950 mm (log scales).

Available phosphorus was generally greatest in the surface layer of soil and declined with depth at most sites (Figure 4). Phosphorus traditionally supplied in superphosphate (9% P, 11% S) is largely retained in the topsoil, increasingly as organic-P as the land is developed, so variation between sites probably reflects different fertiliser histories.

High P levels below 450 mm were found only at inland sites at Kingston (81 ppm), Mossburn (34 pprn) and Waikoikoi (23 ppm); comparable levels (>60 ppm) have previously been recorded in the 0- 100 mm depth in zonal soils in the upperreaches of the Mataura River (eg Athol to Kingston, Smith & Risk unpublished). Future surveys may show more widespread reserves of subsoil P in dry inland situations.

Except for such areas sustainable agricultural systems in Southland will continue to require inputs of P, since it is the key nutrient deficiency in Southland. Such inputs may be reduced by a practice such as subsoiling, where higher soil temperatures and improved aeration may lead to more rapid recycling of organic material and may simultaneously increase reserves of organic matter at depth.

The reserves of potassium (K), organic carbon (OC), and total nitrogen (N), were all concentrated in the surface layer of soil. There were geographical differences between transects; eg soils in the Waiau Valley (Transect 1) had more organic matter (OC, N) throughout the profile reserves than those on other transects ($P < 0.05$); but lower (non significant) exchangeable-K reserves. Exchangeable-K is not a good indicator of potassium reserves; a separate reserve-K analysis provides a better measure. However single factor maps for reserve-K show Southland soils have low potassium reserves (NZ Soil Bureau 1962).

The pattern of sodium concentration varied with soil depth depending on distance from the coast Relatively high concentrations (11-28 ppm) were found in surface soils near the coast, and in the deeper part of the profile for inland soils, contrasting with concentrations below 5 ppm near the surface of inland soils.

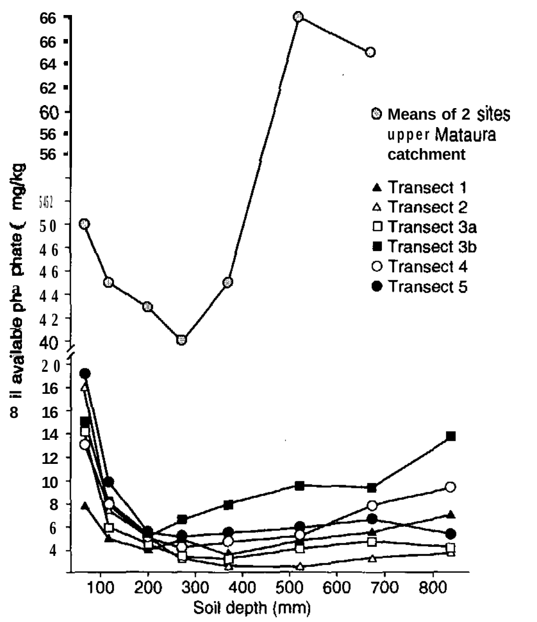

Figure 4 Mean available phosphate concentrations in the roil profiles for different transects and at two sites near Kingston.

There are areas of Southland soils from which reserves of sulphate could be exploited in the absence of S fertilisers without limiting plant production, there are other (inland) areas where natural reserves of Mg should preclude the need for Mg fertiliser in the foreseeable future, and other small inland pockets of soil where P reserves could be exploited while saving on P fertiliser. In all cases the bulk of the reserves are deep in the profile relative to accepted 'normal' pasture rooting depths. Little is known of the possible movement of nutrients within the soil profile. Risk & Boswell (1988) discussed the movement of sulphate upwards with the rising water table in Southland Plains soils in winter. The same mechanism could be expected to move Mg but probably not the P because of both its low solubility and possibly lower water table in the inland P-rich soils.

An alternative strategy would be to encourage plant roots to grow deeper into the profile. With pastures this could involve the removal of physical barriers such as compacted soil layers (Greenwood & McNamara 1992), or choice of species which are known to be deeper rooting than standard species. Cereals are generally deeper rooting than ryegrass and clovers, so cropping could be expected to increase the utilisation of the nutrient reserves. Deeper rooting trees could be expected to exploit the reserves even more, while a combination of tree crops at wide spacings and an understorey of pastoral or cereal or horticultural crops could represent the ultimate in sustainable systems. The trees would act as transport agents of nutrients stored at depth in the soil, returning them to the soil surface in leaf fall from which they would be incorporated into the topsoil and subsequently made available to the more shallow rooting crops. This is the key prerequisite for a sustainable agricultural system using the reserves of nutrients - there must be vertical recycling of the nutrients in the soil. If such systems were to be adopted it has to be recognised that the reserves reported occur in different locations, so that in one area the system might have adequate S for example but still need regular input of other nutrients such as P and K.

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