Initiatives in land use: nutrients, nutrient cycling and soil acidity

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Summary. Application of nutrients and improved genotypes have been the most significant factors responsible for increasing crop and pasture productivity in Australia. The application of single superphosphate, together with white and/or subterranean clover and Stylo have transformed low productivity native grasslands into highly productive pastures. In mixed crop/ pasture areas, the residual effects of fertilised, legume based pastures have had a major impact on the productivity of established areas and in the development of new lands.

Single superphosphate was the basis of the initial fertiliser programs but *as nutrient* limitations, international pricing structures and transport costs have changed, there has been an increasing move to the so-called 'high analysis' materials. In addition soil organic matter levels have fallen as a result of cropping and consequently increasing attention has been paid to the use of nitrogen-containing fertilisers. These trends are likely to continue in the future.

Early studies of nutrient cycling relied on gross estimates of pool sizes in grazing systems. These were refined in the period from 1960-80 by the use of radioisotopes which allowed estimates of both pool sizes and flow rates to be made within defined systems. These data, and the availability of fast powerful computers, have led to the development of mechanistic models of nutrient cycling, again within defined systems. Future developments will see the expansion of these models to regional nutrient management models.

The annual legume based pasture and crop/pasture systems developed in southern Australia have resulted in increased soil acidity. Such problems have not been encountered to the same extent in perennial pasture systems in more northern areas. Whilst liming may be an economical solution in some agricultural systems, long-term changes in the agricultural system are required to alleviate the problem.

With increasing economic pressures, intensification of land use has and will continue. Careful nutrient management will be the key to the productivity and survival of these production systems.

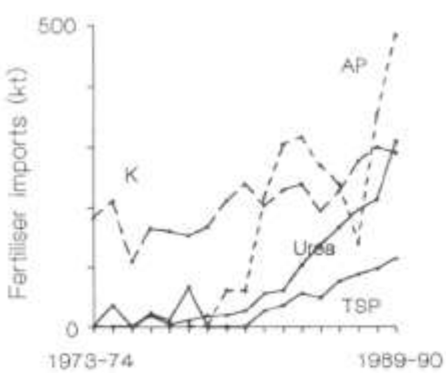
Introduction

Of the 762 million hectares which constitute the Australian continent only 468 million hectares are for used Agricultural production and, of this, only a small proportion of this area is covered by soils which do not require fertilisation. In 1988-89 ABARE (1) estimated that 18.1 million hectares were sown to crops and 30 million hectares sown to pastures and grasses.

In the 40 years since 1950 the area sown to wheat, other crops and pastures has increased by 6.8, 3.3 and 16.5 million hectares respectively. During the same period the numbers of beef cattle and sheep increased by 9.76 and 18.9 million respectively and dairy cattle declined by 2.19 million. Structural changes in the agricultural sector resulted in a decline in the number of agricultural establishments by 30,901 or 15.1% and the number of farm employees dropped by 19.8%.

During the same period the contribution of farm products to the Australian export sector have declined from 85.3% in 1950-51 to 24.4% in 1989-90. This has resulted in a lessening of the political influence of the rural sector.

The increased volume of crop and livestock production has been largely in response to declining agricultural terms of trade which have fallen from 320 in 1950-51 to 77 in 1989-90. At the same time the consumer price index has risen from 17 to 202.



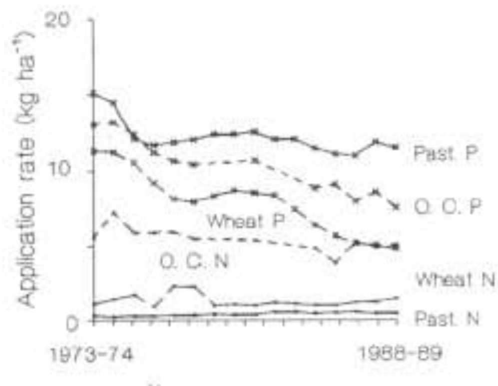


Figure 1. Fertiliser imports (kt/yr) into Australia 1973-90.

Figure 2. Fertiliser application rate Australia 1973-90.

The old and highly weathered soils of Australia are almost all inherently deficient in nitrogen (N) and phosphorus (P), the exceptions being the heavy clay soils of north-west NSW and the Darling Downs of Queensland.

Significant areas are deficient in sulphur, copper, zinc, molybdenum and cobalt and areas in South Australia and western Victoria suffer from boron toxicity. This, together with the decline in organic matter following 60-100 years of cropping on the fertile soils, has forced Australia into a fertiliser based farming system largely dependant on P or P/S containing products with or without micronutrient admixtures and a substantial reliance on legumes to provide N.

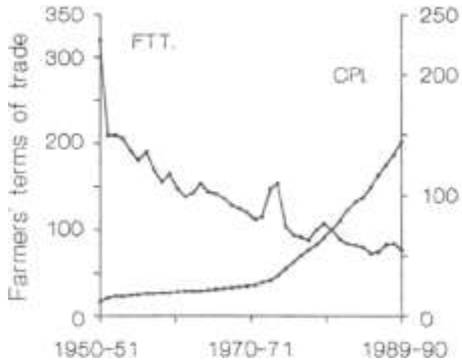
Nutrients

Fertiliser usage has undergone major changes in the last two decades. There has been no appreciable change in sulfur imports for fertiliser manufacture in the 1973-74 to 1989-90 period however, there has been a marked decline from 3.1 to 1.4 million tonnes in phosphate rock imports, in the same period. These have been offset, to some extent, by increased importation of finished products, particularly triple superphosphate (TSP) and ammonium phosphates (AP) (Fig. 1). The total importation of P in rock phosphate, TSP and AP declined from 373 kt in 197374 to 311 kt in 1988-89. There has been a substantial increase in the importation of urea (Fig. 1) over the same period.

There has been little change in the area of pastures or wheat fertilised in 1973 compared to 1990 but the area of other crops receiving fertiliser has increased. These data, together with the change in usage has resulted in a decline in the rate of application of fertilisers and this is shown in Figure 2. The decline has been most marked on pastures where average superphosphate applications have declined from 151 to 115 kg/ha over the 1973-90 period.

The reason for this can be seen in the indices of prices received by farmers which has increased from 48 to 153 over the 1950-90 period whilst the index of prices paid by farmers for inputs has increased from 15 to 199 over the same period. The resultant decline in farmers terms of trade (Fig. 3) has been compounded by a substantial increase in the con sumer price index (Fig. 3) over the same period hence their purchasing power has reduced substantially.

Increased fertiliser prices (Fig. 4) have had a major impact on patterns of use. Farmers have generally responded to this cost/price squeeze by fertilising only part of their property, often every second or third year, or only in years where a tax write off can be used to offset the higher fertiliser price.



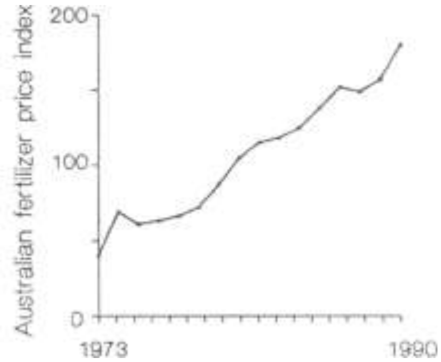


Figure 3. Farmers terms of trade and consumer price index 1950-90.

Figure 4. Change in fertiliser prices in Australia 1950-90.

The increased importation of fertiliser and the decline in local manufacturing has resulted in an increase in the number of fertiliser sellers in the market place and increased competition. The product mix available has also changed with increasing use of high analysis, low S containing fertilisers. This will inevitably lead to an increase in the incidence of S deficiency which will affect both the quality and quantity of output. Processes are available to add S to TSP, AP and MAP, for example that used by Hifert Pty Ltd in their Goldphos product, a recent process developed by University of New England (UNE) (Australian Patent No PK2667) and water dispersable pelleted elemental S produced by Sulchem in Canada. These processes offer a means of re-introducing S to fertilisers. The recent development of a soil test for S (6) will assist in the delineation of areas requiring S. In addition, the wheat grain S test developed by CSIRO (11) will be beneficial in diagnosing S problems.

A second consequence of increased fertiliser import has been the reduction in the output of byproduct phosphogypsum. It has been estimated (28) that up to 100,000 tonnes of this material are used annually for the amelioration of adverse soil physical conditions related to sodium. The closing of phosphate manufacturing at Newcastle and Brisbane will have serious implications for the supply of phosphogypsum to the cropping areas in north-west NSW and south-east Queensland.

Given the world over-capacity for production of TSP, Urea, MAP and DAP and increasing transport costs within Australia it seems likely that Australia will increasingly rely on imported fertilisers and it is my belief that as the existing single superphosphate plants require capital injections they will be shut down so that in the next 10-20 years single superphosphate will disappear from the Australian market.

The increasing internal freight costs and competitive nature of US and Middle Eastern fertiliser miners and manufactures does not auger well for the construction of a major fertiliser facility at Duchess in Queensland despite the availability there of rock, sulfuric acid and natural gas.

Nutrient cycling

Prior 1960 pasture improvement in Australia and New Zealand was synonymous with top-dressing with single superphosphate (usually at 125 kg/ha or 1 cwt/ac) and the oversowing of white and or sub clover with or without ryegrass (45). The superphosphate, entirely as single superphosphate, was applied primarily as a P fertiliser although trials on many soils in eastern Australia showed that the S requirement was often *as* great as P and hence single super was an appropriate fertiliser (2, 34).

Despite the important role of P in Australian agriculture it is surprising how little interest was shown in the 1950s and '60s in developing a clearer understanding of P cycling in grazed pastures and cropping systems. In that period there was a pre-occupation with studying inorganic P transformations and in cataloguing soil inorganic P *via* Chang and Jackson (7) fractionation. At the other extreme soil organic chemists were pre-occupied with sephadex molecular sieve columns to fractionate organic P on the basis of molecular weight. Both groups tended to study what remained in slowly or non-cycling pools rather than the dynamics of P.

Walker (43) stimulated interest in nutrient cycling in pastures when he reviewed N cycling in New Zealand pastures and then adapted the same model to S (44). This model was entirely conceptual in both pool size and flow rate.

The realisation that estimates of the long-term residual effects of fertilisers required a better understanding of pool sizes and flow rates between pools has lead to a major thrust in that area of research via the use of radioisotopes. Because of the cost and difficulty of measuring 15N and the short half life of ^{32}P, ^{35}S was used to pioneer these studies. Such studies were initiated at CS IRO, 'Chiswick', by A.R. Till and P. May (22). Earlier studies (21, 34) had suggested that the residual value of S was low because of leaching but radioisotope studies (35, 36) detected S cycling two years after application and indicated that S stored in organic matter was a major sink for fertiliser S. The measurements made in these isotope trace experiments were processed using an analogue computer. The simple model used consisted of a series of differential equations that described the proposed relationship between the pool sizes and the nutrient flow rates. It was essential to use an analogue computer for this model because the iterative procedures used for integration were inefficient and the digital computers available at that time too slow. This contrasts with the speed and capacity of present day digilect computers.

The concepts of pool size and flow rate of S in a grazed pasture were included in a hydraulic analogue, using water flow with dyes to represent fertiliser additions which was exhibited at the 1970 International Grassland Congress held in Queensland. These studies allowed the development of a quantified pool size/flow rate model of S cycling in a pasture grazed by sheep (35).

Such studies stimulated interest in the use of nutrient cycling models but these required a robust framework of climatic driving variables, pasture growth and pasture/animal interactions which was lacking at that time. The CSIRO and UNE groups approached the problem from a number of a uncoordinated angles. The model developed by Vickery and Hedges (41, 42) at CSIRO, `Chiswick', was constructed for a specific set of site and stocking rate conditions. Because of the specificity of the this model it was not used widely. A more general model of water use and pasture growth was developed in 1975 (31) and this was refined by the inclusion of rainfall probability data (33). The inclusion of pasture/animal interactions (32) and P transformations (5) resulted in a dynamic P model identified under the acronym of PMOD. The nutrient equations used in this simplistic mechanistic model were not validated *as* thoroughly *as* those of water balance and plant growth but it served to focus research on the rates of release of P from fertilisers which lead to the development of a fertiliser incorporating elemental S and partially acidulated rock phosphate (ESPARP) and an increased emphasis on the impact of nutrient recycling via organic components of the system.

At the same time other groups were involved in the incorporation of nutrients into models such as DECIDE and FARMAID (4, 8, 19). These relied on response functions and empirical residual value functions. Studies at Wagga (3) found that the a component used in the a/t+a residual value function in DECIDE was dependent on past history and indicated the need for a more mechanistic approach to model development.

The development of the 1979 S cycling model (35) indicated the need for more detailed studies on aspects of the S cycle in pastures and these focused on the pool size and dynamics of various components of the system such *as* release from organic matter, fertiliser, litter and dung and urine. Studies in both Australia (30, 36, 39) and New Zealand (12, 13, 14, 15, 16, 17) provided valuable data to upgrade our understanding of the S dynamics in grazed pastures.

These studies lead to the development of a dynamic CNSP pasture cycling model by McCaskill (24). The structure of the model and the flow rates of S between pools for a unfertilised and fertilised perennial grass pasture on the Northern Tablelands of NSW (average rainfall 750 mm pa) is presented in Figure 5 (25). Similar fluxes for P and N have been presented earlier (24).

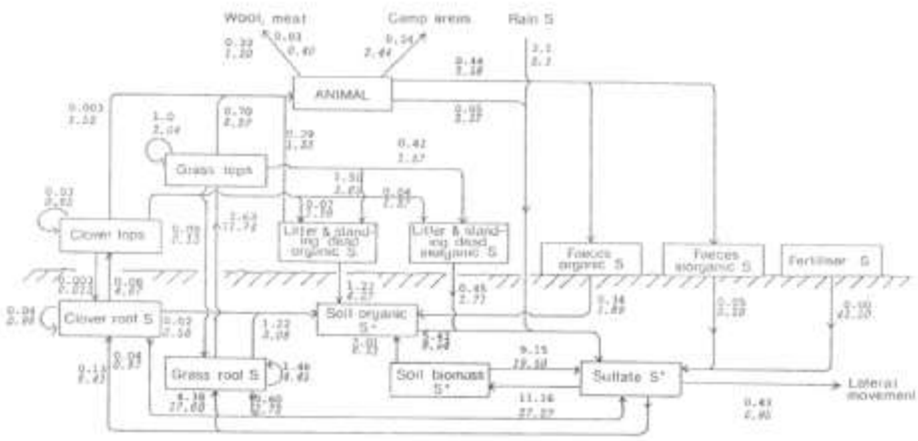


Figure 5. S fluxes in a grazed perennial legume/grass pasture as simulated by McCaskill (24).

The P cycling component of this model indicated that at maintenance in this environment the contribution of fertiliser P to the total P flux is small and the fertilisers with a slow release rate may be satisfactory in such situations. This would also be expected in drier environments. This has stimulated interest in the evaluation of reactive rock phosphates which may result in a substantial cost savings to producers.

The use of single superphosphate and legumes have dramatically altered the N cycle in Australian soils. This, together with the increased use of N fertilisers indicated earlier, has resulted in changes in acid/base reactions in soils and is dealt with in the following section on soil acidity.

As indicated earlier our increased understanding of nutrient cycles has lead to the development of a range of computer models and many of these have been directed at the on-farm decision making. Despite the efforts made to make these user-friendly and to incorporate climatic and financial risk aversion into them they are generally not used widely in fertiliser decision making. Neither are soil tests which have been developed and promoted for a much longer period.

The cost-price pressure on Australian agriculture is likely to increase further in the future as primary input costs of fuel and fertiliser increase and the inability of Australian farmers to profitably compete on markets increasingly dominated by trading blocks. This means that decisions on inputs such as fertiliser will have to be refined and tools such as soil testing and computer models will play an increasing role in this decision making.

Soil acidity

Soil acidification is a natural process which has resulted in the generally acid and infertile soils of the highly weathered tropical region. In temperate areas the rate of acidification has increased in the past few decades because of increased industrial activity which has increased anthropogenic additions and increased the HNO_3/H_zSO_4 loads into soil. The impact of components of the environment on the rate of soil acidification on alkalisation is summarised in (Table 1) (40). In the units used 1 kmol/ha/yr represents 50 kg $CaCO_3$ required for neutralisation. The four components of the table are:

Acid deposition in both wet and dry forms which ranges from 0.1 kmol/ha/yr in areas remote form anthropogenic mission up to 6 kmol/ha/yr in Western and Central Europe.

Internal acid production consists of three components namely the deprotonation of the weak acid CO,. This may add up to 20 kmol/ha/yr in high pH (6 to 8) calcareous soils of the humid region. Organic acids produced during plant growth can contribute from 0.1 to 1.0 kmol/ha/ yr with the upper level produced in acid forest soils. The contribution to acidification which results from nitrification can range from 0 to 10 kmol/ha/yr with the upper limit being found in clear cut forests.

Assimilation by biota which is the net incorporation of captions of strong bases into vegetation and soil biota which can range from zero in undisturbed climax vegetation up to 2 kmol/ha/yr in rapidly growing forests.

Redox processes. These can contribute from 0 in well aerated soils to 10,000 kmol/ha/yr in the formation of acid sulfate soils.

Table 1. Contribution of various processes to soil acidification (kmol/ha/yr) (after 40).

Source	Acidification rate (kmol/ha/yr)		
Acid deposition	0.1	-	6.0
Internal			
CO_2	1.0	-	20.0
organic acids	0.1	-	1.0
nitrification	0	-	10.0
Assimilation by biota	0	-	2.0
Redox	0	-	10,000

Prior to white settlement the Australian environment was characterised by climax communities of vegetation which were subjected to low grazing and food gathering pressures. Since fire was the major intervention practised by aboriginal communities the loss of bases was low. The introduction of cultivation lead to an exploitation of accumulated organic matter and an increase in the rate of nutrient cycling.

The most significant impact on nutrient cycling and consequent acidification rates was the introduction of single superphosphate and legumes to Australian agriculture. This resulted in a significant increase in both the size and rate of turnover of the soil carbon and nitrogen cycles, both of which contribute residual acidity to the soil (18, 20).

In the carbon cycle acids are produced during the accumulation of organic matter (9), with the removal of plant and animal products from the system and the relocation of dung and urine to stock camps or to milking sheds or stock yards (26). Although this latter loss is not a loss from the system, it is to much of the productive area of the farm.

In the nitrogen cycle acids are produced when the N fixed by legumes is nitrified and the nitrate lost by leaching or runoff (18).

Evidence for increased soil acidification began to emerge in the 1970s when moves were made to change commercial and government soil testing services from pH measurements in water to CaC1 This prompted investigations into soil pH and the emergence of widespread discussion of soil pH and a re-assessment of accumulated data. This lead to a flurry of activity in soil pH measurement, mostly with paired (natural *versus* improved), soil samples. At the Australian Agronomy Conference held in Melbourne in 1987 several papers were presented related to soil acidity and most of these failed to show significant effects of agricultural development on soil pH.

This was most likely due to problems of both spatial and temporal heterogeneity. Such effects need to be taken into account when comparing pH changes over time from historical samples. In the study of Duncan (10) significant seasonal variations in soil pH were recorded in samples collected from under a perennial grass/white and sub clover pasture on the Northern Tablelands of NSW with the lowest pH of 4.8 recorded in October and the highest pH (5.8) in July.

Reports of acidification under annual pastures in southern NSW and Victoria were not matched by reports from perennial pasture areas in Northern NSW. In a study conducted by Duncan (10) soil pH was measured on plots at the CSIRO, 'Chiswick' Research Station that had received from 0 to 3750 kg/ha superphosphate over an 11 years period. These studies revealed no significant differences in topsoil (0-7.5 cm) pH between fertiliser treatments despite the long history of clover based pastures. Although there was no statistical difference, the measured difference represents a decline of 0.021 pH units/yr which is approximately half that measured in the Southern Tablelands of NSW. This was ascribed to the presence of both a substantially perennial legume (white clover) and deep rooted perennial grasses such *as Phalaris aquatica.*

Detailed studies of soil acidification under annual pastures have been undertaken by staff of the Rutherglen and Wagga Research Institutes (28, 29). These groups have quantified the contributions of the carbon and nitrogen cycles to acidification in unfertilised (U), fertilised (4.5 t/ha single superphosphate from 1914-48 (F) and F+ lime fields (F + L). The lime applications amounted to 11.25 Oa in nine applications over the 1914-48 period. Stocking rates over the 1914-86 period were U = 4.2, F = 7.5 and F + C = 7.6 dse/ha. The calculated acidification balance is shown in Table 2.

Table 2. Carbon and nitrogen acidification of 3 fields sampled at Rutherglen, Victoria (29).

The authors point out that the estimates in Table 2 are likely to be underestimates because they do not include slow buffering reactions. These rates of acidification translate to annual lime additions of 8 and 71 kg/ha required for the U and F pastures respectively to maintain pH. The application of lime at an average annual rate of 157 kg/ha to the F + L treatment, whilst maintaining pH did not result in a higher carrying capacity.

Given the difficulties that graziers have in maintaining soil P status via fertiliser inputs it seems unlikely that resources will be diverted to the application of lime. This suggests that alternative pastoral and farming systems must be developed and the earlier data from the Northern Tablelands, and that from Rutherglen (29), indicates that a perennial grass must be included. The Rutherglen studies (29) found that such an inclusion reduced the annual acidification rate over a 39 years period from 2.00 kmol/ha under a wimmera rye-grass/subterranean clover pasture to 1.36 kmol/ha under a phalaris/subterranean clover pasture. This translates into a potential lime saving of 31kg,/ha/yr to maintain pH. In addition the better N economy under the perennial pasture is likely to result in higher, longer term productivity.

The additional problems of relying on a lime based pasture system are the difficulties of spreading and incorporation, particularly in areas where sub-soil acidity is a problem. Although gypsum and calcium organic complexes may offer scope to reduce the problem of sub-soil acidity their availability and cost seem likely to limit their use. Introduction of earthworms, which can move ameliorating substances to the sub-soil, may offer some scope for incorpora- tion but the problem of providing sufficient quantities of high quality organic matter to sustain a sufficiently high population of earthworms will most likely limit their contribution to the problem.

Source of acidification	U	F	F+L
	Annual acidification rate (kmol/ha/yr)		
Animal product removal	0.020	0.042	0.042
Animal product transfer dung	0.106	2.60	0.246
urine	0.042	0.074	0.075
Hay removal	0.036	0.268	0.210
Hay return	-0.074	-0.080	-0.063
Organic matter accumulation	0	0.337	0.446
Net bicarbonate export	0.027	0.027	0.027
Total carbon cycle acidification	0.157	0.926	0.984
N cycle acidification	0	0.493	1.377
Alkali addition	0	0	-2.465
Net acidification	0.157	1.419	-0.104

Conclusions

Because of the high dependency on exports and the desire of Europe and USA to protect their rural communities, Australian agriculture is likely to face increasing trading block pressures. The establishment of an Australian or Pacific Rim Block is unlikely to be successful because of the trading power and ability to subsidise from outside the region.

These pressures, together with the inevitable increase in the price of fertiliser, will lead Australia into the use of more water and nutrient efficient crop and pasture genotypes and to the more efficient use of fertilisers closely targeted to the particular climatic/soil/crop system. Soil and tissue testing and computer modelling will become increasingly important decision making aids.

Because of the cost/price squeeze mentioned above it seems unlikely that Australia will come to rely on a lime based agriculture to combat soil acidity. The solution lies in the development of systems which conserve fixed and applied N through the use of deep rooted perennial species and better soil water conservation techniques. Genotypes adapted to the more acid soil conditions will have to be developed.

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