USE OF FERTILIZERS TO INCREASE ANIMAL PRODUCTION

INTRODUCTION

K.J. HUTCHINSON*

Fertilizers are a major and rapidly rising cost in the production of animals from improved pastures. Superphosphate to the value of $350,000,000 p.a. is currently applied to Australian crops and pastures and a better basis for decisions on fertilizer use is required. A new technology based on Landsat is being developed for delineating areas of low nutrient status and this should also facilitate the extension of research results and provide a basis for national resource evaluation.

Other research reported is directed towards a better understanding of the processes of nutrient uptake and cycling in grazed pastures. The importance of cycling in the phosphorus economy is illustrated along with the impact of fertilizers and grazing management on biological processes. This theme is extended in the third paper which also suggests that there is a need for controlled release fertilizers to be developed specifically for use on pastures.

The final paper describes a fertilizer decision model and discusses the problems of parameter selection. A case is argued for more comprehensive models which include more research information and which recognize the wider aspects of agronomic management which may affect the efficiency of fertilizer use.

USE OF LANDSAT TECHNOLOGY TO DETERMINE THE FERTILIZER STATUS OF IMPROVED PASTURES

P.J. VICKERY*

BACKGROUND

The Landsat satellites have been measuring the green, red and shortwave infrared (IR) radiation reflected from 0.4 ha units of the earth’s surface since the early 1970’s. Data for continental Australia became available on a regular basis in late 1979 with the establishment of the Australian Landsat receiving station near Alice Springs. These data are now routinely available for pasture and animal scientists to improve the management of both natural and improved pastures.

The reflection of red and IR radiation from land surfaces can give a good indication of the surface type. McCloy (1977) has summarized the responses of vegetation for Australian conditions; actively growing green pasture has a high IR and low red reflection; dead or dry grasslands and pasture have high reflection at both wavelengths while eucalypt forests and dark objects will show low reflection at both wavelengths. Unvegetated soil and rocks show reflection responses in both red and IR which lie adjacent to the area of vegetation responses.

Landsat data has already been shown to be particularly useful in planning grazing strategies for the Australian arid zones and other similar parts of the world, e.g. Graetz et al. (1980, 1982). A vegetation response model using Landsat data was developed to measure the changes with time of vegetation on

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grazed areas (Honey and Tapley 1981), while overseas the data has been used in planning the development of grazing lands to avoid the exploitation of fragile ecosystems incapable of sustaining animal production except at very low stocking rates.

**LANDSAT TECHNOLOGY AND IMPROVED PASTURES**

In Australia, despite the extensive area of improved pastureland, use of the technology for the management of pasture has been largely neglected although McCloy (1981) has mapped salinised land from Landsat data. The potential of this technology as a method for estimating the fertilizer status of improved pastures has been demonstrated by Vickery, Hedges and Duggin (1980). Using Landsat type data they showed good discrimination between ten year old Phalaris aquatica/Trifolium repens pastures receiving annual applications of 0, 188 or 376 kg/ha of superphosphate, and additional measurements have confirmed this trend (Vickery and Hedges, unpubl.). Figure 1 shows the results of a canonical variate analysis of spring and autumn Landsat type data from these pastures. An additional treatment was included where, after 10 years at 376 kg/ha/yr superphosphate application, further applications were withheld. Reflectance measurements were then taken in the following spring and autumn, six and ten months respectively after the regular dressings of superphosphate were applied to the other treatments for the eleventh year. By combining the Landsat type data from two sampling dates a very sensitive discrimination between the heavily fertilized treatments and the rundown treatments was obtained. In another study (Vickery 1983), it has been shown that it was possible to classify and map the

![Figure 1](image-url)
fertilizer status of improved and developing pastures using similar canonical analysis of Landsat data from standard pasture types with known fertilizer histories.

The advantage of a technique for estimating the nutrient requirements of pastures, using satellite recorded radiance data, compared with more conventional techniques is a greatly increased sampling frequency for the nutrient status information. There can be more samples per paddock than would be possible with soil or tissue tests and measurements can readily be repeated. Further, the information can be presented in the form of a map or as tables of means with paddock by paddock results. The technique offers the opportunity for visual comparisons of relative fertility both within and between paddocks within a farm unit, as well as comparisons between farm units. Such information could be of considerable use in agronomic farm management decisions, by allowing the fertilizer recommendations to be optimised for individual areas within a farm unit. The use of repeated satellite coverage would also provide a valuable record of changes in the pasture, and the success or otherwise of the fertilizer recommendations. Because the information can be readily processed by computer and is geographically referenced, it can be integrated with other geographic based data such as slope and aspect, soil and rock type, roads and paddock or property boundaries. Techniques are being developed to build such data into geographic information systems (Marble 1981). Such systems should provide useful management tools particularly for large and extensive grazing or pastoral enterprises, where the distances are so large as to prevent adequate supervision of the area by management staff. The information could improve the extension of research findings by defining areas or regions where they are most applicable and then by providing information to encourage farmers to use the techniques developed from the research.

Landsat radiance data has been shown to indicate differences in the nutrient status of improved pastures in temperate eastern Australia. Use of this technology in the agricultural extension field offers the possibility of highlighting those areas or farms where nutrient problems exist. These data would then direct attention of advisers to the problem areas and result in increased effectiveness in the extension of the results of agricultural research. They may also improve the precision of techniques such as soil and tissue testing. Further, the technique has the potential to identify cases where production can be raised with the application of current agricultural knowledge.

BIOLOGICAL ASPECTS OF NUTRIENT CYCLING IN GRAZED PASTURES

THE UNDERGROUND MOVEMENT

K.J. HUTCHINSON* AND K.L. KING*

Little research has been done on the roles of consumers and micro-organisms in the return of nutrients in improved pastures. This paper summarizes research findings on the responses of invertebrates and micro-organisms to superphosphate, sown pasture species and stocking and indicates the importance of biological cycling on the phosphorus economy of the pasture-livestock system.

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INVERTEBRATES, MICRO-ORGANISMS AND PASTURE IMPROVEMENT

Responses in temperate improved pastures at Armidale are as follows:

- Most groups of invertebrates respond to improved quantity and quality of pasture production (King & Hutchinson 1980, 1983). Representative Armidale data show an invertebrate biomass of 380 kg/ha for improved pasture grazed at 10 dse/ha which is comparable to the flock live-weight of 530 kg/ha (Hutchinson and King 1980). A conservative estimate of fresh microbial biomass is 2500 kg/ha (authors unpubl.).

- Surface living invertebrates in particular are reduced by high stocking rates because of reduced surface litter, soil pore space and food availability (King and Hutchinson 1976).

- The production of invertebrate excreta and corpses can be a significant item in the phosphorus budget for fertilized pastures (Hutchinson and King 1981).

- The volume and activity of micro-organisms that colonize plant litter are proportional to the decomposition rate of these residues. Values for white clover and perennial ryegrass at Armidale are six times greater that values for the litter of native grasses (Anon. 1982).

- As soil micro-organisms are mainly heterotrophic their activity responds to increased plant production and quality. Increased microbial production may be characterized by a faster turnover rate.

![Diagram](image)

Fig. 1 Preliminary estimates for the net flows of phosphorus, kg/ha/yr, for the sown, fertilized site at Armidale grazed with 10 merino wethers/ha. * denotes assumed values; other data are net flows calculated from experimental results.
Preliminary estimates are given in Fig. 1 for the net flows of phosphorus (kg/ha/yr) in a 20 year old, sown fertilized pasture at Armidale, receiving 23 kg P/ha/yr as superphosphate and grazed at 10 dse/ha. The data are for years of good rainfall and the estimation of phosphorus (P) uptake is based on whole plant production and its P content with a correction for recycling within the plant. The rates of buildup of total and organic soil P (0-15cm) were based on soil samplings between 1963 and 1981 and the estimates support the assumption that all the added fertilizer P has been retained in the system. These data and the estimates of P flows into residues from plants, sheep and invertebrates will be published elsewhere.

The contribution from cycling is a substantial component in the phosphorus economy (40 kg/ha/yr). Three independent estimates were available. The first was based on the balance between fertilizer input, plant uptake and the rate of buildup the residual inorganic P. The second estimate was derived from the difference between the formation of residues of P and the soil organic P buildup. A final calculation was based on a partitioning of microbial production and included resynthesis from metabolites and lysed cells. The calculation was based on microbial biomass and energy expenditure data (authors' unpubl.) and the result supported the value of 40 kg P/ha/yr recycled.

MECHANISMS FOR BIOLOGICAL CYCLING

There is a vast literature on the functions of consumers and micro-organisms in native grasslands. However data for improved pastures are lacking despite evidence that these biota respond to fertilizer and stocking level. Micro-organisms have a central role in the mineral economy of pastures and the main function of consumers is to promote microbial activity.

Grassland micro-organisms are mainly heterotrophs, that is, the production of plant and animal residues provides their energy supply. If plant productivity is high then microbial activity can also be high. Death and lysis of microbial cells, caused by environmental stress, is an established mineralization mechanism. Armidale data for improved pastures indicate frequent seasonal 'crashes' in microbial respiration per year, which are associated with low soil moisture (Hutchinson and King 1982) and these reductions are accompanied by reduced microbial volumes. The moisture effect on microbial death may interact with nutritional stress and be increased by cell rupture following rehydration. Freezing-thawing cycles in the surface soil, where microbial numbers are high, are another source of environmental stress.

Predation of micro-organisms by protozoa and some invertebrates increases mineralization rate substantially (Coleman et al. 1977). Microbivorous invertebrates include nematodes and microarthropods; the latter are an important functional group in temperate improved pastures in Australia where earthworm populations are low by European and New Zealand standards. Invertebrates can promote microbial activity in other ways. These include comminution and abrasion of particles, substrate and micro-organism mixing, gut transactions and excretion. Positive associations between the nutritional value of residues, their degree of microbial colonization and feeding preference by invertebrates for colonized residues suggest a compounding of factors to increase turnover rate of the more labile material. It is often argued that the main role of micro-organism is to mineralize the resistant residues which are 'locked up' in the soil organic matter. However the microbial function of increasing the turnover of labile residues is probably more important.
The emphasis in current fertilizer decision models is on agronomic response; in the future, we must include consumer and microbiological processes along with solute movement. Pasture-based animal production operates in an ecological framework and there has been little attempt to bring studies in the fields of agronomy and production ecology together. The demonstration that biological cycling is important in the phosphorus economy of grazed pastures (see also following paper) provides a new insight into the design of efficient fertilizer strategies which must take into account the need to sustain a high level of cycling activity.

FERTILIZERS FOR PASTURES

A.R. TILL

In this paper I would like to focus attention on the use of fertilizers in improved permanent pastures grazed year-round. The fertilizers in current use have, in the main, been developed for crops and their use on pastures has been a case of adopting what is available. While this approach was acceptable when fertilizer costs were low it is now apparent that special purpose fertilizers may substantially improve the efficiency of utilisation of resources.

FERTILIZER USAGE BY PASTURE PLANTS

Radiotracer studies of continuously grazed improved pastures (Till and May 1971) showed that there was a rapid uptake of fertilizer sulfur ($S$) immediately following the application of sulfatic fertilizers. However, the peak direct contribution of fertilizer $S$ to plant $S$ was never more than 33% of the $S$ content of the plant, and after about 5 months this had declined to about 9%. Data from field trials in a range of environments (Till 1976) have shown that in the year following application of 8 to 15 kg $S$/ha the contribution of fertilizer $S$ to above-ground plant $S$ was about 10%, and in total only about 20% of that applied.

Fig. 1 Fate of a nutrient in a pasture. Boxes show pools of nutrient. Arrows show flows, broken arrows represent slow and/or alternative pathways.

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was taken up by the plants. Significant direct inputs were short-lived, and the fertilizer S entered a recycling system which played a key role in providing plant S. Long term studies (eg. Hilder and Boswell 1982) have shown that only 30–45% of the fertilizer sulfur applied could be accounted for in the top 60 cm of soil. These observations can be explained partly by considering the fate of a nutrient applied to pasture (Fig. 1), and they provide the basis for the case for controlled release of nutrients.

THE CASE FOR CONTROLLED RELEASE FERTILIZERS

The fertilizer nutrient enters the soil solution and is then utilised by way of a large number of competing biological, chemical and physical processes. The relative magnitude and importance of these processes vary for each nutrient, and can be illustrated by contrasting S and P. The amounts of S and P in the soil solution are very low compared with that in the rest of the system. Very little sulfate is adsorbed in the surface horizons of most soils and up to 90% of the S is in organic forms. There are changes in the turnover rates and amounts in these components when large amounts of fertilizer S enter the system, but such changes are limited by biological activity and there is increased potential for losses by leaching. In contrast most soils have a large capacity to adsorb phosphorus; although this reduces the loss of applied P by leaching it can result in a short term reduced availability of P due to increased "fixation" by inorganic processes. Even if this P is eventually recycled the cost of "filling up" the adsorption sites etc. may be prohibitive in both the short and long term.

Consequently for plants to utilise both these nutrients efficiently, at least in the short term, it is desirable for fertilizers to release the

![Figure 2](image)

**Fig. 2** Phosphorus (P) and Sulphur (S) concentrations in successive samples of rye grass tops clipped at intervals of approx. 3 weeks
nutrients at rates which provide acceptable concentrations in the soil solution for the required level of plant production without having very high concentrations for short periods.

Plants appear to require similar amounts of P and S, and in radiotracer studies under controlled conditions it was found that P and S were recycled from plant litter at similar rates (Till and Blair 1978). However, superphosphate, the most commonly used fertilizer in Australia, provides an example of a product which does not necessarily supply nutrients at the appropriate rates. When rye-grass was grown in undrained pots watered to 78% of field capacity in a glass house, and superphosphate surface applied at 0 or 250 kg/ha, the rates of change in the P and S concentrations in plants tops were very different (Fig. 2). Fertilizer application resulted in an immediate increase in the P and S concentrations in the tops, but over the following 27 weeks there was a decline in the P content while the S content showed a gradual rise.

The proportion of fertilizer S taken up by plants must fall after a certain optimum level even though the proportion of plant S derived from fertilizer usually increases with application rate (Till 1976). From these relationships the relative uptake of S by plant tops was calculated for a range of application rates and frequencies (Fig. 3).

These curves suggest that frequent small applications could result in up to three times as much of the fertilizer being used by plants in one year relative to a single application. These figures do not include any carry over of later applications into subsequent years. Although frequent small applications are not practical the use of slow or controlled release fertilizers could
achieve such a situation. Examples of such materials are elemental S, rock phosphate, and partially acidulated rock phosphate which can be used in various combinations. While it is important that trials of such materials continue, it should also be stressed that basic studies are required on:—

- the rates of nutrient input required for maximum production relative to losses
- the influence of soil type and other environmental and management practices on requirements and
- the relative importance of short term direct uptake and storage in other recyclable components of the pasture system.

In evaluating fertilizers it is essential that the materials tested be in similar physical and chemical forms to those likely to be used in commercial farming. The use of powdered materials, which makes handling easier and reduces variability in small trials, should be avoided if the fertilizer would normally be used in granular form. The rates of nutrient release from powdered materials may differ greatly from those obtained from commercial fertilizers in the field.

**DECISION MAKING ON THE APPLICATION OF FERTILIZERS FOR ANIMAL PRODUCTION**

K.R. Helyar* and K.M.S. Curtis**

Maximizing the economic and biological efficiency of fertilizer use for animal production, involves fostering efficiency at each step in the production chain. For example, we need the fertilizer type most efficient at stimulating plant production, the best application techniques, the most responsive plant species that are productive and persistent under grazing, species of high nutritive value to the animal, and animals that are the most responsive and grazed at the optimum stocking rate. Some aspects of fostering the efficiency of fertilizer use in this production chain, have been discussed in other papers in this contract.

Our interest is in development of the 'Farmaid' micro-computer programs that aim to incorporate our best understanding of the soil-plant-grazing animal ecosystem, in a form simply accessed by the farm manager (Curtis and Helyar 1983). These models have been designed

- to take into account the major physical and biological factors affecting animal production and pastures and
- to allow the operator to vary inputs such as fertilizer and stocking rates, pasture type, animal type, good or poor year, costs and prices.

In this way we hope to bridge the gap between experiment and application, by describing production as a function of site variables which may be specified by the farmer (e.g. soil type, pasture composition, soil P level, climate, animal breed, size and breeding status).

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The model which is currently operational uses three main functions; the first describes the effect of the current soil phosphate status and of superphosphate application on pasture production; the second describes an effect of stocking rate on the quantity of pasture produced per hectare; and the third describes the responses of animal production to the quantity, quality and seasonal growth pattern of the pasture. Our approach to describing pasture response to phosphate has been reported in some detail previously (Helyar and Godden 1977).

Wool production and liveweight gains by grazing animals are expressed as curvilinear functions of 'forage allowance', defined as the yearly quantity of pasture grown per unit of metabolic liveweight. The nutritional quality of the pasture and the seasonal variation in quality and the growth rate, are accounted for using animal production-forage allowance curves. Examples of these for steer liveweight gain are given in Fig. 1. These functions have been estimated from experimental data and interpolation between data sets. A particular curve for a given paddock is selected using a table such as the one shown below (Table 1).

![Fig. 1](image-url)  
Steer liveweight gains as a function of forage allowance for high (H), medium (M) and low quality (L) temperate (——) and tropical (----) pastures. Points from the data of Curl (1977b)
TABLE 1 An example of pasture quality/seasonality classes associated with the animal production functions used by 'Farmaid'

<table>
<thead>
<tr>
<th>Pasture attributes</th>
<th>Tropical pasture quality/seasonality class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LOW</td>
</tr>
<tr>
<td>Temperate or tropical legume percentage</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Months of nil to slow pasture growth</td>
<td>&gt;4</td>
</tr>
<tr>
<td>Percentage of the grasses present of high quality*</td>
<td>0-20</td>
</tr>
</tbody>
</table>

* e.g. Setaria, paspalum, kikuyu, green panic or carpet grass rather than native species.

The model has been programmed on the Apple II micro-computer and is available on discettes for the discette cost. The program is interactive and self-guiding. Guidelines for the various inputs required are stored on disc and are accessible during program operation. An inexperienced operator should be able to master its operation within an hour.

WHERE TO FROM HERE?

Currently the model is a useful tool to assist in soil, pasture and animal management. The output is consistent with the historic experimental data, with on farm performance of grazing systems, and accounts quantitatively for some of the important factors affecting the production of grazing animals.

Future developments include both increasing the usefulness of the output to the farm manager via 'the user - programmer feedback process' and reducing the number of qualitative decisions the operator has to make by adding new functions to account for processes not simulated in the current version. For example, we have nearly completed development of an equation to describe wool production as a function of forage allowance, the length of the dry season, the percentages of legume and perennial species in the pasture, the breed of sheep, sheep age and their breeding status (Helyar, Carter and Curtis - unpubl.). The equation has been developed using the data from five field experiments of from two to seven years duration (Carter and Day 1970; Hamilton 1973; Browlee et al. 1974; Thompson et al. 1976; Curl 1977a). Variables in the experiments were several pasture types, breeding ewes or dry sheep, different breeds and strains and ages of sheep, and various stocking rate and fertilizer treatments. The experimental and estimated wool production levels for the treatments used to fit and test the model, are shown on Fig. 2.
Fig. 2  Estimated and experimental wool production (kg/ha/yr)
Data used to fit a function for Merino wethers (●); data used to incorporate factors for breed, pregnancy and lactation, sheep age and a lucerne pasture effect (▼) and data used to test the full model (○).

The divergence of the test points as the production level increases, from those used to fit the model (Fig. 2), is thought to be due to a breed by level of animal nutrition interaction. Animals with a lower genetic capacity for wool production under poor nutrition, also have a lower capacity for wool production response to improved nutrition. Such an interaction has been demonstrated previously (Hamilton and Langlands 1969), so inclusion of an interaction term in the model appears to be justified.

Incorporation of the function for wool production in the micro-computer programme will eliminate the need for Table 1. The table will be replaced with inputs, percentages of legume and perennial species, the number of days the pasture growth rate is near zero, and the breed, age and breeding status of the sheep. Work is proceeding on a similar function to describe liveweight changes in sheep and cattle. Further desirable developments are:-

- the linkage of climatic inputs to pasture growth models rather than nominating the potential pasture yield
- the inclusion of functions to predict pasture legume content. Factors include soil nitrogen and phosphorus status, soil acidity, grass competition, stocking rate and insect and disease effects
- more sophistication in describing soil phosphorus dynamics than is currently used.
After six years work in the area of developing computer models as aids for decision making, we are convinced that they provide a most efficient means of transferring our technological understanding of the soil-plant-animal system in a relevant form, to the farm manager. They are useful today, and continued support at research, model development and model application levels, will yield more useful programs in the future.

SUMMARY AND CONCLUSIONS

In this contract we have reported research on new methods and concepts which may contribute to better fertilizer strategies for livestock enterprises. We have not sought to present a full review of current knowledge on fertilizer and animal production. Landsat data provide highly integrated information which can indicate differences in the nutrient status of temperate, improved pastures. Development of this technology should enable primary producers to monitor the nutrient needs of their pastures. The most effective way of using Landsat image analysis has yet to be determined but at the very least, it will improve the efficiency of fertilizer decisions by providing an initial screening for responsive areas of pasture which can then be examined in closer detail using traditional methods.

The importance of biological cycling in the phosphorus economy of temperate, improved pastures has been demonstrated. The central role of micro-organisms in cycling processes and the function of consumers in regulating microbial activity has been emphasised along with examples of responses of these biota to fertilizer and grazing management. More than a decade ago, Till and May (1970) demonstrated the importance of sulphur cycling in grazed pastures with a radiotracer method. However, very little of the information available on nutrient cycling has yet been incorporated into models for predicting either the short or longer term consequences of fertilizer use. The task will not be an easy one but we cannot afford to ignore the processes which can dominate the mineral economy of grazed pastures. The efficient use of fertilizers also depends on the release of nutrients at rates which allow satisfactory plant growth but which do not result in short term, high concentrations of nutrients in soil solutions. The matching of nutrient release rates from fertilizers with plant and animal requirements provides a challenge for fertilizer technology which, to date, has been tailored for crops rather than pastures.

The expanding use of computers in all facets of animal production will increase demand for the application of research findings to management decisions. The final paper provides an example of a micro-computer based model, "Farmaid", which is built on information about fertilizer, agronomic and livestock production responses. The model illustrates the need for fertilizer decisions to be based on a range of climatic, agronomic and animal management factors. The problem for model builders will be to incorporate the complexity of climate, soil, plant, animal and microbial processes into a structure which can be accessed readily by the manager. Scientists will undoubtedly argue for greater complexity in models as their understanding of physical and biological processes increases. However it is essential that there be an increased awareness for scientists and extension workers to ensure that research results are made available for application on a farm basis.

REFERENCES


