# Long-term effects of grazing on the fertility of soils

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## Abstract

The long-term effect of excreta return was studied on a bull-beef system that had been under stable management for 23 years. Excreta return did not greatly affect organic matter properties. Mineralisable nitrogen showed differences with depth where excreta had or had not been returned, but was not different in the 0–75 mm soil depth. Excreta return positively affected Olsen P, sulphate-sulphur and organic-sulphur soil test values. Single-core sampling studies showed that very high Olsen-P values occur in some cores and can weight the paddock mean upward, resulting in the phosphorus status being overestimated for much of the area. Excreta return strongly influenced potassium cycling, by maintaining a large pool of available potassium. A relatively small amount was lost to drainage water, however, as the cycling potassium displaced calcium and magnesium. Magnesium loss from the system was large compared with the quantity cycling, and appears to be one of the major long-term negative effects of grazing on nutrient reserves.

**Keywords:** excreta return, grazing, soil fertility, soil nutrient reserves

## Introduction

While land development was a prominent part of the New Zealand grassland industry there was a strong, and appropriate, emphasis on "fertility building" in pastures (Sears 1953; Walker *et al.* 1959; Walker 1968). The role of fertiliser, particularly phosphate (P), sulphur (S) and molybdenum, in stimulating legume growth, nitrogen (N) fixation and N cycling, was discussed often and the accumulation of carbon (C), N and S in organic matter recognised as the essence of fertility building. Animals were seen as an integral part of this process, both as defoliators and excretors of nutrients. Those effects are relatively easy to study and define in the short term (Haynes & Williams 1993). Long-term effects are more difficult to resolve, though, as they are often confounded by management changes.

In this paper we take a view of these processes from a different standpoint: that of a mature pasture on a fertile soil which had been subject to a quarter of a century of stable management and inputs. From this perspective we enquire whether grazing animals as excretors, have, over a long time, an effect on: pools of organic matter, mineralisable N in the soil, soil test values, and distribution and loss of cations.

The separation of the animal effects from other management factors and inherent properties of the system was difficult in most situations. The study reported took advantage of the clearly defined strips that develop under electric fences and are grazed and somewhat trodden but not excreted on. These provide a control which received the same inputs of fertiliser as the paddocks and had an active herbage removal regime, but no nutrient, or organic matter return via animals. Comparison of these control areas with parallel transects in the pasture allows the long-term effect of excreta return on key soil properties to be determined.

## Methods

The experimental site was a 1.2 ha area of Kairanga silt loam at the AgResearch Aorangi research station in the Manawatu region. This soil is fertile, being formed on fine-textured flood plain alluvium and having a high organic matter content. In 1969 the study area was subdivided into units 40 m × 42.5 m using permanent electric fences. Bulls were raised for beef production within this system at a stocking rate of 30 stock units/ha. Inputs and management practices were uniform for 23 years. Superphosphate was applied annually at 325 kg/ha by aerial spreading using passes at right angles to the fence-line and paddock transects used for sampling.

The tendency of animals to orient themselves, head on, to electric fences when grazing led to a strip about 400 mm wide developing beneath the fences that was closely grazed but received no excreta return. Soils were sampled from along the centre line of six such strips and from parallel transects 10 m out in the paddock area. Twenty cores of 25 mm diameter were taken from each transect and subdivided into 0–75, 75–150 and 150–300 mm depth sections, bulked, air dried, sieved and stored. A set of 0–75 mm cores was also taken from fence-line and paddock transects and analysed as individual cores

Soils were analysed for total N by a Kjeldahl method, carbon by dichromate oxidation and exchangeable cations by the method of Searle (1986). Mineralisable N was determined by incubating 10 g of air dry soil with 4 ml of water for 14 days and extracting nitrate and ammonium with 2*M* KCl and finishing with automated colorimetry. Cation losses in drainage water from the whole area were estimated by analysing drainwater samples collected weekly during 1985 and 1986, and combining with calculated drainage values.

## Results and discussion

### Nitrogen and carbon

The total amounts of N in the fence and paddock systems differed in the top two depth sections of the soil (Table 1), while C was significantly different in the 0–75 mm section only. A small annual divergence rate was suggested: 38 kg N/ha./year and 533 kg C/ha/year. Since this could be achieved with an export of about 1 tonne of DM at 3.8% N and 50% C, it seems likely that the paddock system receiving excreta was at equilibrium and not gaining C or N. This was supported by previous studies at this site: Hoglund *et al.* (1979) and Crush *et al.* (1983) report similar values for total N in 0–150 mm sections. Carbon:N did not differ between the two systems, which suggests that excreta return was not having any net affect on the composition of the organic matter.

**Table 1** Total nitrogen, carbon and mineralisable nitrogen (kg/ha depth).

| Depth (mm) | Nitrogen: Fence | | Nitrogen: Paddock |
|---|---|---|---|
| 0–75 | 3045 (51.7)[1] | *** | 3902 (76.0) |
| 75–150 | 2623 (52.2) | ** | 2939 (50.4) |
| 150–300 | 3321 (113.0) | ns | 3159 (73.8) |
| | Carbon: Fence | | Carbon: Paddock |
| 0–75 | 33774 (1002) | *** | 46040 (94.5) |
| 75–150 | 25963 (1135) | ns | 28151 (794) |
| 150–300 | 26196 (1417) | ns | 26241 (819) |
| | Mineralisable N: Fence | | Mineralisable N: Paddock |
| 0–75 | 90 (8.8) | ns | 114 (21.5) |
| 75–150 | 53 (6.0) | ** | 83 (4.4) |
| 150–300 | 75 (3.5) | *** | 53 (3.1) |

[1] (+/- s.e. mean); ns non-significant; * P<0.05; ** P<0.01; *** P<0.001

The amount of N that was mineralised from the soil when it was air dried then moistened and incubated gives an indication of N mineralisation in the field and also correlates well with soil biomass N (Franzluebbers *et al.* 1996). Values in the 0–75 mm did not differ (Table 1) but the high standard error of the paddock mean suggests that some variable property, perhaps excreta return, does affect this mineralisable N positively. The lower horizon values differ significantly but in opposite ways at each depth. A decomposition-driven system, the fence-lines, thus appears to enrich a greater depth than one where excreta return to the surface was the dominant cycling mechanism for N.

### Phosphorus and sulphur soil tests

Olsen P, sulphate-S and organic-S tests all clearly reflected the influence of excreta return (Table 2). In each of the three tests, the fence-line value was half or less, of the paddock value for the 0–75 mm section. In the case of the S tests, fence-line values were significantly lower at all depths. Bulk soil samples cannot give any indication whether the elevated values represent an overall shift in test or are the product of sampling a few highly enriched sites.

**Table 2** Soil quicktest values.

| Depth (mm) | Olsen P: Fence | | Olsen P: Paddock |
|---|---|---|---|
| 0–75 | 15 (0.9)[1] | *** | 34 (2.5) |
| 75–150 | 29 (0.5) | *** | 16 (1.5) |
| 150–300 | 6 (0.5) | ns | 8 (0.5) |
| | Sulphate-S: Fence | | Sulphate-S: Paddock |
| 0–75 | 5.2 (0.40) | *** | 9.7 (0.61) |
| 75–150 | 3.5 (0.22) | * | 4.2 (0.17) |
| 150–300 | 2.2 (0.17) | *** | 3.7 (0.00) |
| | Organic-S: Fence | | Organic-S: Paddock |
| 0–75 | 4.3 (0.21) | *** | 10.2 (0.31) |
| 75–150 | 4.3 (0.21) | ** | 6.0 (0.37) |
| 150–300 | 2.2 (0.17) | *** | 3.0 (0.00) |

[1] (+/- s.e. mean); ns non-significant; * P<0.05; ** P<0.01; *** P<0.001

The set of single cores showed that Olsen P values ranged from 15 to 50 in the paddocks and 10 to 17 in the fence-line transects. Furthermore, a quarter of paddock cores showed values between 30 and 50 and thus exerted a strong influence on the mean. A considerable portion of the area may have low values for Olsen P in relation to a mean influenced by a few high values.

### Cations

Large quantities of exchangeable cations – calcium (Ca) magnesium (Mg) sodium (Na) and potassium (K) – are taken up by pasture plants and recycled. Lactating dairy cows excrete 80–90% of ingested cations (Hutton *et al.* 1965, 1967) and other stock classes are probably similar. The fence-line represents a zone of depletion where cations that are removed in herbage, or by leaching, can be replaced only by mineral weathering. However, only K showed signs of depletion in the fence-lines (Table 3) and that was compensated for when total cations are considered.

**Table 3** Soil cations (meq./100 g).

| Depth (mm) | Fence | | Paddock |
|---|---|---|---|
| | Calcium | | |
| 0–75 | 9.9 (0.4)[1] | ns | 8.8 (0.5) |
| 75–150 | 9.9 (0.5) | *** | 7.1 (0.4) |
| 150–300 | 7.4 (0.4) | ns | 6.2 (0.4) |
| | Magnesium | | |
| | Fence | | Paddock |
| 0–75 | 2.5 (0.1) | ns | 2.5 (0.1) |
| 75–150 | 2.4 (0.1) | ns | 2.3 (0.2) |
| 150–300 | 2.6 (0.1) | * | 2.0 (0.2) |
| | Potassium | | |
| | Fence | | Paddock |
| 0–75 | 0.35 (0.02) | *** | 1.60 (0.12) |
| 75–150 | 0.26 (0.02) | *** | 1.31 (0.18) |
| 150–300 | 0.28 (0.01) | *** | 1.19 (0.18) |

[1] (+/- s.e. mean); ns non-significant; * P<0.05; ** P<0.01; *** P<0.001

Weathering appears to release adequate amounts of Ca and Mg to meet the long-term depletion that has occurred, as inputs of these two elements from fertiliser and the atmosphere are equal in both systems. One of the costs of the high rate of K recycling in the paddocks was loss of Ca and Mg. High concentrations of K in urine do not necessarily result in high leaching losses, as K is highly reactive in many soils, quickly combining with clay minerals and displacing Ca and Mg (Early *et al.* 1998)

Analysis of drainage water from the experimental area also demonstrates the vulnerability of Ca and Mg to loss. In Table 4 the quantity of cations leached was shown as a proportion of the quantity cycling through plants and animals, and of the exchangeable (readily available) pool. Magnesium clearly emerges as the nutrient most at risk of depletion, with losses greater than the quantity cycled. In this situation weathering of soil minerals must become the factor determining supply, and when this becomes inadequate inputs will be necessary to sustain the farm system.

**Table 4** Total quantities of cations: readily available (exchangeable pool) taken up by plants and recycled by animals on an annual basis, and lost by leaching and runoff to drains.

| | Exchangeable pool | Annual flow through plants and animals | Annual loss to drainage | % of exchangeable pool leached |
|---|---|---|---|---|
| | kg/ha 300 mm | | | |
| K | 1550 | 450 | 10–20 | 1 |
| Ca | 4250 | 90 | 150+ | 3.5 |
| Mg | 780 | 30 | 80+ | 10 |

## Conclusions

Excreta return has a long-term impact which results in increased organic matter (C and N) storage. No clear effect on mineralisable N, that which is released from organic matter, could be demonstrated. Short-term effects of urine have a more important role in driving production than the long-term processes.

Soil test values for P (Olsen P) and S were raised by excreta and in the case of Olsen P made far more variable. A low P status can exist in much of the sampled area but be disguised by a few very high values from isolated spots.

The large amounts of K cycling through excreta return results in lower Ca and Mg contents and increases the loss of those elements by leaching. This appears to be the one major long-term impact of grazing on the make up of the soil resource.

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