INGESTED SOIL AS A POSSIBLE SOURCE OF ELEMENTS FOR GRAZING ANIMALS

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SUMMARY

Grazing animals ingest considerable amounts of soil under intensive farming conditions. However, even high soil intakes amount to probably less than 2% of the fresh herbage intake. Most elements in soil will be present at much greater concentrations than are found in pasture plants, and so ingested soil is a possible direct source of elements to animals as it passes through the alimentary tract.

The ability of rumen and duodenum liquors to extract elements from different soils was studied *in vitro*. Substantial changes, both increases and decreases, in the concentrations of a number of elements (Ca, Mg, P, Al, Cu, Fe, Mn, Se and Zn) of nutritional interest in the two liquors are reported; different soils produce different effects.

The possible implication of soil ingestion on element uptake by animals is considered; a brief report is made on an animal trial where radioactive soil was fed.

LARGE QUANTITIES of soil are ingested by grazing animals under conditions of intensive farm management. Over a year sheep can ingest up to about 100 lb of soil and dairy cows up to about 1,000 lb. Soil type, stocking rate, management, seasonal variations, individual animal differences, all influence the amount of soil taken in (Healy and Ludwig, 1965; Ludwig *et al.*, 1966; Healy *et al.*, 1967; Healy, 1967, 1968). Greatest amounts of soil are taken in over the winter period when animal appetite is high, D.M. production low, surface earthworm casts are often abundant, and pastures become soiled. At this period, soil content of faeces can exceed 50% of faeces D.M. Some soil appears to be ingested at all times of the year.

While intakes of the order of 100 lb for sheep, and 1,000 lb for dairy animals are high, these are still probably less than about 2% of annual fresh matter intakes, and less than about 10% of D.M. intakes. Most elements are present at much greater concentrations in soil, than are found in pasture, so that ingested soil is a possible source of elements to animals as it passes through the alimentary tract. En route it is exposed to a range of digestive fluids and may contribute to the amounts of elements in these solutions, or it may compete for elements and remove

them from solution. It is from the pool of elements in solution that elements are taken up by the animal into its bloodstream for distribution throughout its tissues.

This paper considers the ability of rumen liquor and duodenum liquor, to extract elements from a number of soils in laboratory studies. Substantial amounts of elements of nutritional interest were shown to be extracted and so increase the concentrations of these elements in solution. In some cases, element concentrations in solution were reduced after contact with soil, suggesting that some soils may compete with the animal for certain elements by removing them from solution.

The implications of this study in relation to animal nutrition are considered, and the extension of laboratory studies to animal feeding trials is discussed. A trial in which radioactive soil was fed to sheep is reported on briefly.

METHODS

Rumen liquor was collected from fistulated sheep, stall fed on flash-dried pasture, at Massey University.

Duodenum liquor was collected from cannulated sheep (cannula 9 cm from abomasum) also fed flash-dried pasture, at the Applied Biochemistry Division, DSIR, Palmerston North. The samples of rumen and duodenum liquors were centrifuged under refrigeration at 80,000 g for 30 minutes. After centrifuging, the rumen liquor had a pH of 7.4, and the duodenum liquor pH 3.0.

The following soils (topsoils) were used in this study. All are reference soils described in *Soils of New Zealand*, Part 3 (N.Z. Soil Bureau, 1968), with the exception of Hauraki clay loam:

Hauraki clay loam	0-3 in.
Kiripaka clay loam	0-4 in.
Papakauri clay loam	0-3 in.
Stratford coarse sandy loam	0-3 in.
Taupo sandy silt	0-3 in.
Timaru silt loam	0-4 in.
Tirau silt loam	0-3 in.
Waikiwi silt loam	0-3 in.

The samples were air-dried and ground to pass a 0.422 mm sieve.

One gram portions of soil, prepared as above, were shaken with 50 ml of both liquors at 5° C overnight (15 hr). The suspensions were recentrifuged at 80,000 g for

30 minutes, and the supernatant solutions filtered through a 0.22 μ millipore filter.

Analyses for the various elements were carried out by appropriate flame photometry, atomic absorption, spectrographic, and colorimetric methods, on control samples of both liquors, and on the liquors after contact with the various soils.

If it is assumed that rumen and duodenal fluids in sheep flow at about 8 litres/day, the ratio of 1 g of soil to 50 ml of liquor corresponds to a rate of soil ingestion of approximately 160 g per day. If intake of D.M. is taken to be approximately 1 kg per day and digestibility as 70%, then soil content of faeces D.M. would be about 30 to 35%, a not uncommon figure. In the case of the strongly phosphate-fixing soils, two levels of soil were used: 1 g of soil to 50 ml of liquor which would correspond to 30-35% soil in faeces D.M. ("moderate" level), and 2 g of soil to 50 ml of liquor which would correspond to about 50% soil in faeces D.M. ("high" level).

RESULTS

The seven soils reported on in this paper have developed under different climatic conditions, show large differences in parent material and stage of development, and would be expected to demonstrate the range of soil differences likely to be met in a study of this kind. They are part of a larger study involving 18 reference soils and almost 20 elements. Since extractions with two liquors were made, over 700 results were obtained. The selection of seven soils and nine elements has been made to bring out the main points; results for rumen and duodenum liquors are set out in Tables 1 and 2, respectively. The effects of four strongly phosphate-fixing soils, each at two levels, on P concentrations in the two liquors are given in Table 3.

Two elements of particular interest, Co and Mo, are not discussed here. This is because they are present at levels too low for spectrographic determination and require specialized analytical techniques. This work is still in progress and it is hoped to report the results in full at a later date.

Typical results, on an element basis, for the selected soils are outlined below:

CALCIUM

Ca levels in rumen liquor fall after contact with soil, with reductions of as much as 50%. Changes in duodenum

TABLE 1: ELEMENT CONCENTRATION (PPM) IN RUMEN LIQUOR SHAKEN WITH SOIL

Soil	*Ca*	*Mg*	*P*	*Al*	*Fe*	*Mn*	*Se*	*Zn*
Hauraki	30	80	157	2.0	3.0	0.4	8×10^{-4}	0.25
	(68)	(195)	(94)	(180)	(900)	(2000)	(160)	(147)
Papakauri	25	58	130	7.5	0.8	1.0	50×10^{-4}	0.22
	(57)	(142)	(78)	(680)	(240)	(5000)	(1000)	(129)
Stratford	23	41	150	8.3	0.7	0.3	18×10^{-4}	0.26
	(52)	(100)	(90)	(750)	(210)	(1500)	(360)	(153)
Taupo	22	56	147	6.7	0.5	0.25	8×10^{-4}	0.22
	(50)	(137)	(88)	(610)	(150)	(1300)	(160)	(129)
Timaru	28	53	180	6.7	2.3	2.5	11×10^{-4}	0.27
	(64)	(129)	(108)	(610)	(700)	(12500)	(220)	(159)
Tirau	33	55	142	9.2	0.6	2.3	15×10^{-4}	0.28
	(75)	(134)	(86)	(840)	(180)	(11500)	(300)	(165)
Waikiwi	25	55	145	8.0	1.0	0.5	21×10^{-4}	0.22
	(57)	(134)	(87)	(730)	(300)	(2500)	(420)	(129)
Rumen liquor	44	41	166	1.1	0.33	0.02	5×10^{-4}	0.17
	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)

Figures in parentheses are relative values obtained when the level of an element in the rumen liquor is taken as 100.

TABLE 2: ELEMENT CONCENTRATION (PPM) IN DUODENUM LIQUOR SHAKEN WITH SOIL

Soil	*Ca*	*Mg*	*P*	*Al*	*Cu*	*Fe*	*Mn*	*Se*	*Zn*
Hauraki	375	124	690	16	< 0.08	7.8	7.8	13×10^{-4}	2.6
	(106)	(113)	(86)	(208)	(< 53)	(104)	(80)	(260)	(130)
Papakauri	370	117	650	28	0.22	1.4	10.4	29×10^{-4}	2.4
	(104)	(106)	(81)	(364)	(147)	(19)	(106)	(580)	(120)
Stratford	395	122	690	43	0.11	1.7	13	16×10^{-4}	2.6
	(111)	(111)	(86)	(560)	(73)	(23)	(133)	(320)	(130)
Taupo	345	109	750	24	0.13	3.2	9.5	8×10^{-4}	2.7
	(97)	(99)	(94)	(312)	(87)	(43)	(97)	(160)	(135)
Timaru	370	115	740	22	< 0.07	2.8	12	9×10^{-4}	2.8
	(104)	(105)	(93)	(286)	(< 47)	(37)	(123)	(180)	(140)
Tirau	375	119	660	23	< 0.08	0.2	17	12×10^{-4}	3.5
	(106)	(108)	(82)	(299)	(< 53)	(3)	(173)	(240)	(175)
Waikiwi	360	112	740	25	< 0.08	1.9	16	21×10^{-4}	2.9
	(101)	(102)	(93)	(325)	(< 53)	(25)	(163)	(420)	(145)
Duodenum	355	110	800	7.7	0.15	7.5	9.8	5×10^{-4}	2.0
liquor	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)

Figures in parentheses are relative values obtained when the level of an element in the duodenum liquor is taken as 100.

TABLE 3: PHOSPHORUS CONCENTRATION (PPM) IN RUMEN AND DUODENUM LIQUORS AFTER SHAKING WITH PHOSPHATE-FIXING SOILS

Soil	P Retention† Capacity (%)	Rumen Liquor "Moderate" Soil* Ingestion	Rumen Liquor "High" Soil* Ingestion	Duodenum Liquor "Moderate" Soil Ingestion	Duodenum Liquor "High" Soil Ingestion
Kiripaka	91	440 (86)	370 (72)	315 (76)	252 (61)
Papakauri	94	408 (79)	360 (70)	310 (75)	208 (50)
Stratford	94	455 (89)	393 (77)	335 (81)	255 (62)
Tirau	95	438 (85)	373 (73)	315 (76)	250 (60)
Liquor		513 (100)		415 (100)	

Figures in parentheses are relative values obtained when the level of phosphorus in each liquor is taken as 100.

*"Moderate" and "high" soil ingestion correspond to 30% and 50% soil in faeces D.M., respectively.

†P retention capacity is a measure of the phosphate-fixing power of a soil, and is the percentage P retained by soil when 5 g soil is shaken for 24 hr with 25 ml phosphate solution (25 mg P added as KH_2PO_4) buffered at pH 4.6 with 0.2 M NaOAc + HOAc.

liquor are smaller and there is a general tendency for Ca to increase. Baseline calcium values for the two liquors are, of course, quite different.

MAGNESIUM

Mg in rumen liquor generally increases after contact with soil, the greatest increase of 95% being with the Hauraki soil which has a high exchangeable Mg content. Increases also occur in duodenum liquor but the percentage increases are smaller, because of the higher baseline Mg value.

PHOSPORUS

Soils generally cause a reduction in P in rumen liquor. The slight rise in P associated with Timaru soil is consistent with the low phosphate-fixing properties of this soil. Reduction in P can also be seen in duodenum liquor with greatest reductions being in strongly fixing soils like Papakauri and Tirau.

In Table 3, the results of shaking four strongly phosphate-fixing soils (all with P retention values greater than 90%) are reported. In this case two levels of soil were used: "moderate" corresponding to approximately 30 to 35% soil in faeces D.M.; "high" corresponding to approximately 50% soil in faeces D.M. The rumen and duodenum liquors were different samples from those reported in Tables 1 and 2, and had pH values of 6.1 and 3.5, respectively. Baseline P values are quite different.

It can be seen that, at "moderate" soil levels, up to 20% of P in the rumen liquor can be absorbed on to the soil; in the case of the duodenum liquor, up to 25% is absorbed. At "high" soil levels, up to 30% of rumen liquor P and up to 50% of duodenum liquor P are absorbed by soil.

Aluminium

While Al is not known to be essential for animal nutrition, it is mentioned here because the changes are striking, and may have indirect effects on the concentration or absorption of other elements (possibly P) or may in some way influence rumen metabolism. In the rumen liquor, Al concentration can increase to 8 times the baseline value, and in the case of the duodenum liquor increases can be as high as five times baseline value.

Copper

Cu levels in the rumen liquor were too low to be measured by standard spectrographic techniques. It is intended to use specialized techniques for this determination.

Cu levels in the duodenum liquor show reductions up to about 50% due to soil. The increase noted for the Papakauri soil is consistent with its relatively high Cu content.

Iron

In the rumen liquor, Fe generally increases, the highest increase being nine times the baseline Fe level. The increases are somewhat surprising in view of the pH of 7.4 in the rumen liquor. In contrast, despite the low pH of 3.0 in the duodenum liquor, Fe concentrations generally fall in duodenum liquor; in the case of the Tirau soil most of the Fe has been removed from solution. Only the Hauraki soil showed no change and this soil was associated with a large increase in Fe in the case of rumen liquor. The high

P levels in the duodenum liquor may play a part in the fall in Fe levels.

It is possible that the increases in Fe (and Al) in rumen liquor are associated with complexing properties of compounds in the pasture (possibly polyphenols or related compounds). Extraction of soils with pasture extracts, in the same way as is reported here for the two liquors, suggest the presence of polyphenol-like compounds which react with Fe and Al.

MANGANESE

Shaking both liquors with soil results in increases in Mn concentration, but the most striking differences from baseline values are seen in the rumen liquor where increases of up to 100 times occur. It should be noted, however, that rumen and duodenum liquors differ greatly in baseline Mn values.

SELENIUM

In both rumen and duodenum liquors, striking increases in Se, up to 10 times, result from contact with soil. In general, increases are greatest where soil Se is highest, and least where soil Se is lowest. Thus Papakauri and Waikiwi soils have Se contents of 1.82 ppm and 0.75 ppm and are associated, respectively, with 10-fold and 4-fold increases in Se in rumen liquor; Taupo and Timaru soils with Se contents of 0.22 ppm and 0.44 ppm result in increases of 60% and 120%, respectively.

ZINC

There is a general increase in Zn levels in both liquors. The Tirau soil, which is known to be relatively high in Zn, produces increases of 65% and 75% in rumen and duodenum liquors, respectively.

DISCUSSION

The changes reported here for nine elements in rumen and duodenum liquors after shaking with various soils indicate that the pool of elements in solution in digestive fluids can be altered by soil ingested along with feed. Although only two solutions, rumen and duodenum, have been used for extraction, the respective pH's, 7.4 and 3.0, are sufficiently different to suggest that the results reported here give a reasonably good picture of the changes

likely to take place, although it is appreciated that complexing agents may play a part.

While some of the changes in element concentration are striking, it must be noted that such changes will be reflected in the composition of animal tissues only if the changes take place at sites of element absorption. The defining of such sites is currently of particular interest. Se is a case in point. Wright and Bell (1966) report no net absorption of Se from the rumen of the sheep, most absorption taking place in the small intestine. The increases reported here for Se in rumen liquor would not necessarily be reflected in absorption of Se by the animal, unless similar changes in Se concentration occur in the small intestine. This aspect is being examined in current studies with liquor from the ileum of sheep.

It must be realized that the present results apply in the main to two particular rumen and duodenum liquor samples from sheep on a particular feed. The analytical programme in a study of this kind is large and has not permitted comparisons between different samples of liquors. It would be expected that rumen liquor with a pH of, say, 6.0 might give some different results as compared with rumen liquor of pH 7.4. In this regard, baseline P values in Tables 1, 2 and 3 are relevant. For rumen liquor, samples with pHs of 7.4 and 6.1 were associated with baseline P concentrations of 166 ppm and 513 ppm, respectively. For duodenum liquor, samples with pH's of 3.0 and 3.5 were associated with P concentrations of 800 ppm and 415 ppm, respectively.

Different results might well be obtained with different feeds. It is also true that in these studies soil has been shaken with duodenum liquor without first being extracted by rumen liquor. In the animal, soil reaching any particular point in the alimentary tract has already been pretreated at previous sites.

Despite these qualifications, it is believed that the results indicate that soil entering the alimentary tract may influence uptake of elements, by increasing or decreasing element concentration in the various digestive fluids. It is emphasized that soil ingestion is usually highest in winter during the mid- to late-pregnancy period, so that any effects would be greatest at this period. Increases in, for example, Mg, Zn, Se or Cu, might have beneficial effects on the health of mother and offspring; decreases — for example in P, Cu or Fe — may have harmful effects.

The present laboratory studies have led to animal trials where soil was fed as a supplement to a basic ration. In

one study (W. J. McCabe, G. F. Wilson, W. B. Healy, unpubl.), soil containing radioisotopes of Co, Mn, Se, and Zn, was fed to sheep and the activities of these radioisotopes in urine, blood, and tissues were used to estimate the amounts of the elements absorbed. The amounts absorbed from the soil were ^{75}Se, 34%; ^{65}Zn, 14%; ^{60}Co, 1%; ^{54}Mn, 0.4%, and these are of the same order as is reported for these isotopes when fed orally in solution.

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