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SOIL INGESTION IN FARM ANIMALS

A review

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PREFACE

The effects of soil ingestion in farm animals have been discussed from time to time especially as soil can be a source for the animals' supply of micro elements. It is also evident that soil can be a source of deposited contaminants. In the industrialised world, heavy metal deposition may be serious. Ground deposition of radioactive elements over large areas following nuclear power plant accidents proved to be a reality after the Chernobyl accident, as also earlier global fallout from nuclear weapons tests. The transfer of deposited elements of different origins to animal products such as meat and milk and then to the human diet may be increased by the animals' soil ingestion.

The present review gives several aspects on the phenomenon of soil ingestion in farm animals. The study is included in research project EKO 2.1, "Transfer of radiocaesium and radiostrontium from soil to vegetation and to lambs", within the research programme of NKS (Nordisk kärnsäkerhetsforskning). A preliminary version of the report was presented at the NKS-Seminar in Nesbru, Asker, Norway in November 1995.

Lund in April 1996

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SUMMARY

Soil ingestion in farm animals occurs mainly during grazing, either as an inadvertent intake due to soil adhered to vegetation or as an active ingestion suggested to be due to lack of essential mineral elements such as Cu, Co and Mn. The ingested soil may also act as an antidote to acidosis. Sheep and cattle have been investigated to a much greater extent in this field than horses and pigs. In horses, soil ingestion has been mostly connected with mass loading of the intestines and digestive disorders, while in pigs, especially piglets, soil ingestion has been associated with Fe supply. However, with the ingested soil, different environmental contaminants like heavy metals, radionuclides, chemicals and pesticides can be consumed. These elements are often found in high concentrations in the upper soil layers and are more or less transferred to meat and milk depending on, e.g. the adhesion of the specific element to soil particles.

Soil content in e.g. feeds and faeces can be determined by the acid insoluble residue of ash (AIR) or by the titanium (Ti) or scandium (Sc) content. The two latter elements can be determined by spectrophotometry and neutron activation analysis, respectively. Using the AIR content, corrections have to be made for plant AIR content. Ti and Sc are not taken up by plants and are not digested by animals and they are therefore useful in determination of soil on plants and in faeces. In Scandinavia, Sc-analysis seems to be most convenient to use as also the detection limit is very low.

Soil adhered to vegetation can be very high (24.7 - 35 % of DM) when grazing animals are present, while on non-grazed plots the soil adhered to vegetation is reported to be none or very low. Grazing sheep cause more soil on vegetation than cattle. Soil is generally found in higher amounts on the lower parts of the plants. In many harvested crops, soil concentration is very low (< 0.2 % of DM). However, in root crops soil has been found to account for about 7 % of DM. Soil adhered to plants does not necessarily reflect the real intake of soil as the animals perform selective grazing or ingest soil directly. Faecal soil analysis is therefore more reliable to determine the percentage of soil in the diet where it is needed to estimate the total digestibility of the ration. Soil ingestion will increase with low amounts of forage available, winter season conditions, high stocking rates, root intake, loose soils and any management that produces pasture conditions with soil contaminating grass.

Deposition of contaminants to soil may derive from e.g. sludge, atmospheric deposition, metalliferous activities and persistent pesticides. Weathering can be a major cause of high concentrations of heavy metals in soils. The transfer and excretion of these environmentally dangerous compounds from soil to animal may be of importance in the calculation of reliable biological half-times and exposure risks. The availability of essential mineral elements is also of interest as it may determine the type and composition of salt licks and additional feeding.

1 INTRODUCTION

Soil ingestion by animals is often an ignored phenomenon, although it can occur under natural conditions in both wild and domesticated animals. The main function of a voluntary intake of soil is suggested to be restoration of lacking essential elements but also other motives may be present, such as soil being an antidote to acidosis (Healy, 1968; Ammerman et al., 1984; Kreulen, 1985). Inadvertent soil ingestion may also happen due to soil adhered to plants caused by rainsplash, resuspension and wind erosion.

Whatever the reason, soil ingestion by farm animals may cause a number of negative effects. It can be a source of uptake of radionuclides and chemicals and heavy metals, jeopardise digestive functions, alter mineral uptake and be a source of parasite and bacteria infections. Environmental contaminants like heavy metals, radionuclides, pesticides and other chemicals are more concentrated in the upper layers of the soil and these will therefore be more readily consumed. In food-chain models for the environmental assessment of nuclear operations and waste-management, data on soil-ingestion are needed in order to improve the reliability of the models for the prediction of food safety (Ronneau et al., 1983). Knowledge on the distribution of radionuclides, e.g. radiocaesium, between soil and plant is important as the uptake of radionuclides in soil by the animal is often less than from those in plants (Belli et al., 1993). The dominating pathway on the intake of radionuclides, from soil or plant, is determined by the plant/soil transfer coefficient and the percent soil ingestion of dry matter intake (Zach & Mayoh, 1984).

The aim of this review is to describe the causes for variation in the ingestion of soil by farm animals and additionally give an outline of the effects on animal and food safety. The topics covered in this review are shown in Figure 1.1. The review focuses on the factors determining soil ingestion, and deals with related issues in a more superficial manner.

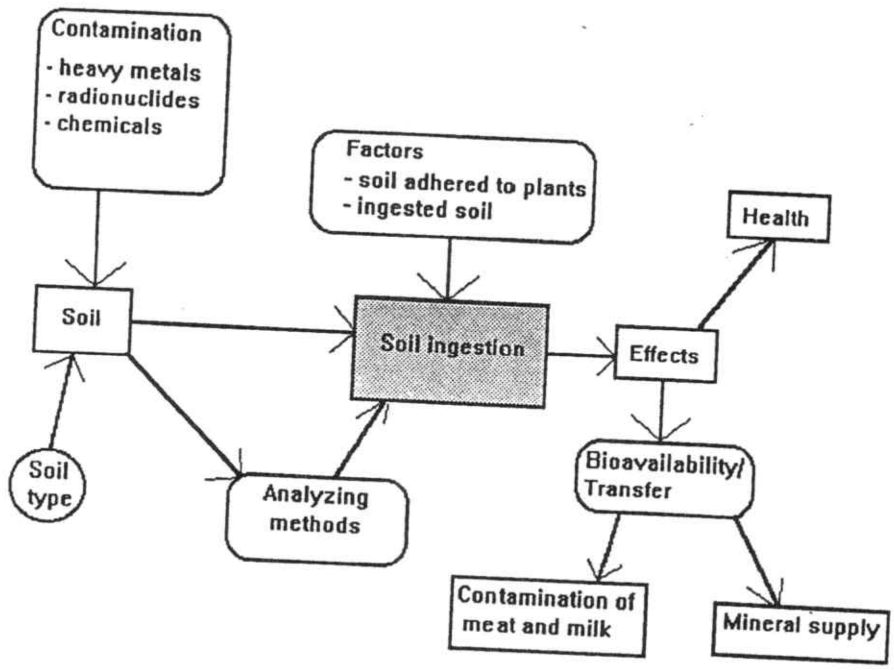

Figure 1.1. A diagram on soil ingestion by farm animals and related issues.

2 WHY ANIMALS INGEST SOIL

2.1 The theory of soil ingestion

As already mentioned, a distinction is often made between factors that determine voluntary intake and factors that determine inadvertent intake. Among the several motives for soil ingestion mentioned in this chapter, it is not always possible to know if these motives trigger voluntary soil ingestion, actively done by the animal, or if they only can be seen as a by-product of inadvertent soil ingestion.

Voluntary soil ingestion by grazing animals is usually considered to be a nutritional phenomenon. Soils may differ in their ability to supply mineral elements to animals via pasture herbage. The content of, e.g. Cu, Co and Se, can be found in such low concentrations in pasture herbage that the requirements in these elements for sheep and cattle can not be fulfilled by intake of herbage alone. The animal will then be at risk of developing deficiency symptoms. Thus, soil ingestion by grazing animals can occur in areas where there is an inadequacy of the soils to supply microelements to the vegetation (Healy, 1968; Healy, 1973).

However, many soil types that have been studied do not uniquely explain that they fulfil a supply of mineral elements. Soils may contain other characteristics that make them attractive for ingestion, as presented below (Kreulen, 1985).

2.1.1 Mineral element supply from soil

The concentration of several mineral elements in soil is often higher than in the herbage. A marked increase of the concentration of several mineral elements like Cu, Mn, Se and Fe in the diet when adding a certain amount of soil (14 %) into the diet of sheep was demonstrated by Healy (1973). However, this increase in mineral elements reflects total amounts ingested and not the available fractions of the elements. It should be noted that soil ingestion on pasture is highest when dry matter (DM) intakes are low due to feed limitations. At such times, mineral elements available to the animal directly from soil can be a significant contribution to intake (Healy, 1973).

Cobalt (Co) is included in vitamin B_{12}. However, very little of Co is taken up by plants. Therefore, it is mainly by soil ingestion that sheep and cattle can fulfil their needs of this mineral element (Healy, 1973; Thornton 1974).

In questioning the above statements on the function of soil ingestion in cattle and sheep as a source of some essential minerals, Russel et al. (1985) concluded that there is a direct intake of soil including mineral elements, e.g. Cu, but the fractional utilisation of a soil element of total intake is very small and the major source is from plants.

It is a well known fact that new-born suckling piglets will be deficient in iron (Fe) and they will very soon develop anaemia if they do not have Fe administered in some way. There is no point in feeding the sow extra Fe as practically nothing will be transferred to the milk. However, piglets display rooting behaviour from the day of birth which, under natural situations, will imply soil ingestion and thus a Fe supply from soil (Per Jensen, pers. comm.).

It is pointed out that the supply of mineral elements to animals is highly dependent on the actual soil ingestion, the concentration of elements in the soil and the availability of the mineral element in the soil. The supply of dietary trace elements is suggested to be a function of both a soil - animal relationship and a soil - plant - animal relationship (Thornton, 1974).

2.1.2 Stabilising digestive function with soil

Soil may have a stabilising effect on the digestive function in ruminants as soil can provide the animal with buffers which stabilise rumen pH and fermentation (Kreulen, 1985). This function can explain voluntary soil ingestion seen in many in wild ruminants in semi-arid areas in Africa. Wild, especially nomadic, ruminants in the Kalahari desert have been observed licking soil during shifts from a dry, nearly straw-like, grass diet to leaf flush and high palatable grass. This change in diet would likely cause digestive disorders like acidosis but, according to Kreulen (1985), this has not been reported in those species that have been observed to ingest soil. Soil ingestion has been noticed in Sweden in both sheep and cattle after the change from indoor winter feeding to grazing (Mats Kullberg, pers. comm.). Kreulen (1985) gives a number of examples and arguments explaining animals' soil ingestion in order to recover from acidosis: Introduction of concentrates which cause gastric irritation induce soil-eating in cattle. The behaviour ceases when bentonite is added to the diet. A clay like bentonite has a high cation exchange capacity and a structure which enables it to form complexes with organic compounds. Thus rumen fermentation can be stabilised by buffering and by reduction of substrate. Soil ingestion is mostly a seasonal phenomenon, in temperate and tropical areas it is displayed predominantly in spring and early wet season, following on leaf flush and associated dietary change. Also a within-day variation is observed. Ungulates in the Kalahari desert often ingest soil in the late afternoon/early evening, which coincides with the peak of the sugar content in the plants a few hours earlier. Minimum pH would be expected in the early evening and would be counteracted by the ingested soil. Ash-eating has been observed in both wild and domestic animals, which would mean that they seek other buffer salts than the suggested Na because ash contains mainly potassium carbonate (K_2CO_3).

3 METHODS FOR MEASURING SOIL CONTENT IN PLANTS AND FAECES - SOIL INGESTION ESTIMATES

There are several methods of measuring the amount of soil adhered to plants or the soil content in faeces. The most commonly used are listed below.

The soil found in animal faeces reflects intake from several sources which cannot be separated. Soil may have been adhered to plants, the plants may have been ripped up with the soil contaminated roots and the whole plant may have been consumed, or there might be a direct ingestion of soil.

Soil ingestion can be estimated by using the acid insoluble residue method (AIR) by which the ash content is determined (Healy & Ludwig, 1965). If the daily faeces output is known as well as the soil concentration of the faeces, then the quantity of soil ingested per day can be determined. However, faeces output data is usually only available from experimental animals. In other cases, the faeces output can be calculated by estimating the feed DM intakes and digestibility of feed. The acid insoluble residue (AIR) is taken as a measure of soil ingested, and is related to it by the formula (Healy & Ludwig, 1965; Fleming, 1986):

$$AIR = (100 - S)X / 100 + Y / 100$$

where S is the percentage of soil in faeces, X is the percentage AIR derived solely from plant material and Y is AIR in percent of soil. The determination of ash content in plant material or faeces is considered to be a rough method which only approximately estimates the soil content (Mayland et al., 1975).

A soil element that is not incorporated by plants and not digested by the animal can be determined and thus, knowing the concentration of the element in the soil, the soil content of the matter (plant surface contamination or faeces) can be calculated. This procedure has been proven to be most convenient and accurate in determinations of the amount of soil (Mayland et al., 1975; Li et al., 1994). Several elements have been suggested and evaluated in order to determine soil concentration in plant material and faeces, such as titanium (Ti) by using spectrophotometry (Sherman & Kanehiro, 1965) and scandium (^{45}Sc) by using neutron activation analysis (Oughton & Day, 1993; Li et al., 1994). Together with titanium and AIR, aluminium has been used to estimate soil content in faeces by Millar et al. (1985).

Titanium determinations may be a little uncertain since the Ti content can change with particle size of soil. Soil fractions with > 100 μm particles have considerably higher Ti concentrations than smaller fractions (Brebner et al., 1985). The determination of ^{46}Sc by neutron activation analysis seems to be reliable and practical for soil mass loading research

(Oughton & Day, 1993; Li et al., 1994). Scandium is poorly absorbed by plant roots and is not mobile in vegetation (O'Toole et al., 1981). A detection limit of 0.5 mg per g dry plant biomass is reached, which is adequate.

The calculation of daily intake (in percent of DM intake) of soil can be made by using the equation suggested by Thornton & Abrahams (1983):

$$\% \text{ Soil ingestion} = (1 - D_h)Ti_f / Ti_s - D_h\, Ti_f\, 100$$

where D_h is the herbage digestibility, Ti_s the titanium concentration (of DM) in soil and Ti_f the titanium concentration (of DM) in faeces. Scandium content and other elements fulfilling the criteria of not being incorporated by plants or digested by the animal could also be used for the calculation.

Russel et al. (1985) suggested that the fraction of intake of an element (F) coming from ingested soil can be calculated using the equation:

$$F = (Ti_f\, E_s) / (E_f\, Ti_s)$$

where E_f is the concentration of an element in faeces and E_s the concentration of an element in soil. This second method avoids estimating herbage digestibility.

4 FACTORS INFLUENCING INADVERTENT SOIL INGESTION

Soil adhered to plants will usually be ingested and should be considered to be an inadvertent intake of soil. The difference between factors determining adhesion of soil to plants and the real soil ingestion must also be distinguished. There is often inadequate data to assess the importance of many of these factors determining how much soil is deposited on and retained by vegetation, and on the real soil ingestion. In many studies, the percentage of soil in faeces is measured but, as mentioned above, this only partly reflects the intake of soil adhered to plants. Other sources may be grooming by licking of soil-contaminated coat and snout and direct soil ingestion. Additionally, there are not always data on the total feed dry matter intake or digestibility of the herbage, which makes it difficult to exactly calculate daily soil ingestion rate.

4.1 Soil adhered to plants

4.1.1 Pasture

Soil may be adhered to plants for various reasons, including action of the wind, rain splash, resuspension and soil distribution by ploughing or livestock activities. The soil contamination on the plants may be heavy on pasture. Soil (determined by titanium content analysis) has been shown to contribute to as high as 35 % of the DM in clover and to 24.7 % in ryegrass on pastures grazed by sheep, while no soil was found on herbage (both ryegrass and clover) in non-grazed plots (Healy, 1973). Hinton et al. (1995) found 7 g soil per kg dry plant in ungrazed plots by determining the scandium content. To which extent soil adhesion occurs will be influenced by a wide range of environmental activities including species of animal, climate, season, soil-type, stocking rate, vegetation species and pasture management (Beresford & Howard, 1991).

Animal species. The influence of cattle and sheep on the amount of soil that adheres to plants has been investigated by Green & Dodd (1988) by the use of the titanium content. Soil contamination of herbage in a sheep paddock was 6.8 % of DM while it was 3.2 % of DM in a cow paddock.

Season. Beresford & Howard (1991) measured the soil content on plants in sheep pastures by using the titanium content. A clear seasonal variation in soil adhered to vegetation was found to be as high as 40 % of DM in winter and less than 2 % of DM in summer.

The soil content of grass on a cattle pasture was analysed from May to October by use of the titanium method. The soil content of the herbage varied between samples but at any given time (apart from one case) was less than about 3 % on dry matter basis (Green et al., 1994).

Grazing intensity. Soil loadings, g soil / kg dry plant of grass, was found to increase with grazing intensity (number of sheep per ha and day) (Hinton et al., 1995) (Figure 4.1). The soil loading was mainly in the lower (2 - 10 cm above ground) part of the plant. In ungrazed plots, total soil loading was below 8 g per kg dry plant and more than twice this amount in the most intensively grazed plots (468 and 624 sheep per ha and day).

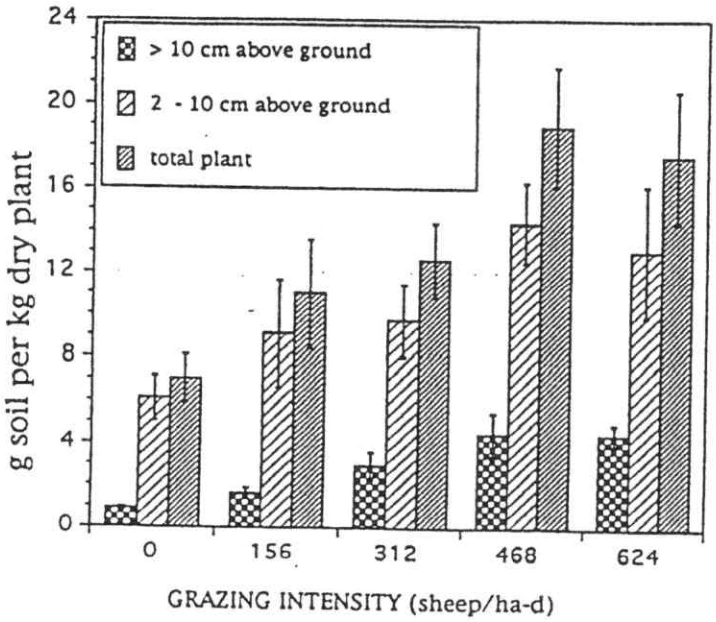

Figure 4.1. Mean soil loadings (± SE, n = 5), as affected by different densities of sheep, are shown separately for two vegetation heights and combined for the entire plant (Hinton et al., 1995).

Grazing intensity and rainfall interaction. With no sheep present, rain would literally wash soil from the plant surfaces. With increasing grazing intensity and increasing rain fall, soil loading on plants will be highest (Hinton et al., 1995). In Figure 4.2, the predicted response on surface soil loadings is shown as affected by grazing intensity and rainfall.

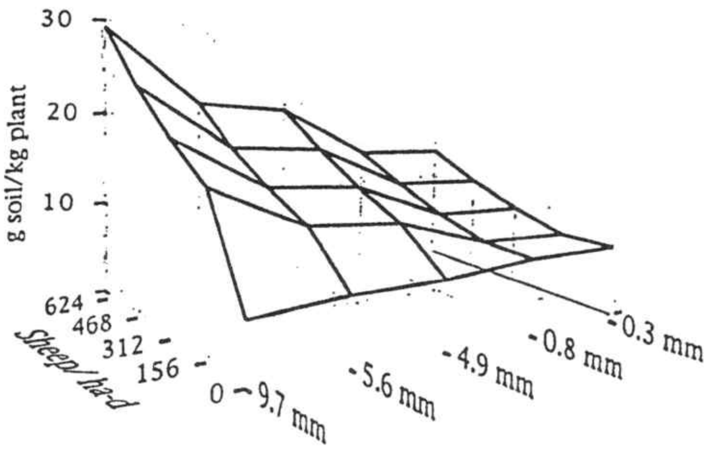

Figure 4.2. Predicted response on surface soil loadings on pasture as affected by grazing and rainfall (Hinton et al., 1995).

Wind erosion, rainsplash and plant species interaction. Li et al. (1994) tried to separate the effects of wind erosion and rainsplash in experimental studies in greenhouse and in unprotected fields. In ryegrass, 53 % of the total soil concentration (total soil content: 5.77 mg / g dry plant) on plant surfaces derived from wind erosion while 47 % derived from rainsplash. In broad bean, wind erosion only accounted for 32 % of total plant surface concentration (total soil content: 9.51 mg / g dry plant) while 68 % derived from rainsplash. The differences between the two plant species might be due to differences in plant anatomy and leaf structure.

Resuspension. Another risk of soil contamination on the herbage (and thus of radionuclides) is by resuspension which is a type of wind erosion where the soil and the attached contaminant becomes airborne. Resuspension of estuarine surface sediment deposited during flooding has been described by Summerling (1981). 137-Cs from resuspended soil can be taken up by the plant by foliar absorption, but this is of very little importance relative to plant root uptake (Hinton et al., 1996).

4.1.2 Harvested crops

Swedes and other root crops can contribute to large amounts of soil in the animals' diet. Ulvesli and Saue (1965) compared feeding of uncleansed whole swedes with dry cleansed whole swedes to dairy cows. The soil content on uncleansed swedes was about 7.3 % of wet weight, while after dry cleansing the soil content was 3.4 - 2.2 %.

Soil contamination of forage plants may be higher in the lower part of the plant than in higher parts. The effect of cutting green forage with two stubble heights (50 and 150 mm, respectively) on the 137-Cs activity in the herbage was studied by Bertilsson et al. (1988). The 137-Cs concentration of the herbage cut with 50 mm stubble height was 17 times higher (6656 Bq / kg DM) than in the 150 mm (385 Bq / kg DM) stubble height. In a feeding experiment with dairy cows, the same authors also studied the 137-Cs transfer from the green cut forage to milk. The transfer coefficient of 137-Cs to milk was 3.5 times higher in the forage cut with high stubble height (0.67×10^{-2}) than that cut with in the low stubble height (0.19×10^{-2}). The difference was explained by the assumption that 137-Cs in the latter case occurred in a claybound, less available form. This may indirectly reflect soil contamination of the lower part of the plants. Aspects on lower bioavailability for soilbound 137-Cs have been given by several authors, e.g. Johnson et al. (1968) and Belli et al. (1993). However, without data on the radioactivity in the soil, no estimation of the soil contamination of the forage can be made.

Soil content, as reflected by titanium content, was found to be very low (< 0.14 % of DM) in concentrates, corn silage, haylage and hay (Fries et al., 1982). In green chopped herbage and in pasture, maximum soil concentrations were 0.73 % and 2.88 %, respectively. The range of concentrations is shown in Table 4.1.

Table 4.1. Apparent concentrations of soil in feeds from study farms (Fries et al., 1982).

Feed	Samples (No.)	Range of concentrations (% DM)
Concentrate	8	<0.01 - 0.01
Corn silage	5	<0.10 - 0.20
Haylage	4	<0.01 - 0.17
Hay	6	<0.01 - 0.14
Greenchop	2	0.19 - 0.73
Pasture	4	0.34 - 2.88

4.2 Ingested soil/faecal soil

Data from investigations on ingested soil measured as faecal soil under different conditions are shown in Table 4.2 (page 18).

4.2.1 Pasture

Animal species. No comparable data have yet been found on the influence of animal species on the amount of ingested soil. However, the earlier given data on soil in herbage (Green & Dodd, 1988) as influenced by different animal species may be mentioned in this context. Soil ingestion in cattle and sheep and other animals may be different due to grazing behaviour: the way of separating the grazed plant parts from the rest of the plant, how close to the ground grazing is performed, and soil contamination of plants by treading due to difference in claw size, weight and amount of locomotion. It might be concluded from the data by Green & Dodd (1988) that sheep are more likely to ingest greater amounts of soil than cattle. This is supported by data given by Thornton & Abrahams (1983) which show that soil ingestion in sheep can account for as much as 30 % of daily DM intake, while the corresponding figure in cattle was 18 %.

Available forage and root intake. The available amount of forage in pasture primarily varies with the growth rate of the plants and stocking rate. These factors are dealt with in greater detail below but as a general conclusion the concentration of soil in faeces has been found to increase when the availability of forage decreases (cattle: Mayland et al., 1975; Kirby & Stuth, 1980; sheep: Healy, 1968; Healy, 1973; Millar et al., 1985). Mayland et al. (1975) considered that the increased soil ingestion could be explained by it primarily being included with the roots of *Bromus tectorum* which were often pulled up and consumed together with the aboveground plant parts. Dust on leaves and stems accounted for only a small portion of the ingested soil. Soil ingestion rates (Ti content) in cattle were here found in the range from 0.1 to 1.5 kg with a median value of 0.5 kg soil /animal day^{-1}.

Season. Seasonal changes in the soil content of ruminant faeces have been observed in several places over the world and most often reflect the available amount of forage: In wet winter climates, as in Ireland (Raffety et al., 1994), soil ingestion was found high in sheep during winter months. Similar observations were also made in New Zealand (Healy, 1968; Healy, 1973; Millar et al., 1985). The faecal soil content was at least three times higher in the winter than in the summer. Peak values of AIR were as high as 40 - 50 % of the DM of the faeces (Millar et al., 1985). On twelve farms in the south-west of England, the percentage of soil (titanium method) of total DM intake by cattle was on average 5.6 %, 1.45 %, and 3.0 % in late April, June and August (Abrahams & Thornton, 1994). Soil ingestion rates varied with season in nearly all the farms but were particularly high in April.

In arid climates, high soil surface temperature (above 30°C), which is dependent on ambient temperature and wind velocity, has been found to be inversely related to soil ingestion (titanium method) in sheep (Vaithiyanathan & Singh, 1994). Sheep, being close grazers, may avoid picking up plant material which is close to the soil surface when soil temperature is high.

Heifers on a pasture with a good stand of crested wheatgrass (*Agropyron desertorum*) under rather mesic conditions (in Idaho, USA) had average soil ingestion rates of 0.73 kg / animal and day in June and 0.99 kg / animal and day in August (Mayland et al., 1977).

Soil type. Low ingestion rates have been found when animals are kept on well-drained soils which have a strong structure. In contrast, soils with a weak structure and poor drainage are associated with high pasture contamination (Healy, 1968).

Table 4.2. Soil ingestion rates in cattle and sheep under different conditions.

Animal category	Kg soil per animal per day (mean, range or medians)	% of DM intake (mean, range or medians)	Conditions	References
Dairy cattle, grazing	0.5 - 1.2	4 - 8	Depending on feeding schedule,	Healy, 1968
	2.2		Poor range conditions	
		<2	Lush plant growth	
		14	Poor plant growth	
Dairy cattle, grazing		3.4		Green & Dodd, 1988
Dairy cattle, grazing		1.38 - 2.43	Pasture + supplementary feeding	Fries et al., 1982
Dairy cattle, confined		0.14 - 0.53	Confined to concrete	Fries et al., 1982
		0.35 - 0.64	Free-stall barn with soil bedding	
		0.60 - 0.96	Access to unpaved lots, no vegetation	
Range cattle	0.5 (median) 0.1 - 1.5	6.2 (median) 1.2 - 18.8	Semiarid conditions	Mayland et al., 1975
Heifers, grazing	0.73		June	Mayland et al., 1977
	0.99		August	
Heifers, confined or with supplement feed		0.52 - 0.81	Confined to buildings and/or paved lots	Fries et al., 1982
		0.25 - 2.26	Unpaved lots, no vegetation	
		1.56 - 3.77	Unpaved lots, sparse vegetation	
		1.38 - 2.43	Pasture with supplemental feed	

Table 4.2 (cont.). Soil ingestion rates in cattle and sheep under different conditions.

Animal category	Kg soil per animal per day (mean, range or medians)	% of DM intake (mean, range or medians)	Conditions	References
Steers, grazing	0.41 - 0.84 0.34 - 0.67 0.28 - 0.61		Mechanically tilled Chemically treated Untreated pasture	Kirby & Stuth, 1980
Cattle, grazing		5.64 (mean) 1.5 - 17.9 1.49 (mean) 0.2 - 3.9 3.01 (mean) 1.4 - 4.7	April June August	Abrahams & Thornton, 1994
Cattle, grazing		4.5 (mean) 1.1 - 10.9 3.3 (mean) 1.6 - 6.0 5.7 (mean) 4.9 - 6.4	November January March	Thornton, 1974
Sheep, grazing		up to 14	Range conditions and soil structure	Healy, 1968
Sheep, grazing		6.8		Green & Dodd, 1988
Sheep, grazing	0. 71 - 0.163	3.7 - 10.7	Arid climate, high temperature, low wind velocity	Vaithiyanathan & Singh, 1994

Stocking rate. Increasing stocking rate results in a greater amount of soil ingested (Healy, 1968). With 16 ewes / ha compared with ewes stocked 7.5 / ha, soil ingestion rates were more than four-fold (8 and 2 % of DM intake, respectively, as measured by AIR content) during summer. In winter, soil content in faeces was found to peak at nearly 40 % with 16 ewes / ha while with 7.5 ewes / ha soil content was about 25 %. A seasonal variation in the pattern of soil ingestion can be seen with different stocking rates (Healy, 1973). Soil ingestion rates increase earlier in the autumn and decrease later in the spring with the high stocking rate compared with the low stocking rate. This interaction of season and stocking rate is shown in Figure 4.3.

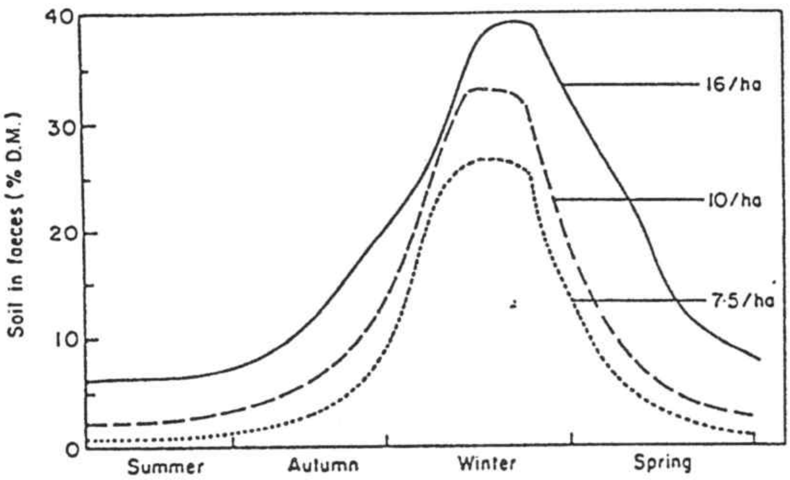

Figure 4.3. Effect of stocking rate and season on soil content of faeces (Healy, 1973).

Bare ground. A positive relationship between percent open ground and faecal soil (AIR) has been shown by Kirby & Stuth (1980) due mainly to the use of mechanical tilling of pastures.

Management. Dry ewes stocked 37/ha when rotationally grazed on a 28-day basis ingested less soil (10 % soil in faeces) than did animals rotated on a 7-day basis (37 % soil in faeces) (Healy, 1973). Supplementary feeding to animals during winter months will result in less soil ingestion than in animals relying on pastures alone (cattle: Fries et al., 1982; sheep: Healy, 1968). Hoggets grazing swedes on a break system, allowing a new area of swedes every five weeks, ingested little or no soil at the start of the break but large amounts of soil were ingested when most of the crop was eaten down to ground level (Healy and Drew, 1970).

Healy (1973) concludes that there is a close correlation between pasture condition and soil in faeces. Where pasture is short and closely grazed, soiled and associated with abundant earthworm casts, high contents of soil in faeces can be expected. Any management practice producing these conditions in pastures will affect soil ingestion.

Soil ingestion by individuals. There is a considerable individual variation in soil intake by individual animals on pasture. In the same sheep herd it may be more than two-fold (Healy & Drew, 1970).

4.2.2 Confined management systems

Soil intake is generally very low under confined conditions for cattle (< 1 % of dry matter intake). However, lactating cows that had access to unpaved lots ingested more soil than cows confined to buildings and paved lots. Cows whose only exposure to soil was bedding of free-stalls, ingested intermediate amounts of soil (Fries et al., 1982). It seems evident that soil intake in these cases was due to coat and snout licking. The same authors showed that dry cows and heifers kept under similar circumstances generally had a higher percentage (> 1 %) of soil ingestion rates than the lactating cows. But in the case of a group of cattle with no soil exposure factor, this might be an artefact due to bedding in the stanchions with wood shavings which had a titanium content equivalent to 0.86 % soil. Ingestion of wood shavings might explain the reported calculated soil ingestion.

5 THE SIGNIFICANCE OF ANIMALS' SOIL INGESTION FOR THE CONTAMINATION OF FOOD

Soil ingestion will be of interest in order to know if any detrimental or positive effect can be expected. Here some factors can be mentioned such as: the amount of soil ingested, the type of contaminant or micronutrient, the transfer of the element to meat and milk and, ultimately, the estimation of the critical load which may endanger human health.

5.1 Deposition and weathering

Soil ingestion may be an important pathway for chemical pollutants, radionuclides (Zach & Mayoh, 1984) and for heavy metals (Thornton, 1974; Thornton & Abrahams, 1983; Abrahams & Thornton, 1994). The deposition may be rain- or airborne (O'Toole et al., 1981), derive from sludge, be residues from metalloferrous activities and, in the case of heavy metals, also be caused by weathering of minerals.

5.2 Transfer of contaminants - from soil to animal

For well-mixed soils it is possible to make a generic evaluation of the relative importance of soil contamination and plant root uptake to the total activity (of radionuclides) or concentration of heavy metals or other substances in the vegetation (Zach & Mayoh, 1984). Briefly, for elements with a soil-plant transfer factor greater than 1 (expressed as concentration in dry mass of plant:concentration in dry mass of soil), soil-associated activity would be only a small contributor to the total intake, whereas when soil-plant transfer factors are around 10^{-3} or less, then soil-associated activity would dominate. However, when deposition is made upon existing pasture, concentrations in the surface soil may be much greater than the average value over the rooting depth. In such circumstances, for a given soil:plant transfer factor the contribution to the intake of the contaminant from ingestion of surface soil would be much greater than in the case of a well-mixed soil (Cooke et al., 1995).

5.3.1 Heavy metals

Deposition and weathering. Elements with a density higher than 4.5 g/cm^3 are called heavy metals. Therefore, iron (Fe) is a heavy metal although a non-toxic one. Some heavy metals are essential elements or micro nutrients (e.g. Cu, Zn, Se) as long as their concentrations remain rather low. Other elements (e.g. Cd, Pb, Hg) are not essential. They are toxic for plants, animals and especially for man. Many rocks and minerals contain very small amounts of heavy metals (concentration levels: ppm, ppb). The metals will come into the soils and reach the food chain by two ways:

a) Weathering and soil-forming processes.

b) Industrial processing and emissions.

Soils are therefore important compartments in the process of heavy metal accumulation, mobilisation or immobilisation within the ecosystems. Heavy metals are subjected to changes in their type of binding, solubility and plant (and animal) availability within ecosystem cycles (Kuntze, 1985). Heavy metals are present in rocks in the crystal lattice of minerals, e.g. silicates or sulphides and in this form they are nearly insoluble. The various weathering processes also free the heavy metals from their insoluble form in the original rocks. Even rocks with very low heavy metal contents can produce soils with a high concentration of heavy metals. The enrichment is explained by the fact that several meters of bedrock, e.g. limestone, must be weathered to produce several decimetres of soil (Kuntze, 1985).

Industrial processing of raw materials that contain heavy metals involves the danger that they will be released into the environment. Industrial dusts from high temperature processing mostly contain oxides of heavy metals which may be soluble. This emission leads to a diffuse distribution. Deposition of wastes containing heavy metals or long-term use of sewage sludge in agriculture creates a high concentration of heavy metals in one place. The heavy metals are then no longer bound in their natural insoluble form, but are present as unfixed ions, exchangeably adsorbed by clay minerals and humic substances, as free oxide or sulphate, and thus more able to enter the food chain (Kuntze, 1985). For example in sludge-treated grass land, the Zn concentration became dramatically higher in the surface layer of the soil. Here, it is also more likely to be ingested (Fleming, 1986).

Geochemical mapping on the occurrence of trace minerals is helpful in order to indicate regional patterns, relating to the composition of bedrock and soil and to contamination from past and present industry. In Southwest England, past mining and smelting is reflected in high concentrations of heavy metals in the agricultural soils (Thornton, 1974). These soils may contain up to 2500 ppm arsenic, 1000 ppm tin, 1500 ppm copper, 1700 ppm lead and 1200 ppm zinc.

There is a great variation in how much an ingested element derives from soil. In cattle, up to 87 % of lead (Pb) (Russel et al., 1984) and 97 % of total intake of arsenic (As) (Abrahams & Thornton, 1994) may originate from ingested soil (Tables 5.1 and 5.2).

Table 5.1 Fractional intake (% of total intake of the element deriving from soil) of Pb and Cu by dairy cows from farms on soils 'highly', 'moderately' and slightly' contaminated with Pb in Derbyshire (Russel et al., 1985)

Contamination, Pb mg/kg in soil	Pb	Cu
'Highly', 2467	87	10
'Moderately', 682	46	9
'Slightly', 252	42	3

Table 5.2 Concentration of five elements in soil. Calculated intake by cattle of the five elements through soil in different periods (months), expressed as per cent of the total intake of each element within each period (adapted from Abrahams & Thornton, 1994)

	As	Cu	Zn	Mn	Fe
Concentration of elements in soil, µg/g	19 - 320	12 - 319	29 - 365	120 -1650	10800 - 58700
Percentage of element intake through soil in					
April[a]	80 - 97	3.7 - 59	2.1 - 28	2.1 - 45	30 - 95
June[b]	41 - 93	2.1 - 34	1.0 - 13	0.4 - 20	45 - 93
August[c]	79 - 96	3.2 - 36	2.6 - 21	1.9 - 29	64 - 92

[a] Soil ingestion (range): 1.5 - 17.9 of total daily DM intake
[b] " " " : 0.2 - 3.9 of total daily DM intake
[c] " " " : 1.4 - 4.7 of total daily DM intake

Abrahams & Thornton (1994) found positive relationships between soil concentration and washed herbage concentration of As and Cu, respectively, while there was a negative relationship for Mn. No relationships between soil and herbage concentrations were found for Fe and Zn.

Bioavailability. Ingested soil, as it passes through the animal's alimentary tract, is subjected to a range of conditions inherent in the digestive process. In ruminants, there are particular differences in pH between the abomasum (pH 3.0) and the rumen (pH 7.0). These differences must exercise significant effects on metal absorption. Other processes such as complexation may also be involved. Alimentary tract conditions may therefore increase or decrease heavy metal availability to the animal (Fleming, 1985).

The complexity of the bioavailability of heavy metals, both toxic and micronutrients, is that of interactions and the involvement of elements acting as antagonists. Copper deficiency can be explained by the presence of FeS which, in the abomasum, can release sulphide in the acid milieu resulting in trapping potentially absorbable copper as insoluble CuS (Suttle et al., 1984). Zinc and cadmium can also act as antagonists towards copper absorption (Fleming, 1986).

Ronneau et al. (1983) plotted the deposition of selenium (Se) on pastures to the Se concentration of hair and milk in cattle and found rather linear positive relationships. The Se deposition was not correlated to the concentration in pasture soils. This could mean that deposited Se is foliar-absorbed

Russel et al. (1984) found that different soil types had different effects on cattle in the plasma concentrations of heavy metals and that there was an interaction with sulphate. It was concluded that there is little information on the reactivity of ingested soil in the animal.

5.3.2 Radionuclides

Deposition. The entire Nordic area has been contaminated by global fallout from atmospheric nuclear weapon tests in the 1960s. In 1986 large areas in Sweden, Finland and Norway were contaminated by radioactive elements, mainly radiocaesium from the Chernobyl accident. The ground deposition was several times greater than earlier global fallout. In Great Britain, the Sellafield nuclear operation suffered a severe radioactive leakage in 1957 which contaminated large land areas in northern parts of the country.

137-Cs is mainly concentrated in the upper layers of soil (0-5 cm) and very little mobility to lower layers of soil is seen (Riise et al., 1990; Chamard et al., 1993; Rosén et al., 1995; Oughton et al., 1995).

Bioavailability. The availability and transfer of radionuclides in the chain soil-feed-animal products have been recently studied *in vivo* by Assimakopoulos et al. (1993), Belli et al. (1993)

and Hansen & Hove (1991) and Amaral et al. (1995). The transfer coefficient for a radionuclide to animal products, e.g. milk is defined as (see e.g. Assimakopoulos et al., 1993)

$$f\mathrm{m} = X_m(t \rightarrow \infty) / P$$

where $X_m(t \rightarrow \infty)$ is the asymptotic value of the radionuclide concentration measured in the milk and the P is the daily input of the radionuclide (unit: day kg^{-1} or day l^{-1}. The concentration ratio is defined as the radunuclide concentration in the animal product divided by the radionuclide concentration in the soil or the feed.

When the soils contain clay minerals the transfer coefficients seem to be very low. Belli et al. (1993) fed two soils contaminated with C137-Cs to lactating ewes. The clay contents were 11 and 16 % and the sand contents were 6 and 38 %, respectively. Even though the ewes had a daily intake of about 1700 Bq day^{-1} (137-Cs) from soil, the activity in the milk was, on average, as low as 0.6 - 1.1 Bq / l. The transfer coefficients (f_m) for 137-Cs from soil to ewes milk were thus calculated to be less than 6.11×10^{-4} day l^{-1}. The transfer coefficient to goat milk of 134-Cs included in an organic soil was only 7 % of that in hay (Hansen & Hove, 1991).

However, the soil-to-milk activity transfer can be much higher for soils with high sand contents (65 %) (Assimakopoulos et al., 1993). When ewes fed 50 g per day of a sandy top soil with a clay content of 12 %, from the Chernobyl area with a dose of 1835 Bq per day of 137-Cs the transfer coefficient (f_m) was 2.6×10^{-2} day kg^{-1}. The radiocaesium concentration reached about 40 Bq per kg milk.

The concentration ratio from soil to eggs in free-range hens was found to vary between 5.5×10^{-3} and 1.06×10^{-2} for whole consumable eggs when the activity of 137-Cs was about 1700 to 3000 Bq /kg in the surface soil (Amaral et al., 1995). The concentration ratio for chicken meat ranged between 2.1×10^{-2} to 5.5×10^{-2} in the same study.

By using extraction or *in vitro* methods, the availability of radionuclides in soil to animals can be estimated. In a procedure by extraction soil using incubation with rumen liquor, Cooke et al. (1995) showed that radionuclides would separate into a liquid and a solid phase. The percentage of the activity found in the liquid phase was generally low and, for 137-Cs, 239-Pu and 241-Am, was never more than 20 %. The radionuclides were most readily extracted from organic soils.

Wilkins & Green (1988) extracted surface soil from land reclaimed from the sea into different phases: water soluble, exchangeable, carbonate, oxide and organic and residual. However, more than 92 % of the total amount of 137-Cs was found in the residual, thus hinting that the availability of the radionuclide in soil was low. Similar results (10 % of radiocaesium easily leachable from the soil) have been found by Riise et al. (1990). Green et al. (1995) found that radioactivity in grass can be dominated by soil even if the soil content in the grass was low. But as only a small portion of the activity was found soluble in rumen fluid (5 %), it was suggested that only a small percentage of the total activity was available for uptake. Clay minerals as bentonite and zeolite have binding effects on 137-Cs (Andersson, 1989; Andersson et al., 1990a,b; Åhman et al., 1990) and can be fed in order to limit the activity transfer.

Crout et al. (1993) tried to predict radiocaesium transfer to sheep under different soil adhesion-to-plant circumstances by using a simulation model (RUINS). Radionuclides in soil adhered to plants may indicate a higher contamination with radiocaesium in the bulk vegetation than that found in soil-free herbage. Therefore, the extent of soil adhesion needs to be considered if predictions of radiocaesium contamination of animal products are to be made on the basis of measured activities in sampled vegetation. The results from the RUINS model are adapted to partitioning between fixed and labile phases of radiocaesium in the soil.

5.3.3 Chemicals

Deposition. Ingestion of soil by animals has been described as a source of dioxin (TCDD) through spreading of waste oil (Fries, 1987), polychlorinated biphenyls (PCB) through the use of sludge (Fries, 1982), and DDT (a well known pesticide containing di-chloro-di-phenyl-tri-chloro-methyl-methan) (Harrison et al., 1970). These chemicals, all of which are detrimental to human health (life time exposure is high enough), can easily be transferred to meat and milk from soil.

Bioavailability. Fries (1982) suggested that in a "worst case" evaluation for each ppm of PCB in surface soil, 0.14 ppm would be predicted in the diet of sheep and with a concentration factor of five, milk fat residues would reach 0.7 ppm. For sheep, it was estimated that for each ppm of PCB in soil, 0.045 ppm would show up in body fat of sheep. The bioavailability of dioxins in soil has been suggested to be over 50 % (Fries, 1987). Ruminants might be expected to absorb dioxins from soil more efficiently than monogastric animals because of the fermentation in the rumen and longer residence time of ingesta in the gastrointestinal tract.

Harrison et al. (1970) fed lactating sheep with soil contaminated with DDT. The DDT was found in milk fat phase and in the lamb fat but here no transfer coefficients were calculated.

5.4 Other effects of soil ingestion

Soil ingestion may have other effects than those mentioned above. The effects have been associated with changes or disorders in the digestive organs and in nutrient balance of animals.

Soil ingestion has been observed to be associated with excessive wear on teeth in sheep (Healy & Ludwig, 1965; Millar et al., 1985). Deposits on rumen epithelium of sheep due to ingestion of soil have also been reported (Healy & Wilson, 1971). Sand deposition in the large intestines of horses can cause diarrhoea (Ramey & Reinertson, 1984)

Molybdenum (Mo) is a constituent of xantine oxidase, a metalloflavo-protein which plays an essential role in purine metabolism. Excessive amounts of Mo are toxic and also hinder the uptake of copper. This may induce copper deficiency illness (hypocuprosis) in both sheep and cattle even if adequate amounts of Cu are present in the herbage. Adding extra Cu to the diet restores the animals. Mo in large amounts can be obtained by soil ingestion. The geographical area distribution of Mo in United Kingdom can explain regional disorders in sheep which relate to trace-element imbalance (Thornton, 1974).

Certain soil types seem to bind elements and "drain" the animals of nutritional elements. This has been demonstrated for the clay bentonite which, added to the diet of dairy cows, had adverse effects on their mineral balance (Ca, P, Mg) (Rindsig & Schultz, 1970). This was also found by Allen et al. (1986) who reported that ingestion of Al (soil) altered Ca, Mg and P metabolism in lactating beef cows. For sheep, soils increased the apparent absorption and retention of Mg and Ca (Grace & Healy, 1973; 1974). Phosphorus deficiency symptoms are often seen in tropical areas and have been suggested to be explained by ingestion of soil with high P-binding capacity. The utilisation of phosphorus (P) may be negatively affected by including soil with high P-binding capacity into the diet to sheep (Ammerman et al., 1984).

6. CONCLUSIONS

A number of conclusions can be made on the topic of soil ingestion and its significance for contaminating human food as meat, milk and eggs.

- Soil can be a severe source of various contaminants.
- Deposited contaminants are often present in the surface soil layers in permanent grassland and are therefore more readily ingested.
- Inadvertent ingestion of soil can be very variable and may depend on animal species, weather, availability of forage, soil type and management practices.
- Ruminants may voluntarily ingest soil as it may level pH-fluctuations in the rumen.
- Only sheep and cattle have been studied more widely for soil ingestion. New forms of keeping pigs in outdoor housing systems will probably be interesting to study also in this aspect as pigs may ingest large amount of soil.
- Not only ingestion of soil may exposure animals to soil contaminants. There may also be an absorption through the skin or lungs. This may need to be investigated.
- Contaminants in ingested soil transferred to, e.g. milk and meat, will depend on the amount of soil ingested, the type of soil (and the property of the binding of the contaminant to the soil), as well as the digestive process, which may release or bind the contaminant.
- Radionuclides in soil generally have low bioavailability but, depending on the soil type and the ratio of the activity in herbage to soil, ingested soil may be of some importance for contamination of animal products.
- The bioavailability of heavy metals in soil is difficult to predict due to interactions of other elements.
- Contaminants ingested together with soil can be of importance if the contaminant is not strongly bound to the soil.

- Ingestion of soil of clay type may have radiocaesium-binding effects which can reduce the intestinal activity absorption.
- When ingested, organic chemicals present in soil will often have high transfer rates to meat and milk.
- Simulation models, e.g. RUINS, can be a useful tool in explaining and predicting transfer of radionuclides to animal products by considering soil adhesion to plants and differences in transfer rates between different phases in the soil.

7 REFERENCES

Abrahams, P.W. and Thornton, I. 1994. The contamination of agricultural land in the metalliferous province of south-west England: implications to livestock. *Agriculture, Ecosystems and Environment 48:*125-137.

Allen, V.G., Horn, F.P. and Fontenot, J.P. 1986. Influence of ingestion of aluminium, citric acid and soil on mineral metabolism of lactating beef cows. *J. Anim. Sci. 62:*1396-1403.

Amaral, E.C. S., Paretzke, H.G., Campos, M.J., Pires do Rio, M.A. & Franklin, M. 1996. Transfer of ^{137}Cs from Soil to Chicken Meat and Eggs. *J. Environ. Radioactivity 29:* 237-255.

Ammerman, C.B., Validivia, R., Rosa, I.V., Henry, P.R., Feaster, J.P. and Blue, W.G. 1984. Effect of sand or soil as a dietary component on phosphorus utilization by sheep. *J. Anim. Sci. 59:*1092-1099.

Andersson, I. 1989. Transfer of ^{137}Cs from Feed to Lambs' meat and the Influence of Feeding Bentonite. *Swedish J. agric. Res. 19:*85-92.

Andersson, I., Teglöf, B. & Elwinger, K. 1990a. Transfer of ^{137}Cs from Grain to Eggs and Meat of Broiler Chickens, and the Effect of Feeding Bentonite. *Swedish J. agric. Res. 20:* 35-42.

Andersson, I., Håkansson, J. & Annér, K. 1990b. Transfer of ^{137}Cs from Grain to Muscle and Internal organs of growing Finishing Pigs, and the Effect of Feeding Bentonite. *Swedish J. agric. Res. 20:* 43-48.

Assimakopopoulos, P.A., Ioannides, K.G., Karamanis, D.T., Pakou, A.A., Stamoulis, K.C. and Mantzios, A.S. 1993. Radiocesium tranfer to sheep's milk as a result of soil ingestion. *The Science of the Total Environment 136:*13-24.

Belli, M., Blasi, M., Capra, E., Drigo, A., Menegon, S., Piasentier, E. and Sansone, U. 1993. Ingested soil as a source of ^{137}Cs to ruminants. *The Science of the Total Environment 136:*243-249.

Beresford, N.A. and Howard, B.J. 1991. The importance of soil adhered to vegetation as a source of radionuclides by grazing animals. *The Science of the Total Environment 107:*237-254.

Bertilsson, J., Andersson, I. and Johanson, K.J. 1988. Feeding green-cut forage contaminated by radioactive fallout to dairy cows. *Health Physics 55:*855-862.

Brebner, J., Thornton, I., McDonald, P.& Suttle, N.F. 1985. The release of trace elements from soils under conditions of simulated rumenal and abomasal digestion. In: C.F. Mills, I. Bremmer and J.K. Chesters (Eds), *Trace Elements in Man and Animals. TEMA 5*, Commonwealth Agricultural Bureau, Slough, 850-852.

Chamard, P., Vealsco, R.H., Belli, M., Di Silvestro, G., Ingrao, G. and Sansone, U. 1993. Caesium-137 and strontium-90 distribution in a soil profile. *The Science of the Total Environment 136:*251-258.

Cooke, A.I., Green, N., Rimmer, D.L., Weekes, T.E.C. and Wilkins, B.T. 1995. Development of an In Vitro Method to Assess the Availability of Soil-Associated Radionuclides for Uptake by Ruminants. *J. Environ. Radioactivity 28:*191-207.

Fleming, G.A. 1986. Soil ingestion by grazing animals; A factor in sludge-treated grassland. In: R.D. Davis, H. Haeni & P. L'Hermite (eds). *Factors influencing sludge utilisation practices in Europe*. Elsevier Applied Science Publishers 43-50.

Fries, G.F. 1982. Potential polychlorinated biphenyl residues in animal products from application of contaminated sewage sludge to land. *Journal of Environmental Quality 11:*14-20.

Fries, G.F. 1987. Assessment of potential residues in foods derived from animals exposed to TCDD-contaminated soil. *Chemosphere 16:*2123-2128.

Fries, G.F., Marrow, G.S. and Snow, P.A. 1982. Soil Ingestion by Dairy Cattle. *J. Dairy Sci. 65:*611-618.

Grace, N.D. and Healy, W.B. 1973. The effect of soil ingestion on the Mg (magnesium) and Ca (calcium) metabolism of sheep. *Proc. New Zealand Society Animal Prod. 33:*164-165.

Grace, N.D. and Healy, W.B. 1974. Effect of ingestion of soil on faecal losses and retention of Mg, Ca, P, K and Na (magnesium, calcium, phosphorus, potassium, sodium) in sheep fed two levels of dried grass. *N. Z. J. Agric. Res. 17:*73-78.

Green, N. and Dodd, N.J. 1988. The uptake of radionuclides from inadvertent ingestion of soil by grazing animals. *The Science of the Total Environment 69:*367-377.

Green, N., Wilkins, B.T., Davidson, M.F. and Hammond, D.J. 1995. The Transfer of Plutonium, Americium and Technetium along the Soil-Pasture-Cow Pathway in an Area of Land Reclaimed from the Sea. *J. Environ. Radioactivity 27:*35-47.

Green, N., Wilkins, B.T. and Hammond, D.J. 1994. The Transfer of ^{137}Cs and ^{90}Sr along the Soil-Pasture-Cows' Milk Pathway in an Area of Land Reclaimed from the Sea. *J. Environ. Radioactivity 23:*151-170.

Hansen, H.S. and Hove, K. 1991. Radiocesium bioavailability: Transfer of Chernobyl and tracer radiocesium to goat milk. *Heath Physics 60:*665-673.

Harrison, D.L., Mol, J.C.M. and Healy, W.B. 1970. DDT residues in sheep from the ingestion of soil. *N. Z. J. Agric. Res. 13:*664-672.

Healy, W.B. 1968. The influence of soil type on ingestion of soil by grazing animals. *International Society Soil Science Transactions, 9th Congr. 3:*437-445.

Healy, W.B. 1973. Nutritional aspects of soil ingestion by grazing animals. *Chemistry and Biochemistry of Herbage 1:*567-588.

Healy, W.B. and Drew, K.R. 1970. Ingestion of soil by Hoggets grazing Swedes. *N. Z. J. Agric. Res. 13:*940-944.

Healy, W.B. and Ludwig, T.G. 1965. Wear of sheep's teeth. I. The role of ingested soil. *N. Z. J. Agric. Res. 9:*157-164.

Healy, W.B. and Wilson, G.F. 1971. Deposits on rumen epithelium associated with ingestion of soil. *N. Z. J. Agric. Res. 14:*122-131.

Hinton, T.G., Stoll, J.M. and Tobler, L. 1995. Soil Contamination of Plant Surfaces from Grazing and Rainfall Interactions. *J. Environ. Radioactivity* 29*:*11-26.

Hinton, T.G., McDonald, M., Ivanov, Y., Arkhipov, N. & Arkhipov, A. 1996. Foliar Absorbtion of Resuspended ^{137}Cs Relative to Other Pathways of Plant Contamination. *J. Environ. Radioactivity 30:*15-30.

Johnson, J.E., Ward, G.M., Firestone, E. & Knox, K.L. 1968. Metabolism of radioactive caesium (^{134}Cs and ^{137}Cs) and potassium by dairy cattle as influenced by high and low forage diets. *J. Nutr. 94:*282-288.

Kirby, D.R. and Stuth, J.W. 1980. Soil-ingestion rates of steers following brush management in central Texas. *J. Range Manage. 33:*207-209.

Kreulen, D.A. 1985. Lick use by large herbivores: a review of benefits and banes of soil consumption. *Mammal Revue 15:*107-123.

Kuntze, H. 1985. Geological and Pedological factors affecting the heavy-metal load capacity of soils. In: R.D. Davis, H. Haeni & P. L'Hermite (eds) *Factors influencing sludge utilisation practices in Europe*. Elsevier Applied Science Publishers 2-10.

Li, J.G., Gerzabek, M.H. and Mück, K. 1994. An experimental study on mass loading of soil particles on plant surfaces. *Die Bodenkultur (Journal für landwirtschaftliche Forschung) 45:*15-24.

Mayland, H.F., Florence, A.R., Rosenau, R.C., Lazar, V.A. and Turner, H.A. 1975. Soil ingestion by cattle (grazing) on semiarid range as reflected by titanium analysis of feces. *J. Range Manage. 28:*448-452.

Mayland, H.F., Shewmaker, G.E. and Bull, R.C. 1977. Soil ingestion by cattle grazing crested wheatgrass *(Agropyron desertorum)*, nutritive and health effects. *J. Range Manage. 30:*264-265.

Millar, K.R., Allsop, T.F., Kane, D.W. and Webster, M.C. 1985. Failure of copper or vitamin D Supplements to affect the dental condition of young sheep on two Wairarapa farms. *New Zealand Veterinary Journal 33:*41-46.

O'Toole, J.J.O., Wessels, T.E. & Malaby, K.L. 1981. Trace element levels and their enrichment processes in terrestrial vegetation. *J. Plant. Nutr. 3:* 397-407.

Oughton, D.H. and Day, J.P. 1993. Determination of cesium, rubidium and scandium in biological and environmental materials by neutron activation analysis. *Journal of Radioanalytical and Nuclear Chemistry 174:*177-185.

Oughton, D.H., Tronstad, E. & Skipperud, L. 1995. Mobility of Cs in Soil. EKO-2 Report, presented at the NKS-seminar in November, Nesbru, Norway.

Rafferty, B., Dawson, D.E. and Colgan, P.A. 1994. Seasonal variations in the transfer of 137Cs and 40K to pasture grass and its ingestion by grazing animals. *The Science of the Total Environment 145:*125-134.

Ramey, D.W. and Reinertson, E.L. 1984. Sand-induced diarrhea in a foal. *Journal of the American Veterinary Medical Association 185:*537-538.

Riise, G., Brorstad, H.E., Lien, H.N., Oughton, D.H. and Salbu, B. 1990. A study on radionuclide association with soil components using a sequential extraction procedure. *Journal of Radioanalytical and Nuclear Chemistry, Articles 142:*531-538.

Rindsig , R.B. and Schultz, L.H. 1970. Effect of bentonite on nitrogen and mineral balances and ration digestibility of high-grain rations fed to lactating dairy cows. *J. Dairy Sci. 53:*888-892.

Ronneau, C., Detry, M., Lardinois, P. and Hallet, J.P. 1983. Transfer of heavy elements towards the human food chain via elemental deposition on pastures. *Heavy metals in the environment.* CEP Consultants Ltd *2:*757-759.

Rosén, K., Andersson, I. & Lönsjö, H. 1995. Transfer of Radiocaesium from Soil to Vegetation and to Grazing Lambs in a Mountain Area in Northern Sweden. *J. Environ. Radioactivity 26:* 237-257.

Russel, K., Brebner, J., Thornton, I. and Suttle, N.F. 1985. The influence of soil ingestion on the intake of potentially toxic metals and absorption of essential trace elements by grazing livestock. *The fifth international symposium on trace elements in man and animals.* Commonwealth Agricultural Bureaux *TEMA 5:*847-849.

Sherman, G.D. and Kanehiro, Y. 1965. Titanium. *Methods of Soil Analyses* .American Society of Agronomy *Part 2:*974-977.

Summerling, T.J. 1981. In-vivo Estimates for the uptake of caesium-137 by cattle grazing contaminated pasture around the Esk and Irt Estuaries, Cumbria, U.K. *The Science of the Total Environment 22:*39-50.

Suttle, N.F., Abrahams, P. & Thornton, I. 1984. The role of a soil x dietary sulphur interaction in the impairment of copper absorption by ingested soil in sheep. *J. Agric. Sci. Camb. 103:* 81-86.

Thornton, I. 1974. Biogeochemical and soil ingestion studies in relation to the trace-element nutrition of livestock. *International Symposium on Trace Element metabolism in Animals (1973)* 451-454.

Thornton, I. and Abrahams, P. 1983. Soil ingestion - a major pathway of heavy metals into livestock grazing contaminated land. *The Science of the Total Environment 28:*287-294.

Ulvesli, O. & Saue, O. 1965. *Rensning og raspning av rotvekster til melkekyr.* Institute of Animal Nutrition, Agricultural College of Norway. Report No. 125.

Vaithiyanathan, S. and Singh, M. 1994. Seasonal influence on soil ingestion by sheep in an arid region. *Small Rumin. Res. 14:*103-106.

Wilkins, B.T. and Green, N. 1988. Factors affecting the uptake of radionuclides by cattle grazing on pasture reclaimed from the sea. *The Science of the Total Environment 69:*261-268.

Zach, R. and Mayoh, K.R. 1984. Soil Ingestion by Cattle: A Neglected Pathway. *Health Physics 46:*431-434.

Åhman, B., Forberg, S. and Åhman, G. 1990. Zeolite and bentonite as caesium binders in reindeer feed. *Rangifer 3:*73-82.

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This review deals with several aspects of the phenomenon soil ingestion in different farm animals. Soil ingestion occurs mainly during grazing, either as an inadvertent intake due to soil adhered to vegetation or as an active ingestion suggested to be due to lack of essential mineral elements such as Cu, Co and Mn as well as Fe. Sheep and cattle have been investigated to a much greater extent in this field than horses and pigs. With the ingested soil, also different environmental contaminants like heavy metals, radionuclides, chemicals and pesticides can be consumed. These elements are often found in high concentrations in the upper soil layers and are more or less transferred to meat and milk depending on, e.g. the adhesion of the specific element to soil particles.

Deposition of contaminants to soil may derive from e.g. sludge, atmospheric deposition, metalliferous activities and persistent pesticides. The transfer of these environmentally detrimental compounds from soil to animal may be of importance in the calculation of reliable ecological half-times and exposure risks for humans through consumption of animal products.

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