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Trace elements in sheep - History taking

Trace elements (TE) impact the health and productivity of UK sheep flocks when supply isn't optimal. The consequences of suboptimal supply can result in various clinical presentations (Table 1). However, in some instances, unproven TE deficiencies and their correction have been lauded as a panacea for all manner of conditions [1]. Therefore, it is important to gather sufficient evidence to support a presumptive diagnosis and justify laboratory test expenditure. These tests are often not as diagnostically definitive as we would like[2] and should be interpreted in conjunction with background evidence. In addition, a better understanding of the factors contributing to each particular presentation of deficiency may improve targeted nutritional management.

Gathering such evidence requires thorough history-taking, which will be the focus of this article. This history-taking goes beyond the scope of individuals or groups of animals to encompass a holistic understanding of farm management and geographical factors. These factors may influence the likelihood that a clinical scenario results from a TE imbalance, thereby moving TE imbalance up or down a differential diagnosis list.

Table 1: Clinical presentations that could be associated with trace element deficiencies in sheep and some considered differential diagnoses				
Stage of production	Problem	Indicator	Trace element	Major differential diagnoses
Breeding/ Pregnancy	High return rate	Raddle markings Ongoing ram activity >35 days	Zinc Selenium Iodine	Poor ram fertility Low ram:ewe ratio Low ewe ovulation rate Poor breeding conditions
	Low scanning percentage	Ultrasound pregnancy scanning results	Zinc Cobalt Selenium Iodine	Above plus: Undernutrition Infectious disease Parasites Prolonged stress Medications
	High barren rate at lambing	Empty or unproductive ewes	Zinc Cobalt Selenium Iodine	Above plus: Infectious abortion Severe stress Toxins Severe nutritional restriction
	Extended lambing	<60% of lambs born in the first 17 days	Selenium Iodine Cobalt Zinc	Poor ram fertility Low ram:ewe ratio Low ewe ovulation rate (low body condition etc.) Poor breeding conditions

Peri-natal period	Ewe colostrum/ milk quality	Poor lamb survival Poor lamb growth rates	Cobalt	Nutritional insufficiency Low ewe BCS Parity Maternal disease
	Stillbirths Weak lambs	Stillbirths Poor lamb survival Weak lambs	Iodine Selenium Cobalt Copper	Toxoplasma Campylobacter Enzootic abortion of sheep Border Disease Virus Poor ewe nutrition and BCS Maternal disease Toxins Genetic predisposition
	Swayback	Clinical signs	Copper	Congenital form Border disease • Septicaemia • Hypoglycaemia/ hypothermia Delayed form • Trauma • Spinal abscess • Vertebral body osteomyelitis
Growing lambs	Sudden death	Sudden death High mortality rates	Selenium	Clostridial disease Pasteurellosis Misadventure
	Reduced mobility	Not keeping up with the dam Increased lying time	Selenium Copper	Spinal abscess Trauma Joint ill Vertebral body osteomyelitis Pneumonia
	Ill thrift	Reduced 8-week lamb weights Anorexia	Cobalt Selenium Copper	Parasitic gastroenteritis Coccidiosis Nematodirosis Liver fluke (autumn/winter) Poor nutrition Poor milk production of ewes Lameness Chronic suppurative disease
Miscellaneous	Adult ill thrift	Ill thrift, poor wool	Cobalt (severe)	Poor nutrition Poor dentition Iceberg diseases (MV, Johnes, OPA …) Liver fluke Sheep scab

			Selenium (severe)	Chronic pneumonia
			(Iodine)	
BCS – Body condition score				
MV – Maedi Visna				
OPA – Ovine pulmonary adenocarcinoma				

Ascertaining if a clinical scenario is due to an underlying TE imbalance requires investigating the provision of that element in the previous and current diet. Therefore, obtaining a thorough dietary history for the affected group of animals over three, or even six, months is critical for assessing poor supplementation. All dietary input over the relevant months should be accounted for during an investigation. This includes:

- Conserved forage
- Pastures grazed (including all fields grazed during the period
- of interest, also brassicas, fodder beet etc)
- Concentrate feed
- Mineral and feed supplements (eg buckets or blocks)
- Anthelmintic drenches containing trace elements (eg selenium
- and cobalt).

In addition, an assessment of access to and intake of the diet on offer should be made, as feed intakes may vary within a group if feed space or palatability are poor. Ideally, samples from each dietary constituent would be retained and analysed for TE concentration or frozen at the time of feeding in case analysis is required at a later date.

Dietary composition and presentation are also important as they influence both feed intake and the ruminal environment. Changes to this environment (e.g., pH variation) may affect trace-element bioavailability; for example, a low rumen pH can increase the antagonistic binding of copper (Cu), reducing its bioavailability [3].

In the author's experience, most clinical scenarios related to TE deficiencies are associated with animals at pasture. Therefore, this article will focus on pasture-associated factors impacting TE provision and availability.

Clinical history

When presented with a clinical scenario, a standard clinical history needs to be taken. This should include the following:

- The clinical signs observed
- How do these differ from the farmer's expectations
- Their duration and progression
- The proportion of animals affected per group
- The age of affected animals
- If similar signs have been seen before

- If treatment was attempted and what, if any, was the response
- Have any other group issues been noted in the flock in recent years?

Signs associated with TE deficiencies can affect various areas of flock performance. Assessing recent flock performance compared with previous years' or reasonable targets can highlight areas of concern. The investigation could include (but should not be limited to):

- Scanning results – the percentage of ewes that were barren, the percentage of ewes carrying single, twin or triplets lambs
- Lamb vigour at birth
- Lamb weaning rate
- Lamb growth rates
- Lamb age at finishing
- Fleece quality

Taking the long view of a farm's clinical history can strengthen or weaken the suspicion that TE are involved in a clinical syndrome. For example, there may be a history of poor autumn lamb growth, which increases our suspicions of TE involvement when presented with a fertility problem. Such co-morbidities can often move TE deficiency up the differential diagnosis list. Other areas of sheep health to assess that may influence flock performance include overall nutrition (energy, protein, macrominerals), ewe body condition scores (absolute scores and fluctuations), nematodes, liver fluke, sheep scab and the presence or absence of iceberg diseases.

Local knowledge

The possibility of a TE-related problem occurring on a farm can be predicted to some degree from local history. As a new graduate, or when moving to a practice in a new location, it can be helpful to call upon the experience of local vets, farmers or surveillance service officers (APHA and SRUC). These sources may know if farmers in a particular valley have previously struggled to finish lambs off pasture or if goitres were once a typical post-mortem finding in lambs from another area. If specific local knowledge is unavailable, resources such as the UK Soil Observatory (Figure 1) provide maps that give a broad overview of UK soil TE concentrations at a granularity of 1 km squared.

Even routine management practices, which are inherited or appear to be habitual, could be pertinent. Information concerning these is not always volunteered during a standard history discussion with clients and, therefore requires intimate questioning or knowledge of the farm's practices. For example, lambs may never be grazed on specific fields after weaning, or other areas are avoided for ewes at flushing and breeding time. This suggests historical knowledge of a geographically associated clinical presentation, which may have been associated with TE deficiency.

It is important to remember that these factors only indicate a potential for TE involvement and do not provide sufficient evidence to make a definitive diagnosis.
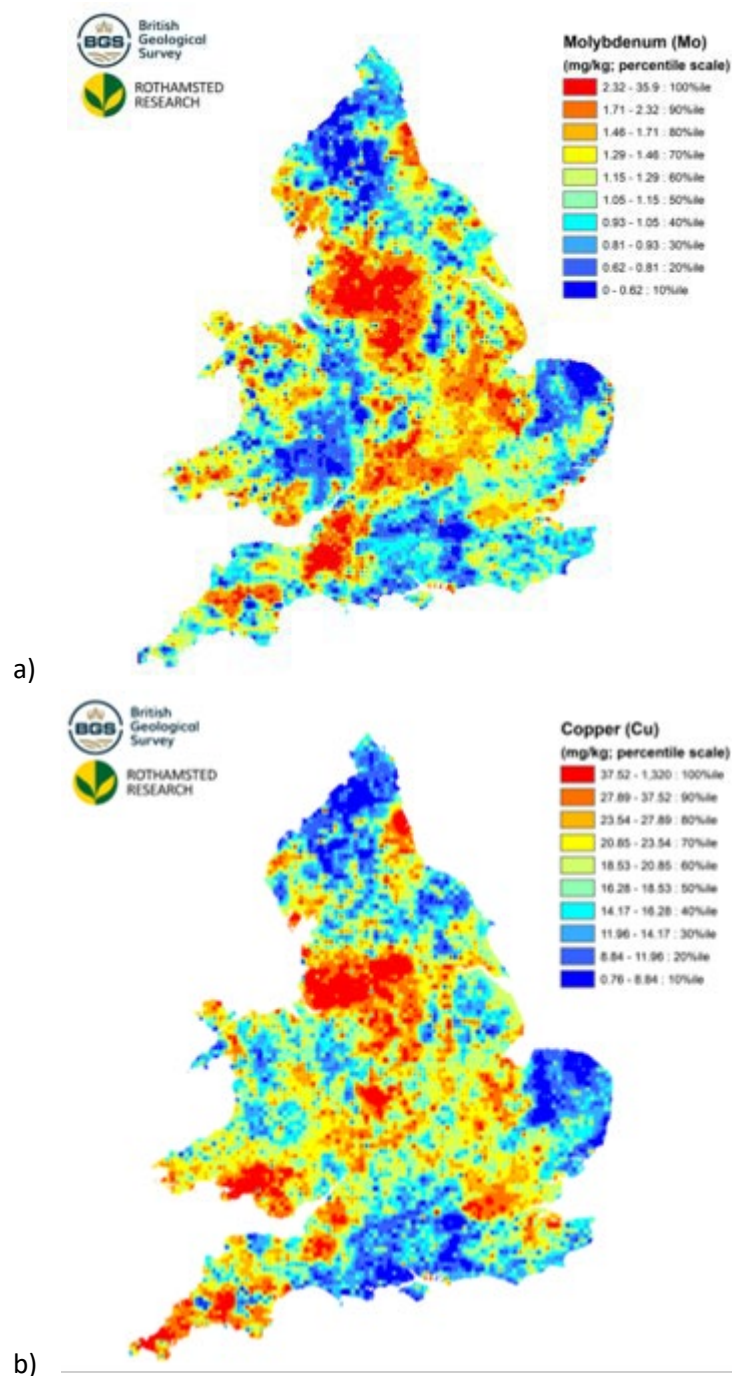
Figure 1: Example maps of (a) molybdenum and (b) copper soil concentrations available from British Geological Survey

Soil type

In addition to the collective historical knowledge of syndromes associated with TE deficiency, quantitative and qualitative aspects of an area, farm, or particular field can indicate risk. Soil type can be used to estimate which TE may be over or under-supplied and the availability of those TE for uptake by plants in a particular pasture. Soil type can vary between fields across a farm, and farmers may be able to advise on which soil types are present. If not, maps from the British Geological Survey provide a rough indication of the

soil type in an area (Figure 2). Table 2 provides a simplified summary of the relative risk associated with the major soil types. However, other soil characteristics can influence TE availability; for example, high organic matter content can limit Cu availability.

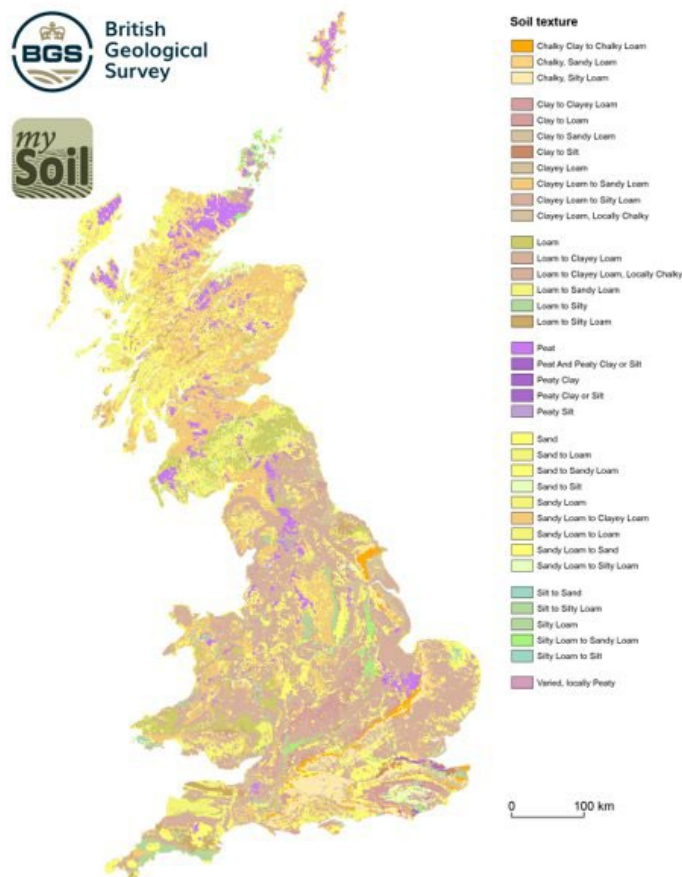| Table 2: Relative risk of deficiency as defined by likely low soil content and plant availability [5; 6]				
Mineral	Calcareous	Clay	Peat	Sand
Cobalt	Variable soils implicated in cases of deficiencies			
Copper	High	Moderate	Low	Low
Iodine	Moderate-High	Moderate	High	Moderate
Selenium	Low-Moderate	Moderate	High	Low-Moderate
Zinc	-	-	-	High

Figure 2: Soil type map of the UK - available from British Geological Survey

Soil pH

Soil pH affects the uptake of TE by plants. As with soil type, farmers may know the pH of their soils; if not, the UKSO provides an interactive map on which this information can be found [4]. Soil pH affects the plant's ability to absorb TE, and different pHs benefit or hinder the uptake of different elements. In Figure 3 [5], we see that acidic soils benefit cobalt (Co), manganese (Mn) and zinc (Zn) uptake, and as soil pH increases, plant uptake of these elements decreases. Soil pH doesn't significantly affect plant Cu uptake; however, Molybdenum (Mo) uptake increases as soils become more alkaline. Molybdenum is a Cu antagonist; therefore, the improved plant Mo availability seen in alkaline soils can increase Mo consumption reducing animal Cu availability, even if sufficient Cu is being consumed. The effect of soil pH on iodine (I) uptake varies depending on the form of I in the soil. Iodide uptake by plants is improved in acidic soils, whilst iodate uptake is improved in alkaline soils. For more information on the factors that affect soil and plant concentrations of TE, see Kao et al., 2020[7]

Soil pH can differ within a field; therefore, plant TE concentrations can vary considerably in different sections, even in monoculture pastures.
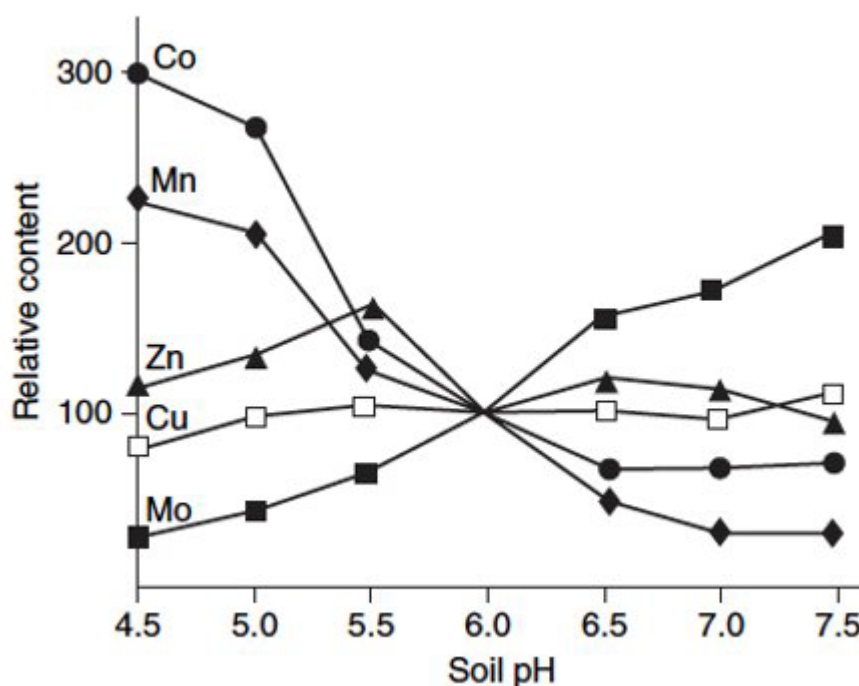

Figure 3: Effect of soil pH on plant uptake of different trace elements [5]

Pasture

Plant species vary in TE concentrations. Generally, herbaceous plants (eg chicory and sainfoin) have higher TE concentrations than grass-type plants. Whereas leguminous plants, like clover, can have higher Co, Cu and Mo (Burridge et al, 1983; Kincaid et al, 1986) but lower I concentrations when compared to grass. Certain plant species, like forage brassicas, are fed for a limited time, primarily as winter forage. Most brassicas contain low TE levels and anti-nutritional constituents (eg high sulphur (S) levels and goitrogenic compounds), which limit TE absorption and utilisation (see the antagonists and interactions section).

Figure 4: Plant species and stage of plant maturity can affect trace element concentrations in grazed pastures

Not only do TE concentrations differ by plant species, but they also differ by stage of plant maturity and plant section (root, stem, leaf, flower, Table 3). Cobalt, Cu and Zn tend to be concentrated in the leaf and flower heads rather than in the stem [10-12]. Therefore, the concentration of these TE in the plant reduces as the stem-to-leaf ratio increases with increasing maturity. Consequently, TE concentration decreases as the season progresses from spring to late summer [13-17].

This within and between plant variability (Figure 4) makes measuring and interpreting the TE content of pasture challenging. Previous pasture testing may no longer represent the current diet fed, and current pasture testing may no longer reflect the diet fed when the dietary insult occurred. Samples for analysis should, therefore, be taken from several points within a field and at various times throughout the year to build a robust picture of the evolving pasture TE content. Nevertheless, selective grazing will further impact TE consumption levels, necessitating that pasture testing is interpreted in conjunction with animal-based evidence.

Table 3: Comparative trace element concentrations in different plant sections and at various stages of plant maturity		
Plant parts		
Cobalt	Leaves > Flower heads > Stem[10; 15]	Davey and Mitchell, (1968) Fleming & Murphy, (1968)
Copper	Leaves > Stems [10]	Davey and Mitchell, (1968)
Iodine	Leaves > Stems[11]	Blom, (1934)
Zinc	Flowering heads > Leaves > Stem[12]	Fleming (1963)
Maturity		

Cobalt	Content reduces as leaf content reduces BUT may be inconsistent in clover [15-17]	Fleming and Murphy (1968) Fleming (1970) Whitehead and Jones (1969)
Copper	Content reduces as leaf content reduces and stem matures[14]	Minson, (1991)
Iodine	Concentration decreases over the growing season[13]	Alderman and Jones, (1967)
Selenium	Potential seasonal variation with lower values in late summer [18]	Gissel-Nielsen, (1975)
Zinc	Inconsistent reduction with maturity[17; 19]	Gladstones & Loneragan, (1967) Whitehead and Jones (1969)

Weather

Recent weather and longer-term climactic conditions will influence pasture TE contents as both soil concentrations, and plant uptake will be affected [20]. In high-plant-stress situations, like droughts, heat waves or cold snaps, TE uptake will decline due to low root activity. Some weather events can result in a beneficial change to pasture TE status. For instance, Se uptake by plants may increase in dry weather. In contrast, Co, Mn and Mo (and, to a degree, I) uptake can increase in wet or waterlogged conditions [8]. However, extreme waterlogging can lead to the leaching of TE from pastures, especially I (Figure 5).

Figure 5: Water logging can increase cobalt, manganese and molybdenum uptake by plants, but it can also result in the leaching of trace elements from soils, especially iodine.

Water may also be a source of TE and can be variable when natural sources or bore-hole water is supplied.

Element antagonists and interactions

As previously mentioned, certain TE and biologically active compounds can influence the absorption and metabolism of other TE by plants and animals (Table 4).

The effects of Mo and S on Cu are well documented [21-24]. Mo and sulphides combine in the rumen to form thiomolybdates, which form insoluble complexes with Cu, making the Cu unavailable for absorption by the ruminant. Thiomolybdates may also be absorbed into the bloodstream, causing; 1) Cu release from the liver into the bile; 2) an increase in Cu binding to albumin, which reduces Cu transport; 3) scavenging of Cu from metalloenzymes. Sulphur can reduce Cu bioavailability independently of Mo by forming insoluble Cu-sulphide in the gastrointestinal tract. The antagonistic effect of Fe on Cu is less well described but occurs only in the presence of S and only in ruminants.

Goitrogenic compounds are the main antagonists of I. These goitrogens are mainly found in brassicas, with levels varying depending on the species, growing conditions and growth stage. Modern brassicas contain lower concentrations of goitrogens than traditional cultivars. Goitrogens can act in two ways[25]; 1) as thyroperoxidase inhibitors preventing the incorporation of I onto thyroglobulin when producing thyroid hormones (T3 and T4); 2) as an iodothyronine deiodinase inhibitor preventing the conversion of T4 to T3. Identifying the type of goitrogen involved can help determine the correct treatment. This may be achived by contacting the seed supplier for the variety of plant under suspicion. Supplementation with additional I will successfully counter thyroperoxidase inhibitors, whereas animals should be removed from pastures containing excessive iodothyronine deiodinase inhibitors [5]. Excess Ca in the diet has also been reported to interfere with the I status of animals.

High levels of phosphorus and S in soil can inhibit selenium (Se) uptake by plants, as they are absorbed through similar pathways, thereby in competition. High dietary S can also reduce Se uptake in the animal as it is chemically similar to Se and therefore competes for receptors [26].

Table 4: Antagonists of the commonly supplemented trace elements		
Element	Antagonist	Site
Cobalt	↑ Manganese	Reduces plant absorption
Copper	↑ Iron, Molybdenum, Sulphur ↑ Zinc	Reduces animal absorption/retention
Iodine	Goitrogens (↑ Calcium)	Inhibit utilisation
Selenium	↑ Phosphorus, Sulphate ↑ Molybdenum, Sulphur, (Calcium)	Reduces plant absorption Reduces animal absorption

Pasture management

Some pasture management practices can increase the risk of TE deficiency. Therefore, knowing how pastures were managed could guide a clinical investigation. Poor pasture management or adverse weather conditions can lead to overgrazing, poaching and subsequent soil ingestion. Soil ingestion can be beneficial by increasing Cu, Co, I, Se and Zn uptake. However, it can also be detrimental by increasing Fe and Mo uptake, thus reducing Cu absorption [6].

Fertilisers change the chemical composition of topsoil and plant growth. The application of a nitrogen fertiliser increases plant growth which can reduce the concentrations of some TE in the plant, particularly Cu and I [27]. Magnesium, sodium and Zn concentrations have been shown to increase when nitrogen fertiliser is administered, although this is inconsistent.

As noted above, soil pH affects TE uptake by plants. High S fertilisers can acidify soil, resulting in reduced Se uptake [28]. Conversely, lime increases soil pH, reducing Co [29], Mn and Zn[30; 31] and increasing Mo uptake by plants, which interferes with Cu availability [32].

Other management practices, such as harvesting grass for silage or hay, can reduce Zn concentrations in re-grown herbage. Each successive cut results in lower Zn concentrations, which cannot be remedied by applying Zn-rich fertilisers [33].

Both grass and soil mineral analysis are common tools used by farmers when investigating poor crop/grass yields or when planning a fertiliser protocol with an agronomist. However, they can also be used to indicate when pastures pose a risk of clinical TE deficiency to livestock. As with animal-based testing, understanding what, when, and how samples were tested is essential for appropriate interpretation.

Grass should be collected at regular intervals in a zigzag or "Z" pattern across a field at several time points throughout the grazing season. Handfuls of grass should be cut with scissors near the base of the stem, placed in a bag, mixed, and immediately refrigerated. Tearing grass from the ground will likely result in soil contamination and erroneous test results. Samples should be sent for analysis as promptly as possible.

Soil testing is most useful when soils within the root growth area are sampled and tested for plant-available nutrients, as the total nutrient content does not guarantee plant sufficiency[34]. Soils from permanent pastures can be tested every 2-3 years, ensuring that tests are performed at the same time of year and in roughly the same area to allow for consistency. Unless significant work has been done to alter the nutrient composition of soils between tests, large variations are likely to indicate inconsistent sampling procedures; therefore, pastures should be re-sampled. Nutrient-specific information on soil test interpretation can be found on Oregon State University's extension service webpage (https://catalog.extension.oregonstate.edu/).

Summary

Sheep can be clinically affected by inadequate (or excess) TE provision. Many factors can influence the availability of these elements. In order to determine whether TE are implicated in a clinical presentation, a thorough investigation must be undertaken. This

includes a detailed history of the clinical presentation, nutrition and grazing, including the permanent and temporary characteristics of the pasture grazed (Tables 5 and 6). Many of the clinical TE conditions encountered have numerous common differential diagnoses. These must be ruled out in order to confirm TE deficiency as the sole cause of disease (Table 1).

Table 5: Summary of conditions that favour or inhibit trace element availability for grazing animals					
Factor	Cobalt	Copper	Iodine	Selenium	Zinc
Soil type	Fe-rich, alkaline, Mn-rich ↓	Calcareous, clay, Fe, Mn, Mo, S-rich↓	Inland, calcareous ↓	Acidic, peat ↓	
Fertilisers	Lime: ↓	Nitrogen, Sulphur: ↓ (Lime: ↑ Mo)	Nitrogen: ↓ (N + S: ↓ goitrogens)	Sulphur: ↓ Lime: ↑	↑
Pasture type	Leguminous plants ↑	Leguminous plants ↑ (↑ Mo)	Leguminous plants ↓	Leafy brassicas ↑	Very variable
Rainfall/ drainage	Low rainfall / Well drained ↓	Excessive rainfall ↓ (↑Mo)	Excessive rainfall ↓	High rainfall ↓	
Season	↓ later in summer	↓ later in summer	↓ later in summer		↓ later in summer

Table 6: Nutrition history questions to guide trace element deficiency investigations
What forage, concentrates and supplements have the animals been fed in the last 3-6 months?
How is each part of the diet fed? Assess the accessibility of each element to the whole group.
Is there a history of trace element deficiencies   - in the area   - on the farm   - on relevant field(s)?
For any relevant fields: - What is the soil type?   - What is the soil pH?   - What herbage is present? Single species, mixed species, which species?   - How long has the ground been used for pasture? What was its previous use?   - What height was the herbage during grazing?   - Is it dry or wet pasture? Have there been any adverse weather events?   - Has the pasture been overgrazed or poached?   - What fertilisers have been applied and when? What was the weather like after application?   - How many, if any, cuts of grass have been taken?   - Has mineral analysis been carried out on soil, grass or forage?

| What time of year was the pasture being grazed? |
| What was the weather like during grazing? |

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