A comparison of the requirement and intake of selected minerals on beef finishing units

Executive summary and industry messages

Recent studies have indicated that dietary mineral imbalances in some sectors of the UK cattle farming industry, particularly dairy, are not uncommon and there was evidence of over supplementation.

Information from other sectors, including beef finishing, is incomplete.
A dietary mineral audit was conducted on 14 English beef finishing farms, 7 of which finished cattle indoors, and 7 finished cattle at pasture. Subsequently, blood and liver samples were collected from 6 cattle from each farm at slaughter.

Evidence of dietary imbalances were found on both indoor and pasture finished farms. Herbage alone met the macromineral requirement with grass finished animals, but four of these farms had dietary copper and iodine contents below requirement, with 19% of pasture finished cattle having a liver copper content categorised as deficient. In contrast, indoor finished cattle all had dietary copper, selenium, cobalt and iodine contents above requirement, with some evidence of over supplementation. Glutathione peroxidase (GSHPx) activity in indoor finished cattle was classed as being high or above target in 36% of cattle.

On the basis of this study, our advice to beef finishers is:

- Mineral audits should be routinely used to check for evidence of over or under supplementation of both macrominerals and microminerals within finishing diets

- Analysis of liver and blood samples collected at slaughter provides further evidence of dietary adequacy, particularly where interactions or antagonisms exist between minerals

- This data can be used to tailor mineral supplementation to requirement and aid selection of the most appropriate means of delivery

Introduction

It is known that beef cattle require at least 17 different minerals (NRC 2016) that are essential for normal maintenance, growth and production. The quantities required vary between macrominerals with individual daily requirements expressed in grams; and micro-minerals, or trace elements, with much smaller daily requirements expressed in terms of milligrams or micrograms.

The mineral requirements of dairy and beef fattening cattle have been well described (ARC, 2000; NRC, 2016). Analysis of feed (including mineral content) such as grass and silage is commonplace and relatively straightforward through laboratory testing (Thompson and Joseph, 2018). On some farms, there is input in terms of nutritional advice through feed companies or independent nutritionists.

Despite this availability, evidence suggests that, on many farms, minerals are being fed at inappropriate levels. In a study examining intakes of selected minerals on 50 dairy farms in Northern England, Sinclair and Atkins (2014) found that, in a majority of herds, levels fed were generally in excess for all minerals. Levels of copper being fed were above the UK industry maximum guideline of 20 mg Cu/kg DM (ACAF, 2011) in 32 of the 50 herds. This over supplementation of copper was also reflected in a study by Kendall et al. (2015), which measured copper levels in 510 cull cattle at a single slaughterhouse and found that nearly 40% of dairy cows had liver copper levels above the Animal Health and Veterinary Laboratories Agency (AHVLA) reference range (8000µg/kg DM), 16.9% of beef cattle also exceeded this reference value for copper.

Excess supplementation of minerals increases cost and excretion into the environment, particularly of phosphorus and can risk toxicity. Deficiencies are also an issue; between 2012–2018 (inclusive), the GB Cattle Disease Surveillance Dashboard recorded 785 cases of hyposelenaemia and 617 cases of hypocupraemia (APHA, 2019). The signs of many mineral deficiencies are sometimes vague, and diagnoses not straightforward. Deficiencies of cobalt or copper can both elicit signs including weight loss and anaemia (NRC, 2016), as can a number of other diseases that may be unrelated to a mineral deficiency.

Comparative studies on mineral inputs on farms finishing beef cattle are lacking.

This study had a number of objectives:

1. To collect information on ration formulation and samples of feed, to conduct a mineral audit on the finishing ration and examine if there was evidence of over or under supplementation of certain macrominerals and microminerals on 14 beef finishing farms.

2. To determine whether a difference in the level of mineral supplementation existed between cattle finished indoors and cattle finished at pasture.

3. To collect liver and blood samples at slaughter for mineral analysis, and assess whether this data, from samples that are relatively simple to collect, could be of benefit when used in conjunction with the farm mineral audit, to highlight mineral imbalances and assist in ration formulation.

Method

A group of 14 farms located mainly in North Yorkshire, but also including two farms in Shropshire, one in County Durham and one in Northumberland, were recruited to take part in the project. Farms were identified from groups and invited to participate. These included members of the Pasture Fed Beef Association, AHDB project farms, suppliers to particular slaughterhouses and farms previously known to the author. Seven farms finished cattle on an indoor basis and seven at pasture. The farms ranged in size, finishing between 30 and 850 cattle per annum.

Table 1. Participating beef farms and slaughterhouses (anonymised), presented in order of farm visit

Farm	Finishing system	Number cattle finished per annum	Slaughterhouse
1	Indoor, intensive cereal	200	A
2	Indoor, silage-based TMR	500–600	B
3	Indoor, intensive cereal	100	A
4	Indoor, silage-based TMR	750	A
5	Indoor, intensive cereal	850	A
6	Pasture finished	70	C
7	Pasture finished	200–250	D
8	Pasture finished	140	D
9	Pasture finished	90	B
10	Pasture finished	80	D
11	Pasture finished	70	B
12	Pasture finished	30	A
13	Indoor, cereal, silage	75	A
14	Indoor, silage-based TMR	170	D

Five of the pasture finishing farms had organic status. Nine of the fourteen farms had a history of trace element deficiency, confirmed or suspected, involving one or more minerals. The criteria for inclusion as a farm mineral deficiency was either as the result of soil or forage analyses reports, clinical issues that had been investigated by a vet, and a diagnosis confirmed. On one farm, a positive response following increased supplementation of copper was considered the basis for confirming a suspected deficiency.

On some farms, it was thought only certain fields and paddocks were affected by ‘mineral issues’, while on other farms there was a much wider geographical spread affecting the whole farm and surrounding area. This previous experience was a factor in ration formulation, particularly for purchased complementary feeds, which, in some cases, were bespoke to a particular farm, to address underlying specific issues. None of the farms visited considered there were current clinical issues with mineral imbalances, but some

farmers considered a mineral deficiency may be a factor in suboptimal performance, such as a failure to achieve a desired daily liveweight gain.

In this study, the length of the finishing period (taken as that period of time from when cattle commenced their final ration to slaughter) varied from 3 weeks to 10 months. For pasture finished cattle, this finishing period wasn't simply the time after turnout, but reflected the use of additional supplementary feeds, such as a compound or cereal that may have been provided in addition to grazing, and the time this commenced.
On all indoor finished farms, the diet was supplemented with a complementary feed or blend that was mineralised and added to either a cereal-based mix or part of a total mixed ration (TMR). On pasture finished farms, mineral supplementation was more varied, with two farms feeding a compound nut, two farms feeding a home-mixed cereal-based diet that included a mineral blend, one farm offering free access minerals via a trough in the field, and two farms where no minerals were fed in the finishing period.

Farm visits were made between 30 August and 18 October 2018; subsequently liver and blood samples (for mineral analysis) were collected from six cattle from each farm at one of four different slaughterhouses in Northern England. All samples, including feed and tissue samples, were analysed at NUVetNA laboratory (School of Veterinary Medicine and Science, University of Nottingham).

Farm protocols

Information on the system of finishing, ration formulation, production targets, health status and any previous history of mineral imbalances was obtained. Feed samples from the finishing diet (defined as the final ration before slaughter) were taken. Samples collected for mineral analysis included components of the diet that were largely home-grown and bore hole water samples for those farms not on a mains supply. Feed manufacturer's feed labels were used as a reference for the mineral content of compound feeds and complementary mineral blends. A book value was used for other bought-in feed that may have originated from several sources.

For farms on a mains water supply, information from water quality reports, including mineral content, was obtained from regional water companies (Yorkshire Water, 2017). This data allowed the production of a dietary mineral audit for a particular farm. Subsequently, one farm was revisited, and samples collected from a purchased proprietary mineral feed for analysis. This followed analysis of liver and blood samples collected from cattle that could not be correlated with the initial dietary mineral audit and information contained on the feed label.

Feed sampling

Individual components of the diet that were grown on farm were collected for mineral analysis. Where silage was stored in a clamp, samples were taken from 9 or 10 sites, 15 cm back from the face of the clamp, in a 'W' format. The samples were placed in a plastic bowl and mixed thoroughly. A composite sample of approximately 50 g was placed in a plastic bag, which was sealed, labelled and placed in a cool box.

Where big bale silage was fed, samples were taken from 3–4 bales that were representative of the field or forage area, the samples were mixed, bagged and labelled in the same manner as for clamp silage.

With grazing cattle, grass samples were collected by making a ‘W’ transect across the pasture, that was representative of the complete grazing area, and sampling at 9 or 10 sites on the transect. At each site, a small clump of grass was cut 2–3 cm from the base of the stem and placed in a plastic bowl. Samples were mixed and a composite sample of approximately 150 g collected.

Feedstuffs such as rolled cereals, were collected by grab sampling, at approximately 9 or 10 sites, these were placed in a plastic bowl, mixed, and a 100 g composite sample placed in a plastic bag, which was handled in the same manner as silage samples.

Water samples were collected on farms that were on a bore hole supply. A water tap, or inlet valve on a trough was run for approximately one minute and a sample collected mid-stream into a 30 ml universal tube. The tube was labelled.

A single proprietary mineral blend was sampled. This was mixed in a large plastic bag; small pinch samples were collected from 6–8 sites within the bag and placed in a labelled sealable bag. A 150 g sample was submitted for analysis.

Feed samples were delivered to the NUVetNA Laboratory directly or posted using a guaranteed next day delivery service. On occasion, such as a visit to a farm before a weekend, some samples of grass and silage were stored frozen before delivery.

Slaughterhouse protocols

Animals from project farms were identified pre-slaughter, their ear tag numbers recorded and verified against details provided by farmers. A record of the ear tag number and corresponding slaughterhouse kill number was also taken.

Following the slaughter of each animal, blood from the bleed out was collected into a 250 ml sterile plastic beaker and, immediately, blood was drawn from the beaker into a 9 ml LH tube and a 10 ml BD Clot Activator Tube (CAT) vacutainer. Each tube was gently inverted 6 times to ensure mixing, and labelled with the corresponding kill number for each animal. The tubes were placed in a labelled bag.

Liver samples were collected from carcases recognised by their ear tag number or slaughterhouse kill number. A portion of liver (approximately 20 g) was dissected away from the main body of the liver, either by a slaughterhouse employee or meat inspector, under direct supervision, and placed in a universal screw-top plastic container (30 ml). The container was labelled with the slaughterhouse kill number.

Liver and blood samples were placed in a cool box with ice blocks before leaving slaughterhouse premises and either delivered to the NUVetNA laboratory directly or stored refrigerated and posted using a guaranteed next day delivery service.

Sample testing

Liver samples were analysed for copper, selenium, manganese and cobalt content. Blood sample analysis included plasma copper concentration, superoxide dismutase activity (SOD), caeruloplasmin activity, plasma selenium concentration, erythrocyte glutathione

peroxidase activity (GSHPx), plasma zinc concentration, plasma cobalt concentration, haemoglobin concentration and packed cell volume.

Laboratory analysis was run using normal commercial protocols (NUVetNA, University of Nottingham). Plasma minerals and water were determined by ICP-ms following dilution. Forage, feed and liver mineral content were measured by ICP-ms following microwave acid digestion. Haematocrit measured by capillary tube method. Haemoglobin, GSHPx and SOD were determined by colorimetric assay on a clinical chemistry analyser (Randox). Caeruloplasmin (ppd oxidase) activity was measured by colorimetric assay on a clinical chemistry analyser using a method based on Henry et al. (1974).

Results

A farm visit allowed the completion of a questionnaire and the collection of feed samples to produce a mineral audit. A total of 27 feed and 4 bore hole water samples were analysed. Samples of blood and liver were collected at slaughter from 26 heifers, 42 steers and 16 bulls, their respective average deadweights were 337 kg, 328 kg and 399 kg, with an overall average of 344 kg. This compared similarly to the UK average dressed carcase weight (provisional) for steers, heifers and young bulls in 2017 of 349 kg (Defra, 2018). Results from the analysis of blood and liver samples from these animals, on different indices such as caeruloplasmin, plasma copper, and caeruloplasmin/plasma copper ratios were categorised individually into classes using categories employed by NUVetNA. These categories are highlighted under a comment on each farm's report.

Dietary requirements are those recommended by the Committee on Nutrient Requirements of Beef Cattle (NRC 2016).

Calcium and Phosphorus

Table 1. Dietary mean mineral concentration (% DM), standard deviations and requirement range for calcium and phosphorus calculated for all farms from the mineral audit

	Indoor		Pasture	
		Requirement range (NRC)		Requirement range (NRC)
Calcium (% DM)	0.58 ± 0.28	0.24 - 0.41	0.7 ± 0.05	0.18 - 0.35
Phosphorus (% DM)	0.3 ± 0.08	0.14 - 0.22	0.37 ± 0.05	0.12 - 0.19

The dietary requirement for calcium and phosphorus is based on that required for maintenance and for growth or gain, particularly for the development of frame. Requirement as a proportion of diet will decline in the finishing period but, if this period is lengthy, it requires dietary content that can accommodate for the demands of growth. Both minerals were generally fed in excess of requirement. There was a dietary deficiency of calcium on one farm (indoor); on the same farm dietary phosphorus only just met requirement.

Magnesium, Sodium and Potassium

Table 2. Dietary mean mineral concentration (% DM) and standard deviations for magnesium, sodium and potassium calculated for all farms from the mineral audit

	Indoor	Pasture	Requirement (NRC,2016)
Magnesium (% DM)	0.15 ± 0.03	0.25 ± 0.06	0.1
Sodium (% DM)	0.15 ± 0.05	0.26 ± 0.18	0.06 - 0.08
Potassium (% DM)	1.02 ± 0.28	2.52 ± 0.52	0.6

Dietary content of magnesium, sodium and potassium were generally in excess of requirement on both indoor and pasture finished farms. The mean concentration of potassium on pasture farms was 2.52% (25.2 g/kg DM) a figure that is over 300% in excess of that recommended for growing and finishing cattle by NRC (2016). This figure is also in excess of the Maximum Tolerable Concentration recommended by NRC of 20 g/kg DM. The mean dietary potassium concentration of indoor finished cattle was 1.02%.

Copper, Molybdenum, Iron and Sulphur

Table 3. Dietary mean mineral concentration and standard deviations of copper, molybdenum, iron (mg/kg DM) and sulphur (% DM) calculated for all farms from the mineral audit

	Indoor	**Pasture**	Requirement (NRC,2016)
Copper (mg/kg DM)	18.2 ± 5.5	13.2 ± 10.4	10
Molybdenum (mg/kg DM)	0.6 ± 0.2	1.2 ± 0.5	-
Iron (mg/kg DM	91.3 ± 88.1	122.5 ± 52.1	50
Sulphur (% DM)	0.16 ± 0.03	0.27 ± 0.03	0.15

Table 4. Blood and liver mean values and standard deviations for the indices of copper status including caeruloplasmin (mg/dl), plasma copper (μmol/l), superoxide dismutase (U/g Hb) and liver copper (μmol/kg DM) calculated for all farms

	Indoor	**Pasture**	NUVetNA normal range
Caeruloplasmin (mg/dl)	31.1 ± 2.1	30.9 ± 11.8	15 - 35
Plasma copper (μmol/l)	16.3 ± 2.1	12.6 ± 3.5	12 - 19
SOD (U/g Hb)	1920 ± 232	1918 ± 321	2000 - 2500
Liver copper (μmol/kg DM)	4991 ± 2272	1446 ± 1276	1405 - 5619

The mean dietary mineral content of copper with indoor finishers was 18.2 mg/kg DM, and 13.2 mg/kg DM on pasture finished farms, while mean dietary concentration of molybdenum, iron and sulphur was higher on pasture finishing farms, and would have contributed to a reduced copper availability on these farms.

The copper content of 18 liver samples, all from indoor finishers and representing 43% of the livers sampled from indoor systems, had copper analyses classed as above normal, 5619μmol/ kg DM, on the NUVetNA lab reference range. Three of these cattle had copper values above the AHVLA upper reference range of 8000μmol/kg DM. In contrast, 24 cattle, all finished at pasture, had a liver copper content of less than 1405μmol/kg DM, classed as marginal on the NUVetNA scale, with 8 of these cattle having a copper value of less than 281μmol/kg DM, regarded as deficient. Six of these cattle were from the same farm. No indoor finished cattle had marginal or deficient copper liver values.

Well-recognised antagonisms exist between copper, iron and sulphur, but also copper, sulphur and molybdenum via the formation of tetrathiomolybdates (TTM). Provided caeruloplasmin and plasma copper have values within their normal range, the caeruloplasmin/plasma copper ratio can be used to differentiate between the effects of iron and molybdenum, but also determine the presence of thiomolybdate toxicity. Ratios of 1.5 or less are indicative of a thiomolybdate issue, while ratios of 1.6–1.8 are classed as marginal or the 'possibility' of thiomolybdate toxicity (Telfer et al. 2004).

Two cattle from pasture finished farms had ratios of between 1.6 and 1.8, while 7 cattle from indoor finished systems had a ratio of 1.5 or below, indicating a TTM issue, and 8 cattle had a marginal ratio, suggesting the possibility of a TTM effect.

Zinc, Manganese, Selenium, Cobalt and Iodine

Table 5. Dietary mean mineral concentration (mg/kg DM) and standard deviations for zinc, manganese, selenium, cobalt and iodine calculated for all farms from the mineral audit

	Indoor	**Pasture**	Requirement (NRC,2016)
Zinc (mg/kg DM)	55.8 ± 11.4	44.0 ± 15.9	30
Manganese (mg/kg DM)	53 ± 6	77 ± 38	20
Selenium (mg/kg DM)	0.21 ± 0.07	0.15 ± 0.12	0.1
Cobalt (mg/kg DM)	0.35 ± 0.18	0.09 ± 0.05	0.15
Iodine (mg/kg DM)	1.40 ± 0.72	1.03 ± 1.39	0.5

Table 6. Blood and liver mean values and standard deviations for indices of selenium status including glutathione peroxidase (U/ml PCV), plasma selenium (μmol/l) and liver selenium (μmol/kg DM) calculated for all farms

	Indoor	**Pasture**	NUVetNA normal range
GSHPx (U/ml PCV)	150 ± 50	80 ± 38	80 - 180
Pl Se (μmol/l)	0.83 ± 0.17	0.7 ± 0.16	0.8 - 1.5
Liver selenium (μmol/kg DM)	13.6 ± 3.7	8.5 ± 2.4	11.3 - 22.6

The mean dietary selenium concentration for indoor finishers was 0.21 mg/kg DM ± 0.07 and for pasture finished farms 0.15 mg/kg DM ± 0.12. Two of the pasture farms had dietary selenium concentrations below requirement, with values of 0.03 and 0.04 mg/kg DM respectively. These dietary intakes are reflected in plasma selenium analyses, an indicator of selenium intake over the last 1–2 days (Kendall, 2011), in which 40% of samples from indoor finished cattle were categorised as suboptimal using NUVetNA classes; this rose to 69% in pasture finished animals.

Measurement of GSHPx activity can be used as a long-term measure of selenium status in cattle (Macrae et al. 2006). This indicated some degree of over supplementation in indoor finished cattle, 36% of indoor finished animals had GSHPx values classed as either above target or high; no pasture finished cattle were recorded in these categories.

Some 29% of indoor finished cattle had a liver selenium value within the marginal range classed as being less than 11.3μmol/kg DM, while 88% of pasture cattle were below this threshold.

The dietary iodine content was above requirement on all indoor finished farms, while, on grass finished farms, iodine was below dietary requirement on four farms. On two of these farms, this low iodine content will have been compounded by a dietary content of selenium that was also below requirement. The conversion of thyroxine (T4) to the active triiodothyronine (T3) is a selenium-dependent step.

Table 7. Mean values and standard deviations for plasma zinc (μmol/l) and cobalt (nmol/l) analyses, and liver, cobalt and manganese contents (μmol/kg DM) calculated for all farms

	Indoor	**Pasture**	Normal range (NUVetNA)
Plasma zinc (μmol/l)	14.4 ± 2.4	15.1 ± 2.7	12 - 20
Liver manganese (μmol/kg DM)	189 ± 31	210 ± 31	163 - 390
Plasma cobalt (nmol/l)	8.0 ± 7.3	2.7 ± 2.3	5 - 15
Liver cobalt (μmol/kg DM)	2.9 ± 0.8	2.7 ± 0.5	1 - 5

With both pasture and indoor finished cattle, there appeared a significant dietary excess of manganese, with mean values of 77 mg/kg DM ± 38 and 53 mg/kg DM ± 6, respectively. The most ‘marginal’ farm had a dietary excess of 80% over requirement.

The mean dietary concentration of zinc was generally above the requirement of 30 mg/kg DM. One pasture farm had a dietary zinc concentration below requirement of 23.7 mg/kg DM, but plasma zinc analyses for this farm were all categorised as within the normal range.

The mean dietary concentration of cobalt for indoor finishers was 0.35 mg/kg DM ± 0.18, this is comfortably in excess of requirement of 0.15 mg/kg DM. In contrast, the mean dietary concentration of cobalt on pasture finished farms was 0.09 mg/kg DM ± 0.05, with only one farm meeting cobalt requirement. Plasma cobalt analyses, a guide to recent cobalt intake, had mean values of 8 nmol/l ± 7.3 and 2.7 nmol/l ± 2.3 for indoor and pasture finished farms, respectively. However, liver cobalt concentrations were more closely aligned with indoor finishers having a mean cobalt concentration of 2.9 nmol/l ± 0.8 and pasture farms 2.7 nmol/l ± 0.5. All individual liver cobalt concentrations for both indoor and pasture finished farms were within a normal range of 1-5 nmol/l.

Examination of basal diets (diet before the inclusion of a complementary mineral or blend) indicated that mineral supplementation was required on all farms. This diet was deficient in iodine and copper on every farm, selenium on 13 farms and cobalt on 12 farms.
On all pasture finished farms, grazing alone met the macromineral requirement but, in the final, complete diet, deficits were present of 2 or more microminerals on 4 farms. This was the result of either inadequate, or the complete absence of, mineral supplementation and low herbage content of microminerals.

The greatest range of macromineral and micromineral deficits within the basal ration were observed on indoor, intensive cereal fed farms with individual mineral deficits of 9,10 and 10 (of the 14 minerals analysed) on three farms. However, all these farms exhibited evidence of over supplementation of some minerals in the final ration and from analysis of slaughterhouse samples.

Discussion

The nutritional management of beef fattening cattle is generally considered in three phases that encompass rearing, growing and finishing (AHDB, 2016).The length of each phase is governed by the type of system and, particularly for growing and finishing cattle, these phases may not be discrete, there is often a transition from one ration to another, mitigating against consequences of abrupt diet change, and avoidance of conditions such as acidosis.

Mineral audits

Analysis of feed samples provides a foundation for a mineral audit but, for the process to be meaningful, it also requires an accurate estimation or prediction of other factors that may be difficult to quantify or measure. Examples may include dry matter intake, water intake and the effect of season on grass mineral content.

A mineral audit is only a snapshot, particularly on pasture finishing farms, where herbage mineral content can differ between fields and over seasons. Grass forage samples were collected from seven farms between 12 and 27 September 2018. For both indoor and pasture finished farms, the macromineral dietary content largely met requirements, but there was a significant dietary excess of potassium in grass finished cattle. High pasture potassium is attributable to large inputs of organic and artificial fertilisers (Suttle, 2010), with levels of dietary potassium above 2% being categorised as being above Maximum Tolerable Concentration (NRC, 2016); only one pasture finisher farm was below this level. While cattle can tolerate high potassium intakes, the concentration in spring grass can be as high as 3.4% (Thompson and Joseph, undated), thus there is an inhibitory effect on the absorption of magnesium, which increases the requirement for this mineral.

Grass mineral trends vary throughout the year and knowledge of underlying seasonal patterns allows a greater degree of interpretation from a single set of samples. In a UK survey of the mineral analysis of 2000 grass samples over a five-year period (Thompson and Joseph, undated), there were recognised trends over the growing season for calcium, phosphorus and potassium. These were linked to the grass growth cycle and the balance between vegetative growth, with a high proportion of leaf and reproductive growth seen as the plant matures, and an increase in the proportion of fibrous tissues. For minerals such as calcium, which is associated with the fibre portion of grass, content fell in April and May but increased as more grass growth entered the reproductive phase, followed by a decline in the late summer as vegetative regrowth occurred. In contrast, phosphorus concentrations decline markedly with advancing maturity, reflecting an increase in the proportion of stem to leaf. This seasonal trend is also observed with microminerals, with a decline in content of minerals including cobalt, copper, iron, manganese, molybdenum and zinc as grass matures. Samples were collected in mid-September, a time when grass regrowth would be expected, and this may in part be responsible for the high potassium levels recorded.

Analysis is further complicated by local effects, particularly for macrominerals where variation in mineral content can exist between pastures on the same farm and from one year to the next, in contrast this variation tends to be more uniform with microminerals (D. Atherton, Pers. Comm.)

The elemental composition of pasture is affected by the underlying soil composition (Neville and Knowles, 2012). It has been suggested the primary reason for several mineral deficiencies in grazing animals, including phosphorus, sodium, cobalt, selenium and zinc, is the low soil content of plant available minerals (Suttle, 2010). Soil analyses can be used as an adjunct to the mineral analysis of grass and forage, but this also adds another layer of interpretation. Several soil characteristics such as pH, texture, organic matter, moisture content and redox potentials influence mineral solubility and availability to plants, meaning total mineral content of soil is frequently not a reliable index of the available trace element status, with many elements occurring in soils at much higher concentration than in the plants growing on them (Silanpaa,1972).

However, soil contamination of herbage and subsequent ingestion represents an additional mineral input and has been shown to increase the plasma and liver content of selenium and cobalt (Grace, 1996).

In this study, there appeared to be a significant difference between the mean dietary concentration of cobalt for indoor finishers, 0.35 mg/kg DM ± 0.18, and the mean dietary value for cattle finished at pasture, 0.09 mg/kg DM ± 0.05. All individual liver cobalt concentrations for both indoor and pasture finished farms were within a normal range. Suttle (2010) considers that liver cobalt concentration broadly reflects cobalt intake, suggesting either the cobalt requirements of cattle in this study were below the NRC (2016) cobalt requirement, or some supplementation, possibly from soil, was occurring. The degree of soil contamination of herbage is at its greatest in wet conditions, with Healy (1970) suggesting soil intakes to be probably less than 2% of fresh herbage intake, and less than 10% of dry matter intake, and a peak effect in outwintered animals. The summer of 2018 in the UK was very dry, which would be associated with low soil contamination of herbage. No estimate was made for the level of soil contamination in herbage samples collected.

On study farms, farmers estimated dry matter intake varied between 1.9% and 2.5%. On two farms, both pasture finishers, no estimate was made and a figure of 2.1% was assumed. On farms where the fresh weight of feed was known (usually from weigh scales on mixers and the dry matter content of the dietary portions known), farmers own estimates of dry matter intake in finished cattle were high. Prediction of dry matter intake, particularly at pasture, is difficult; equations used to calculate intake rely on knowledge of factors including diet metabolisability (ARC, 1980), and this was often not available. More general estimates for growing cattle are 2–2.5% and for finishing cattle 1.7–2% (AHDB, 2016), indicating a fall in dry matter intakes as cattle approach finishing. These estimates are less than those used to calculate mineral intakes on the majority of study farms.

Where the diet fed was mixed, such as a TMR, errors in the estimation of dry matter intake may not be significant, as mineral requirements are expressed as dietary concentrations. However, errors, particularly overestimation of dry matter intake on pasture finished farms that were feeding a supplement such as a compound feed, will be of more importance because of the effect of substitution.

The varied nature of mineral supplementation of pasture finished cattle was, in all likelihood, a reflection of a high proportion being organic farms, with restrictions on use of certain products, but also the challenge of mineral supplementation of cattle at pasture (Grace and Knowles, 2012), particularly where no additional feeds that could act as a ‘carrier’ for minerals were fed. While the use of free access minerals (used on one finishing farm), is commonplace and convenient, individual variation in intake in cattle from mineral

blocks or licks can be marked (Bowman and Sowell, 1997), resulting in unnecessary expense and dietary mineral imbalances.

In the study, these factors reflect the level of micromineral supplementation in the diet, all indoor finished cattle had a dietary copper content above requirement, of 10 mg/kg DM. However, in the pasture finished group, four farms were below this required level, including one farm with no previous history of copper issues that had liver copper contents in all six animals sampled, classed as deficient on the NUVetNA range.

A voluntary intake of 5.4 kg water/kg dry matter intake (McDonald et al. 2011) was used to calculate mineral intake from water and based on an environmental temperature of less than 16°C during the period that farms were visited. This will be influenced by a number of factors including environmental, physiological and diet composition (ARC, 1980) and significant variation in intake does occur. Wright (1978) demonstrated a 4-fold difference in water consumption between individual cattle at grazing, with intakes reduced after rain.

The main macromineral present in drinking water was calcium, with a concentration that varied with water hardness. On indoor finished farms, calcium from predicted drinking water intakes met 9–21% of the total calcium requirement, while, on pasture finishing farms, predicted drinking water intakes met 6–28% of calcium requirement. The micromineral content of drinking intakes as a proportion of the overall diet was relatively small. A borehole water iron concentration of 0.12 mg/L was measured on one farm but the iron content of feedstuffs, and particularly home-grown forages contained over 98% of the total dietary iron intake.

Information contained on feed labels of complementary feeds and compounds that were included in the diet was largely used in the calculation of individual mineral audits; this information includes an analysis of some mineral content (analytical constituents) and details of microminerals and vitamins added (additives). For a number of minerals, analytical information provided from feed labels is incomplete or absent.

Specific mandatory labelling particulars require that, for ruminants, details of analytical constituents must include the macromineral concentrations of calcium, sodium, phosphorus and magnesium and additives used were a maximum content (MPL) is set for at least one food producing animal must also be recorded (Commission Regulation (EU) No 767/2009). This Regulation also makes general recommendations including a requirement that labelling shall not mislead the user, with particular reference to a number of factors including composition and quantity. A register of additives that records product authorization, and where available details of Maximum Permissible Level (MPL) of trace elements in complete feedstuffs (using a moisture content of 12%) is available (European Commission 2019).

For some compound and complementary feeds, minerals may be present that do not fit the criteria for mandatory labelling and, with compound feeds in particular, the number of individual constituent feedstuffs mean there will be some ‘background’ mineral present that is outwith details provided on the feed label.

Approaches were made (often repeatedly) to suppliers or manufacturers of feeds that were fed on study farms for a more detailed product specification than that provided on the feed label. However, with a few exceptions, there was a reluctance to disclose any further information beyond that which was on the feed label, and requests for more information

were generally unsuccessful. This may possibly reflect commercial concerns, and the competitive environment of the animal feed industry.

During the study, one farm was revisited, and a sample of a complementary mineralised feed collected and submitted for analysis at NUVetNA labs. This followed the calculation of an initial mineral audit, using data provided on the feed label, that could not be reconciled with subsequent results from blood and liver analyses and, in particular, the sulphur content, an important antagonist of copper.

For the purposes of the study, it was decided ‘to adopt best available information’ and, on the majority of farms, use data on the mineral analyses provided on the feed label. However, for farmers and advisers wishing to use best practice and marry mineral requirement against supplementation, a full mineral analysis of complementary or compound feed is a prerequisite, to complete an accurate mineral audit, and a reluctance or refusal to provide this data is a barrier.

Mineral supplementation in the form of boluses, injectables, or in combination with other therapeutic agents such as anthelmintics were not practised on any of the farms. The legislative framework under which a number of these products are categorised differs, and this can also contribute to confusion over the total level of mineral supplementation (Brown and Smith, 2018).

Blood and liver analyses

The interval between farm visits and the collection of blood and liver samples at slaughter varied between 3 and 67 days, with an indoor mean of 25 days ± 13 days and on pasture finished farms the mean was 28 days ± 21 days. While the mineral content of the diet on indoor finished farms, including those feeding large quantities of conserved forages, will have largely remained the same, the effect of seasonality will have had an influence on the dietary mineral content for grass finished cattle.

Blood sampling allows a direct measure of nutritional status from analysis of mineral concentration, or activity of mineral containing proteins or enzymes and avoids some issues associated with dietary audits where there can be variation in biological availability, dry matter intakes can be difficult to predict, especially at pasture, and pasture composition can be hard to determine (Herdt et al. 2011).

The collection of blood samples during finishing on farm, from groups including animals at pasture, or fattening bulls, presents managerial challenges that would be considered time-consuming and stressful. Using blood sampling as a stand-alone procedure to assess mineral status means the interpretation of some analyses is not straightforward, and there are attached caveats. In cattle over supplemented with copper, significant increases in blood copper concentration do not occur until after excessive accumulation of liver copper has already taken place and it has been suggested that liver copper is the most accurate method of identifying copper status and liver accumulation (Laven and Livesey, 2004).

A description of the stages in the development of clinical disease associated with a trace element deficiency has been given by Suttle (2010), (Fig. 1), commencing initially with dietary depletion.

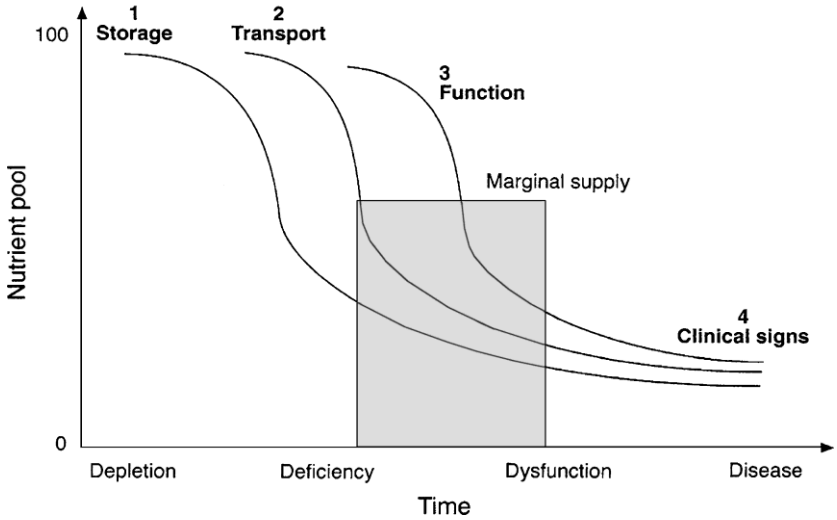

Figure 1. Chronological depiction of events associated with the development of trace element deficiency (Reproduced from Suttle N, The Mineral Nutrition of Livestock, 4th edition)

For a particular mineral such as selenium, analyses of different indices provide an assessment of the degree of any imbalance. Indices measured reflect transport, function and storage pools, these differ between minerals. With selenium, the storage pool represents an accumulation of a mineral in a tissue, it is not actively controlled. Kendall (2011), in a review of 1767 blood samples from cattle submitted to a laboratory for selenium assessment, found a relatively poor correlation between erythrocyte glutathione peroxidase (eGSHPx) and plasma selenium (Pl Se), r^2 of 0.365 and suggested, as Pl Se was a measure of dietary content over a 1–2 day period and eGSHPx measured functional levels, the result was not unexpected. Insufficient intakes of selenium result in depletion of eGSHPx, but this is delayed in comparison to selenium within other tissues, including the liver. Comparative changes in selenium content, or GSHPx activity, can therefore be used to assess depletion versus states of deficiency (Suttle, 2010). A similar protocol, using different indices to assess copper and cobalt status is used to determine levels of accumulation, transport and functional pools.

There may be a tendency to see mineral supplementation as being ‘binary’ with diets either meeting a certain requirement or not. This does not recognise the complex nature of interactions that occur. An overall assessment of mineral status based on a range of procedures including dietary audits, blood and liver samples to determine accumulation, transport and functional pools of a particular mineral, offers a greater level of detail, but also reflects this complexity.

Conclusions

a) Dietary mineral audits and the analysis of blood and liver samples can be used to identify mineral imbalances on beef finishing farms, which are not uncommon.

b) On the farms involved in this study, dietary trace element deficiencies were more likely on farms that finished cattle at pasture. Grazing met macromineral requirements, with high potassium contents (over 2%) on most pasture farms.

c) Indoor finished cattle had higher dietary intakes of copper and selenium and some farms show evidence of over supplementation (based on liver copper analyses and GSHPx activity).

d) Feed manufacturers should be encouraged to provide to their clients mineral analyses containing a full product specification of mineral content beyond that which is provided on the feed label.

e) The collection and subsequent submission for analysis of blood and liver samples could be easily undertaken by slaughterhouse personnel.

f) Farmers should seek independent advice about the level of mineral supplementation and the most appropriate means of delivery.

g) Where dietary deficiencies exist, the effect on production is very difficult to establish without evidence from increased supplementation.

h) On some farms, the supply of macrominerals, particularly calcium, within drinking water is significant and should be included in a mineral audit. For farms on a mains supply, details of a basic mineral analysis for individual post codes, or zones, are available from regional water companies.

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