CAN THE GEOCHEMICAL TOPSOIL ATLAS BE USED TO PREDICT TRACE METAL DEFICIENCY IN CATTLE?

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Introduction

Figure 1. Healthy cows grazing.

Just as trace metals are important to humans, they are also vital to the health of cattle. The metals investigated in this report were copper, iron, manganese, molybdenum and zinc, and they each play a vital part in cattle physiology. They have many uses within the body, especially in the action of enzymes. Copper for example, is involved in the breakdown of lysine and superoxide radicals. Iron is involved in electron transfer and carbohydrate breakdown. Manganese plays an important role in removing antioxidants, as well as blood clotting mechanisms and cartilage development. The role of Molybdenum is centred on oxidation and metabolism, while zinc is an important contributor to the structural stability of molecules and membranes. For these reasons, incorrect trace metal levels can be the cause of both toxicity and deficiency diseases.

An example of such a disease in cattle is Hypocupraemia, caused by copper deficiency. It is a condition which includes symptoms of diarrhoea, anaemia, cardiovascular disorders and infertility (Underwood 1999). In the same way, too much zinc in the diet of cattle is capable of causing infertility (in males), anorexia and reproductive disorders (Underwood 1999). Therefore, it is important to be able to predict where such diseases might occur, so that they can be managed.

Literature values for the requisite levels of each metal in the blood plasma vary between sources, and were not available for molybdenum and iron, however the approximate levels for copper, zinc and manganese (in microgrammes per litre of plasma) are as follows: Cu = 576 – 960 µg L^{-1}, Mn = ~ 1.98 µg L^{-1}, Zn = 780 – 1235 µg L^{-1}.

A major contributor to trace metal concentration in cattle is soil, due to intake during grazing. Soil makes up 2 to 20% of a cattle's dry matter intake (Thornton 2002). Many reports suggest that season and location also affect trace metal ingestion by cattle due to soil conditions (Ross 1994b), plant availability (Néel 2007) and feeding habits (Kellaway 2004).

The aim of this investigation was to establish whether the likely occurrence of deficiency or toxicity diseases in cattle can be predicted using soil data alone. It was designed to test for a relationship between levels of essential trace metals found in blood plasma, the location of herds and seasonal changes.

Individual aims were as follows:

- To test for relationships between trace metals in cattle blood plasma and the levels of trace metals in soil at specific locations.
- To test for relationships between different trace metals within cattle blood plasma.
- To test for relationships between trace metals in cattle blood plasma and time of year.

Methods

Blood Plasma Sampling:

The blood used in this investigation came from 431 cows from 64 different farms around England and Wales (Figure 2). Sampling occurred over a period of nine months between 08/12/06 and 20/09/07. The dates from each herd were available for an analysis of seasonal data. The samples were taken by individual vets and sent to NUVetNA, an analysis service in the School of Veterinary Medicine and Science, University of Nottingham. Here it was centrifuged to allow collection of the blood plasma, which was then analysed using Inductively Coupled Plasma Mass Spectrometry (ICPMS). The blood plasma was analysed for copper, iron, manganese, molybdenum and zinc.

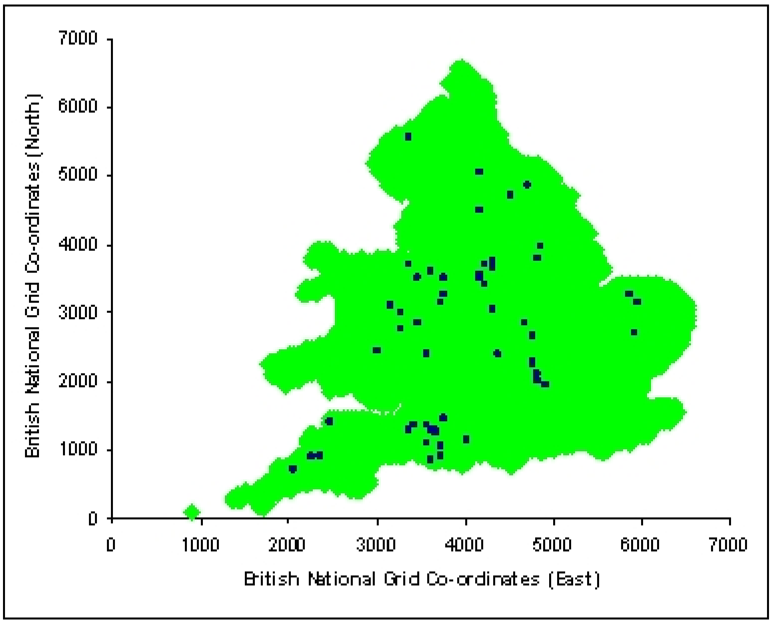

Figure 2. Locations of the herds from which blood samples were collected between December 2006 and September 2007

Comparison of Soil and Blood Data:

The soil data (copper, iron, manganese, molybdenum and zinc) was taken from the Geochemical Topsoil Atlas of England and Wales (McGrath 1992) and matched up with the grid co-ordinates for each farm. The resolution of the map is 5 square kilometres.

Results

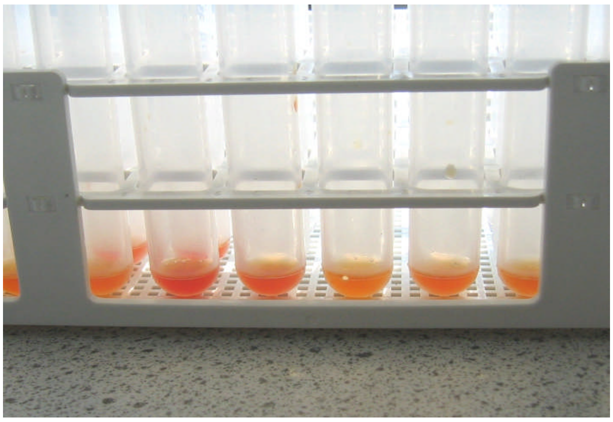

Figure 6: An example of haemolysed plasma samples. These tubes contain blood plasma (a straw coloured liquid). The dark red samples are those which have haemolysed, in other words the red blood cells have been damaged, releasing Fe, Zn and Mn into the plasma.

The only significant relationship to be found between plasma metal and soil metal concentration was that of copper (P = 0.030), in which high plasma copper existed in low soil copper areas. This is illustrated by the fact that a low plasma copper level of just 75.26 µg L^{-1} occurred in an area where the soil contained 40800 µg L^{-1}. Conversely, high plasma levels of 1541 µg L^{-1} were found in areas with just 8400 µg L^{-1} copper in soil. Average metal levels found in this study are compared to typical literature values in Table 1 below.

Although no other significant relationships were found, the chance of relationships occurring can still be assessed by converting the statistical output to a percentage. By doing this it was apparent that the chance of a positive relationship between plasma levels and soil content was 89% for molybdenum, 85% for zinc and 73% for iron and manganese. All of the relationships between soil and plasma, with the exception of copper, were positive, so as the metal in the soil increased, so did the metal in the plasma.

There were many significant relationships between metals within blood plasma. An increase in iron occurred alongside an increase in manganese (P = 0.001). This can be seen in Figure 3, which shows some extremely high levels of both iron and manganese. Plasma copper increased as molybdenum decreased (P = 0.001), as demonstrated in Figure 4 and 5. Plasma iron was found to increase as copper decreased (P = 0.004) and an increase in iron occurred with an increase in zinc (P = 0.020). Unusually high levels of iron, manganese and zinc were found in the blood plasma (Figure 3) and are demonstrated pictorially by Figure 6.

No significant relationships were found between metal in blood plasma and time of year, however reasonable chances of relationships did exist. Blood was analysed approximately every 2 weeks over a 9 month period, so no blood data was available between September and December 2007. The strongest of the relationships was that of zinc at 85%, which decreased in cattle from 7.5×10^4 µg L^{-1} in December to 5.8×10^4 µg L^{-1} in July before increasing slightly to 5.9×10^4 µg L^{-1} in September. Iron, copper and manganese showed slight relationships with time of year; however no distinct pattern was visible overall. No relationship was found in the case of molybdenum.

Plasma Metal Levels (µg L^{-1})	Copper	Iron	Manganese	Molybdenum	Zinc
Average in this study	897.4	2968	3.319	17.89	942.4
Typical from literature	576 – 960	-*	1.980	-*	780 - 1235

Table 1. The average plasma metal concentrations found in cattle in this report compared to typical concentrations displayed in the literature.
*Typical concentrations for iron and molybdenum in plasma were not available in the literature.

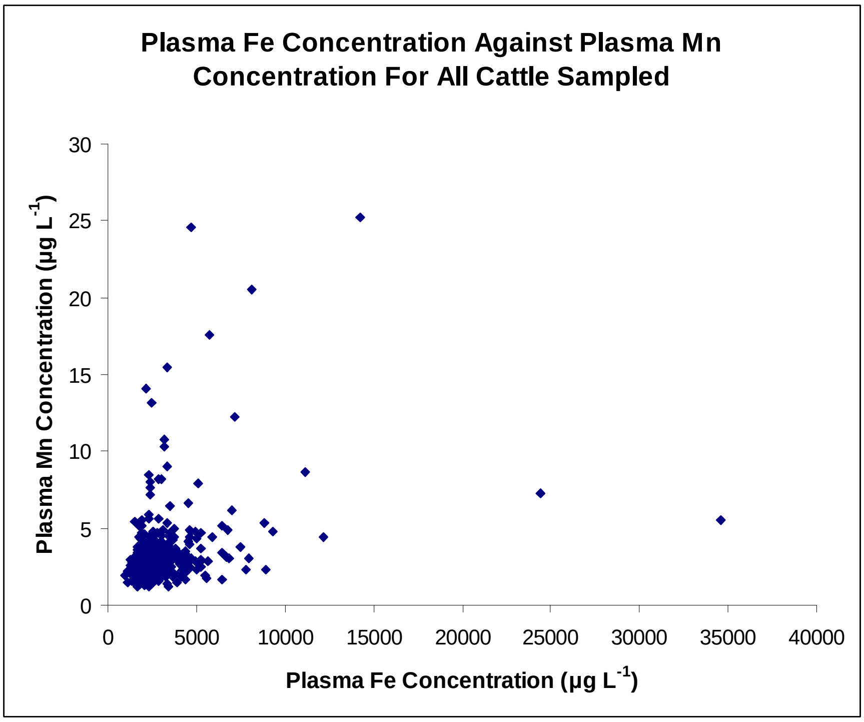

Figure 3

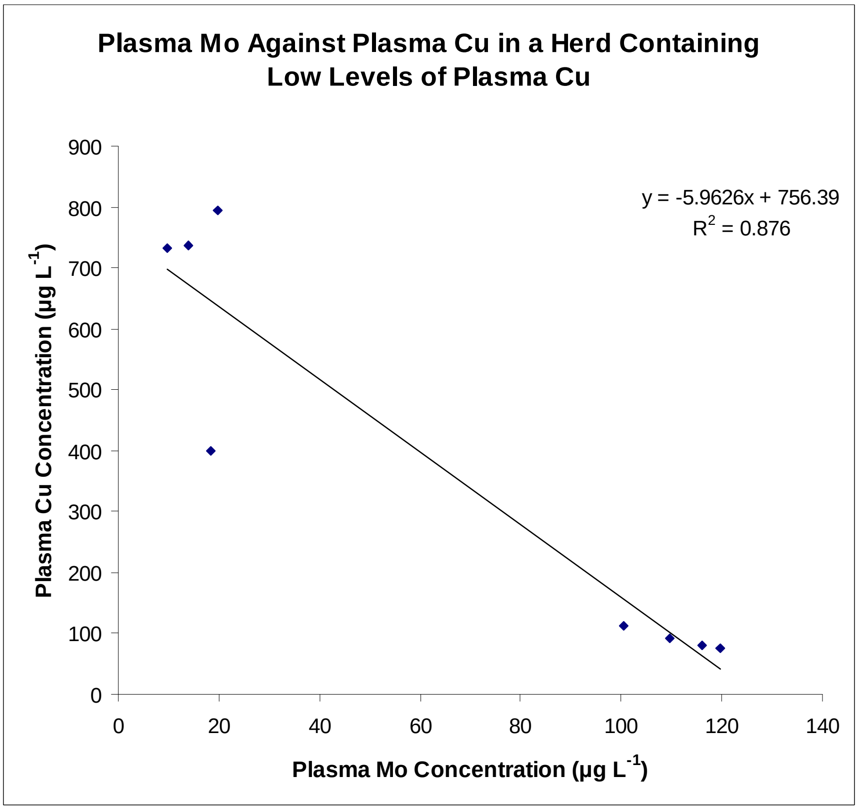

Figure 4

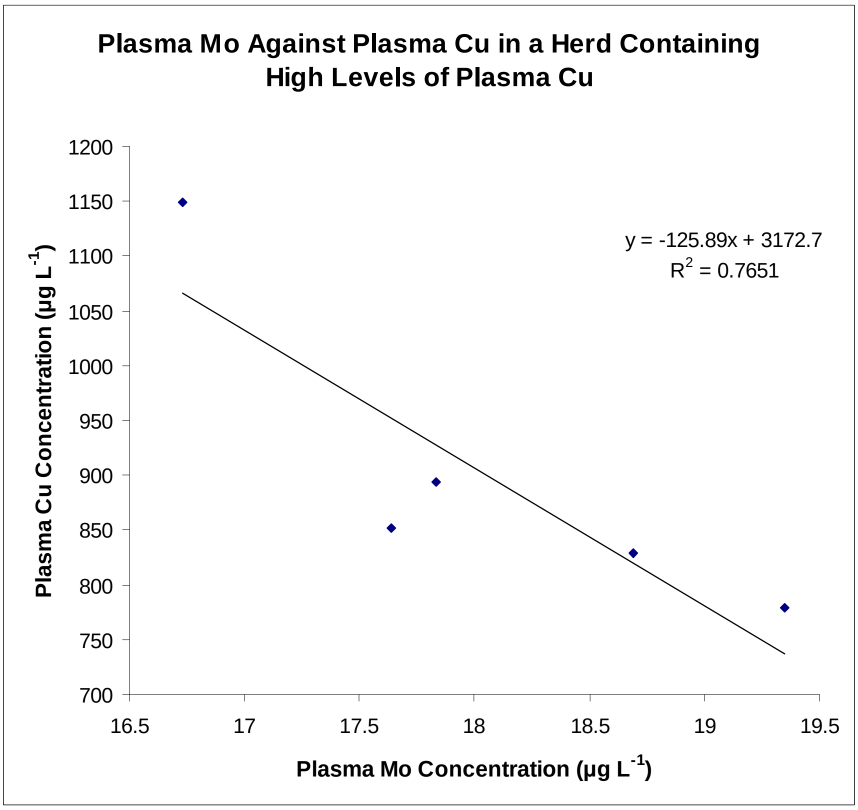

Figure 5

Discussion

From a comparison of blood plasma metal values in the literature with plasma values of the cattle in this investigation, the majority of cows fell into the "typical literature values" category (Table 1), showing that samples were suitable to represent a larger population. When compared to blood plasma metal values in the literature: 32% of cattle in this report were found to be deficient in copper, while 3% suffered from copper toxicity, 23% of cows in this study were deficient in zinc, while 7% had toxic zinc levels, 15% of cows were found to be deficient in manganese. No other standard blood plasma metal levels were available in the literature.

Haemolysis, the rupture of blood cells and the release of their contents into the blood plasma, may be a confounding factor. It can occur due to illness or delays in sampling (Hall 2006) and could have caused excessively high iron, zinc and manganese levels (Figure 6). The anomalies in Figure 3 are most probably explained by this phenomenon.

Plasma Metal and Soil Metal

An unexpected result occurred when copper levels in soil and plasma were analysed. Copper in cattle was found to increase as soil levels decreased. This shows that plasma copper could not have been predicted by soil sampling, possibly due to confounding variables such as copper supplementation by farmers.

In terms of molybdenum there was a strong possibility that plasma content rose with soil content. This could be explained by the presence of marine black shales in some parts of the UK, which contain high levels of molybdenum (Thomson 1972), while other sandier areas would contain less soil molybdenum (Underwood 1999), due to the geological characteristics of the parent material. Molybdenum is readily absorbed by livestock once it is taken into the body (Underwood 1999); therefore soil concentrations are likely to be reflected in the blood plasma.

Zinc also showed a strong possibility of a relationship, explained by the prevalence of zinc in soils nationwide (Suttle 2004). The pH of soil however can play a role (Schwedt 2001). Within cattle, zinc levels can also be influenced by disease (Hall 2006) and supplementation (Suttle 1999), further explaining the lack of statistical significance.

Iron and manganese both showed the lowest chance of a relationship. Soil pH and oxidation and reduction (redox) conditions affect these metal levels in soils (Underwood 1999) and plants (Norrish 1975). Redox conditions vary with rainfall (Underwood 1999), changing the availability of soil metals, particularly Fe and Mn, which act as secondary electron acceptors. In dry, aerobic soil Fe and Mn are immobilised. This, coupled with annual rainfall variation (Underwood 1999) suggests a possible relationship between redox, metal availability and seasonality, thus confounding spatial results.

Iron and manganese levels, along with the other metals were all affected by physiological relationships too, as discussed below. Additionally, the resolution of the geochemical topsoil atlas was set at 5 km^2, which could be too great to accurately represent the soil on which a particular cow grazed, due to rapid spatial changes in soil properties and soil pH.

Plasma Metals within Cattle

Physiological relationships affect the ability to predict plasma trace metal content from trace metals in soils. Iron, manganese and zinc are all directly or indirectly involved in antagonisms with each other and with other metals (Suttle 1975, Underwood 1999).

The most significant antagonism is that of molybdenum and copper. These elements combined with sulphur in the rumen to form an un-absorbable triple-complex, copper tetrathiomolybdate, which depletes copper (Suttle 1991). During ruminal digestion copper is precipitated as un-absorbable copper sulphide; however in post-ruminal digestion, copper becomes partially bound to undigested constituents (Underwood 1999). Molybdenum acts as an antagonist when its intake increases, and it decreases copper absorptivity to as low as 1%. Thus, where there was high molybdenum content in the soil, plasma copper was found to decrease (Figure 3), making it impossible to predict copper and molybdenum levels in blood plasma from the geochemical topsoil atlas.

Plasma Metal and Season:

The absence of any relationships between seasons and trace metals can be explained by a combination of factors. Firstly, soil conditions vary with season, particularly those of iron and manganese, which become more available for biological uptake in wet soil (Haudin 2007) (Underwood 1999). Zinc and copper were also found to be affected by rainfall (Teutsch 1999), which explains possible relationships between season and plasma for these metals. High rainfall values in summer 2007 and different rainfall intensities possibly accounted for the lack of statistical significance, as a result of redox conditions, pH and rain splash. This was because plant-available metals were more abundant when soil was wet (Sumner 2000), which would disguise any spatial patterns present.

Secondly, plant metal concentrations change seasonally. An example of this is the decreasing concentration of manganese and iron in leaves throughout the season due to growth dilution (Fergusson 1994). As cattle eat grass, such changes in plants could contribute to seasonal variation. As well as the change in plant metals, cattle have been shown to be selective about the type of plant that they eat (Underwood 1999); this could be a reason for the lack of significant relationships, because the whole plant metal profile, and therefore the soil metal content, may not be relevant.

Thirdly, cattle are often housed during winter periods, particularly between October and April, causing fewer seasonal relationships. Some animals are always housed, while others never are. It is unknown how the cattle in this report were kept, or how they were fed, which could influence results. For example, hay contains more absorbable copper but lower molybdenum concentrations than grass (Suttle 2004); possibly explaining lower winter molybdenum levels due to the copper-molybdenum antagonism.

Conclusions

From the results it can be concluded that trace metal deficiency cannot be predicted from the geochemical topsoil atlas alone. This was due mainly to confounding variables such as physiological antagonisms, compounded by the resolution of the geochemical topsoil atlas, which is too large to accurately describe the soil conditions from where the cattle originate.

Future Work

To ensure that pasture land and plasma trace metal levels can be compared more accurately, a more precise soil survey is required, along with more detailed information about each herd, including feeding habits, supplementation and housing.

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Profile

Emily graduated in 2008 from the School of Biosciences, University of Nottingham, with an upper second BSc. (Hons) in Environmental Science. Emily enjoyed every aspect of her degree, showing particular interest in soil and atmospheric sciences. She will continue her studies next year with a Masters degree in Meteorology and Climatology at the University of Birmingham.