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Mineral elements in clover- and grass forage in Sweden

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Mineral elements in clover- and grass forage in Sweden

Mineralämnen i klöver- och gräsvall i Sverige

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Abstract

Minerals are essential elements for all living organisms. Plants and animals need minerals to function and maintain a balanced physiological state. Minerals are also important in the ecological cycle. The minerals originate in the soil and makes the foundation of the plants nutritional value for the animals. The minerals can later recirculate to the soil in form of manure.

Forage is the main feed giving to ruminants and knowledge about the mineral content in the forage is important to avoid deficiencies or toxicities and to get a good understanding about the mineral balance of the farm.

This study aimed to map the contents of calcium, phosphorus, magnesium, potassium, sodium, chlorine, sulphur, iron, manganese, zinc, copper, cobalt, selenium, iodine and molybdenum in clover- and grass forage in Sweden and to correlate those with the content of minerals in the soil of Sweden.

The results generated 15 different maps showing the content of each mineral in samples of forages from all over Sweden. The results from the regression analysis between minerals in soil and feed, showed a varied relation, where calcium, phosphorus, copper and molybdenum had the strongest determinations coefficient of 50% - 65%.

It was concluded that this study showed mean concentration of calcium, phosphorus, magnesium, potassium, sulphur and copper comparable, to previously reported for Swedish forage. The mean contents of zinc, manganese and selenium, were however higher than those reported earlier and should therefore be the new refrence values for Swedish forage. This study also showed a difference in the phosphorus concentration between the northern and southern Sweden, which contradicts previously reported values of phosphorus in Swedish forage.

Keywords: Soil, Forage, Macro minerals, Micro minerals

Sammanfattning

Mineraler är livsnödvändiga för alla levande organismer. Växter och djur behöver mineraler för att fungera och upprätthålla ett normalt biologiskt tillstånd. Mineraler är också viktiga i det ekologiska kretsloppet. Mineraler kommer ursprungligen från jorden och är grunden till växtens näringsinnehåll för djuren. Näringsämnena kan sedan återvända till jorden i form av gödsel.

Vall är den huvudsakliga födokällan till idisslare i Sverige och kunskap om vallens mineralinnehåll är därför viktig att känna till för att undvika brister eller förgiftningar hos djuren och ha en god kännedom om gårdens mineralbalans.

Syftet med denna studie var att kartlägga innehållet av, kalcium, fosfor, magnesium, kalium, natrium, klor, svavel, järn, mangan, zink, koppar, kobolt, selen, jod och molybden i svensk gräs- och klövervall och att korrelera dessa data med motsvarande mineraler i jorden.

Resultatet genererade 15 olika kartor, som visade variationen av innehållet för varje mineral i svensk vall. Resultatet för determinationskoefficienten mellan mineraler i jorden och fodret, visade en varierad regressionsanalys, där kalcium, fosfor, koppar och molybden hade det tydligaste sambandet mellan 50%-65%.

I denna studien drogs slutsatsen att medelvärden i vallen för kalcium, fosfor, magnesium, kalium, svavel och koppar, var jämförbara med tidigare tabellvärden för svensk vall. Innehållet av zink, mangan och selen, visade dock högre medelvärden i vallen, än tidigare visat och borde därför bli de nya tabellvärdena för svensk vall. Den här studien visade även skillnader i fosforkoncentrationen i vallen mellan norra och södra Sverige, vilket motsäger tidigare tabellvärden för fosfor i svensk vall.

Nyckelord: Jord, Vall, Makromineraler, Mikromineraler

Populärvetenskaplig sammanfattning

Växter och djur behöver mineraler för att upprätthålla normala biologiska funktioner. Mineraler är också viktiga i det ekologiska kretsloppet. Mineraler kommer ursprungligen från jorden och är grunden till växtens näringsinnehåll, som i sin tur förser djuren. Mineralämnena återvänder sedan till jorden i form av gödsel.

God kännedom om mineralinnehållet i foder är viktigt för att kunna utfodra rätt mängd till djuren. En obalans av mineralerna i foderstaten kan ge brister, förgiftningar och ekonomiska förluster. Analys av mineralämnena i fodret kan även ge en uppfattning om gårdens mineralbalans.

Mineralinnehållet i vallfodret påverkas, förutom innehållet i jorden, främst av artsammansättningen av vallen, vilken typ av jordmån man har, vilket klimat gården ligger i och hur man sköter vallen. Syftet med detta examensarbete var att kartlägga djurens livsnödvändiga mineraler i svensk vall och undersöka sambandet av dessa mineraler med motsvarande mineraler i jorden.

Kartorna från den här studien var baserade på ca 52 000 foderanalyser från kött- och mjölkproducenter från hela Sverige. Foderanalyserna var hämtade från Växa Sverige och var sammanställda under åren 2010–2017. Jordanalyserna var hämtade från en tidigare studie från SLU (Eriksson *et al.* 2010). Jämförelsen mellan jord- och foderprover baserades på ett urval av 26 kommuner från 21 län.

Sambandet mellan jord och foder var högst för kalcium, fosfor, koppar och molybden, för de utvalda kommunerna. Kalcium och fosfor påverkar varandra och det är därför viktigt att ha god kännedom om halten i både jorden och fodret. Likadant påverkas koppar och molybden av varandra och årliga foderanalyser är därför viktiga.

Resultaten för makromineralerna visar att medelvärden i vallen för kalcium, fosfor, magnesium, kalium och svavel var jämförbara med äldre tabellvärden för svensk vall. Den här studien visade dock, högre fosforkoncentration i vall från södra Sverige jämfört med norra, vilket motsäger tidigare tabellvärden för fosfor i svensk vall (Spörndly, 2003).

Kaliumhalten i vallen har stor betydelse vid utfodring av bland annat sinkor. En hög mängd kalium i vallen kan påverka kalciumomsättningen tiden före kalvning och bidra till ökad risk för kalvningsförlamning. Mängden tillförd kalium från stallgödsel och konstgödsel på vallen, i kombination av jordmånen, kan inverka på mängden kalium i vallfodret.

Resultaten för mikromineralerna visar att medelvärdet för koppar var jämförbart med äldre tabellvärden av koppar (Spörndly, 2003). Innehållet av zink, mangan och selen, visade dock högre medelvärden i vallen, än tidigare visat.

Molybdenhalten i vallen kan påverka andra mineralämnen och höga halter kan orsaka bland annat kopparbrist. I den här studien hade ca 20% av proven högre molybden än rekommenderade värden. Gårdar i dessa områden kan ha högre risk för kopparbrist. För att minska risken bör totalfoderstatens innehåll av koppar vara minst fyra gånger högre än molybden.

Resultaten visar stor variation inom varje mineralämne. Kartorna gjorda i denna studie kan användas för att få en uppfattning om hur variationen ser ut inom ett visst område. Dock är kontinuerliga analyser av mineralämnen viktiga att göra för användning vid foderplaneringen på gården.

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Table of contents

List of Tables

List of Figures

Abbreviations & Definitions

Ca	Calcium
CEC	Cation Exchange Capacity
Cl	Chlorine
Co	Cobalt
Cu	Copper
DCAD	Dietary Cation and Anion Difference
DM	Dry Matter
ECM	Energy Corrected Milk
Fe	Iron
I	Iodine
K	Potassium
Kommun	Swedish community, defined as municipality
Län	Region in Sweden with several municipalities, defined as county
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Na	Sodium
P	Phosphorus
QGIS	Quantum Geographical Information System
S	Sulphur
Se	Selenium
SLU	Swedish University of Agricultural Sciences
Zn	Zinc

1 Introduction

Minerals are essential elements for all living organisms. Plants and animals need minerals to function and maintain a balanced physiological state. Minerals are also important in the ecological cycle. The minerals originate in the soil and makes the foundation of the plants nutritional value for the animals. Minerals that are not retained in animal tissues, will recirculate to the soil in the form of manure.

The essential minerals can be categorized as macro minerals, gram per kilogram dry matter (g/kg DM) and micro minerals, milligram per kilogram dry matter (mg/kg DM), depending on the amount present in the plant or required by the animal. Macro minerals and micro minerals essential for both plants and animals are calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), sulphur (S), manganese (Mn), zinc (Zn), copper (Cu), cobalt (Co) and molybdenum (Mo). Some minerals are essential for animals but are nonessential for plants, which includes sodium (Na), chlorine (Cl) and iron (Fe). Boron is a micro mineral for plants but not essential for animals, while selenium (Se) and iodine (I) are both essential micro minerals for animals but not for plants (Whitehead, 2000). In this study boron will not be investigated.

Forage is the main feed of ruminants in Sweden. In this study, forage will be defined as cultivated grassland, used as fodder. Knowledge about the mineral content of the forage is important to avoid deficiencies and toxicities (Suttle, 2010). This study will mainly focus on the effect on lactating dairy cattle. An excessive use of some minerals can also lead to environmental pollution (Öborn *et al.*, 2003) and therefore, knowledge about the farm's mineral status and animals' requirements are important.

Researcher at SLU have, on behalf of Swedish Environmental Protection Agency, performed inventory and environmental monitoring of Swedish arable land for 30 years. Samples of soil have been collected from the same coordinates, once every ten years. The results were presented in maps where the mineral status of the soil was illustrated (Eriksson *et al.*, 2010).

The aim of this study was to map the concentration of macro minerals, Ca, P, Mg, K, Na, Cl and S and the micro minerals, Fe, Mn, Zn, Cu, Co, Se, I and Mo of forage samples from all over Sweden, and to correlate those data with concentration of minerals in the soil. For the present study, data on chemical composition of feed samples (2010-2017) from Växa Sverige, and data from SLU on topsoil analyses were used.

2 Literature review

2.1 Mineral content in forage

Mineral content in forage is influenced by many different factors such as species, management, weather and soil attributes. Minson (1990) has reviewed mineral content in forage from different countries in the world and mineral concentration in legumes and grasses. Concentration of K, S and Se in forage in the UK has been reviewed by MAFF (1990) (see Suttle, 2010) (Table 1). New data on mean concentration of all essential mineral in forages in Nordic countries are scarce. However, the content of Ca, P, Mg and K in silage and hay from different parts of Sweden and the content of S, Mn, Cu, Zn and Se in mixed ley, have been compiled by Spörndly (2003) (Table 2).

Table 1. Mean values of mineral content in different forages

	Unit	**Forage**	**Temperate legume**	**Temperate grass**	**Reference**
Ca	g/kg DM	9	14.2	3.7	Minson, 1990
P	g/kg DM	2.9	3.2	3.5	Minson, 1990
Mg	g/kg DM	2.3	2.6	1.8	Minson, 1990
K	g/kg DM	-	27.4	25.8	MAFF, 1990; see Suttle, 2010
Na	g/kg DM	2.2	1.6	1.9	Minson, 1990
S	g/kg DM	-	-	2.2	MAFF, 1990; see Suttle, 2010
Mn	mg/kg DM	86	-	-	Minson, 1990
Zn	mg/kg DM	36	38	34	Minson, 1990
Cu	mg/kg DM	6.1	7.8	4.7	Minson, 1990
Se	mg/kg DM	0.05	-	-	MAFF, 1990; see Suttle, 2010
I	mg/kg DM	0.26	-	-	Minson, 1990

Table 2. Content of Ca, P, Mg and K (g/kg DM) in samples of silage and hay from different parts of Sweden and content of S (g/kg DM), Mn, Cu, Zn and Se of mixed ley (Spörndly, 2003)

	Whole Sweden	Northern Sweden	Southern Sweden
Silage			
< 25% legumes			
Ca	6.0	6.3	5.8
P	2.7	2.6	2.7
Mg	1.8	1.8	1.8
K	22	20	23.9
Silage			
25-50% legumes			
Ca	7.8	7.7	7.7
P	2.7	2.6	2.7
Mg	2.0	2.0	1.9
K	23.8	19.4	24.6
Hay			
Ca	3.7	4.3	3.7
P	2.1	2.1	2.1
Mg	1.2	1.4	1.2
K	18.1	16.4	19
Mixed ley			
S	1.9		
Mn	60		
Cu	7		
Zn	30		
Se	0.02		

2.1.1 Species

The macro- (Kuusela, 2006; Pirhofer-Walzl *et al.*, 2011) and micro- (Lindström *et al.*, 2013; Lindström *et al.*, 2014a; Lindström *et al.*, 2014b) mineral content of the sward is dependant of the species that are present. Several studies have shown that legumes, in general, have higher mineral content than grasses (Minson, 1990; Kuusela, 2006; Suttle, 2010; Lindström *et al.*, 2013; Lindström *et al.*, 2014a; Lindström *et al.*, 2014b).

In the study by Lindström *et al.* (2014b) the concentrations of Fe, Mn, Zn, Cu, Co and Mo in common grasses (timothy and meadow fescue), legumes (red- and white clover) and chicory were compared. The authors concluded that even though the concentration of micro minerals were higher when chicory was present in the sward, the total concentration of the minerals in relation to DM showed that inclusion of red clover in the mixture contributed to increased micro mineral content. This agrees with Pirhofer-Walzl *et al.* (2011) who studied the levels of macro- and micro minerals of grasses, forage legumes and forage herbs and concluded that legumes had higher concentrations of micro minerals than grasses. The study also concluded that an inclusion of herbs in forage mixtures could increase the levels of some of the minerals.

Kuusela (2006) studied the content of Ca, Mg, P, K and Na as affected by botanical composition. In general, the mineral content was higher in swards with high inclusion of clover, mostly in white clover mixtures, than in grass mixtures. The content of Ca, Mg and Na were higher in clover mixtures, while P and K were higher in grass mixtures. Schlegel *et al.* (2016) studied the influence of botanical composition on mineral content. The different mixtures consisted of grass (>70% grass), clover- grass mixture (50–70% grass) or herbaceous plants (>50% other herbaceous plants). The grass rich and clover- grass mixture both had a subclass with a lager inclusion of ryegrass, (>70% grass with more than half as ryegrass) and (50–70% grass with more than half as ryegrass). In general, the grass rich classes had lower concentration of minerals than the other mixtures. The two classes with ryegrass had however, even lower concentrations compared to classes with less ryegrass. Lindström *et al.* (2014a) showed that the content of micro minerals was higher in red clover with highest content of Fe, Mn, Cu, and Co concentration. Timothy had in general lower concentrations of all micro minerals but higher concentration of Zn in comparison to red clover and ryegrass (Lindström *et al.*, 2014a).

The plants different morphological parts can differ in mineral content (Whitehead, 2000). In common forage grasses timothy, meadow fescue, perennial ryegrass and cocksfoot, the concentration of Ca and Mg were higher in the leaves, while the content of P was higher in the inflorescence. The concentration of K had similar levels in the leaves and the stems of all the grasses except for perennial ryegrass, where the content was higher in the leaves (Fleming, 1963). The content of micro minerals was lower in the stems of all species and particularly in timothy grasses (Lindström *et al.*, 2014a).

2.1.2 Management and other external factors

The growth stage of the plants can have an impact on the nutritional value and can differ between grasses and legumes. As the plants grow, the fibre content will increase and thereby the nutritive value might change. Due to the different morphology of grasses and legumes, the nutritive value including the mineral content might differ (McDonald *et al.*, 2011). The time of harvest and maturity state of the plant is therefore important to be aware of when dealing with minerals in forage. Schlegel *et al.* (2016) conducted a study were the composition of essential minerals, both macro and micro, in fresh herbage was assed. The results showed that the concentration of all minerals, except for Fe, increased with the cutting number. This agrees with Pirhofer-Walzl *et al.* (2011), who found an increase in mineral content in grasses and herbs from first to third cut, while the mineral concentrations in legumes remained more stable among cuts. Schlegel *et al.* (2016) also looked at mineral concentration in relation with growth stage. The concentration decreased for most of the minerals as the growth continued. The exceptions were Na and Cl, which had increasingly concentrations and Ca, which was stable throughout the process (Schlegel *et al.*, 2016). The effect of phenological development on micro minerals in timothy, perennial ryegrass and red clover was investigated by Lindström *et al.* (2014a). The mineral concentration had a significant decreased for all micro minerals in the grasses, except for Mo in timothy grass and Mo and Co in perennial ryegrass. In red clover, the concentrations of Fe, Mn and Co were stable throughout the growth stage, while the concentration of Mo decreased in red clover, by more than 50%. For all three species the content of Cu and Zn decreased through all the phenological stages. Due to the decreased content of Cu and Zn, the harvest time might have a large impact on the total amount of these micro minerals in the forage (Lindström *et al.*, 2014a).

How the forage is conserved can have an impact on the content of minerals (Whitehead, 2000; Schlegel *et al.*, 2018). Hay production (barn-dried and field-dried) and silage production were compared for mineral concentration during harvest and conservation process (Schlegel *et al.*, 2018). At each harvest, samples were taken from fresh herbage, wilted herbage (not from field-dried) and conserved herbage. The mineral content for barn-dried hay changed through the conservation. Iron and Co had a significant increase ($p<0.01$), mainly due to soil contamination, according to the authors. Calcium, Mg and Zn decreased ($p<0.05$) and Cu tended to decrease ($p<0.10$), explained by losses during mechanical treatment at harvest. The concentrations of P, K, Na, Cl, S, Mn and Se were constant throughout the whole process. For field-dried hay the Cl content increased ($p<0.01$), and the Ca, Mg and Zn contents decreased ($p<0.001$). The authors did not have an apparent explanation of why the Cl increased. During the production and the conservation of silage, the process did not influence the concentration of Ca, K, Cl, S and Cu. The contents of P, Mg, Na, Fe, Mn, Zn, Co and Se, all increased significant during the conservation of silage (Schlegel *et al.*, 2018).

Supplying fertilizers in different forms, to enhance sward growth, is a common practice for farmers. Usually fertilizers containing N, P and K, or slurry from livestock naturally high in N and K are applied (Whitehead, 2000). While fertilizers might often increase the content of the applied minerals N, P and K, a secondary effect might cause an alteration of the botanical composition in the mixed ley and thereby, affecting the mineral content of the ley (Whitehead, 2000; Pirhofer-Walzl *et al.*, 2011).

The mineral concentration can also be influenced by weather conditions such as temperature, sun hours and rainfall (Whitehead, 2000; Roche *et al.*, 2009). Temperature, both in soil and air, affects the uptake of the minerals by plants and have therefore a major impact on the total concentration of mineral (Roche *et al.*, 2009). According to Roche *et al.* (2009), trace minerals, such as Mn was negatively correlated with rainfall, while Zn increased with greater rainfall. Copper, together with its antagonist, Mo and S, were all negatively correlated with the number of sunlight hours.

2.1.3 Attributes in the soil

The amount of minerals in the soil are firstly dependant on the parent material in the soil and the rate of weathering (Whitehead, 2000). The rate of weathering has a large impact on the amount of nutrients available for the plants. The rate might be affected by external factors such as: temperature, climate and soil type, or by the traits of the mineral particle itself: composition of mineral, pH in the soil and the content, production and decomposition of organic matter (Whitehead, 2000; Fogelfors, 2015). Silicon is presents in many mineral particles and has a great effect on the weathering rate (Fogelfors, 2015).

The content of available minerals in the soil can vary depending on the soil texture, clay content and bedrock geology. Based on bedrock geology, Sweden can be divided into three different geological parts: Fennoscandian shield, Caledonides and Sedimentary limestone, where for example the island Gotland is dominated by sedimentary limestone (Stephens *et al.*, 1997; Eriksson *et al.*, 2017).

Another important attribute of the soil that establish the nutrient content is the organic matter. Decomposition of dead plant material is depended on the amount of microbial activity, pH and the activity of earthworms and insects. In the process of decomposition, both mineralization and immobilization occur. Mineralization means that elements are converted from organic molecules into inorganic form. Immobilization implicates that the overbalance of the mineralized elements is immobilize to microbial biomass. Organic matter influences the amount of several mineral elements. The amount of macro minerals such as S is depended upon the amount of organic matter (Whitehead, 2000). When it comes to some of the trace elements, Eriksson *et al.* (2017) found that Cu and Mo occurred in higher concentration when the content of organic matter in the soil was higher than 20%.

The pH of the soil influences the availability of many mineral elements and can also have a large impact on the plant uptake. For optimal plant uptake, the mineral soils should have a pH of approximately 6.3. Some minerals have, however, better availability for plant uptake at different pH values. For instance, the availability of Cu and Fe for the plant increases, at a low pH. The availability of Mn increases in more acidic soils, while availability of Mo thrives in more alkaline soils (Frame & Laidlaw, 2011).

The process of cation exchange capacity (CEC) involves positive charged ions to change place with the negative charged ions in the soil, which results in an increase of the available minerals (Fogelfors, 2015). The availability of some macro minerals, Ca, Mg, K and Na is dependent on the CEC in the soil (Whitehead, 2000).

2.1.4 Mineral requirement and available minerals in forage-based diets for ruminants

Mineral requirement for the animals is firstly determined by the physiological state of the animal. Besides physiological state, the animal's age, production level, gender and breed affect the requirements. When formulating a feed ration it is important not only to know the concentration of the mineral elements in the feed, but also their availability. Availability is defined as the proportion of the mineral or nutrient that can effectively be utilized by the animal. The amount of absorbed mineral is affected by the chemical form present in the feed or its interactions with other minerals or nutrients, which may result in antagonist effects (Suttle, 2010). Antagonism means that one mineral inhibits or interfere the uptake of another mineral, which can contribute to cause deficiencies or toxicities. There are also some mineral interactions that might have beneficial effects, for instance, small amount of Cu might enhance Fe utilization (Suttle, 2010).

An important aspect to consider regarding mineral requirements in diet formulation, is the maximum level of inclusion. The maximal tolerance of a mineral is determined by the level of dietary mineral concentration that can be fed without negatively affecting animal health or performance (NRC, 2005). Table 3 and 4 shows the requirement, maximal tolerance, function in body, symptom and antagonists of essential minerals for dairy cattle, weighing 600 kg and milking 30 kg ECM.

Forages with high inclusion of legumes are often a good source of Ca for dairy cattle. The physiological state of the animal can, however, alter the requirement and supplementation might be needed, especially for lactating animals with high production level (Goff, 2018). Due to the high Ca content in clover, a high inclusion of clover in the forage portion of the diet, around parturition, can according to the author Minson (1990), contribute to an increased risk of milk fever for the cows. Recent studies have also pointed out that a high Ca intake before parturition can have a negatively effect on Mg metabolism and thereby might indirectly increase the risk of milk fever (Kronqvist *et al.*, 2011). The dietary cation and anion difference (DCAD) is a highly used tool for the prevention of milk fever in dairy production.

The formula most commonly used for the DCAD is: ($Na^+ + K^+$) – ($Cl^- + S^{--}$), where the cations (Na^+ and K^+) affect the Ca metabolism negatively and the anions (Cl^- and S^{--}), affects the Ca metabolism positively. The weeks before parturition, the DCAD of the feed ration should be aimed to be below 0 and preferably around, –100 mEq/kg (McDonald *et al.*, 2011). Forage often contains high levels of K (Table 1 and 2), and due to the high proportion of forage in the diets of dairy cows, the DCAD value of the feed ration are often high. A study in Norway, investigated the possibility to decrease the DCAD value in the feed by applying fertilizers high in Cl. The researchers concluded that an application of Cl fertilizers containing 140 kg /ha of Cl, can reduce the DCAD value in the forage (Nesheim *et al.*, 2015)

Forages grown on soils low in P are deficient in P. When forage contain high concentrations of Ca, but low in P, a deficiency in P is most prevalent, due to Ca reducing the resorption of P from the bones and the absorption of P in the intestinal tract (Minson, 1990).

The availability of Mg is influenced by several factors, such as, Mg content of forage, rumen pH or maturity stage of the grass. One of the most important factors is, however, the dietary level of K (NRC, 2001; Suttle, 2010). The Mg levels in forage are often low early in spring, whereas the K concentrations are high. Potassium inhibits the uptake of Mg in the rumen and can cause Mg deficiency, also known as tetany (Minson, 1990; Suttle, 2010).

Copper is a mineral with several antagonists, where Mo and S are the two most important ones. Ruminants are more sensitive for these, due to Mo and S forms complex in the rumen with Cu, which inhibits the uptake of Cu and can cause secondary Cu deficiency (Suttle, 1991). The dietary content of Mo and S can affect the absorption of Cu. A higher level of dietary Mo and S decreases the absorption of Cu (NRC, 2001). When, however, the dietary content of Mo and S are low, and the Cu level is high, the risk of Cu toxicity increases (NRC, 2005). Other minerals that can interfere or influence the Cu absorption are Fe, Mn and Zn (Suttle, 2010).

For some of the minerals the interactions with vitamins are essential for the animal health and performance. Ruminants requires Co, among other things, for the synthesis of vitamin B_{12} by the rumen microbes. An inadequate concentration of Co may therefore cause deficiency of vitamin B_{12} (Minson, 1990). Another trace mineral that is dependant of a vitamin, is Se with its close interaction with vitamin E. A deficiency of Se might be cured, to some extent, by supplementation of vitamin E, as well as a deficiency in vitamin E could be cured, by a supplementation of Se (Goff, 2018).

For cattle, I toxicities is very rare. The maximal tolerance is therefore firstly set after the tolerance of humans (NRC, 2005).

Table 3. Requirements and maximal tolerance of the total feed ration, function in body, symptoms and antagonists of macro minerals in dairy cattle

Element	Requirement [a] g/kg DM	Maximal tolerance [b] g/kg DM	Function in body	Symptom deficiencies /toxicities	Antagonist
Ca	5.6	15	Skeleton Enzyme activity Muscles and nerve impulses	Reduce growth Affect fertility and milk production	P, Mg, K
P	3.6	7	Bone and teeth Genome The metabolism Osmotic and acid-base buffer system	Reduce appetite, production and conversion rate Affect the fertility	Ca
Mg	2.0	6	Muscle function Nerve conduction Bone formation Enzyme activity	Tetany	K
K	10.6	20	Osmoregulation Acid-base balance Water balance Nerve impulse function Muscle contraction Enzyme activity Metabolism O_2 and CO_2 transport Cardiac and renal tissue Na^+/K^+ ATPase pump	Deficiencies rare Affects growth, muscles and appetite	
Na	1.2	30 [c]	Acid-base balance osmoregulation Water balance Muscles contraction Na^+/K^+ ATPase pump	Dehydration Appetite Affects production	K, Cl
Cl	2.7	30 [c]	Osmoregulation Water balance Acid-base balance Important anion in the body	Alkalosis	Na, K
S	2	4 [d]	Constituents of amino acids, vitamins and hormones Present as SO_4 in keratin, heparin and chondroitin	Reduce fur and hoof quality Reduce production and appetite	

a)Requirement is calculated on the minimum amount for a 600 kg LW dairy cow with ≥30 kg ECM (NRC, 2001; Volden, 2011) b)Maximal tolerance is based on (NRC, 2005) c) Based on amount salt (NaCl) d)Diets with at least 40% forage.

Table 4. Requirements and maximal tolerance, based on a DMI, function in body, symptoms and antagonists of micro minerals in dairy cattle

Element	Requirement [a] mg/kg DM	Maximal tolerance [b] mg/kg DM	Function in the body	Symptom of deficiencies/toxicities	Antagonist
Fe	50	500	Important component in haemoglobin and transport of oxygen	Anemia Reduce growth and general state of health	
Mn	40	2000	Enzyme activation	Reduced growth Skelton abnormalities and ataxia	Ca, P, K
Zn	50	500	Enzyme component and activator	Parakeratosis, poor growth and reduced appetite	Cu, Fe
Cu	10	40	Haemoglobin synthesis, enzyme systems and pigments	Anaemia Poor growth Depigmentation of hair and wool Reduced reproduction Ataxia	Mo, S, Fe, Mn, Zn
Co	0.11	25	Component of vitamin B_{12}	Emaciation, anaemia and listlessness	
Se	0.20	0.5 [c]	Component of glutathione peroxidase, iodine metabolism, immune function	Myopathy, exudative diathesis, White muscle disease	S
I	1.0	50	Thyroid hormones	Goiter, hairless, weak or dead young Reduced fertility	
Mo [d]	-	2.5[c]	Enzyme activation	Cu deficiency	

a)Requirement is calculated on the minimum amount for a 600 kg LW dairy cow with ≥30 kg ECM (NRC, 2001; Volden, 2011). b)Maximal tolerance is based on (NRC, 2005) c) Maximal content (mg/kg) of total feedingstuff as additive (EC No 1831/2003) d) No data available for the requirement of Mo of dairy cattle.

3 Materials and Methods

3.1 Data

This study was conducted at the Swedish University of Agriculture Sciences (SLU) in Uppsala.

3.1.1 Feed samples

The data used in this study consisted of analytical results from the NorFor feed analysis system (Växa Sverige, 2017). Samples of cereals and forages were originally, sent by dairy and beef farmers, all over Sweden, to be analysed by commercial laboratories. Macro and micro minerals were analysed, using the method Inductively coupled plasma (ICP) or Inductively coupled plasma mass spectrometry (ICP-MS) (Holst Kjellingbro, 2019, oral source). The measurement uncertainty and detection level reported from one of the laboratories is found in Table 5. The measurement uncertainty for Ca, for instance was interpreted as the value ≥ 2 g/kg having an uncertainty of ±7.2% (Holst Kjellingbro, 2019, oral source).

Table 5. Measurement uncertainty and detection level of analysed mineral elements

Macro mineral	Measurement uncertainty	Detection level	Unit	Micro mineral	Measurement uncertainty	Detection level	Unit
Ca	≥2.0; 7.2%	0.1	g/kg	**Fe**	≥60; 10.8%	7.0	mg/kg
P	≥1.0; 7.2%	0.1	g/kg	**Mn**	≥30; 7.2%	3.0	mg/kg
Mg	≥2.0; 7.2%	0.1	g/kg	**Zn**	≥30; 7.2%	3.0	mg/kg
K	≥10.0; 7.2%	0.3	g/kg	**Cu**	≥15; 7.2%	1.0	mg/kg
Na	≥1.0; 7.2%	0.1	g/kg	**Co**	≥300; 10.8%	40	µg/kg
Cl	Not reported		g/kg	**Se**	≥60; 14.2%	5.0	µg/kg
S	≥2.0; 7.2%	0.15	g/kg	**I**	≥1.0; 7.2%	0.1	mg/kg
				Mo	≥3.0; 7.2%	0.15	mg/kg

At the start, the total amount was 80064 samples, from eight consecutive years (2010-2017).

The feed analyses were sorted by feed code and forage type (Table 6), so the remaining samples were mineral analysis of grass and clover forages. The total number of forage analyses were 59148 samples and out of these, 6903 samples were deleted due to lack of mineral analysis.

Table 6. Definition of feed code in NorFor feed analysis system and number of samples for each feed code, used in the study

Feed code	Forage type	Proportion of clover	No. of samples
161	Fresh grass ley	0	568
162	Silage of grass ley	0	1210
164	Fresh mixed ley	<50%	11 606
165	Silage of mixed ley	<50%	35 944
383	Hay of grass-clover		834
437	Fresh mixed ley	>50%	400
438	Silage of mixed ley	>50%	859

The forage samples were combined with coordinates for the location of the farms, provided by Växa Sverige, (Eskilstuna, Sweden). Approximately 300 samples lacked coordinates, and a search for coordinates for each farm was done via the websites, hitta.se or eniro.se and the coordinates for WGS84 DD (LAT, LONG) were selected. Due to lack of herd ID, 1030 samples were discarded and therefore, no coordinates for those farms were found. After sorting, the forage samples used for the analysis in this study, were 51449, coming from 4698 different farms, all over Sweden.

3.1.2 Soil samples

The soil samples used in this study were collected from the database Miljödata, SLU (2019a) and were based on a national environmental programme (SLU, 2019b). For more details about the programme see the report by Eriksson *et al*. (2010).

The soil samples were downloaded during the period of 2018-10-17 to 2018-11-25 (SLU, 2019a). The selected parameters for the soil samples were Ca exchangeable, P-AL, Mg exchangeable, K exchangeable, Na exchangeable, S, Fe-AL, Mn, Zn, Cu, Co, Se and Mo. P-AL and Fe-AL is an analytical method used for estimating readily available P and Fe for plant uptake (Eriksson *et al.*, 2010). The mean values of the chosen parameters of the soil, from the years 1988-2018 were selected.

To get a homogenous comparison between soil samples and forage samples, 26 municipalities placed in 21 of the counties in Sweden were chosen. The municipalities with the largest number of dairy farms within each county (LRF Mjölk, 2017) were selected. In counties, with high density of dairy farms, several municipalities were selected to get a geographical spread within that county. For each selected municipality, the mean value of the forage samples was calculated.

3.2 QGIS and preparing of maps

Spatial treatment of the forage data set was performed in QGIS, Bonn 3.2.3. The forage samples were divided by each mineral element in different layers and then interpolated within Swedish borders, using inverse distance weighted interpolation (SAGA GIS, 2.3.2). The search radius was set to 15 kilometres (km) and the cell size was set to 15 km x 15 km. For each cell the concentration represents an average for the 15 km x 15 km area. For each map five different colours were chosen to represent intervals with different concentrations. The intervals were calculated using equal interval in QGIS. To easier explain the results of the maps, the different colours were defined as:

Red = Low concentration
Orange = Medium low concentration
Yellow = Medium concentration
Green = Medium high concentration
Blue = High concentration

Geographical information of municipalities, counties and borders of Sweden were retrieved from the website of Lantmäteriet (Lantmäteriet, n.d.).

3.3 Statistical analysis

Statistical analyses were performed by using Excel, Microsoft® Office © 2016. The forage samples were, before calculating the mean value, sorted and outliers for each mineral were discarded. A general linear model was fitted to the forage samples mean values with soil samples mean values, of the same municipality, as explanatory variable. One model was fitted for each mineral. The r-squared (R^2) value, also known as the determination coefficient, was used to judge how much the level of the parameter in the forage could be explained by the level of the parameter in the soil.

Histograms for each mineral in the forage were created in Excel. No outliers were discarded in the histogram.

The mean, standard deviation, median, minimum, percentile 25, percentile 75, maximum and mode values for each mineral, were calculated using the function “statistics” in the program QGIS, Bonn 3.2.3. The most frequent value of each mineral was defined as the mode value. The value of percentile 25, was defined as the value that 25% of the observations of the samples were below or equal as and percentile 75 was defined as the value 75% of the observations was below or equal as.

4 Results & Discussion

4.1 Macro minerals

The results of the descriptive statistics of macro minerals in the forage are presented in Table 7. The maps of the macro mineral's concentrations are found in Appendix 1 – 7.

Table 7. Descriptive statistics of macro minerals in samples of forages from all Sweden

	Ca	**P**	**Mg**	**K**	**Na**	**Cl**	**S**
N	48775	48774	48773	48775	48621	25965	48743
Mean	6.4	2.8	2.0	23.0	0.9	4.1	2.1
Median	6.0	2.8	2.0	23.0	0.7	3.6	2.1
St.Dev.	2.4	0.6	0.6	5.2	0.7	3.3	0.5
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pctl (25)	4.7	2.5	1.6	19.5	0.5	1.2	1.8
Pctl (75)	7.5	3.2	2.4	26.4	1.2	6.0	2.4
Max	48.0	30.0	27.0	52.4	35.0	63.0	31.0
Mode	5.0	2.8	1.8	25.0	0.5	0.4	2.0

Calcium

The content of Ca in the forage were similar in a large part of Sweden with, 25% of the observations having, a medium concentration of 4.8-7.5 g/kg DM (Table 7 and Appendix 1). Areas around the lakes Storsjön, Vänern, Vättern and Mälaren, the islands Öland and Gotland in east and a small area in southern Skåne, all had medium high to high concentrations of Ca in the forage with approximately 7.5 - 13.5 g Ca/kg DM (Appendix 1). The mean value and the mode value were found to be, 6.4 g/kg DM and 5.0 g/kg DM, respectively (Table 7). In areas were the Ca content in the forage was higher, one explanation could be the bedrock geology, where for example, Gotland and Öland have soils naturally high in Ca (Eriksson *et* *al.*, 2010; Eriksson *et al.*, 2017). The content of Ca in forage might also be higher in mixtures with more clover inclusion (Kuusela, 2006), which might be due to the higher content of Ca in the leaves of the plant (Fleming, 1963). Something else that might be good to be aware of is the harvest time. The Ca content in forage increases between first and third cut, according to Schlegel *et al.* (2016).

The mean value of the results in this study, correspond to the average value of Ca concentration in whole Sweden, presented by Spörndly (2003) (Table 2). The distribution of the Ca analysis showed a normal distribution of the forage samples (Figure 1). Of the Ca analysis, 75% of the observations had a value of less or equal to 7.5 g/kg DM. High values such as, 48 g/kg DM (Table 7), might indicate a human error either at the time of the sample-taking or at the time of the analysis.

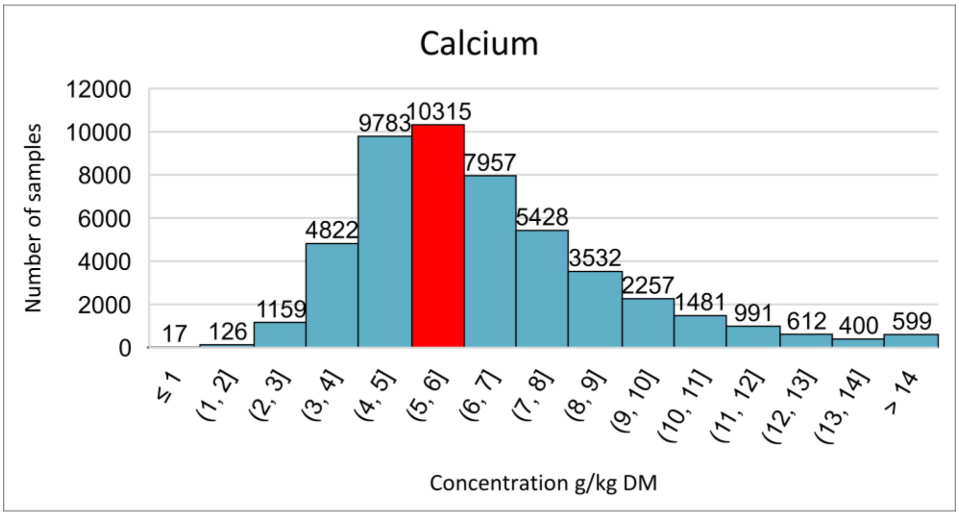

Figure 1. Histogram of the Ca content in forage samples. Red column is where the mode value of 5.0 g/kg DM lays.

The requirement of Ca for the lactating cow is 5.6 g/kg DM (Table 3) (Volden, 2011). The mean Ca content of forage in Sweden, showed to have an adequate amount of Ca. However, it can be necessary to supplement Ca for high yielding cows, due to an increased requirement of Ca at the peak of lactation (Goff, 2018). The Ca content increases when the inclusion of clover increases (Minson, 1990; Kuusela, 2006; Suttle, 2010), which might negatively affect the metabolism of Mg (Kronqvist *et al.*, 2011). To lower the incidence of milk fever, the DCAD value of the feed ration for the dry cow should be aimed to be below zero. According to Nesheim *et al.* (2015), this might be achieved, by applying fertilizers with approximately 140 kg/ha of Cl.

The results from the regression analysis indicates a positive linear relation between Ca in the soil and Ca in the forage (Figure 2). The R^2 was 57%, which means that approximately 60% of the variation in Ca concentrations in the forage can be explained by Ca content in the soil.

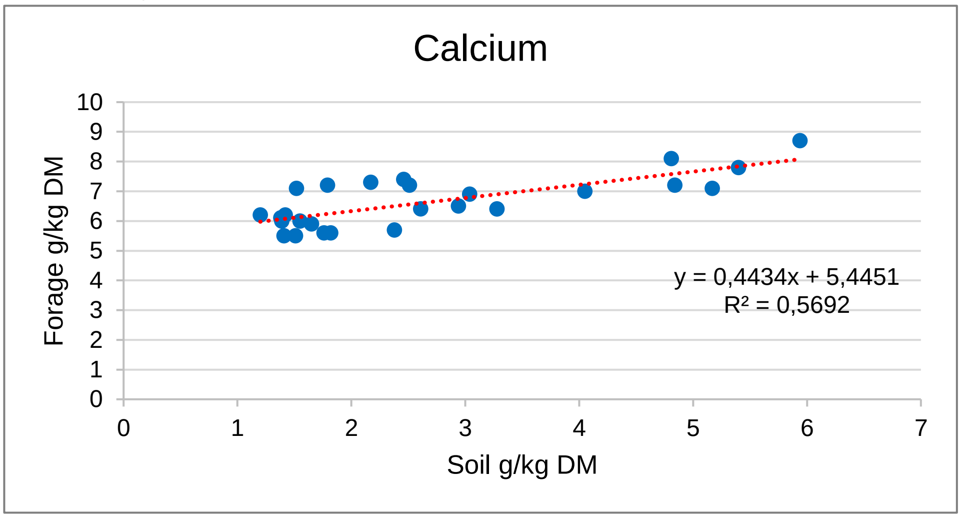

Figure 2. Regression analysis between Ca in soil and Ca in forage, where each dot represents the mean value of the soil sample and forage sample for each selected municipality.

Based on the results from this study, areas with high Ca in the soil might lead to high concentrations of Ca in the forage. However, several factors may influence the Ca content of the forage. Analysing the content of minerals in the forage yearly, is therefore recommended to make sure not to over feed Ca, which might cause P deficiency and interfere with the metabolism of Mg. Supplementing the animals with a customized mineral feed might also be a good strategy to ensure that the animals could be provided with right amount of Ca.

Phosphorus

The observed mean and mode values of the content of P in grass and clover forage in Sweden both were 2.8 g/kg DM (Table 7). A large proportion of the forage samples had similar concentrations of 2.4-2.8 g P/ kg DM, in the whole country. However, concentration of P in the forage showed to be different in different regions of Sweden. Some areas in middle of Sweden had concentrations between 2.0-2.4 g/kg DM, while an area in southern Sweden, concentrations of P, were found to be medium high (2.8-3.2 g/kg DM), with some small areas with high concentrations (3.2-3.6 g/kg DM) (Appendix 2).

Factors that may influence the P content in the forage and might be good to be aware of is the botanical composition of the sward, as grass mixtures, can according to Kuusela (2006), might increase the content of P in the ley.

The mean value of the P concentration, in the forage of whole Sweden in this study, agrees with the mean value of P concentration presented by Spörndly (2003) (Table 2). However, while Spörndly reported similar concentrations of P in northern and southern Sweden, results from this study showed a difference in concentration of P, in samples of forage from the north and from the south of Sweden (Table 2). A clear explanation of this cannot be found, but one might speculate that the concentration of P in the soils varies between the north and south of Sweden and this might therefore contribute to different values in the forage.

The histogram of the P analysis in the forage showed a normal distribution (Figure 3).

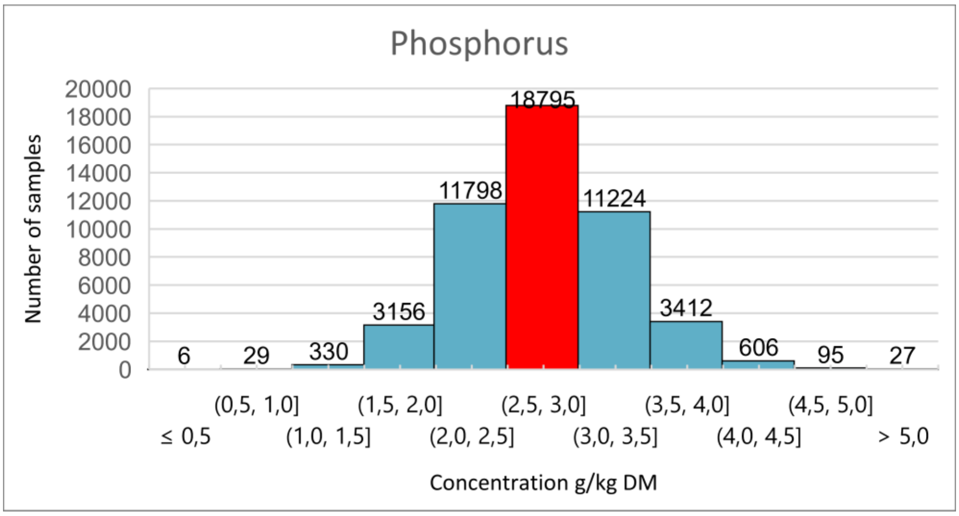

Figure 3. Histogram of the P content in forage samples. Red column is where the mode value of 2.8 g/kg DM lays.

As it was observed for Ca, the linear regression for P in soil and forage showed a R^2 of 57% (Figure 4). The content of P is mainly affected by soil properties such as soil-pH and management factors, like for instance, amount fertilizer applied (Whitehead, 2000; Eriksson *et al.*, 2010). It can also be important to be aware of the content of Ca in the forage, as the P content in the forage might be lower when grown of P deficient soils with high Ca (Minson, 1990).

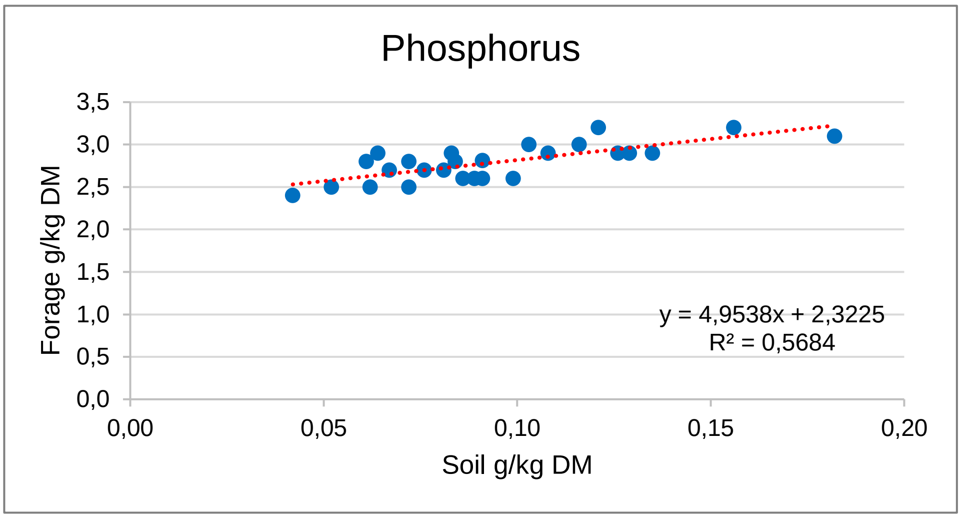

Figure 4. Regression analysis between P in soil and P in forage, where each dot represents the mean value of the soil sample and forage sample for each selected municipality.

The requirement of the lactating cow is 3.6 g/kg DM (Table 3) (Volden, 2011). Many of Sweden's dairy farms may be in risk of P deficiencies disorders, if the animals only were offered forage, as a diet. Due to a large proportion of Swedish livestock is being fed cereals, which contains high P levels, deficiencies might not be a huge problem. But knowledge about the mineral content in the forage might also be of help to prevent environmental pollution and lay out strategies for fertilizers and crop production. As previously mentioned, yearly analysis of the mineral content in the forage should be recommended to be aware of the farm's mineral status.

Magnesium

The content of Mg in forage was generally the same in whole Sweden with concentrations of 2.0-2.5 g/kg DM. The most frequent value was 1.8 g/kg DM (Table 7) and was mostly found in areas in middle of Sweden, east around Uppland and in south-east on the islands Öland and Gotland, where the concentrations were 1.5-2.0 g/kg DM (Appendix 3).

The content of Mg in the forage might be influenced by the proportion of clover in the sward, as the Mg content might increase with higher inclusion of clover (Kuusela, 2006). The harvest time might also affect the content of Mg, as the content increases from first to third cut (Schlegel *et al.*, 2016).

The mean value of the Mg concentration presented in this study is comparable to the mean value, reported by Spörndly (2003) (Table 2). The distribution of the Mg analysis of the forage samples were found to be normal distributed (Figure 5).

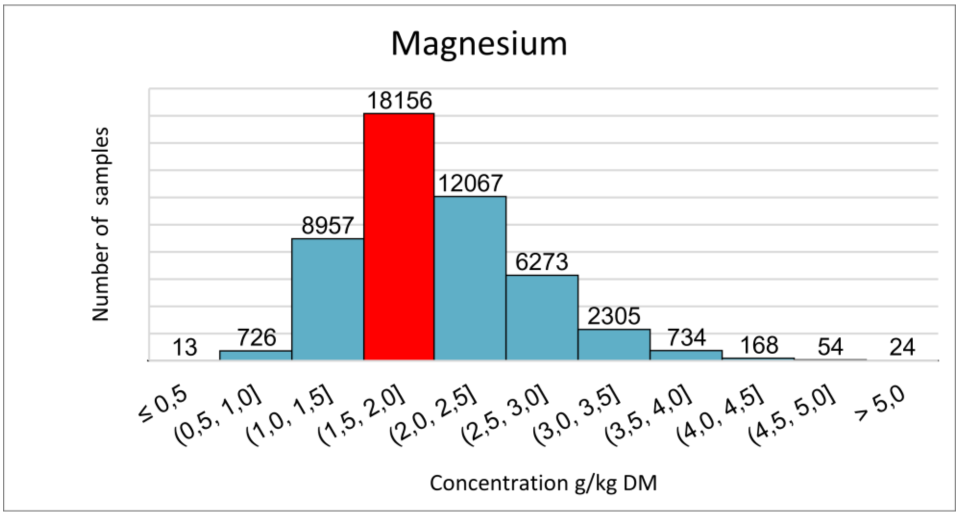

Figure 5. Histogram of the Mg content in forage samples. Red column is where the mode value of 1.8 g/kg DM lays.

The regression of Mg between soil and forage, showed a poor relation, with a R^2 of approximately 10% (Figure 6). The content of Mg in the plant increases as the availability for the plant increases, when pH is around 6 (Frame & Laidlaw, 2011).

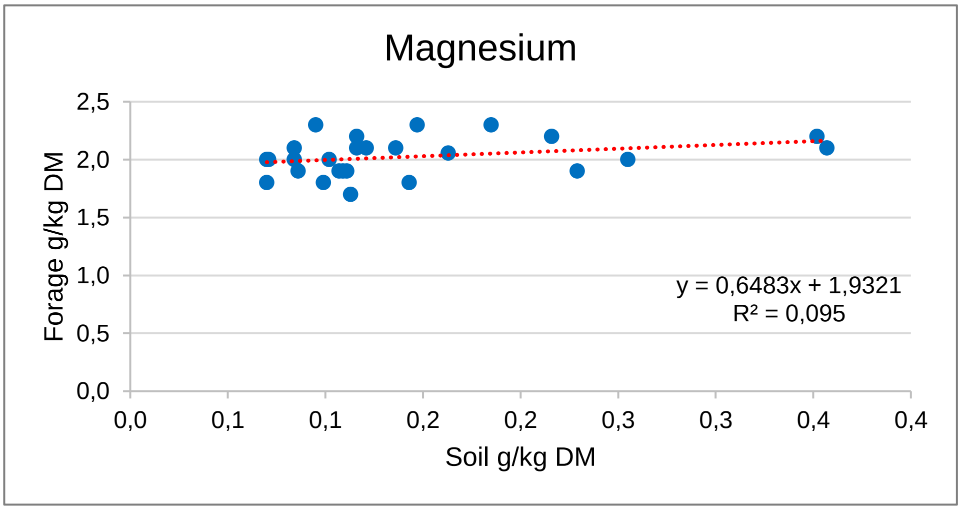

Figure 6. Regression analysis between Mg in soil and Mg in forage, where each dot represents the mean value of the soil sample and forage sample for each selected municipality.

The requirement of the lactating dairy cows is 2 g/kg DM (Table 3) (Volden, 2011). In areas where the K content in the forage is high, the Mg absorption might be affected negatively and can cause tetany. Farmer's in these areas should therefore consider giving their animals a mineral feed with extra Mg, which might prevent tetany. It might also be good to not apply slurry right before letting the animals out for pasture or harvest for feed, due to the high content of K in slurry (Whitehead, 2000). Magnesium availability might also be negatively affected by a high Ca intake (Kronqvist *et al.*, 2011) and therefore it is important to yearly analyse the forage.

Potassium

A large part of Sweden showed medium high (20.6-25.6 g/kg DM) to high (25.6-30.7 g/kg DM) concentrations of K in the forage. Some regions in middle of Sweden, the east coast in north and a small area in south-west, concentrations of 15.6-20.6 g/kg DM, in the forage were found (Appendix 4). The mean value was 23 g/kg DM and the mode value, 25 g/kg DM (Table 7).

The mean value of K in forage presented in this study agrees with the mean value of Sweden, presented by Spörndly (2003) (Table 2).

The content of K in forage can be highly influenced by application of fertilizers and slurry (Whitehead, 2000). You can speculate that, the areas with high concentration of K in the forage, might partly be explained by the high proportion of cattle in those areas and thereby a higher application of slurry. As mentioned previously, supplementation of Mg might therefore be necessary in these areas, to prevent tetany. The distribution of K analysis in the forage was found to be normal distributed (Figure 7).

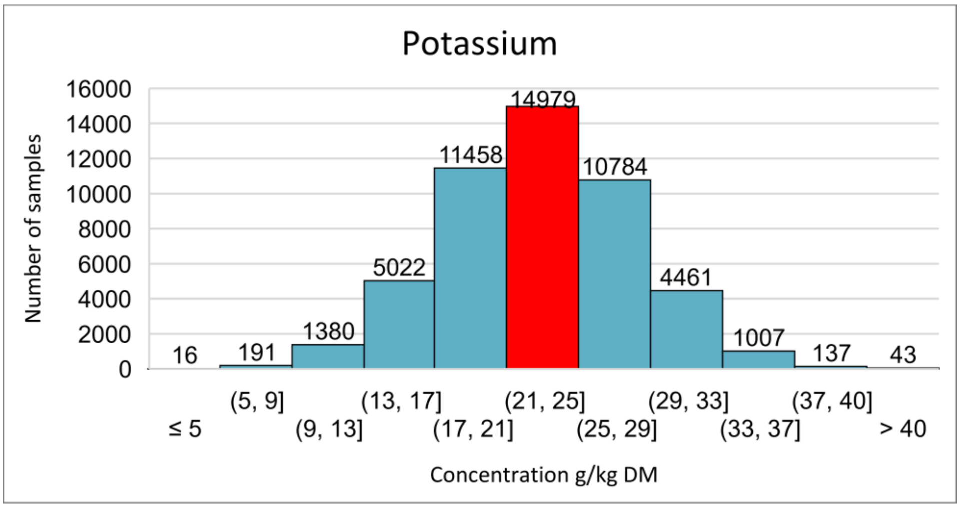

Figure 7. Histogram of the K content in forage samples. Red column is where the mode value of 25 g/kg DM lays.

The regression of K between the soil and the forage, showed a R^2 of approximately 40% (Figure 8). This might be due to what soil type the selected municipalities had and it might also be influenced by the CEC of the soils in the selected municipalities.

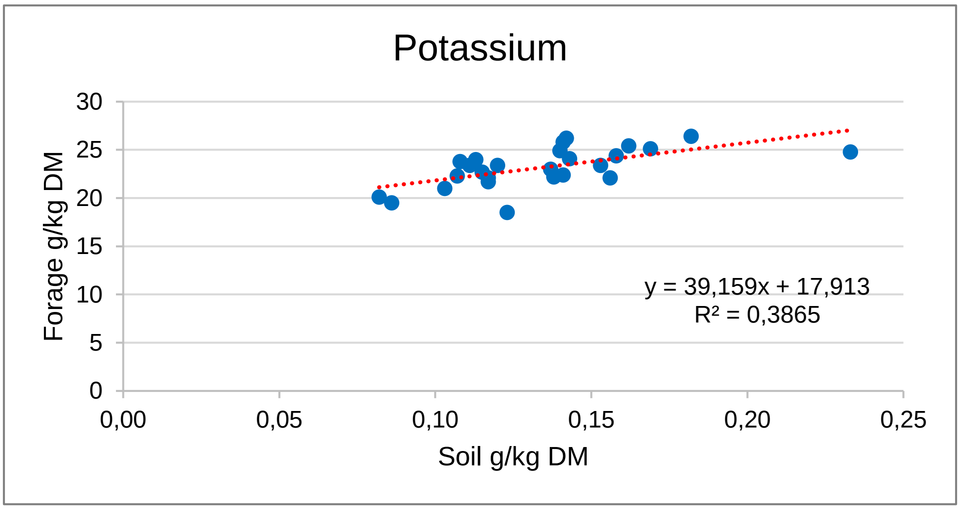

Figure 8. Regression analysis between K in soil and K in forage , where each dot represents the mean value of the soil sample and forage sample for each selected municipality.

Deficiencies of K are rare for the lactating dairy cattle, since the requirement is 10 g/kg DM (Table 3) (Volden, 2011). Due to the relatively high content of K in the forage of Sweden, it might be more important to be aware of the maximal tolerance for the animal. For dairy cattle the maximal tolerance for K is 30 g/kg DM (Table 3) (NRC, 2005). A high K content might also affect the availability of Na, Ca and Cl negatively and the awareness of the respectively content in the feed might therefore be important to maintain a good animal health and performance.

Sodium

The content of Na in forage were found to be similar in a large part of Sweden with concentrations of 0.08-0.8 g/kg DM. The mean value was 0.9 g/kg DM and the mode 0.5 g/kg DM (Table 7). The exception was southern Sweden in areas near Skåne and Halland, where the concentrations in the forage were approximately 0.8-2.3 g Na/kg DM (Appendix 5). The amount of Na in forage might be affected by factors such as cutting number and selected conservation method (Schlegel *et al.*, 2016; Schlegel *et al.*, 2018).

The mean value presented by Minson (1990) (Table 1), does not agree with the mean value of Na in the forage found in this study (Table 7). It is unclear, why the mean Na concentration of forage in Sweden, is that low, comparing with Minson. You might speculate that, Minson’s values are globally reviewed and that the climates from the different places, the values are retrieved from, differs a lot from each other.

The distribution of the Na analysis in the forage showed a tendency of normal distribution (Figure 9). The reported detection level was 0.1 g/kg (Table 5). Looking at the histogram a quite high number of samples was equal or less than 0.1 g/kg DM. This might indicate a very low level or due to human error the values might have been presented wrong at the laboratory.

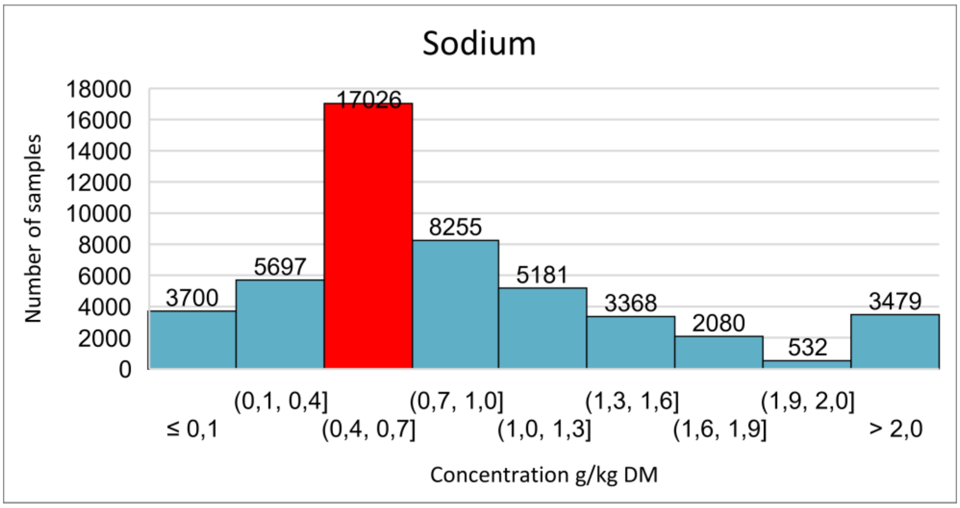

Figure 9. Histogram of the Na content in forage samples. Red column is where the mode value of 0.5 g/kg DM lays.

The relation between Na in the soil and Na in the forage, showed a non-linear regression, with a R^2 of close to 0 (Figure 10).

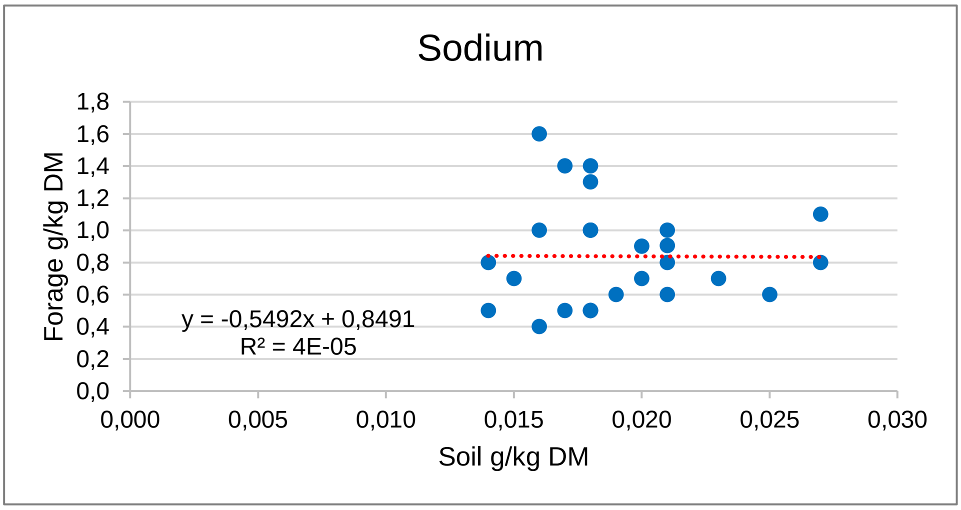

Figure 10. Regression analysis between Na in soil and Na in forage, where each dot represents the mean value of the soil sample and forage sample for each selected municipality.

The requirement for the lactating dairy cattle is 1.2 g Na/kg DM (Table 3) (Volden, 2011). Sodium has K as an antagonist and it is important to be aware of K content to prevent possible deficiencies. To avoid deficiency in Na, a good practice is to provide the animal with free access of salt.

Chlorine

In south of Sweden the content of Cl in the forage, was found to be medium (3.0-5.5 g/kg DM) to medium high (5.5-8.1 g/kg DM). A large part of middle to north of Sweden showed concentrations of Cl in the forage between 0.5-3.0 g/kg DM (Appendix 6). The mean value was 4.0 g/kg DM, while the most frequent value was found to be 0.4 g/kg DM (Table 7). The distribution of the Cl analysis was not normal and a clear explanation of this cannot be found (Figure 11). You could speculate that Cl is the only mineral analysed by a different method, compared to the other minerals. The detection level was not reported, and the lower levels may not have been properly presented by the laboratory. The number of samples were also different compared to the other macro minerals, and the analyses of Cl started 2011.

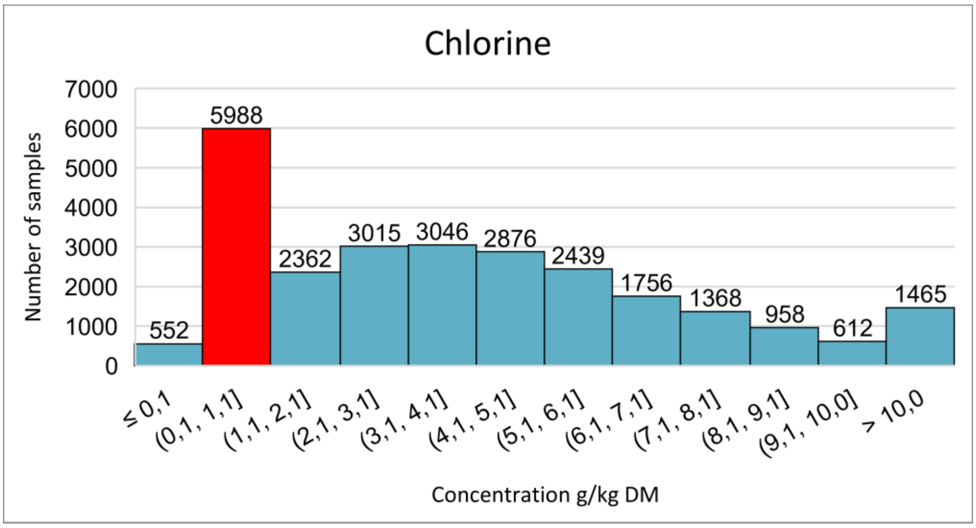

Figure 11. Histogram of the Cl content in forage samples. Red column is where the mode value of 0.4 g/kg DM lays.

The requirement of the lactating cow is 2.7 g Cl/kg DM (Table 3) (Volden, 2011). As for Na, deficiencies of Cl are easier to prevent by proving free access of salt to the animals.

Sulphur

The amount of S in forage was similar in most part of Sweden with a concentration range of 1.8-2.2 g/kg DM (Appendix 7) and was represented by 25% of the observations (Table 5). Areas in south-east of Sweden, were found to have medium high concentrations in the forage (2.2-2.7 g/kg DM), while parts in the west, around Vänern and middle of Sweden were found to have concentrations of 1.3-1.8 g/kg DM (Appendix 7). According to Roche *et al.* (2009), the content of S in the forage could be affected negatively by the number of sunlight hours.

Out of the S analysis, 75% had concentrations less than or equal as 2.4 g/kg DM. The maximum value of S (31 g /kg DM) (Table 7), might indicate a human error performed at the laboratory or at the farm, when the samples were taken. The histogram of S analysis of the forage showed a normal distribution (Figure 12).

The mean concentration of S found in forage in this study agrees to the mean concentration found in forage in the UK, reported by MAFF (1990) (see Suttle, 2010) (Table 1) and the reference value of S content in forage, previously reported from Sweden (Table 2) (Spörndly, 2003).

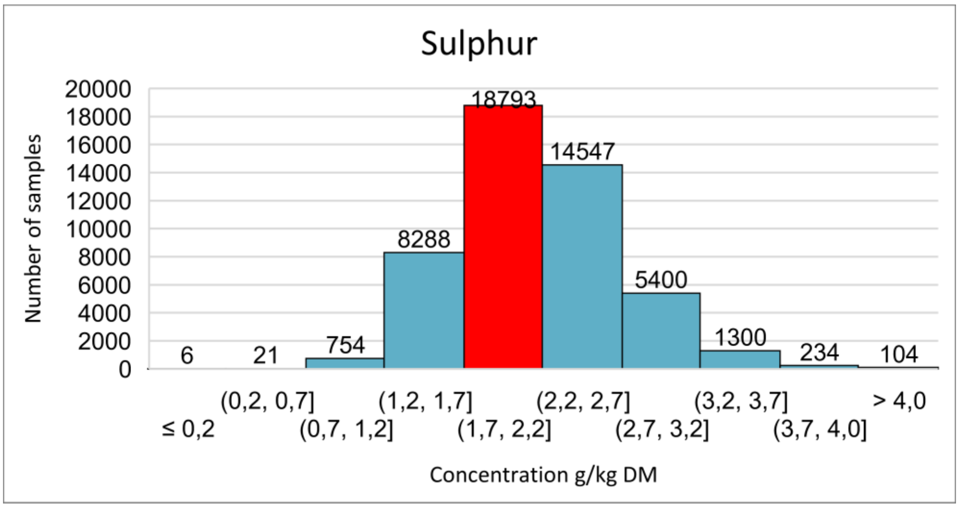

Figure 12. Histogram of the S content in forage samples. Red column is where the mode value of 2.0 g/kg DM lays.

Based on the results of the regression analysis between soil S and forage S, about 13% of the S content in the forage, could be explained by content of the S in the soil (Figure 13).

The requirement of S for the lactating cow is 2 g/kg DM (Table 3) (Volden, 2011). Due to the complex formation between S, Mo and Cu, a high content of S and Mo can cause Cu deficiency (Suttle, 1991) and yearly analysis of these minerals in the forage might be necessary.

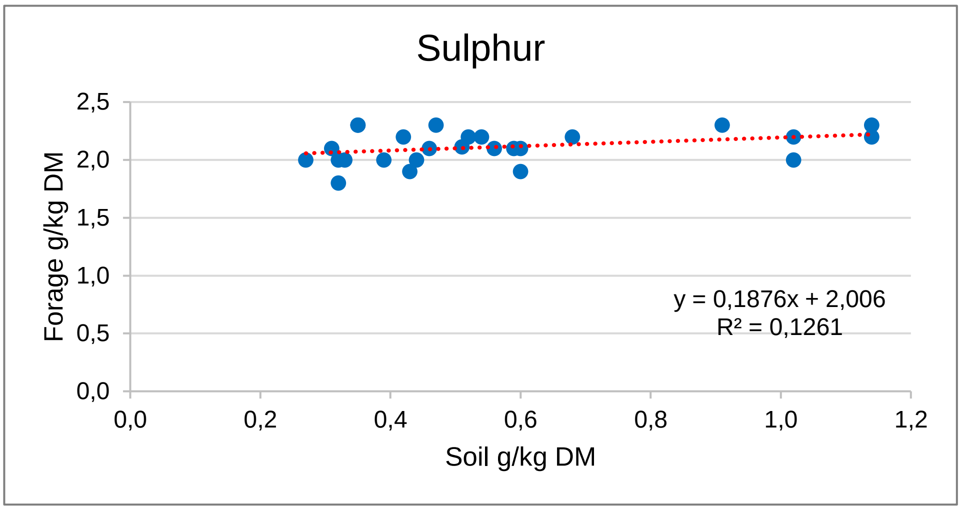

Figure 13. Regression analysis between S in soil and S in forage, where each dot represents the mean value of the soil sample and forage sample for each selected municipality

4.2 Micro minerals

In Table 8 the results of descriptive statistics of the micro minerals in the forage are shown. The maps of the micro mineral's concentrations are found in Appendix 8 – 15.

Table 8. Descriptive statistics of micro minerals in samples of forages from all Sweden

	Fe	Mn	Zn	Cu	Co	Se	I	Mo
N	48348	48347	48341	48347	3631	3767	3631	3748
Mean	190	66	34	7.0	0.09	0.04	0.2	1.9
Median	131	60	30	6.6	0.07	0.02	0.2	1.3
St.Dev.	332	34	45	8.0	0.08	0.06	0.4	2.0
Min	10	1.0	0.0	0.0	0.03	0.0	0.1	0.1
Pctl (25)	93	46	25	5.6	0.04	0.01	0.1	0.9
Pctl (75)	201	80	35	7.8	0.1	0.04	0.3	2.3
Max	50491	1900	4500	1220	1.2	1.9	14.1	38.0
Mode	110	56	28	5.1	0.04	0.02	0.1	0.8

Iron

The concentration of Fe in the forage were found in a large part of Sweden to be approximately 50-300 mg/kg DM (Appendix 8). A small region in northern Sweden had concentration of 300-545 mg/kg DM, in the forage (Appendix 8). The mean value was found to be, 190 mg/kg DM and the mode value, 110 mg/kg DM (Table 8). The distribution of the Fe analysis of the forage did not show a clear normal distribution (Figure 14). The amount of Fe in forage might often be influenced by soil contamination and in some cases, human error at the time of sample-taking.

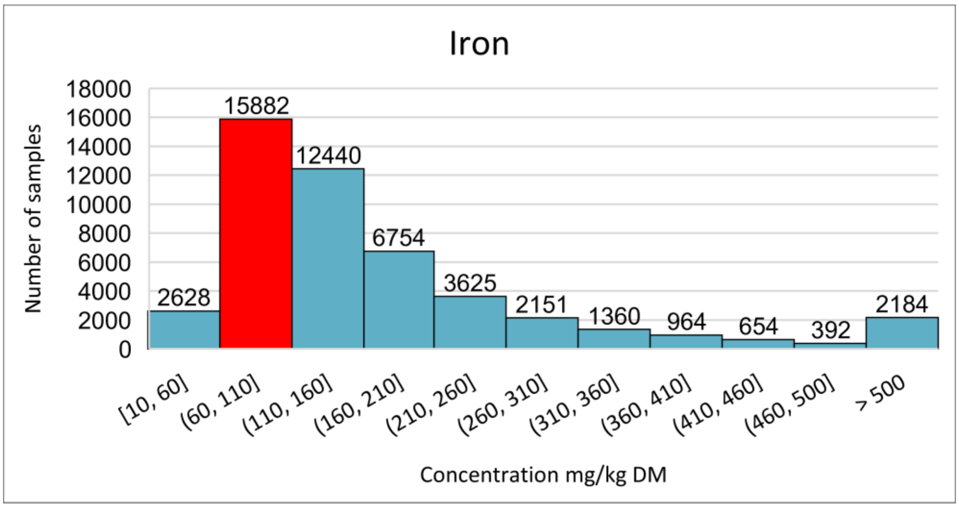

Figure 14. Histogram of the Fe content in forage samples. Red column is where the mode value of 110 mg/kg DM lays.

The results from the regression analysis between Fe in the soil and Fe in the forage showed a R^2 of 3% and had a small negative slope (Figure 15). This might be due to some of the selected municipalities had observations less than 10 and therefore these values were not included in the regression analysis.

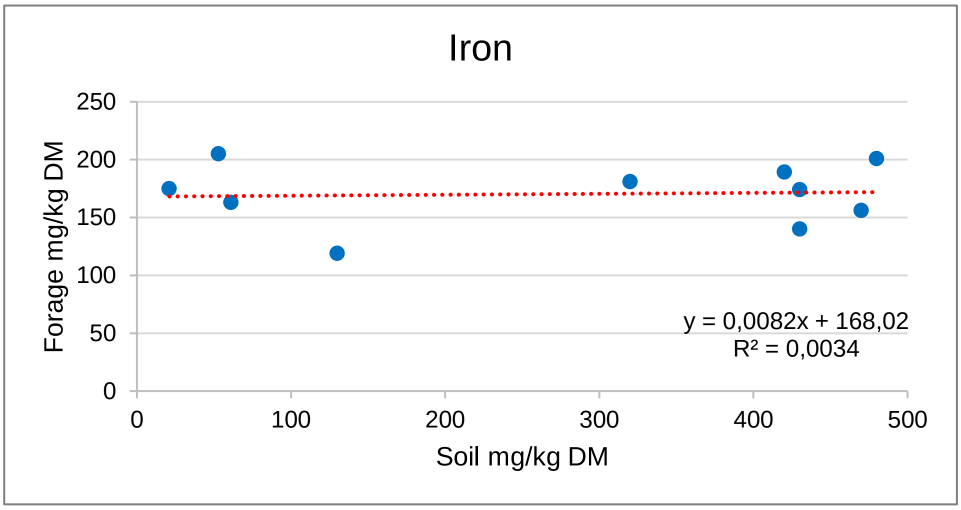

Figure 15. Regression analysis between Fe in soil and Fe in forage, where each dot represents the mean value of the soil sample and forage sample for each selected municipality.

The requirement of Fe for the lactating cow is 50 mg/kg DM (Table 4) (Volden, 2011). The availability can be enhanced by for instance Cu, but the Fe content may also influence the Cu availability of the feed, negatively (Suttle, 2010).

Manganese

The most frequent value of Mn in forage was 56 mg/kg DM and the mean value 66 mg/kg DM (Table 8). The content of Mn in the forage was found to be medium low (21-65 mg/kg DM) to medium (65-109 mg/kg DM) in most parts of Sweden. A small region in the north had a concentration of approximately 109-152 mg/kg DM (Appendix 9). The Mn content can be influenced by a high inclusion of red clover (Lindström *et al.*, 2014a) and the amount of rainfall, might decrease the content of Mn in the forage (Roche *et al.*, 2009).

The mean value of Mn in this study, was quite similar with the mean concentration reported by Minson (1990) (Table 1), but more comparable with the mean Mn concentration compiled by Spörndly (2003) (Table 2). The distribution showed a normal distribution with some high values that might indicate human error at sampling or at analyse of forage (Figure 16).

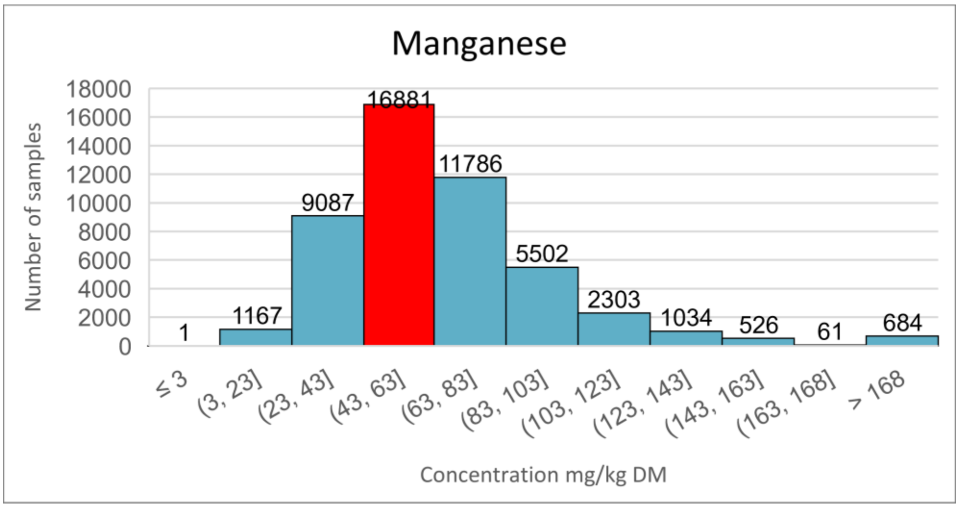

Figure 16. Histogram of the Mn content in forage samples. Red column is where the mode value of 56 mg/kg DM lays.

The results of the regression analysis showed a poor linear relation between the Mn soil and Mn forage, having a R^2 of 9% (Figure 17). This might be explained by the selected municipalities and a selection of other municipalities might have shown different results. The concentration of Mn in the forage is highly influenced by the soil properties and the availability of Mn of the plant increases at a pH of 6 (Frame & Laidlaw, 2011).

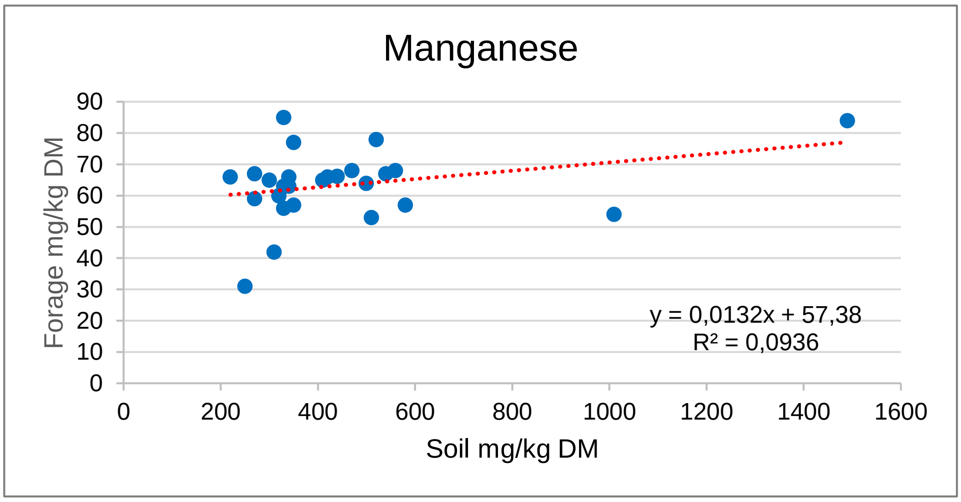

Figure 17. Regression analysis between Mn in soil and Mn in forage, where each dot represents the mean value of the soil sample and forage sample for each selected municipality.

The requirement of Mn for the lactating cow is 40 mg/kg DM (Table 4) (Volden, 2011). Based on the results from this study, forage produced in Sweden, have adequate concentration of Mn. Areas where the content of Mn is high, it might be good to be aware of the content of Cu as well, due to Mn, can interfere with Cu absorption and cause Cu deficiency (Suttle, 2010).

Zinc

The content of Zn in forage, was found to be similar in a large part of Sweden with concentration of 20-88 mg/kg DM. Some areas in middle of Sweden showed low concentration of less than 20 mg Zn/kg DM (Appendix 10). The mean value was 33.5 g/kg DM and the mode was 28 mg/kg DM (Table 8). The Zn content in forage is influenced by both attributes in the plant and the weather, for instance timothy grass contains higher concentration of Zn, than other species (Lindström *et al.*, 2014a). The content of Zn might be positively influenced by rainfall (Roche *et al.*, 2009). Harvest time might also influence the content of Zn, due to a decrease of Zn through the phenological development (Lindström *et al.*, 2014a).

The mean concentration of Zn in forage found in this study, was more comparable with the mean concentration of Zn, reported by Minson (1990) (Table 1), than the mean value presented previously for Swedish forage by Spörndly (2003) (Table 2).

The minimum value of Zn presented in Table 8 was most likely due to a human error as the detection level of Zn was 3 mg/kg and the minimum value showed 0 mg/kg DM. The maximum value was very high, which also might indicate a human error at the laboratory or at the site of the sample-collection (Table 8). The distribution of the Zn analysis in the forage showed a tendency of normal distribution (Figure 18).

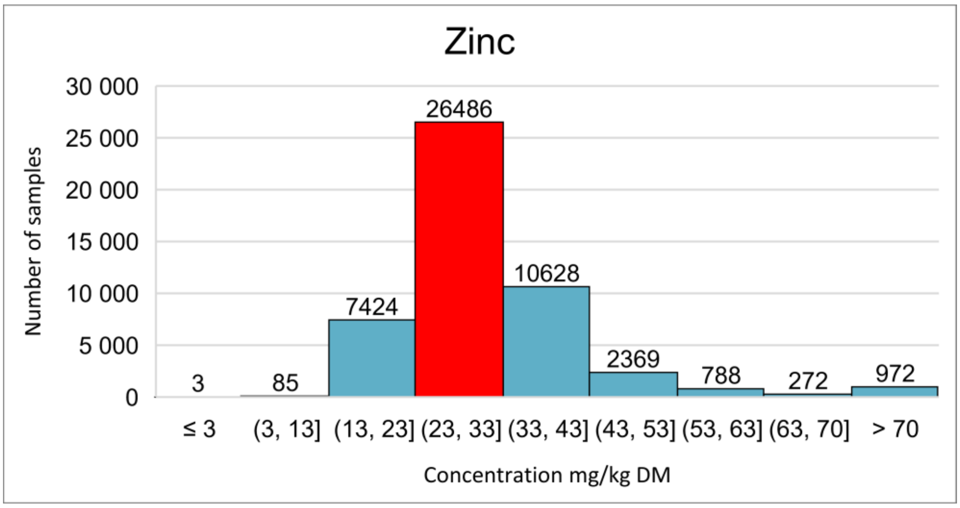

Figure 18. Histogram of the Zn content in forage samples. Red column is where the mode value of 28 mg/kg DM lays.

The results of the regression analysis showed only a R^2 of 2%, between Zn in soil and Zn in forage (Figure 19), which indicates a non-linear relation.

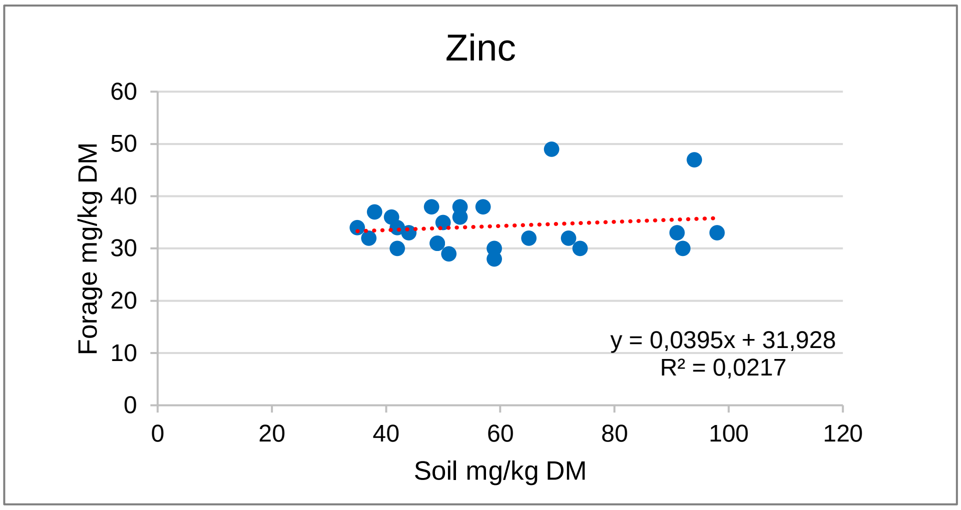

Figure 19. Regression analysis between Zn in soil and Zn in forage, where each dot represents the mean value of the soil sample and forage sample for each selected municipality.

The requirement of Zn of the cow is 50 mg/kg DM (Table 4) (Volden, 2011). To minimize the risk of Zn deficiency, supplementation of Zn or a customize mineral feed might be necessary.

Copper

Copper had a similar pattern of the concentration in the forage in the whole country. The content was found to be 5.0-9.0 mg/kg DM, with some smaller regions of 9.0-13.0 mg/kg DM (Appendix 11). The mode value was 5.1 mg/kg DM and the mean value was 7.0 mg/kg DM (Table 8).

The content of Cu in the forage might be affected by the proportion of red clover in the sward (Pirhofer-Walzl *et al.*, 2011; Lindström *et al.*, 2014a; Lindström *et al.*, 2014b). The Cu concentration decreases during the phenological development and the harvest time might therefore affect the Cu content of the forage (Lindström *et al.*, 2014a). The number of sunlight hours might also affect the Cu content, due to the negative correlation, Cu has to the number of sunlight hours (Roche *et al.*, 2009).

The mean Cu concentration of forage found in this study, were a bit higher than the mean Cu concentration presented by Minson (1990) (Table 1). The distribution of the Cu analysis of the forage samples showed a tendency of normal distribution with, however a larger proportion of higher values (Figure 20).

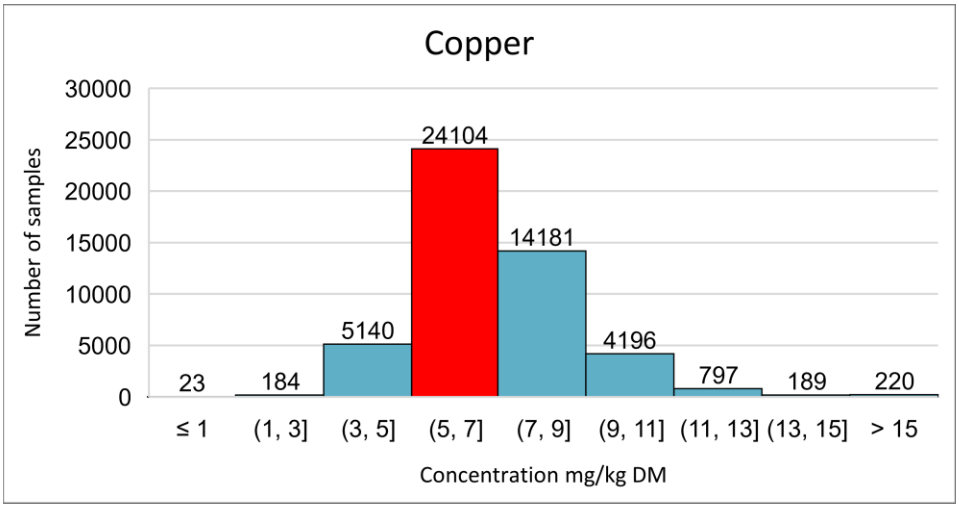

Figure 20. Histogram of the Cu content in forage samples. Red column is where the mode value of 5.1 mg/kg DM lays.

The results from the regression analysis indicated a good relation, with a R^2 of 65%, between Cu in soil and Cu in forage (Figure 21). The Cu concentration might be influenced by the pH of the soil, as the availability of Cu is better when pH is around 5 (Frame & Laidlaw, 2011). The Cu concentration might also be affected by the organic matter of the soil, as the Cu content increased when the organic matter in the soil was higher than 20% (Eriksson *et al.*, 2017).

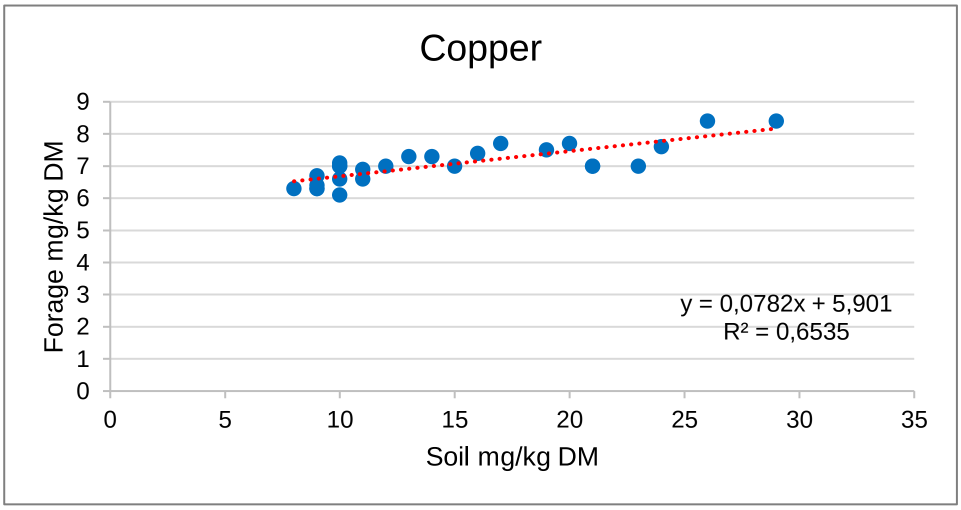

Figure 21. Regression analysis between Cu in soil and Cu in forage, where each dot represents the mean value of the soil sample and forage sample for each selected municipality.

The requirement of the lactating cow is 10 mg/kg DM (Table 4) (Volden, 2011). The availability of Cu for the animals are however mainly influenced of the content of Mo and S in the forage, due to the formation of complex of these minerals in the rumen (Suttle, 1991). In areas were the content of Mo or S is high, there might be a risk of the animal developing Cu deficiency. If the farmer is aware to have high concentrations of Mo or S in the soil, a mineral feed with extra Cu might be necessary. However, based on the result from this study, the regression analysis of S in the soil and S in the forage, showed a poor relation (Figure 13), while the regression analysis of Mo in the soil and Mo in the forage, showed a good relation (Figure 28). Additional analysis of the soil or the forage might therefore be required to make sure what kind of mineral feed is the most suitable for each individual farm.

The content of Fe, Mn and Zn might also influence the Cu availability for the animals and cause Cu deficiency (Suttle, 2010).

Cobalt

The concentration of Co in the forage varied in southern Sweden, where a large part had concentrations of 0.05-0.15 mg/kg DM. In south-east, some areas including Öland and Gotland, were found to have a content of less than 0.05 mg/kg DM (Appendix 12). The mode value for Co in forage was 0.04 mg/kg DM and the mean value 0.09 mg/kg DM (Table 8). The content of Co in grass and clover, might be influenced by a higher inclusion of red clover in the sward, due to the general higher mineral content of red clover (Pirhofer-Walzl *et al.*, 2011; Lindström *et al.*, 2014a; Lindström *et al.*, 2014b). The conservation method of the forage might increase the Co content, mostly due to soil contamination during the ensiling process (Schlegel *et al.*, 2018).

The detection level of Co was reported from the laboratory to be 0.04 mg/kg (Table 5) and the mode value of Co in Swedish forage was found to be the same, 0.04 mg/kg DM. This might explain the distribution of the Co analysis (Figure 22),

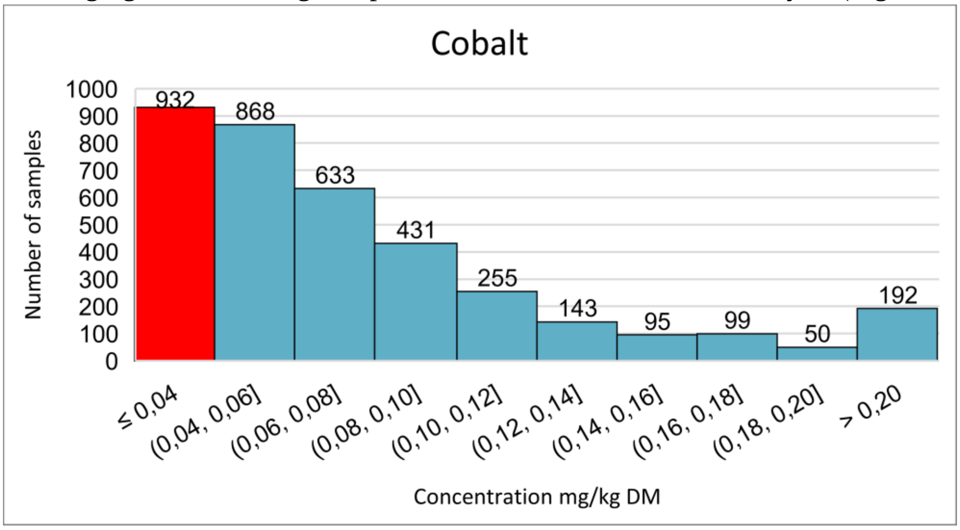

Figure 22. Histogram of the Co content in forage samples. Red column is where the mode value of 0.04 mg/kg DM lays.

which shows that the content of Co in the forage is very low and a large proportion of the analysis is close to the detection level.

The regression analysis between Co in soil and Co in the forage, shows a poor linear regression, with a R^2 of 8.6% (Figure 23).

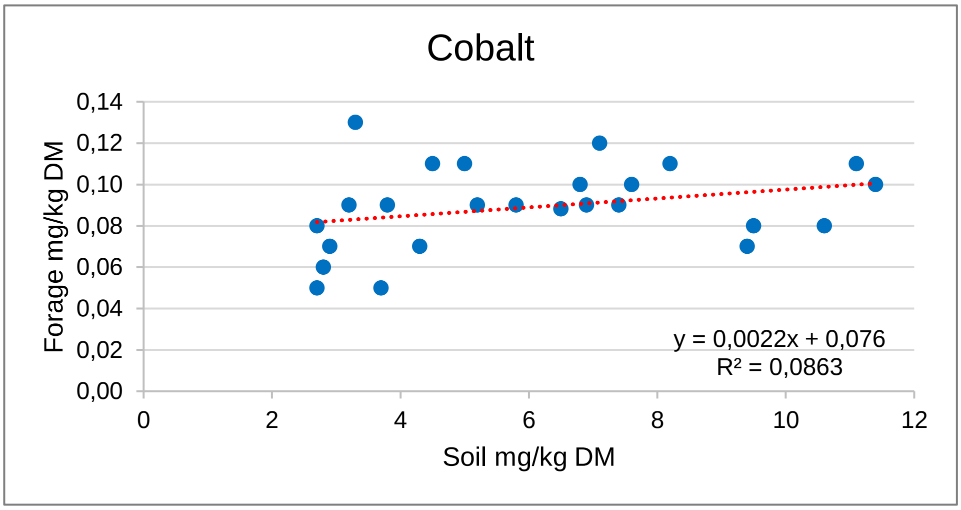

Figure 23. Regression analysis between Co in soil and Co in forage, where each dot represents the mean value of the soil sample and forage sample for each selected municipality.

The requirement of the lactating cow is 0.11 mg Co /kg DM (Table 4) (Volden, 2011). Cobalt is needed in ruminants' diets, so the rumen microbes can synthesis vitamin B_{12}. A deficiency of Co in the forage might indicate that Co supplement may be needed to avoid vitamin B_{12} deficiency.

Selenium

The content of Se in the forage had a similar concentration of less than 0.02 mg/kg DM in the east with similar concentrations along the east coast. In the west the content in the forage was a bit higher, with concentrations of 0.02-0.08 mg Se/kg DM (Appendix 13). The mode value was found to be 0.02 mg/kg DM and the mean value, 0.04 mg/kg DM (Table 8). The content of Se in the forage might be increased by the proportion of clover in the sward (Pirhofer-Walzl *et al.*, 2011; Lindström *et al.*, 2014a; Lindström *et al.*, 2014b).

The distribution of Se analysis showed not to be normal (Figure 24), which might be explained by possible soil contaminations. The mean concentration of Se in forage in this study, was in more agreement with the mean value of Se reported in forage in the UK (MAFF 1990, See Suttle, 2010) (Table 1), than the mean value of Se in forage in Sweden reported by Spörndly (2003) (Table 2).

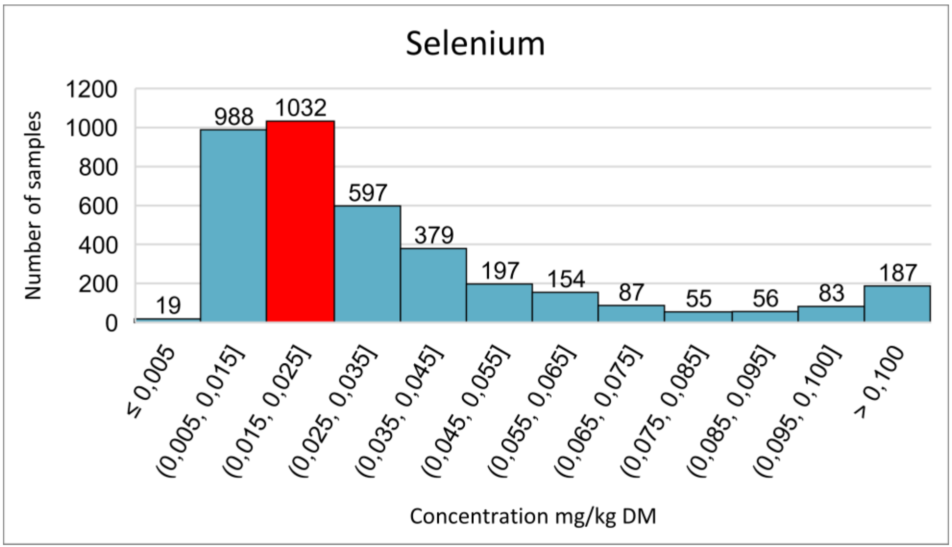

Figure 24. Histogram of the Se content in forage samples. Red column is where the mode value of 0.02 mg/kg DM lays.

The regression analysis between soil Se and forage Se showed a non-linear relation with a R^2 of 6% (Figure 25).

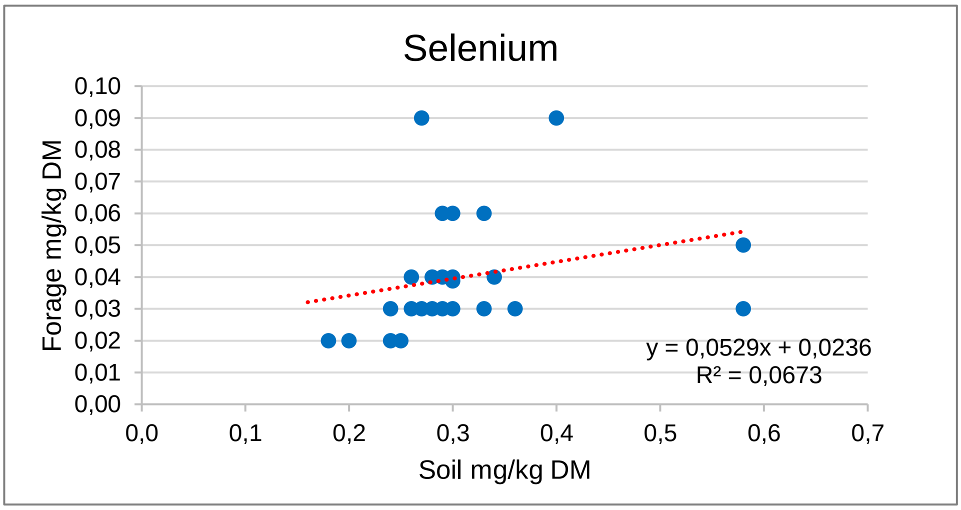

Figure 25. Regression analysis between Se in soil and Se in forage, where each dot represents the mean value of the soil sample and forage sample for each selected municipality.

The requirement for the lactating cow is 0.2 mg/kg DM (Table 4) (Volden, 2011). A deficiency in the forage can, in some extent, be prevented by supplementation of vitamin E (Goff, 2018).

Iodine

The large part of Sweden had a content of less than 0.2 mg/kg DM Iodine in the forage. Some areas near the sea in west and east had a concentration of 0.2-0.5 mg/kg DM (Appendix 14). The mean value was 0.2 mg/kg DM and the mode value was 0.1 mg/kg DM (Table 8). The mean concentration of I presented in this study was comparable to the mean concentration of I, reported by Minson (1990) (Table 1).

The detection level reported by the laboratory was 0.1 mg/kg (Table 5), which also was the mode value (Table 8). The mode value lays close to the detection level and might have contributed to the distribution of the I analysis (Figure 26).

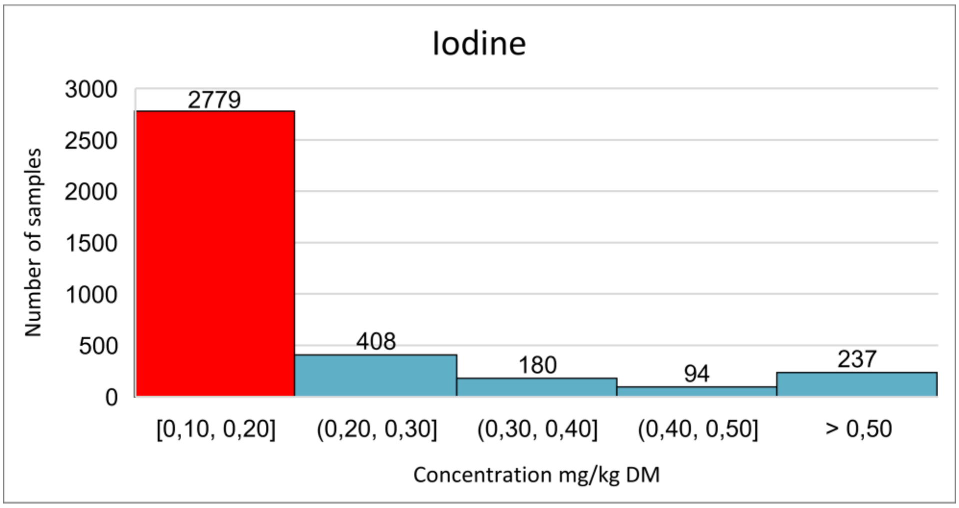

Figure 26. Histogram of the I content in forage samples. Red column is where the mode value of 0.1 mg/kg DM lays.

The requirement of the lactating cow is 1 mg/kg DM (Table 4) (Volden, 2011). Having forage as a single source to lactating cows, might lead to deficiencies in I. The maximal tolerance for cattle is 50 mg/kg DM (Table 4) (NRC, 2005). It is very rare that cattle be afflicted by I toxicities. However, the maximal tolerance is important to be aware of, due to its effect on human health (NRC, 2005).

Molybdenum

The content of Mo in the forage was similar in large part of Sweden and was on the range 0.5-1.6 mg/kg DM. Areas around the two lakes, Vänern and Vättern in south and near the cost in east had varied concentrations but with a majority of 1.6-2.8 mg/kg DM (Appendix 15). The mode value was 0.8 mg/kg DM and the mean value 1.9 mg/kg DM (Table 8).

The content of Mo in forage could be mainly influenced by the growth state of the plant. The content of Mo decreased with, more than 50% in red clover, as the plant continued to grow (Lindström *et al.*, 2014a).

The distribution of the Mo analysis in the forage showed a tendency to normal distribution (Figure 27).

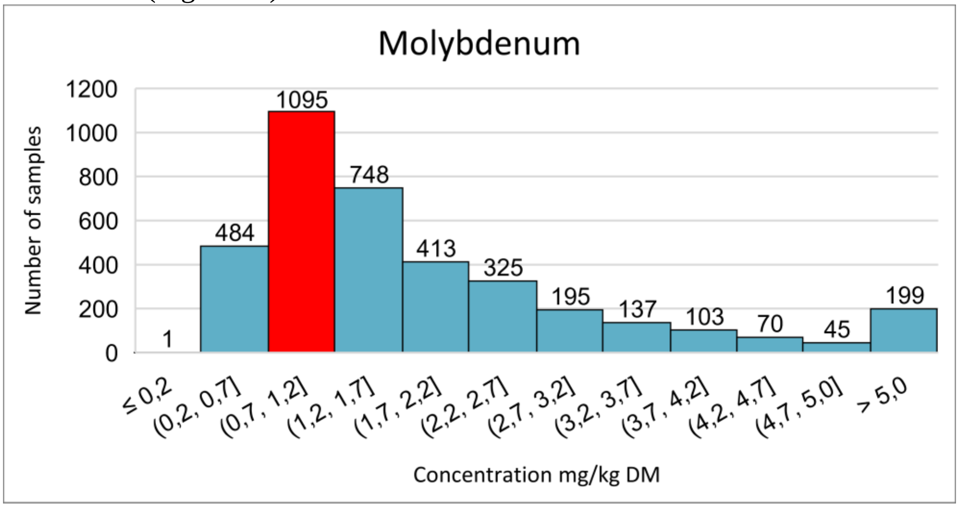

Figure 27. Histogram of the Mo content in forage samples. Red column is where the mode value of 0.8 mg/kg DM lays.

The linear relation between Mo in the soil and Mo in the feed, shows a good relation with a R^2 of 50% (Figure 28), in comparison to the other micro minerals.

The content in the soil is highly influenced by the soil pH, where the availability is higher with a pH at 6 (Frame & Laidlaw, 2011). The Mo concentration may also be higher when the organic matter in the soil is more than 20% (Eriksson *et al.*, 2017).

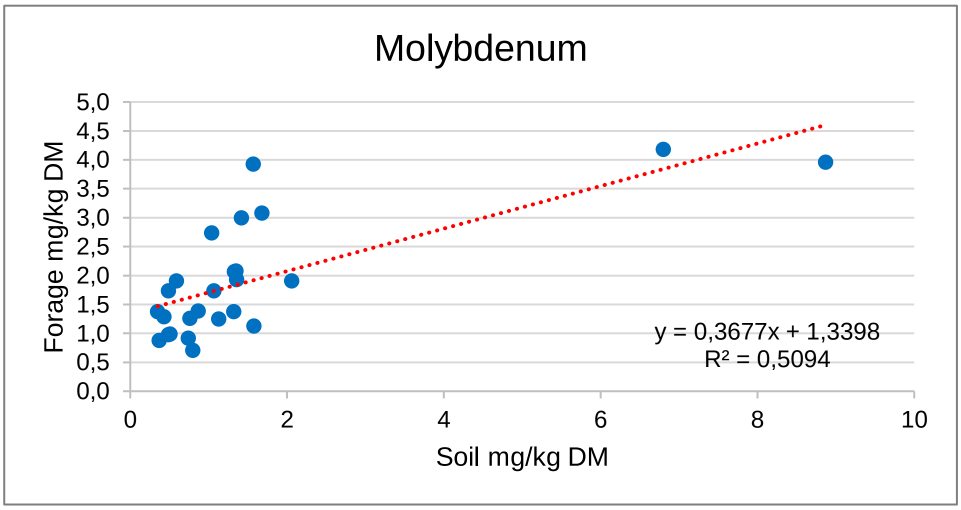

Figure 28. Regression analysis between Mo in soil and Mo in forage, where each dot represents the mean value of the soil sample and forage sample for each selected municipality.

No minimal requirement of Mo for cattle is available. The maximal inclusion of Mo for the cattle is 2.5 mg/kg of the total feedstuff (Table 4) (EC No 1831/2003). Molybdenum in the forage can interfere with the absorption of Cu in the animal and cause Cu deficiency. When the content of Mo is low, however, and the Cu is high, the animals can develop Cu toxicity (NRC, 2005). As previously mentioned, Cu, Mo and S forms complex in the rumen, that interferes with the Cu absorption negatively and the awareness of the Cu, Mo and S content in the forage is therefore, important to ensure good animal health and performance. Based on the result from this study, approximately 20% of the Mo analysis of the forage samples (Figure 27), had higher concentrations than the recommended maximal inclusion of Mo (EC No 1831/2003). In the areas where these 20% of the samples were taken, there might be a higher risk of Cu deficiency.

4.3 General discussion

The forage samples used in this study were collected and sent in by farmers from all over Sweden. The farmer's selected themselves what type of feed code the sample should be analysed as. This means that it is not completely trustworthy that the samples were sent in with the correct feed code. This study did not investigate the different mineral concentration in relation to botanical composition or in this case, feed code. A separate study might, therefore be needed to see the fully extent of what effect the botanical composition has on the mineral content in Swedish forage.

The climate of Sweden differs a lot from north to south. The number of sunlight hours are general known to be more in the south of Sweden and you might therefore speculate that the mineral content might be affected by the climate in some way. This study has not looked at the effect on weather and further studies are therefore needed to understand the effect of climate on the content of minerals in Swedish forage.

The results could have also been influenced by the difference in number of farms between north and south of Sweden. Due to the long distance in the north the density of the dairy farms is lower, and the set search radius used in the interpolation in this study might not have included all the farms in the north and thereby affected the average concentration.

5 Conclusion

Forage analysis is essential in the field of animal nutrition, to ensure the animals gets adequate amount of the needed minerals. Maps like those developed in this study can be of use for advisors, researchers or farmers to get an idea of what mineral status a specific area has. The results from this study showed mean concentrations of calcium, phosphorus, magnesium, potassium, sulphur and copper comparable, to previously reported values for Swedish forage. The mean content of zinc, manganese and selenium showed, however, increased mean values, compared to earlier values of Swedish forage and should therefore be the new recommended values for Swedish forage. This study also showed a difference in the phosphorus concentration between the northern and southern Sweden, which contradicts previously studied values of phosphorus. According to the result from this study, approximately 20% of the forage samples had higher concentrations of Molybdenum, than the recommended maximal inclusion level. In the future more, research is needed on the effect of mineral content, mentioned in this study, but for Swedish conditions.

It was also concluded that for the selected municipalities in this study, calcium, phosphorus, copper and molybdenum had the strongest determination coefficient, between soil and forage, with 57%, 57%, 65% and 50% respectively. In the future, a new study might be needed where the soil and forage determination coefficient can be investigated in other municipalities and perhaps whole Sweden.

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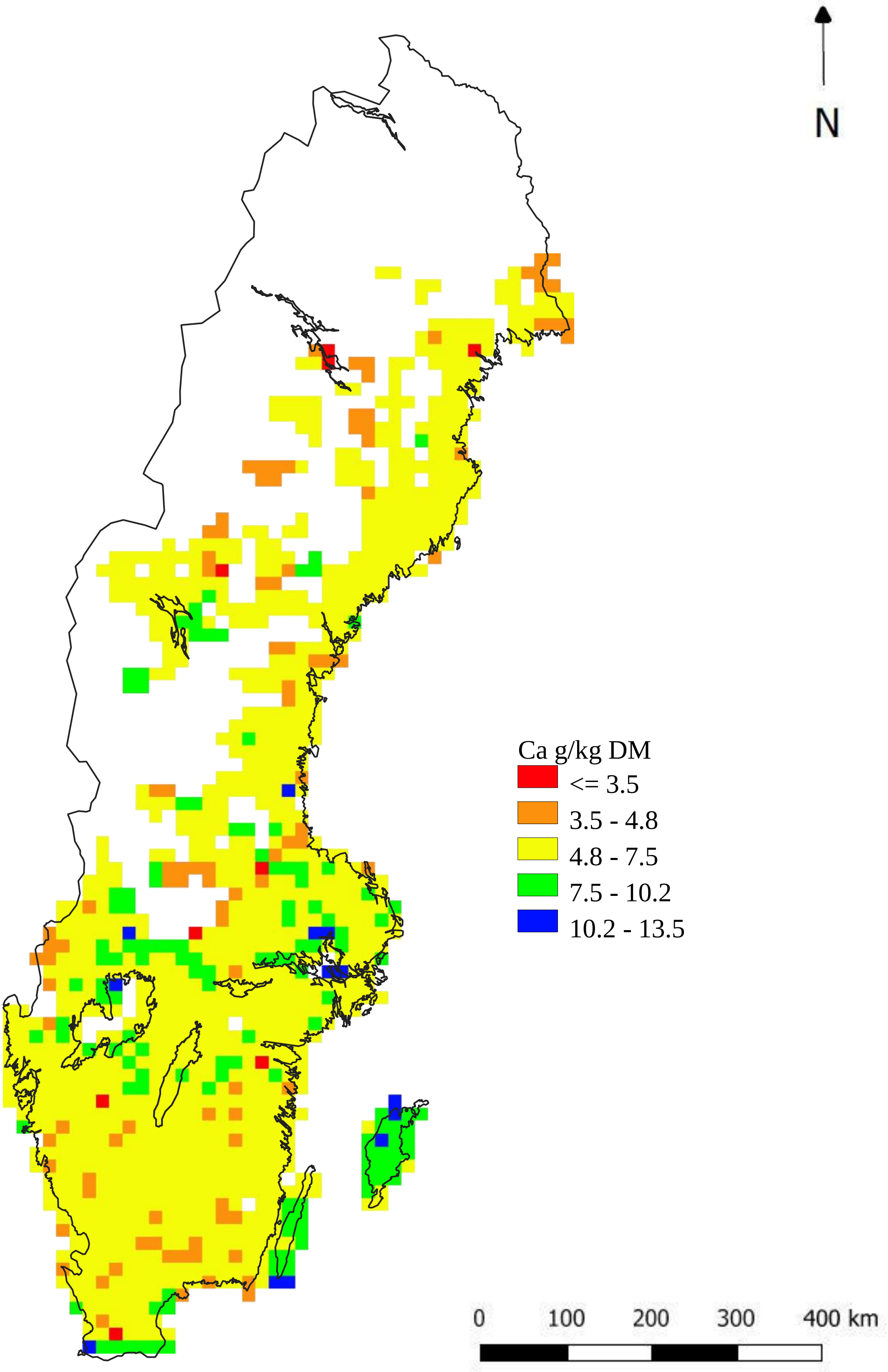
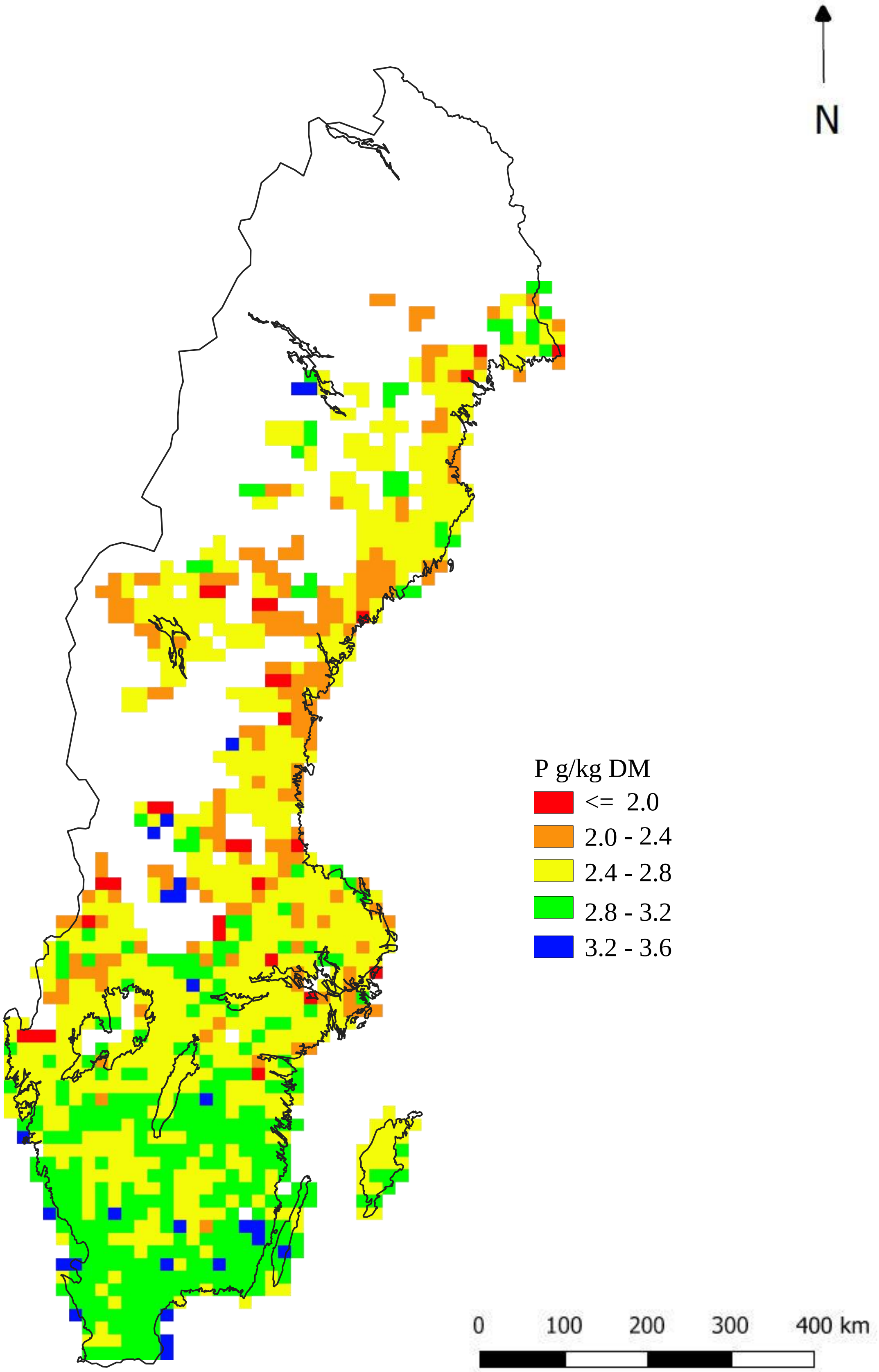
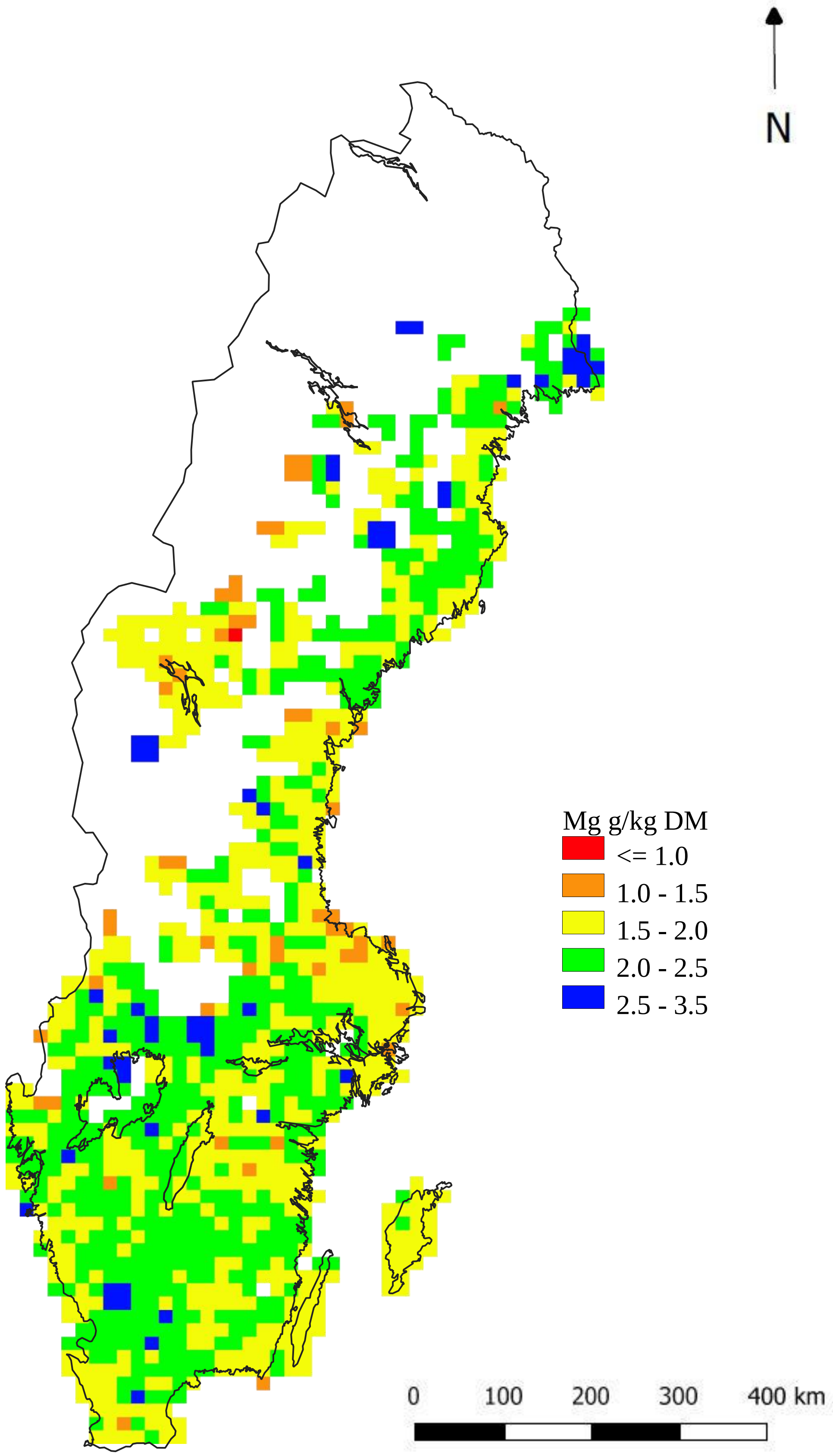
Appendix 1 Map of calcium (kalcium) concentration



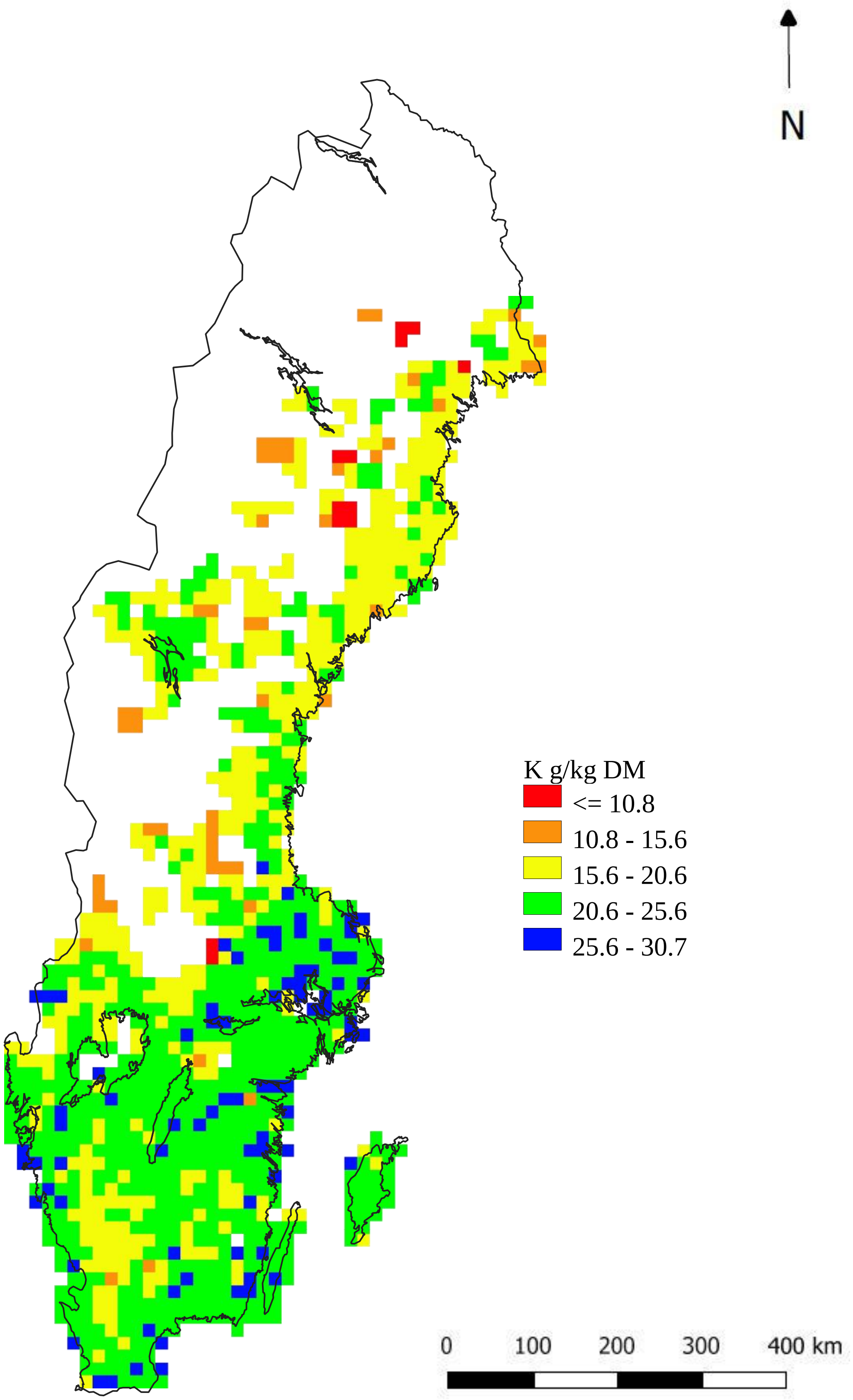
Appendix 2 Map of phosphorus (fosfor) concentration



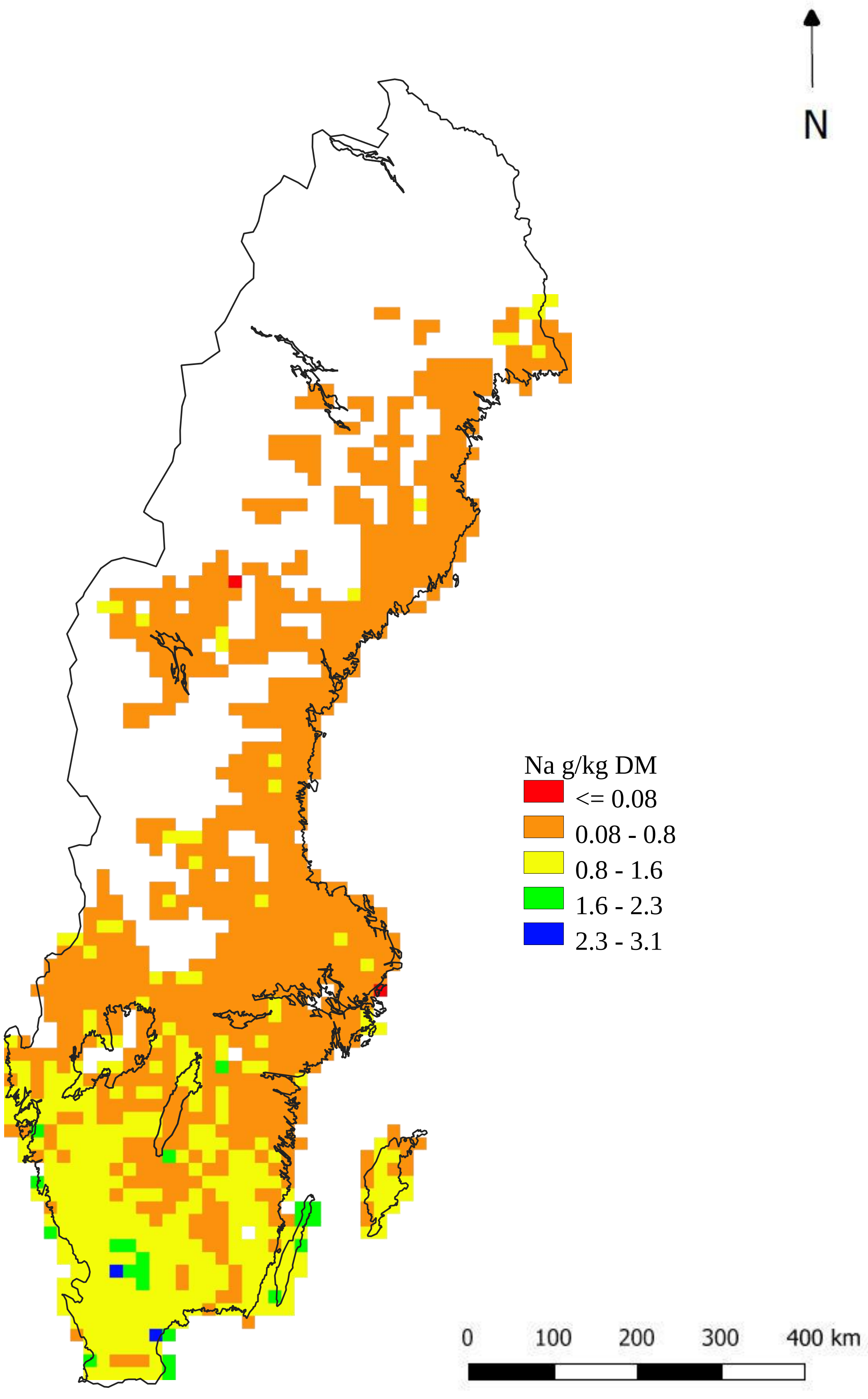
Appendix 3 Map of magnesium (magnesium)concentration



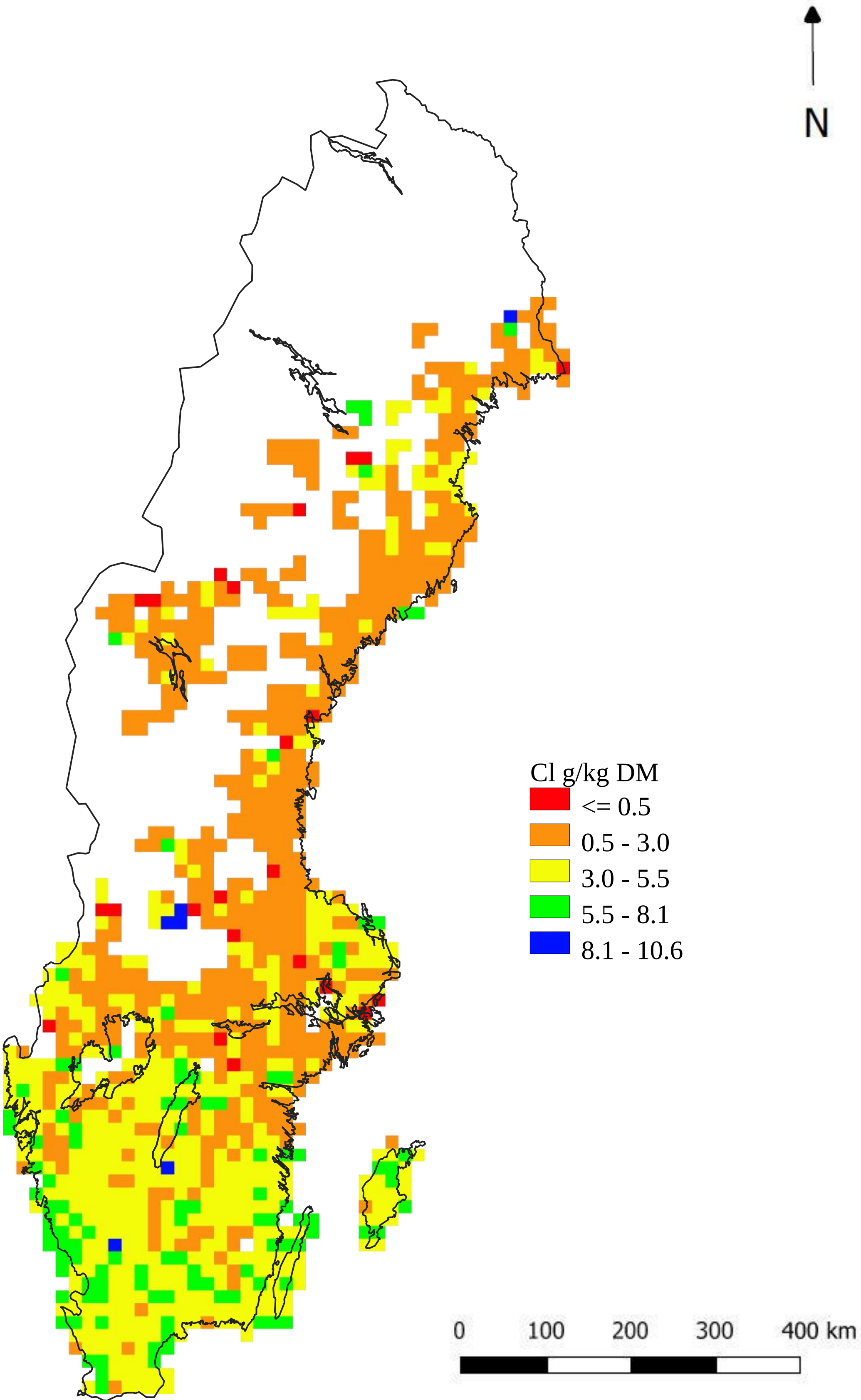
Appendix 4 Map of potassium (kalium) concentration



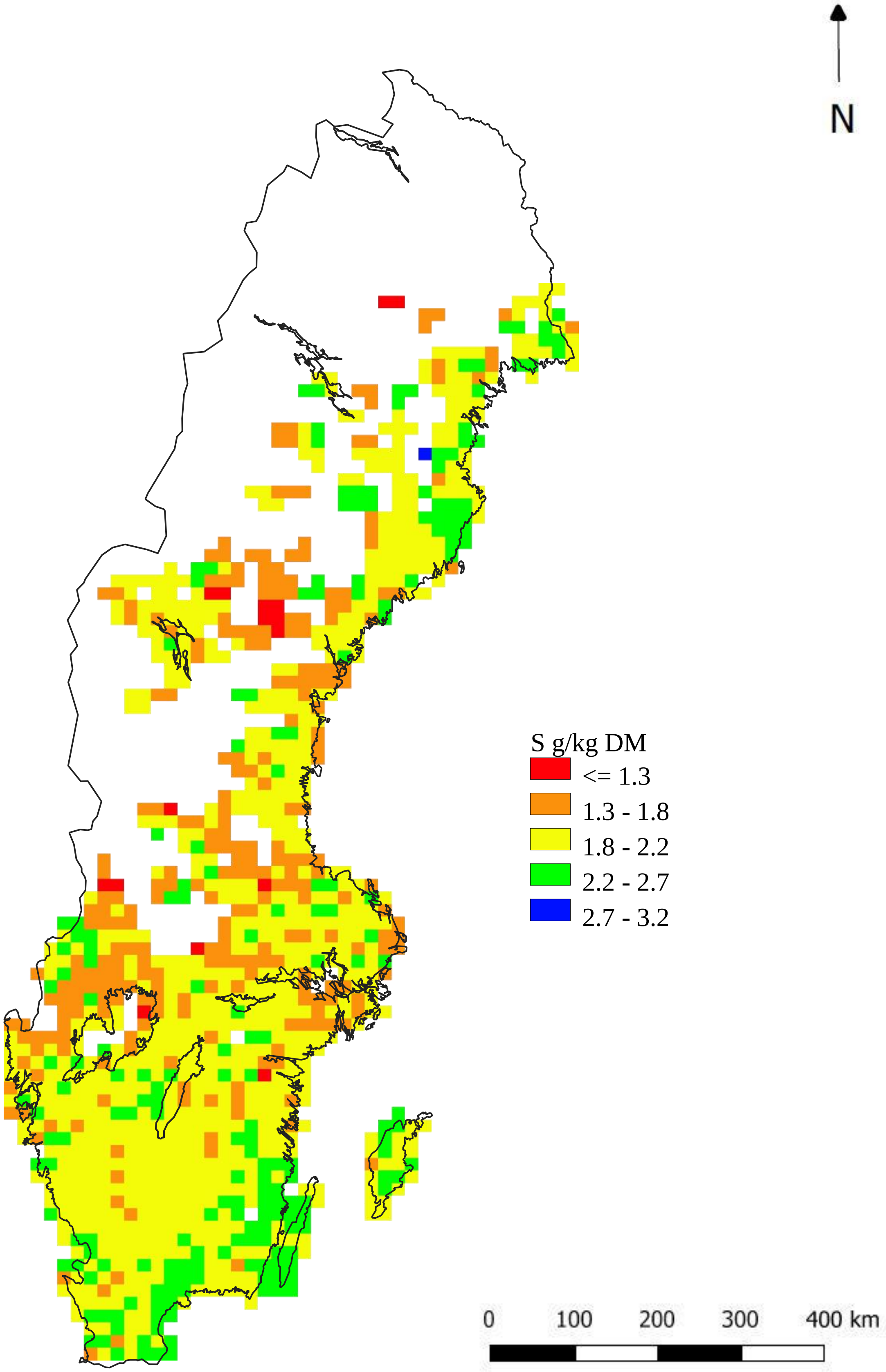
Appendix 5 Map of sodium (natrium) concentration



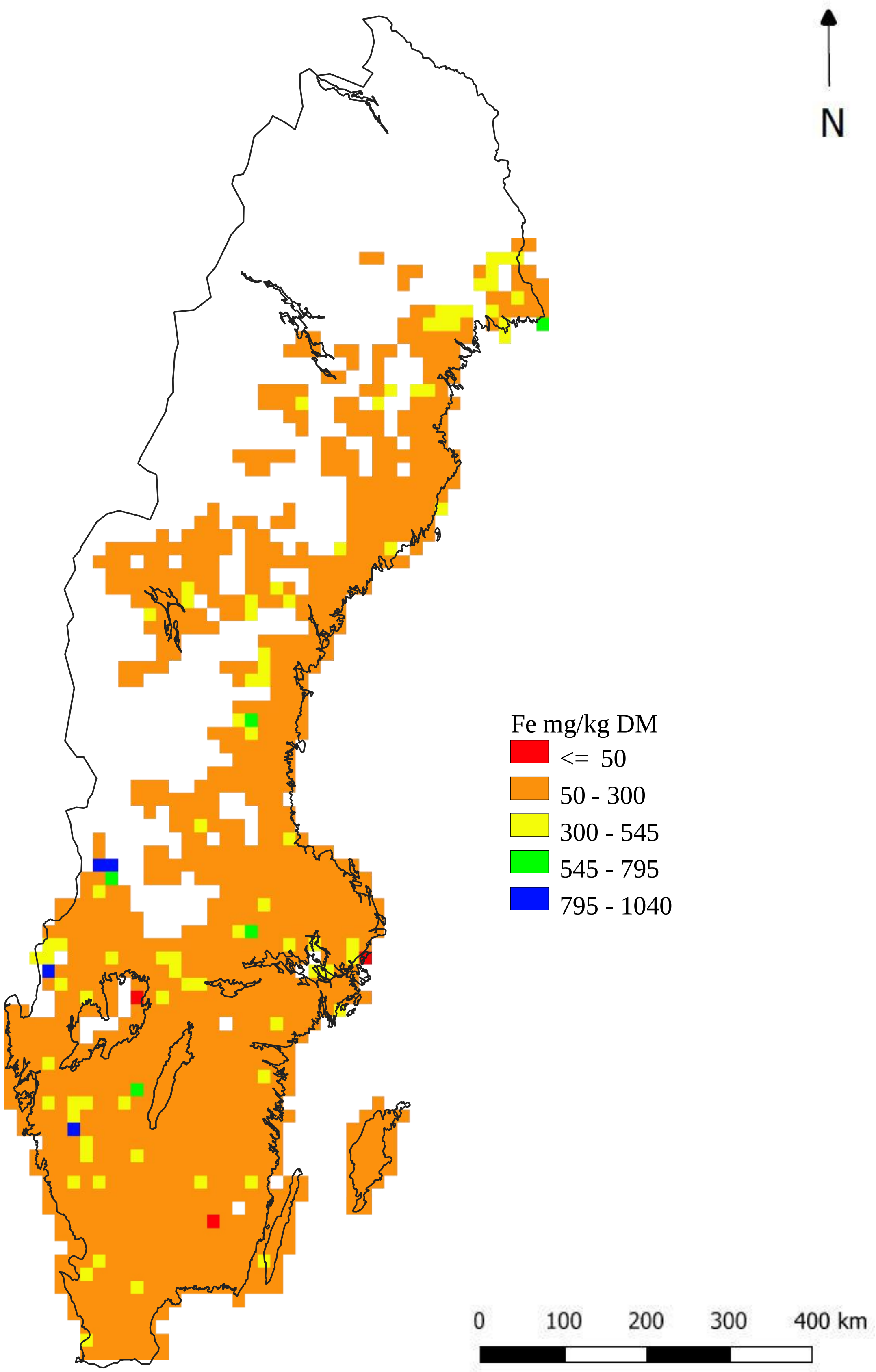
Appendix 6 Map of chlorine (klor) concentration



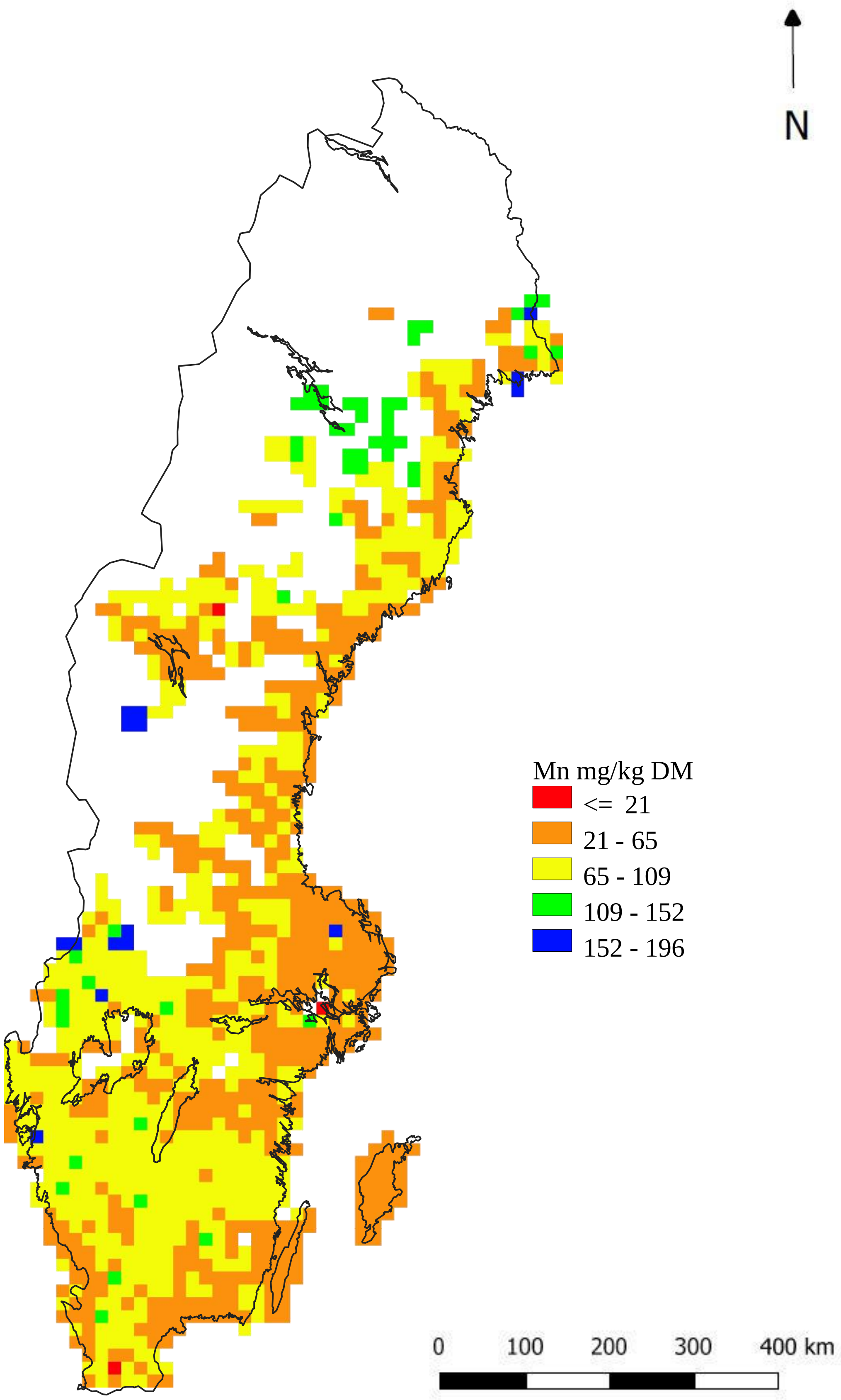
Appendix 7 Map of sulphur (svavel) concentration



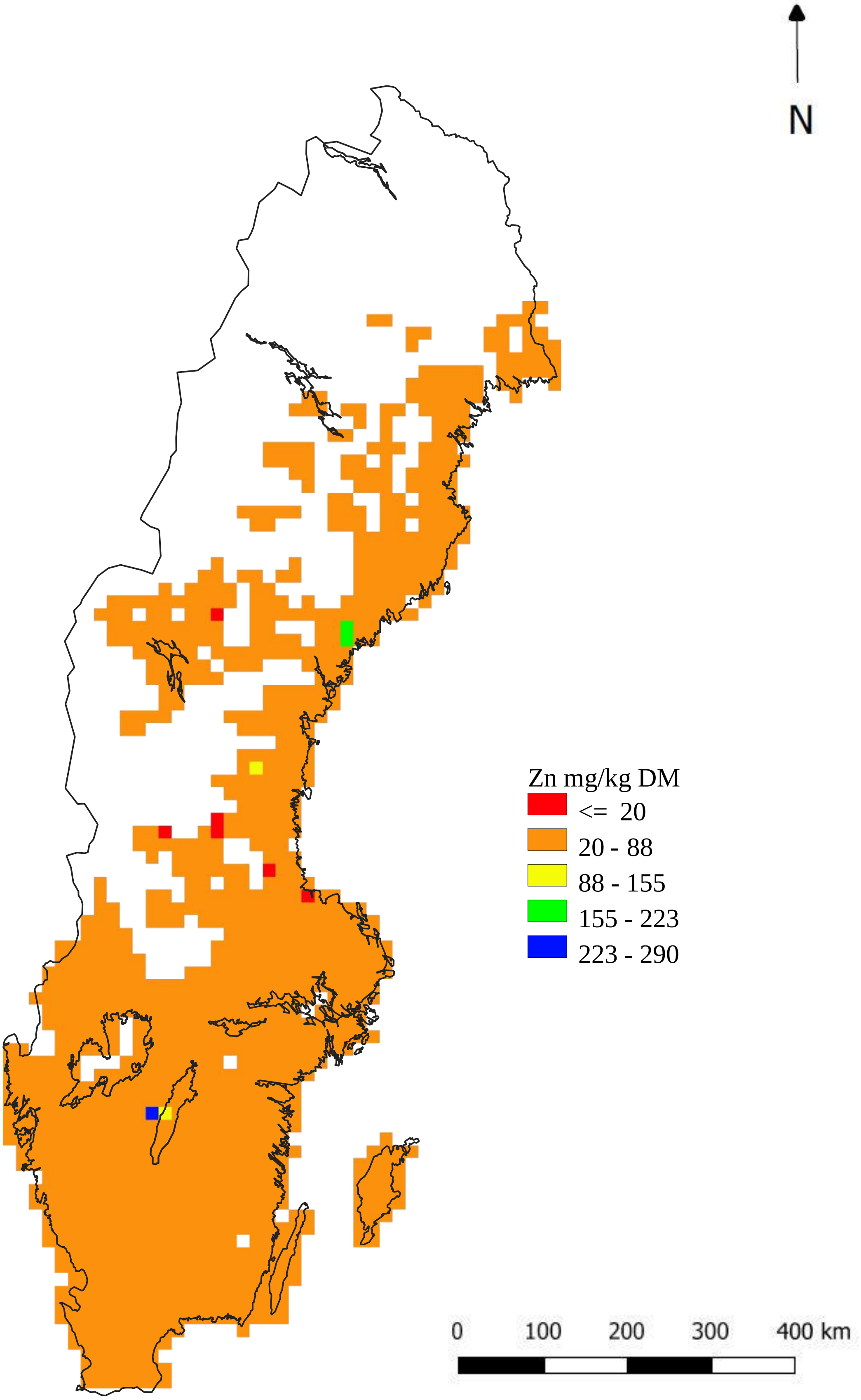
Appendix 8 Map of iron (järn) concentration



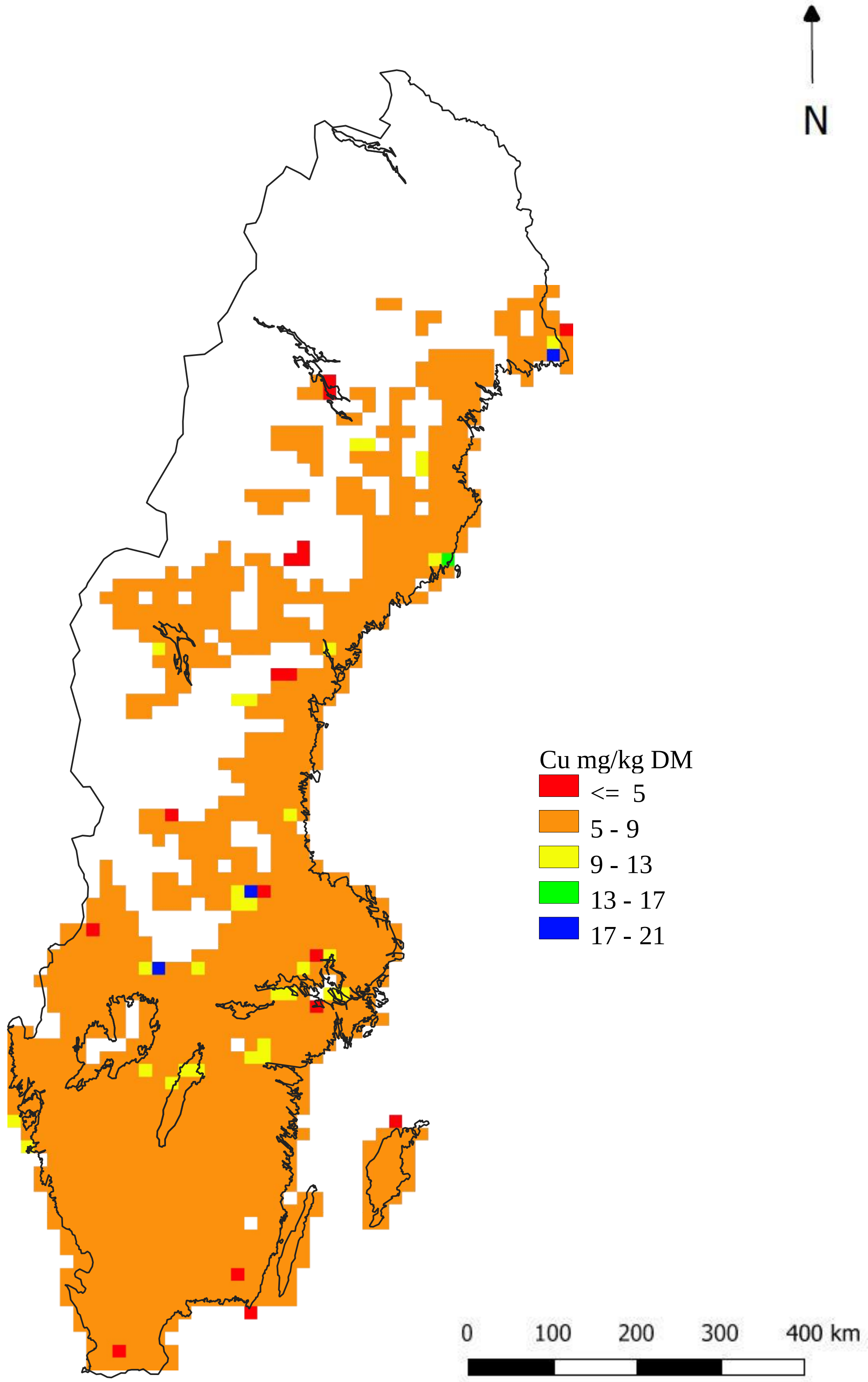
Appendix 9 Map of manganese (mangan) concentration



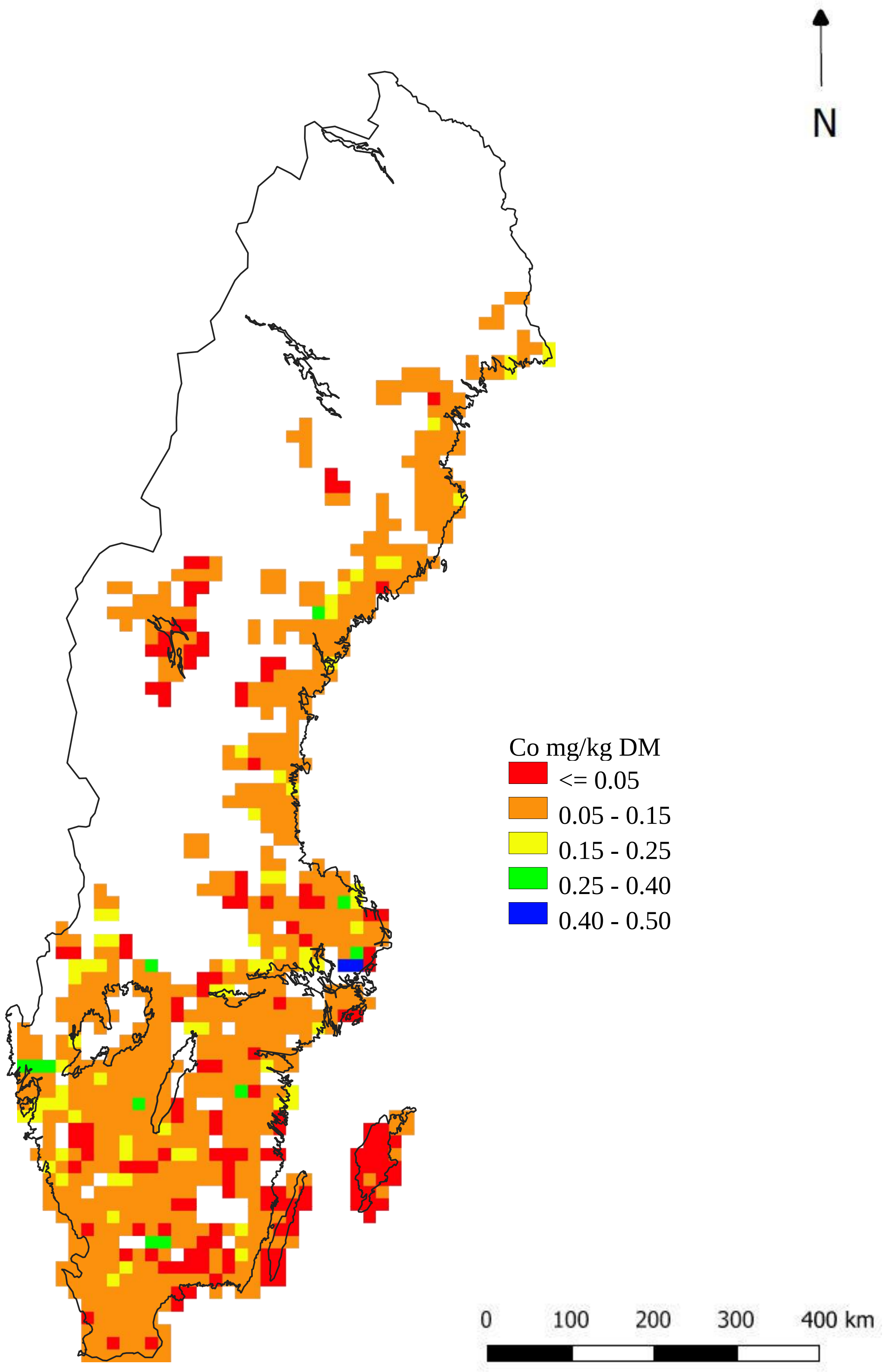
Appendix 10 Map of zinc (zink) concentration



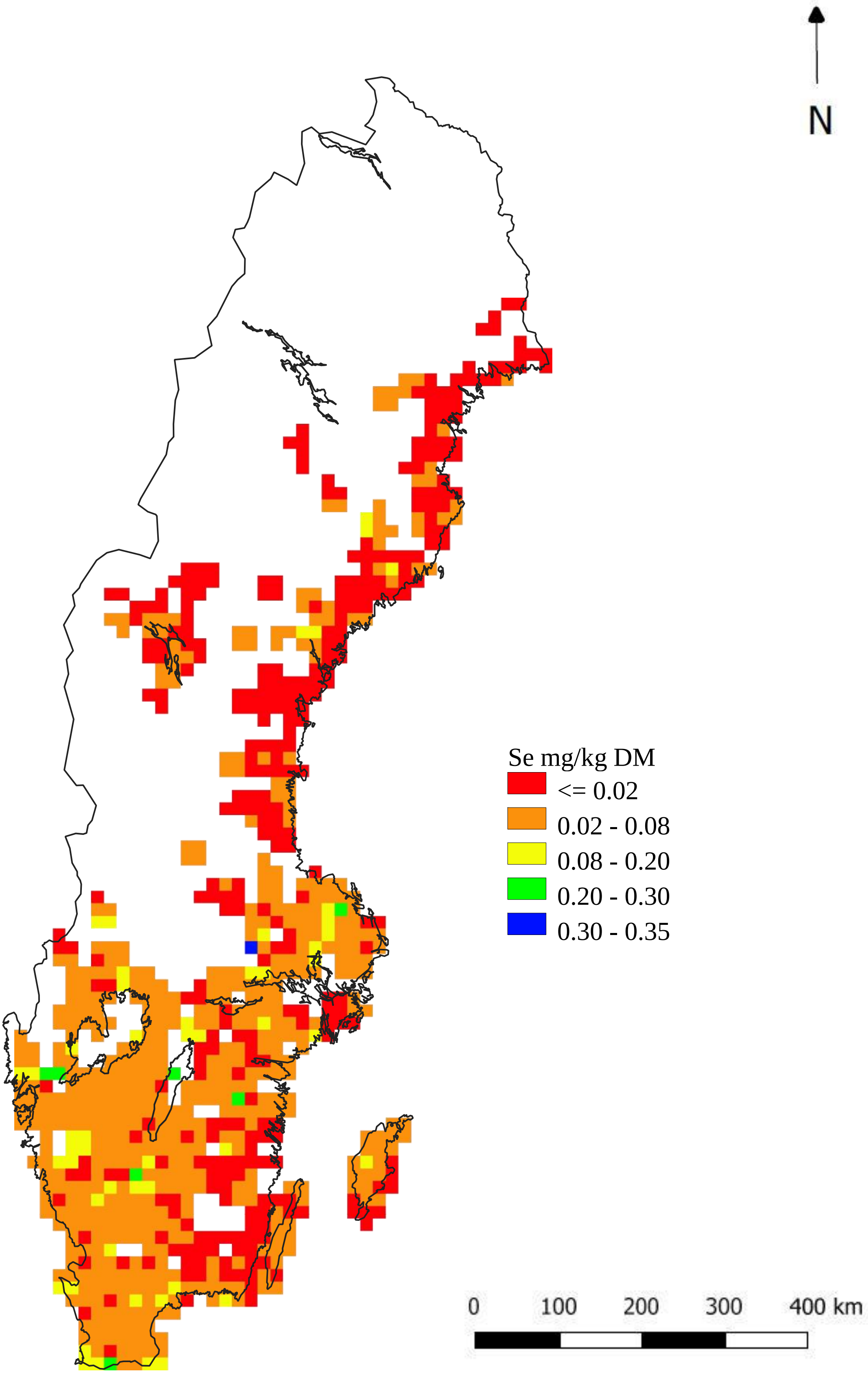
Appendix 11 Map of copper (koppar) concentration



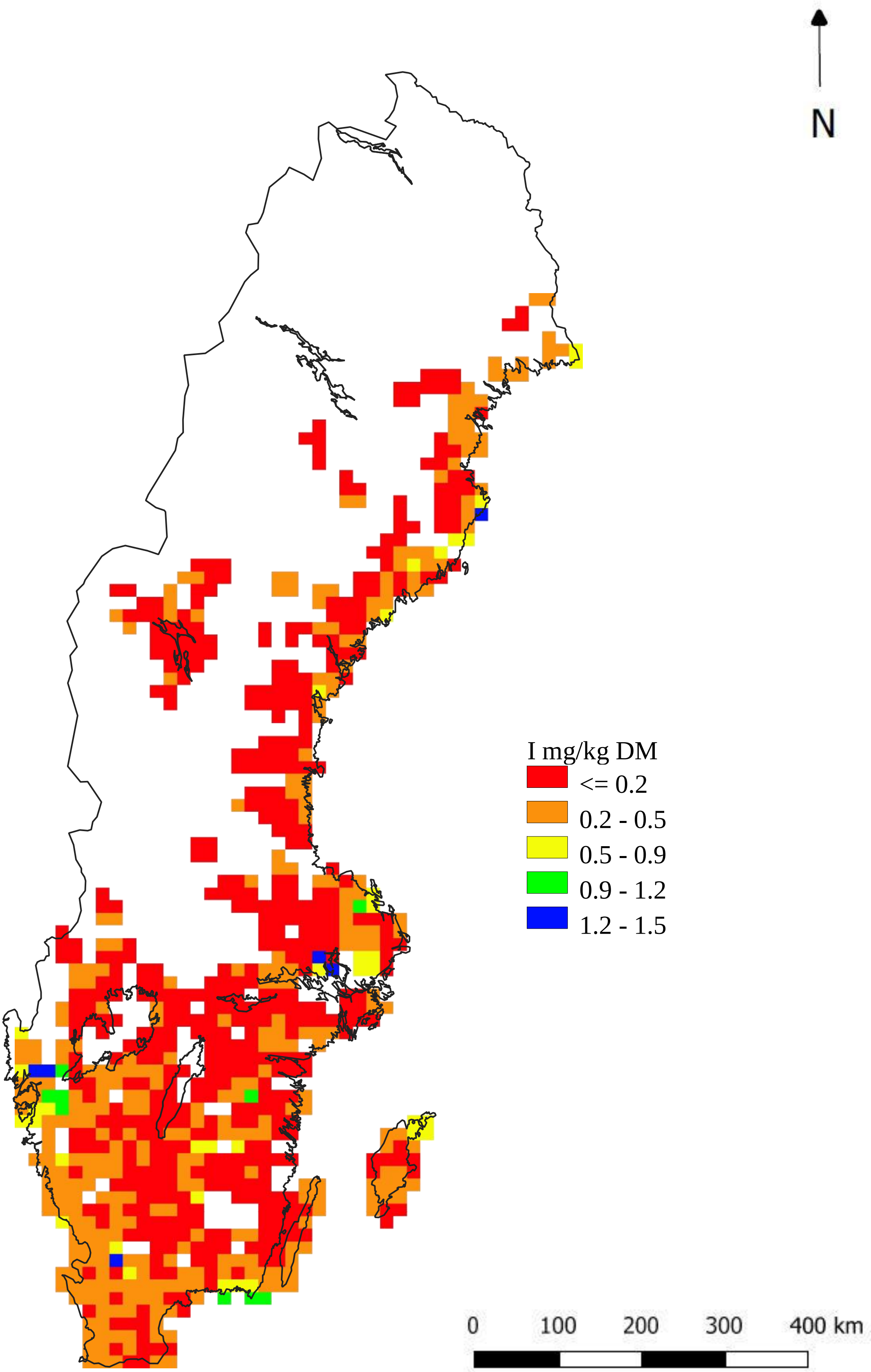
Appendix 12 Map of cobalt (kobolt) concentration



Appendix 13 Map of selenium (selen) concentration



Appendix 14 Map of iodine (jod) concentration



Appendix 15 Map of molybdenum (molybden) concentration