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Swedish University of Agricultural Sciences
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Abstract

A study of the macro- and micromineral contents in wrapped forages in Sweden and Norway was conducted. A total of 124 forage samples collected from 124 farms were analyzed for contents of Ca, P, Mg, K, Na, Co, Cu, I, Fe, Mn, Se and Zn. Information regarding forage production management was collected from each farm and included factors such as fertilization, botanical composition, sward age, etc. Mean (standard deviation) concentrations were: Ca, 5.3 (3.41); P, 2.7 (0.80); Mg, 1.8 (0.76); K, 21.7 (7.44); Na, 0.3 (0.45) g/kg dry matter (DM); and Co, 0.09 (0.15); Cu, 4.9 (1.61); I, 0.2 (0.39); Fe, 194 (288); Mn, 85 (49); Se, 0.02 (0.03); Zn, 23 (9.5) mg/kg dry matter (DM). Comparisons with the daily mineral requirements of horses of different categories indicated that most samples had sufficient levels of Mg, K, Fe and Mn while a minority was sufficient in Na, Co, Cu, I, Se, and Zn. The contents of Ca and P were enough to cover requirements of horses at maintenance but borderline to deficient for heavily exercising, gestating, lactating and rapidly growing horses. Thus, supplementation with Ca, P, Na, Co, Cu, I, Se, and Zn minerals is suggested to horses fed only forages. Forage management practices influenced the content of some macro- and microminerals. Contents of several minerals were positively correlated with increasing harvest number and negatively correlated with increasing wilting time.

Keywords: minerals, forage, haylage, silage, horse

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1. Introduction

Macrominerals are typically reported in units of g/kg or percentage and microminerals in mg/kg or parts per million (NRC, 2007). Both groups of minerals are important for animal health. Calcium, phosphorus, magnesium, potassium, sodium, chlorine and sulphur are the seven macrominerals. The microminerals, regarded to be practically significant for horses, are cobalt, copper, iodine, iron, manganese, selenium and zinc (NRC, 2007). Although minerals are nutrients that horses require in minor quantities, they play an essential role in the health of horses. Minerals are involved in a number of functions in the body, including the physiological roles of K, Na and Cl in acid-base balance, the structural roles of Ca, P and Mg in skeletal tissue and teeth, and the energy transfer involving P, and enzymatic cofactors such as Mg, Zn, Cu, Fe and Se. Some minerals are integral parts of vitamins (cobalt), hormones (iodine), and amino acids (sulphur) and mineral deficiencies or imbalances can bring about many health problems for horses (NRC, 2007).

The content of minerals in forages for horses has recently received increased attention, especially in the Nordic countries. Research in equine nutrition has shown that different horse categories may be fed a diet consisting of 100 (or near) percent forage (Jansson *et al.*, 2012). The exclusion of concentrates may however also result in an increased requirement of mineral supplementation of the diet if the forage alone cannot cover the mineral requirements of the horse.

Information regarding mineral content in forages is therefore important, but scarce in Sweden and Norway. The mineral content of forages varies widely with soils, forage species, grassland managements and climate conditions (Givens *et al.*, 2000). Values for macro- and microminerals in current equine feed tables in Sweden are based on old data from forages used for dairy cows (Spörndly, 2003). Such forages are harvested in a much earlier plant maturity and commonly consist of more legumes than is common for forages intended for horses. Other factors in forage production also differ with the intended use of the forage and information on mineral content in forages used for horse feeding is therefore required. The aim of this study was therefore to analyze existing haylage samples from commercial farms in Sweden and Norway for content of macro- and microminerals, and to investigate if forage production factors influence mineral content in the harvested forage.

2. Literature study

2.1. Factors influencing the content of macro- and microminerals in forages

Forage in fresh state or conserved as silage or hay is the primary feedstuff and supplies horses with most of the necessary minerals. However, the mineral content of forages vary widely with: (a) soils (soil mineral concentration and soil characteristics); (b) forages (plant species, varieties and genotypes, plant parts and plant maturity); (c) grassland management (fertilizer applications and harvesting); (d) environmental and climate conditions; and (e) conservation methods (Givens *et al.*, 2000).

Soils

Soil is the main source of mineral elements taken up by plants. Most mineral imbalances (deficiency or excess) naturally occurring in livestock is related to the mineral status of feeding forages harvested in specific geographic regions and, in other words, is associated with soil mineral concentration (Givens *et al.*, 2000). However, the total quantity of an element in the soil is not the only factor affecting mineral uptake by plants, as the 'availability' of minerals in soils also depends on the effective concentration in soil solution and on soil characteristics such as soil texture, pH, moisture content, drainage capacity and organic matter content (Williams, 1959; Reid and Horvath, 1980).

The content of minerals in soil differs with soil type. Old, sandy and acid soils have lower concentrations of most minerals compared to young and alkaline soils (Hartmans, 1970). The concentrations of microminerals also generally decrease with soil depth (Gupta *et al.*, 2008). In humid tropical and temperate regions, mineral deficiencies in plants are common since leaching and weathering of the soils have occurred under conditions of high temperature and long periods of heavy rainfall (Pfander, 1971; Gupta *et al.*, 2008).

Soil acidity and pH is considered a primary factor affecting the availability of minerals to forage crops (Gupta *et al.*, 2008), especially for minerals present in the soil in ionic form or as partially soluble salts (Mitchell, 1972). With the exception of Mo, plant availability of most microminerals has been reported to be reduced with increasing soil pH (Gupta, 1969; Gupta *et al.*, 2008). Red clover (*Trifolium pratense*) has been reported to show reduced uptake of Co, Ni and Mn by 50 % with increasing soil pH from 5.4 to 6.4, while that of Mo was raised six-fold (Mitchell, 1972). However, physiologically impaired uptakes of Ca, P and Mg in plants have also been observed when soil pH was lower than the optimum range for absorption of these three cations (6.5~8.5, 6.5~7.5 and 7.0~8.5, respectively) (Reid and Horvath, 1980).

Forages

Several studies have reported that large variations in mineral content exist within various forage plant species and varieties grown on the same site (Butler *et al.*, 1962; Matthews and Thornton, 1982). Herbs and legumes generally contain higher concentrations of several minerals than grasses (Hemingway, 1962; Loneragan et al., 1968; McNaught, 1970; Metson et al., 1979; Reid and Horvath, 1980).

As forages mature, most mineral contents decline due to a dilution effect (Butler and Bailey, 1973), and a process of nutrient translocation to the root system (Tergas and Blue, 1971). With increasing photosynthetic areas, DM yield exceeds mineral uptake, which in turn leads to a decrease in mineral content. The effect of nutrient translocation is larger in tropical plants than temperate plants, since freezing conditions in temperate areas will stop translocation, while the movement of nutrients to the root system is continuous throughout the dry season in tropical regions (Givens *et al.*, 2000). In a study in central Brazil, Gomide *et al.* (1969) found that remarkable declines in K, P, Mg, Cu and Fe of six tropical grasses ($P<0.1$) occurred with increasing plant maturity from 4 to 36 weeks. Forage K concentration was most affected by increased stage of plant maturity, while the content of Ca in forage was less influenced by increasing maturity (Gomide *et al.*, 1969).

Grassland management

Grassland management involves *e.g.* liming, fertilizing with manure and/or inorganic fertilizers, and harvesting. In general, suitable liming and fertilization can increase forage macromineral contents (Givens *et al.*, 2000). However, overuse of N and K fertilizers increases the incidence of Mg deficiency in forages (Kemp *et al.*, 1961), and K fertilization also dramatically reduces forage Na content (Underwood, 1999).

Environmental and climate conditions

Climate exerts an effect upon the mineral composition of forages. Reith (1965) concluded that the maximum content of major nutrients is obtained at soil temperatures that produce maximum growth, and low temperatures generally produce crops containing lower percentages of N, P, K, Ca and Mg. Under abundant rainfall and high temperatures of the wet tropics and semi-tropics, forages generally have low content of minerals due to that soils in such places are often low in soluble minerals and plant growth is fast as well (Allman and Hamilton, 1948).

2.1.1. Macrominerals

Calcium

Species and genotypes

Herbage species varies markedly in Ca content (Jumba *et al.*, 1995). Dicotyledonous plants like clovers tend to have higher Ca concentrations than monocotyledonous plants like grasses (Loneragan *et al.*, 1968). Among legumes, sainfoin (*Onobrychis viciifolia*) had consistently lower concentration of Ca than white clover (*Trifolium repens*), red clover and lucerne (*Medicago sativa*) harvested at advancing stages of growth from 29 April to 18 July in the same field (Whitehead and Jones, 1969). Tropical grasses generally have lower concentrations of Ca than temperate grasses based on worldwide literature (Minson, 1990). Among tropical grasses, mean Ca concentration was lower in setaria (*Setaria sphacelata*) than in Rhodes grass (*Chloris gayana*) when they were grown on sites where soil extractable Ca levels did not show any difference (Jumba *et al.*, 1995). Tetraploid varieties of Rhodes grass have been reported to have higher Ca concentration than the diploid varieties (Jones *et al.*, 1995).

Plant parts and plant maturity

Leaves of tropical grasses have been reported to contain twice as much Ca as stems (Minson, 1990). A study conducted in three sheep farms of the páramo (a variety of alpine tundra ecosystems) in Colombia also found that leaves of forage species had higher ($P<0.05$) concentrations of calcium than stems (Pastrana *et al.*, 1990). Setaria and Rhodes grasses had higher leaf:stem (L:S) ratio and contents of Ca than kikuyu grasses (*Pennisetum clandestinum*) (Jumba *et al.*, 1995). However, species differences in concentration of Ca cannot be explained simply in terms of L:S ratio, since species differ in their rates of maturation which may alter mineral availability as well (Jumba *et al.*, 1995). Powell *et al.* (1978) reported that the apparent absorption of Ca in temperate grasses decreased with advancing maturity.

Soil type

Information on the effect of soil type on forage Ca content is scarce.

Fertilizer application

Wilcox and Hoff (1974) suggested that ammonium absorption by plants due to application of N fertilizers could result in a greatly declined uptake of Ca. Reid and Horvath (1980) stated that a change in botanical composition of pastures is one frequent response to nitrogen fertilization, *e.g.* loss of the legumes leading to a reduction in total herbage concentration of Ca. However, a study on ryegrass [*Lolium* (*multiflorum* x *perenne*) x *perenne*]-white clover (*Trifolium repens* L.) pastures in New Zealand found that the use of fertilizer N had little effect on the concentration of Ca in the mixed herbage (Molloy *et al.*, 1978). Application of K fertilizers have been reported to cause a depression of Ca concentration in herbage (Brown *et al.*, 1969; Kemp, 1971).

Climate and seasonal changes

An increase in ambient temperature tends to increase the Ca content of herbage (Evans *et al.*, 1986; Grunes and Welch, 1989). Brome grass (*Bromus inermis leyss.*) and timothy (*Phleum pretense L.*) cultivated at warm (32–24 ℃ day–night) temperatures contained more Ca compared to when grown at lower temperatures (18–10 ℃ day-night) (Reid and Horvath, 1980). In alfalfa, however, higher temperatures resulted in decreased concentration of Ca in four temperature regimes (32–27, 27–21, 21–15, and 15–10 ℃ day–night) (Smith, 1970). The concentration of Ca in herbage showed marked seasonal changes. In young ryegrass (*Lolium*) leaves, the content of Ca was lowest in the spring and rose about two-fold to a maximum in early autumn before falling to a low level in late autumn (Reay and Marsh, 1976). Ryegrass and clover (*Trifolium*) leaves were found by McNaught *et al.* (1968) to have their maximum contents of Ca in the late summer. In New Zealand, Ca concentration in a herbage mixture (grasses, clovers and other species) showed a maximum value in summer and minimum in late winter to early spring (Metson and Saunders, 1978) However, Loneragan *et al.* (1968) reported that herbs and all legumes except lupins (*Lupinus*) maintain high Ca concentrations throughout the growing season. By contrast, in grasses and especially in cereals, Ca concentrations were low in young plants and declined further as season progressed (Loneragan *et al.*, 1968).

Phosphorus

Species and genotypes

Concentrations of P in grasses and legumes have been reported to be similar (Spedding, 1972). In cultivated pastures, McNaught (1970) commented that perennial ryegrass (*Lolium perenne*) normally contain higher contents of P than white clover, but the difference varied with soil type and season. In contrast, a study in Uganda reported that legumes contained higher concentrations of P than grasses at all stages of maturity (Reid, 1979). White clover was higher in P than red clover, lucerne and sainfoin (Whitehead and Jones, 1969). Temperate grasses generally had higher concentrations of P compared to tropical species (Minson, 1990). In tropical grasses, pangola grass (*Digitaria eriantha*) presented higher P contents than natural savanna forages (Aumont *et al.*, 1996).

Plant parts and plant maturity

The concentration of P in whole plants have been reported to decrease with advancing maturity in tropical grasses, but there was little difference in content of P between leaf and stem (Minson, 1990)**.** Powell *et al.* (1978) also showed that the apparent absorption of P in plants decreased with plant maturity in temperate grasses.

Soil type

Herbage P content has been reported to be correlated with extractable soil P, soil pH (Jumba *et al.*, 1995), soil moisture and temperature (Saunders and Metson, 1971; Reid and Horvath, 1980). Herbage P content was positively correlated with extractable soil P and soil pH, and the concentration of P increased by 0.032 (0.0067) g/kg DM for every mg of extractable soil P (Jumba *et al.*, 1995). In general, concentration of P in the plant tended to increase with increasing soil moisture level; and mineral P was absorbed by plants faster at high soil temperatures (Reid and Horvath, 1980).

Fertilizer application

Whitehead (1966) concluded that the P concentration of herbage in general was little affected by fertilization unless the soil phosphorus was severely deficient. This was also observed in a study on ryegrass mixtures (*Lolium* (*multiflorum* x *perenne*) x *perenne*)-white clover (*Trifolium repens* L.) pastures in New Zealand (Molloy *et al.*, 1978). Nitrogen fertilization generally tended to raise P concentrations of plants when the soil P was adequate, and to decrease uptake of P in the plant when soil P reserves were low (Whitehead, 1970).

Climate and seasonal changes

Reid and Horvath (1980) found that Brome grass, timothy and alfalfa grown at warm (32-24 °C day-night) temperatures contained higher concentrations of P than those grown at lower temperatures (18-10 °C). The herbage P concentration changed with season but also varied with species. For young ryegrass leaves, P concentration was highest in spring and lowest in autumn before rising again at the last harvest (7th of May in New Zealand) (Saunders and Metson, 1971; Reay and Marsh, 1976). In young leaves of red clover, P content decreased from spring to late summer (Reay and Marsh, 1976). For herbage consisting of grasses, clovers and other species in New Zealand, Metson and Saunders (1978) reported maximum levels of P in late autumn to late winter (May or June to August or September), and minimum levels in summer (December to January or February).

Magnesium

Species and genotypes

Under both tropical and temperate conditions, legumes generally contain higher concentration of Mg than grasses at all stages of maturity (Reid, 1979; Reid and Horvath, 1980)**.** This was also observed in cultivated pastures where white clover normally contained higher Mg levels than associated perennial ryegrass (McNaught, 1970). Leaver (1985) also concluded in a review that clovers generally were richer in Mg compared to grasses. Tropical grasses have been reported to have higher Mg concentrations than temperate grasses (Minson, 1990). In tropical grasses, kikuyu grass have been reported to have higher Mg concentrations than setaria and Rhodes grasses (Jumba *et al.*, 1995), while pangola presented higher Mg contents than natural savanna forages (Aumont *et al.,* 1996).

Both Hill and Guss (1976) and Hacker (1984) reported wide variations in the Mg content of various plant species and concluded that plant breeding had considerable potential for increasing mineral contents in a number of forage species. For example, tetraploid varieties of Rhodes grass have been reported to have higher Mg concentration than the diploid varieties (Jones *et al.*, 1995).

Plant parts and plant maturity

Stemmy plants in tropical areas have been reported to have low concentration of Mg (Minson, 1990). A general decline in concentration of minerals has been noted with increased plant maturity, but the concentration of Mg in plants was noted to increase with advancing maturation (Minson, 1990), probably due to the lower levels of interfering compounds like N and K in the more mature herbage (Powell *et al.*, 1978).

Soil type

A study in Alabama (USA) showed that tall fescue (*Festuca arundinacea*) grown on poorly drained soil had lower concentrations of Mg than the same species grown on well-drained soil (Elkins et *al.*, 1978). Further information about the effect of soil type on forage Mg content has not been found.

Fertilizer application

Contradictory results have been reported for effects of N fertilization on Mg concentration of herbage. Reid *et al.* (1970) found that the herbage Mg concentration increased with the use of N fertilizer when soil Mg levels were not limited. Two other studies (Wilcox and Hoff, 1974; Reid and Horvath, 1980) however reported a decline in herbage concentration of Mg with N fertilization. Further on, Molloy *et al.* (1978) observed that fertilizer N had little effect on concentrations of Mg in mixed herbage in New Zealand. For K fertilization, a depression of Mg concentration in herbage was demonstrated (Brown *et al.*, 1969; Kemp, 1971), but this depressing effect could be offset through the use of N in conjunction with K fertilizer (Kemp, 1971; Whitehead *et al.*, 1978).

Climate and seasonal changes

A review study found that the concentration of Mg tended to increase with increasing air temperature in plants like brome grass and timothy during growth (Reid and Horvath, 1980). However, the concentration of Mg was found to decrease in crested wheatgrass (*Agropyron desortorum*) (Stuart *et al.*, 1973) and alfalfa (Reid and Horvath, 1980), when air temperature increased. Mg concentration of herbage showed large seasonal variations in ryegrass and clovers (McNaught *et al.*, 1968; Reay and Marsh, 1976). For ryegrass maturing into a hay-cutting stage, Fleming (1968) reported that Mg levels rose after the spring to reach a peak in the autumn. In New Zealand, Mg concentration in herbage components (grasses, clovers, other species) also showed marked seasonal variations with maximum values in summer and minimum in late winter to early spring (Metson and Saunders, 1978).

Potassium

Species and genotypes

In a review of European and American literature, Spedding (1972) concluded that legumes and grasses contained similar concentrations of K. Contrary, a study in Uganda reported that legumes had higher concentrations of K than grasses at all stages of maturity (Reid, 1979). In cultivated pastures, McNaught (1970) found that perennial ryegrass normally contained higher levels of K than associated white clover. For genotype variations, Jones *et al.* (1995) recorded that tetraploid varieties of Rhodes grass contained higher K concentration than diploid varieties.

Plant parts and plant maturity

In a Colombian study, Pastrana *et al.* (1990) reported that forage species had higher ($P<0.05$) concentration of K in leaves than in stems. This may however alter with advancing plant maturity. It has been shown that the apparent absorption of K in temperate grasses declined with advancing maturity (Powell *et al.*, 1978).

Soil type

Not much data were found about the effects of soil type on forage K content.

Fertilizer application

Nielsen (1969) concluded that K concentration in grasses and legumes increased with increased K fertilization when analyzing results from periods covering year 1900 to 1927, 1900 to 1952, and 1960 to 1965 in Denmark. It was also found that the content of K in white clover increased with application of potash (Evans *et al.*, 1986).

Nitrogen fertilization seems to influence herbage K concentration (Whitehead, 1970), but effects are not consistent (Hopkins *et al.*, 1994) as other studies reported contradictory results. Taube *et al.* (1995) found that different levels of N fertilization caused great variation in herbage K content. However, it was reported that ammonium (Wilcox and Hoff, 1974) and fertilizer N (Molloy *et al.*, 1978) had little effect on concentration of K in herbage. In general, N fertilization seemed to increase content of K in the plant when K concentration was adequate in the soil, and to decrease uptake of K when soil K reserve was low (Whitehead, 1970).

The application of sodium fertilizer has been reported to cause an increase in K content of herbage (Chiy *et al.*, 1999), particularly in clover (Chiy and Phillips, 1996).

Climate and seasonal changes

The concentration of K tended to increase with increasing air temperature in plants like crested wheatgrass (Stuart *et al.*, 1973), brome grass, perennial ryegrass, timothy and alfalfa (Reid and Horvath, 1980) during growth.

Seasonal changes of K concentration seem to exist in grasses and clovers (McNaught *et al.*, 1968), but trends are not very clear, with minimum levels in early summer and peaks in early autumn and again in winter (Metson and Saunders, 1978).

Sodium

Species and genotypes

McNaught (1970) reported that white clover normally had lower level of Na than associated perennial ryegrass, but the magnitude of difference changed with soil type, season and degree of mineral deficiency in soil. Reid (1979) also reported that legumes showed lower concentrations of Na than grasses at all stages of maturity in a study in Uganda. Within legumes, sainfoin had lower Na-content than white clover, red clover and lucerne (Whitehead and Jones, 1969). Tetraploid varieties of Rhodes grass have been reported to have lower Na concentration than the diploid varieties (Jones *et al.*, 1995).

Plant parts and plant maturity

There is little published data on variations of Na concentration in different plant parts, but Na concentration of rangeland pasture were reported to decrease from 0.5 to 0.2 g/kg DM as they matured between March and September in a study in California, USA (Morris *et al.*, 1980).

Soil type

Pastures grown on pumice soils of New Zealand tended to contain low levels of Na, because Na is readily leached from these soil types as they have low cation exchange capacity (Edmeades and O'Connor, 2003). Pastures in coastal areas (within 25 km of the east coast of New Zealand) were richer in Na comparing to those grown inland, due to the deposition of sea spray in the former (Edmeades and O'Connor, 2003).

Fertilizer application

Several studies (Brown *et al.*, 1969; Nielsen, 1969; Kemp, 1971) have demonstrated that application of K fertilizers had a depressing effect on the concentration of Na in herbage (grasses and legumes). Kemp (1971) and Whitehead *et al.* (1978) found that the application of N in conjunction with K offset the depressing effect of high levels of K on uptake of Na by the plant. Fertilizer N increased the concentration of Na in herbage (Hopkins *et al.*, 1994). Chiy and Phillips (1993) reported that Na fertilizer increased herbage content and uptake of Na in perennial ryegrass. Application of phosphate have been reported to increase the Na content of white clover (Evans *et al.*, 1986).

Climate and seasonal changes

Seasonal changes of Na concentration in ryegrass (Fleming, 1968) and white clover (McNaught *et al.*, 1968) have been reported, but trends were not consistent as Na concentrations in both grasses and clovers were generally low (Metson and Saunders, 1978).

Chlorine

There is a scarcity of data on the content of chlorine in forages, probably because Cl is usually considered together with sodium in plants, and most pastures are appreciably adequate and much richer in Cl than Na irrespective of plant species or their states of maturity (Suttle, 2010).

Sulphur

Species and genotypes

Sulphur concentrations vary in different forage species. Legumes generally contain higher levels of S than grasses (McNaught, 1970). Among grasses, Jumba *et al.* (1995) found that kikuyu grasses and Rhodes grasses were richer in S compared to Napier grasses (*Pennisetum purpureum*).

Plant parts and plant maturity

There is little data on variation in S concentration in different plant parts, but forage S concentrations declined with increased plant maturity. Sulphur and protein contents are highly correlated and protein concentration of forage decreases with advancing plant maturity (Minson, 1990). Powell *et al.* (1978) also found that the apparent absorption of S in temperate grasses declined with advancing maturity.

Soil type

Soil bedrock affects herbage concentrations of S, as it has been found that mean herbage S concentrations were low when the plant grew on volcanic and metamorphic gneiss associations (Jumba *et al.*, 1995).

Fertilizer application

Use of sulfur fertilizer increased herbage sulfur content (Chiy *et al.*, 1999), mostly by increasing the SO_4 component in plants (Spears *et al.*, 1985). However, application of fertilizer N reduced concentration of S in forages (Hopkins *et al.*, 1994). Application of fertilizer Na did not affect the content or uptake of S in perennial ryegrass (Chiy and Phillips, 1993).

Climate and seasonal changes

There is little published information on seasonal variation in sulfur concentration in forage. Sulphur concentrations in a mixed sward tended to rise with the approach of summer due to an increase in the contribution from legumes with high content of protein (Suttle, 2010). It has been reported that sulfur deficiency in forages was more rare in arid regions (<250 mm rainfall per year) compared to humid regions (>500 mm rainfall per year) (Suttle, 2010).

2.1.2. Microminerals

Cobalt

Species and genotypes

Several researchers have reported that legumes tend to contain higher Co concentrations than grasses (Latteur, 1962; Price and Hardison, 1963; Andrews, 1966). However, similar contents of Co were reported in legumes and grasses when they were grown on soils with low Co content (Andrews, 1966). Although not consistent, differences in Co content between different legumes and grasses have been reported in the following order: red clover > white clover > perennial ryegrass > Italian ryegrass (*Lolium multiflorum*) > cocksfoot (*Dactylis glomerata*) > meadow fescue (*Festuca pratensis*) > timothy (Givens *et al.*, 2000). Little variation, however, has been reported in the Co concentration within various legumes when grown on soils relatively high in Co (Givens *et al.*, 2000). Hill species (like heather and white bent) contain more Co than plants from upland reseeding and land-improvement schemes, which in turn contains more Co compared to grasses like ryegrass and timothy. Timothy has generally been considered to have low Co concentrations (Givens *et al.*, 2000).

Plant parts and plant maturity

Grass leaves contain more Co than flowering heads, which contain more Co than stems (Fleming and Murphy, 1968). The concentration of Co tends to decrease with increasing plant maturity in some species, *e.g*. perennial ryegrass (Fleming and Murphy, 1968; Fleming, 1970), sainfoin and red clover (Whitehead and Jones, 1969).

Soil type

Forage Co concentrations are mainly related to different Co concentrations in soil Co. Cobalt-content in forages generally tends to be low when plants have been growing on soils with low availability of Co, like those derived from Old Red Sandstone, limestone and granitic parent materials (Givens *et al.*, 2000). Forage grown on poorly drained soils can have up to 7-fold more Co than forage from well drained soils, possibly a result of increased Co concentration in soil solution released from the soil minerals due to waterlogging (Givens *et al.*, 2000). It is also known that Co uptake in forage plants can be decreased by high concentration of Mn in the soil (Adams *et al.*, 1969; Norrish, 1975).

Following soil drainage, soil pH is another important determinant of soil Co availability for plants (West, 1981). Cobalt concentration in forage decreases with an increase of soil pH due to liming or if the forage has been cultivated on limestone soils, but have little further decline when pH increases over 6.0 (Givens *et al.*, 2000).

Fertilizer application

Fertilizer N and P have been reported to have inconsistent effects on forage Co content (Hopkins *et al.*, 1994). The Co concentration increased (Voss and MacPherson, 1977), decreased (Reith *et al.*, 1983), or did not change (Mudd, 1970; Bolland *et al.*, 1993) when N and P were applied to forage leys. This variation could be explained by clover dieback when applying fertilizer N, and a dilution effect on herbage Co content if the rate of Co uptake was lower than growth rate (West, 1981). It has also been suggested that soil availability of Co (Mills and MacPherson, 1982; Klessa *et al.*, 1988) and acidification of the soil by fertilizers (Klessa *et al.*, 1988) could contribute to the variable results.

Climate and seasonal changes

Only one study was found on the subject of climate and season effect on Co content in forages, and reported that Co concentrations in forage tended to be higher in spring and autumn during the growth period (Voss and MacPherson, 1977).

Copper

Species and genotypes

Large variations of Cu content exist between different plant species growing on the same soil in both temperate and tropical regions. Studies have shown that Cu content was highest in temperate herbs and weeds (10.8-16.6 mg/kg DM) (Thomas and Thompson, 1948), medium in temperate legumes (7.8 mg/kg DM) (Minson, 1990), and lowest in temperate grasses (4.0-4.7 mg/kg DM) (Thomas and Thompson, 1948; Minson, 1990). There was no difference in soil Cu content where the different plant species were cultivated. Conversely, tropical grasses contained more Cu than tropical legumes (Jumba *et al.*, 1995). The inconsistent differences in Cu-content between species are probably the consequence of diverse geographical and climate conditions within the different studies.

Large variations of Cu content were found between some cultivars and genotypes of alfalfa (Sengul and Haliloglu, 2008), barley genotypes (Wu and Zhang, 2002) and ryegrass varieties (Gray and McLaren, 2005). However, diploid and tetraploid cultivars of Rhodes grass did not show differences in Cu concentrations (Jones *et al.*, 1995).

Plant parts and plant maturity

On average, leaves of temperate grasses and legumes contain more Cu than stems (Davey and Mitchell, 1968; Hendricksen, 1980). In immature plants, Cu content however do not differ largely between leaf and stem (Davey and Mitchell, 1968). It has been reported that increased plant maturity resulted in a decline in Cu concentration of many forage plant species (Minson, 1990). The reduction in Cu content with increasing plant maturity of forage crops is probably caused by the concomitant decrease in proportion of leaves and lowering of Cu concentration in stems.

Soil type

The forage Cu levels depend not only on the total Cu content of soil, but also on the availability of copper in soils to plants. Copper contents may therefore also be low in forage harvested on soils of normal Cu concentration, if the available proportion is low (Alloway and Tills, 1984). The availability of Cu can be reduced due to the formation of copper-organic complexes, which may take place in peat soils and mineral soils with more than 10% organic matter (Givens *et al.*, 2000).

Fertilizer application

The addition of N-fertilizer to regularly cut perennial ryegrass and cocksfoot swards decreased forage Cu contents due to soil Cu depletion (Givens *et al.*, 2000). If soil available Cu was high, fertilizer-N had no effect on the Cu concentration of tall fescue and cocksfoot (Reid *et al.*, 1967b), or of star grass (*Cynodon nlemfuensis*) (Rudert and Oliver, 1978). No consistent effects of N fertilization on Cu content of permanent swards of mixed species (predominantly beet grass (*Agrostis* spp.), tufted grass (*Holcus lanatus*), red fescue (*Festuca rubra*), perennial ryegrass, meadow-grass (*Poa* spp.), *etc.*) have been reported (Hopkins *et al.*, 1994). On low-Cu soil, one study reported that P fertilizers could dilute the Cu content of subterranean clover by up to 50% through a growth-stimulation effect (Reddy *et al.*, 1981), while another study found no effect of P fertilizers on forage Cu concentrations (Hemingway, 1962).

Climate and seasonal changes

Content of Cu in forage generally declined during the growing season (Minson, 1990) and at the beginning of a rainy period (Pott *et al.*, 1989). In northeastern Mexico, Cu content was higher during summer than in other seasons in ten browse species (Ram ŕez *et al.*, 2006). In North Florida, USA, Cu deficiency in cool season pasture forages was found during the late fall, winter, and spring grazing seasons (Chelliah *et al.*, 2008). Suttle (2010) reported increased temperatures and advancing plant maturity as causes for low Cu concentration in forage.

Iodine

Species and genotypes

Under the same soil conditions, forage I concentration showed variation within plant species (Alderman and Jones, 1967; Hartmans, 1974; Watkins and Ullrey, 1983). Large variations in I content within species were attributed to cultivar differences of plant species like white clover (Alderman and Jones, 1967), perennial ryegrass (Butler *et al.*, 1962) and prairie grass (Rumball *et al.*, 1972).

Plant parts and plant maturity

Forage leaves tend to have higher I concentration than stems (Givens *et al.*, 2000). The content of I was higher early in the growing season (Alderman and Jones, 1967), but decreased with advancing plant maturity (Johnson and Butler, 1957; Groppel *et al.*, 1989).

Soil type

Forage I concentrations tended to be high on soils of younger marine clays and peats, and low on sandy soils and river clays (Givens *et al.*, 2000). On sandy soils, Hartmans (1975) found lower I concentration (0.09 mg/kg DM) of forages in the Netherlands, while Johnson and Butler (1957) reported a higher level (0.42 mg/kg DM) for forages in New Zealand.

Fertilizer application

Fertilizer N lowered I content in cocksfoot, perennial ryegrass and timothy, but variation was similar between species. The I-lowering effect of N fertilization was greater in younger herbage than in mature plants (Givens *et al.*, 2000). Surface applications of potassium iodide and potassium iodate fertilizer largely increased I levels in pasture, and iodide fertilizer was slightly more effective in increasing herbage I contents than iodate (Smith *et al.*, 1999).

Climate and seasonal changes

Forage I concentrations in most grasses and legumes were highest during winter and spring (the early growing season), declined during summer, and increased again in autumn (Watkins and Ullrey, 1983). Similar seasonal trends in I concentrations have been found for Welsh pasture grasses (Alderman and Jones, 1967) and for perennial ryegrass pasture in the Netherlands (Hartmans, 1974). These variations may be related to a dilution effect due to summer growth.

Iron

Species and genotypes

Legumes would usually contain more Fe than grasses (Hemingway, 1962; McNaught, 1970). In cultivated pastures, McNaught (1970) commented that white clover normally contained higher Fe concentrations than associated perennial ryegrass, but the magnitude of differences changed with soil type, season and degree of mineral deficiency in soil.

Plant parts and plant maturity

In one study, it was found that leaves of several forage species cultivated at the paramo in Colombia had higher ($P<0.05$) Fe content than stems (Pastrana *et al.*, 1990). However, the highest amount of Fe (235 mg/kg) was found in roots of alfalfa during the mass flowering stage (Vitkus and Tamulis, 1977).

Soil type

Forages are naturally rich in Fe due to well supplied soils. Grass grown on soils derived from serpentine soils usually have abundant Fe content, but Fe values above 300 mg/kg DM reflect soil contamination of the sample, rather than intrinsic iron in the forage. Such adventitious Fe can depress the availability of Cu to the ruminant (Givens *et al.*, 2000).

Fertilizer application

Not much information has been found about effects of fertilizer application on forage Fe content. Hemingway (1962) reported that the use of ammonium sulphate increased iron content of herbage cut repeatedly at the silage stage over a 3-year period and at each time of sampling.

Climate and seasonal changes

Brome grass, timothy and alfalfa grown at warm (32-24 ℃ day-night) temperatures contained higher concentrations of Fe compared to the same species cultivated at lower temperatures (18-10 ℃) (Reid and Horvath, 1980). Pasture Fe sampled during growing season showed marked seasonal fluctuations with peaks in spring and autumn, and Fe values can range from 70–111 to 2300–3850 mg/kg DM in New Zealand (Campbell *et al.*, 1974). This was in accordance with the findings by Halvorson and White (1983), who reported that Fe contents of western wheatgrass (*Agropyron smithii* Rydb.) and green needlegrass (*Stipa viridula* Trin.) in the northern Great Plains decreased as the growing season progressed until maximum forage yield was reached in June. Iron then started to accumulate in these forages during the remainder of the growing season (Halvorsen and White, 1983).

Manganese

Species and genotypes

When Mn concentrations are not higher than 60 mg/kg DM in the soil, grass and legumes grown on the same location have similar Mn values. However, grasses are more likely to have considerably higher Mn content than legumes, if soil concentration of Mn is above 60 mg/kg DM (Mcnaught, 1970; Reay and Marsh, 1976; Metson *et al.*, 1979). Manganese concentration in grass species seems to follow the descending order: cocksfoot and red-top bent > tall fescue and brome grass > meadow grass and timothy (Givens *et al.*, 2000). Among legume species, white clover have been reported to have higher Mn values than lucerne (Givens *et al.*, 2000).

Plant parts and plant maturity

It has been reported that the highest amount of Mn in alfalfa was present in inflorescence (48 mg/kg) and in leaves (34 mg/kg) during mass flowering stage (Vitkus and Tamulis, 1977). Leaves of cocksfoot contained twice the content of Mn as sheath and stem (Davey and Mitchell, 1968), but similar Mn contents have also been reported in stem and leaf (Fleming, 1963). In perennial ryegrass and meadow fescue, Mn content has been reported to be higher in stems than in leaves (Fleming, 1963). The various results may attribute to different availability of soil Mn in the cited experiments.

Soil type

The Mn availability for plants is inversely associated with soil pH, thus high Mn contents were observed in forages grown on acid soils (Givens *et al.*, 2000). There was also a decline in forage Mn concentration from 702 to 127 mg/kg DM with the basification of acid soil (Whitehead, 1966). Poor drainage is likely to increase Mn content of forages (Givens *et al.*, 2000).

Fertilizer application

The use of ammonium sulphate as fertilizer have been reported to result in higher Mn concentrations compared to unfertilized control treatments (63 vs 31 mg/kg DM) of mixed pasture (Hemingway, 1962). However, application of ammonium nitrate as a source of N has been reported to have no effect on Mn concentration in cocksfoot (Reid *et al.*, 1967a).

Climate and seasonal changes

No consistent climate and seasonal trends in forage Mn content have been reported (Reay and Marsh, 1976; Minson, 1990).

Selenium

Species and genotypes

Consistent differences in Se content between grasses and legumes have not been reported. In a comparison of Se content between grasses and legumes growing in New Zealand, grasses were found to contain more Se than legumes irrespective of soil types and Se fertilizers (Davies and Watkinson, 1966). The same result has been reported from some tropical areas (Long and Marshall, 1973). However, in experiments from Australia, selenium content was similar in subterranean clover (*Trifolium subterraneum*) and associated grasses (Caple *et al.*, 1980). In Denmark, lucerne and grasses also contained similar concentrations of Se (Gissel-Nielsen, 1975).

Plant parts and plant maturity

Cocksfoot spikelets had twice as much Se as the leaf fraction, while stems had intermediate content of Se (Davey and Mitchell, 1968). It has been reported that stage of plant maturity had little effect on the Se value of lucerne (Ehlig *et al.*, 1968).

Soil type

Selenium concentration differed markedly between different plants ranging from above 300 mg/kg DM for accumulator plants growing on Se rich soils, to below 0.05 mg/kg DM for herbage growing on Se deficient soils (Givens *et al.*, 2000).

Forage Se concentration is directly associated with Se content of the soil and the parent rock material from which it is derived. Forage Se is likely to be low when growing on sandy soils and lower on mineral upland soils than on organic moorland soils (Givens *et al.*, 2000; Antanaitis *et al.*, 2008). Se deficient areas have been identified in China, Australia, USA, New Zealand, many parts of Africa, UK and many parts of continental (particularly northern) Europe.

Fertilizer application

Increasing application rates of Se fertilizer (sodium selenate) resulted in an increase of Se concentration in alfalfa hay (Hall *et al.*, 2013). Fertilization of soil with Se has recently been reported to be an effective way to improve Se status in weaned calves fed with forages grown in fields with low soil Se content (Hall *et al.*, 2013). Mineral fertilizers with alkali effect could increase Se availability in soil for fodder plants due to the increase of plant incorporation of Se affected by raised soil pH (Bahners and Hartfiel, 1987).

Climate and seasonal changes

Temperature could affect the Se concentration in forage, for instance, oats (*Avena sativa)* used as forage contained more Se when grown at a mean temperature of 19 ℃ than 14 ℃ (Lindberg and Lannek, 1970). No consistent seasonal trends in forage Se content have been reported.

Zinc

Species and genotypes

Tropical forages have been reported to have on average 2 mg higher Zn/kg DM compared to temperate forages (Minson, 1990). In general, legumes were likely to contain more Zn than grasses when grown on the same site (Metson *et al.*, 1979), and this difference increased when soil Zn level was higher (Gladstones and Loneragan, 1967). Different grass species growing at the same site showed large divergence in Zn values, but without consistency in rank (Gomide *et al.*, 1969; Perdomo *et al.*, 1977).

Both small (Whitehead and Jones, 1969) and considerable (Gladstones and Loneragan, 1967) differences in Zn concentrations have been found among legume species. In grasses, the maximum variation among different genotypes of prairie grass and perennial ryegrass were 136 and 21%, respectively (Butler *et al.*, 1962; Rumball *et al.*, 1972), while only a 10% variation in Zn content was recorded among five species of *Digitaria* grasses (Minson, 1984).

Plant parts and plant maturity

Cocksfoot, meadow fescue, perennial ryegrass and timothy were reported to contain a mean Zn content of 20 mg/kg DM in the leaves compared to the stems with a mean of 15 mg/kg DM (Fleming, 1963). Flowering heads of white clover and grasses had considerably higher Zn concentrations (40 and 36 mg/kg DM, respectively) than stems (12 and 15 mg/kg DM, respectively) (Givens *et al.*, 2000), while results from one study (Vitkus and Tamulis, 1977) showed that seeds of alfalfa had the highest Zn content (36 mg/kg) at full maturity.

Changes in Zn concentration following plant maturity have been confirmed, but were not always consistent. In some studies, Zn concentration declined with increasing plant maturity in 24 different forages without any influence of the Zn status of the soil (Gladstones and Loneragan, 1967; Karn *et al.*, 2003). No such differences, however, were found in other studies comprising species like tall fescue and white clover (Reid *et al.*, 1967b; Gomide *et al.*, 1969; Whitehead and Jones, 1969).

Soil type

Application of lime to Bermuda grass decreased Zn content from 37 to 28 mg/kg DM as soil pH increased from 4.9 to 6.8 (Givens *et al.*, 2000). Increasing soil pH had a much larger reducing effect on Zn content in clover than in ryegrass growing on the same site in Scotland (Givens *et al.*, 2000).

Fertilizer application

Various results have been reported on the effect of fertilizer N on the content of Zn in forages (Miller *et al.*, 1964; Hopkins *et al.*, 1994; Karn *et al.*, 2003) such as western wheatgrass forage and green needlegrass (Halvorson and White, 1983). Zink accumulation in fescue could be improved by using N containing fertilizers, as they influence the Zn solubility in soils (Bryson and Barker, 2007).

2.2. Content of minerals in forages from selected studies

The contents of macro- and microminerals in forages from a number of studies are summarized in Table 1 and 2, respectively.

Table 1. Macromineral content (g/kg DM) in forages from selected studies

Element	Location	Mean (SD) and/or range or median (10th-90th percentile) (g/kg DM)	Reference
Ca	Ireland	Hay: 8	Wilson *et al.*, 1968
	Pennsylvania State	Over 9500 forage samples grown in 5 years: 8.4 (Legume hay: 11.5; Grass: 4)	Adams, 1975
	Worldwide basis	1263 forage samples: 9.0	Minson, 1990
	Wales, UK	Perennial ryegrass pasture mixed with white clover with Na fertilizer: 4.8-5.0	Chiy *et al.*, 1999
P	Worldwide basis	1823 forage samples: 2.9	Minson, 1990
	Northern Mato Grosso, Brazil	Forage: 0.8 and 2 in the dry and wet season, respectively	Sousa *et al.*, 1979
	Pennsylvania State	Over 9500 forage samples grown in 5 years: 2.6 (Legume: 3; Grass: 2.2)	Adams, 1975
	Wales, UK	Perennial ryegrass pasture mixed with white clover with Na fertilizer: 3.9-4.1	Chiy *et al.*, 1999
Mg	Worldwide basis	Forage: 2.8	Minson, 1990
	Wales, UK	Perennial ryegrass pasture mixed with white clover with Na fertilizer: 2.0-2.1	Chiy *et al.*, 1999
	Mount Elgon, Western Kenya	Dry-season herbage: 1.6 (0.53)	Jumba *et al.*, 1995
K	Worldwide basis	Forage: 27.0	Minson, 1990
	Wales, UK	Perennial ryegrass pasture mixed with white clover with Na fertilizer: 28.8-31.4	Chiy *et al.*, 1999
	Brazil	Six grasses: 14.2 at 4 weeks of age; 3 at 36 weeks of age	Gomide *et al.*, 1969
Na	Worldwide basis	Forage: 0.07-1.2 g	Minson, 1990
	Wales, UK	Perennial ryegrass pasture mixed with white clover with Na fertilizer: 2.2-3.6	Chiy *et al.*, 1999
Cl	Worldwide basis	Forage: 4.2	Minson, 1990
S	Mount Elgon, Western Kenya	Dry season herbage: 1.5 (0.59)	Jumba *et al.*, 1995

Table 2. Micromineral content (mg/kg DM) in forages from selected studies

Element	Location	Mean (SD) and/or range or median (10th-90th percentile) (mg/kg DM)		Reference
Co	-	Forages: <0.01-1.26		Beeson, 1950
	Virginia	Legumes: 0.06-0.48	Grasses: 0.02-0.24	Price and Hardison, 1963
	New Zealand	Fodder plants: 0.03-0.39		Andrews, 1966
	Norway	Herbage, first cut: <0.05 (<0.05-0.08)	Herbage, second cut: 0.06 (<0.05-0.15)	Govasmark, 2005
	North Florida	Cool season pasture forages: 0.02-0.14		Chelliah *et al.*, 2008
Cu	UK	Herbs and weeds: 10.8-16.6	Grasses: 4.0-8.2	Thomas and Thompson, 1948
	Worldwide basis	Temperate legumes: 7.8 Tropical legumes: 3.9	Temperate grasses: 4.7 Tropical grasses:7.8	Minson, 1990
	Norway	Herbage, first cut: 5.3 (3.9-6.8)	Herbage, second cut: 7.0 (5.7-9.3)	Govasmark, 2005
	North Florida	Cool season pasture forages: 3.9-8.2		Chelliah *et al.*, 2008
I	New Zealand	Forages: 0.42		Johnson and Butler, 1957
	Wales, UK	Pasture grasses: 0.08-0.69		Alderman and Jones, 1967
	Netherland	Forages: 0.09		Hartmans, 1974
Fe	UK	Grasses: 73-154 with a mean value of 103		Whitehead, 1966
	Norway	Herbage, first cut: 50 (36-88)	Herbage, second cut: 84 (52-171)	Govasmark, 2005
	North Florida	Cool season pasture forages: 56-190		Chelliah *et al.*, 2008
Mn	New Zealand	Grass-clover pastures: 166		Smith and Edmeades, 1983
	Worldwide basis	Forages: 86		Givens, 2000
	Norway	Herbage, first cut: 34 (22-86)	Herbage, second cut: 66 (36-205)	Govasmark, 2005
	North Florida	Cool season pasture forages: 70-152		Chelliah *et al.*, 2008

Table 2 (Continued)

Element	Location	Mean (SD) and/or range or median (10th-90th percentile) (mg/kg DM)		Reference
Se	Denmark	Cereals: 0.016-0.021	Pasture species: double as cereals	Nielsen, 1975
	Worldwide basis	Normal herbage: <0.05 - Accumulator plants: >300		Givens, 2000
	Norway	Herbage, first cut: <0.01 (<0.01-0.03)	Herbage, second cut: 0.02 (<0.01-0.06)	Govasmark, 2005
	North Florida	Cool season pasture forages: 0.01-0.08		Chelliah *et al.*, 2008
Zn	British Columbia	Forages: 22		Miltimore *et al.*, 1970
	Pennsylvania	Forages: 3-300 with a mean value of 29		Adams, 1975
	Louisana	Forages: 27		Kappel *et al.*, 1985
	Worldwide basis	Forages: 36		Minson, 1990
	Norway	Herbage, first cut: 19 (14-34)	Herbage, second cut: 21 (16-37)	Govasmark, 2005
	North Florida	Cool season pasture forages: 30-82		Chelliah *et al.*, 2008

2.3. Macro- and micromineral requirements of different horse categories

Minerals are thought to make up approximately 4% of the bodyweight of the horse. They are present either as components of biological molecules such as hemoglobin (iron), enzymes, the skeleton or hormones or as ions in fluids, all of which are essential for normal functions of the horse (NRC, 2007) Macro- and microminerals for which nutrient recommendations, functions, signs of deficiency or excess are described for horses, are presented in Table 3. When describing macro- and micromineral requirements of different horse categories, the maximum tolerable concentration of a mineral is also provided. This tolerable concentration is defined as the dietary amount rather than a toxic amount.

Table 3. Mineral functions and signs of deficiency or excess (NRC, 2007)

Element	Normal function	Symptoms of deficiency	Symptoms of excess
Ca	Making up 35 % equine skeleton	Weakened skeleton, osteopenia	Osteochondrosis
	Muscle contraction, blood coagulation	Dramatic impact on skeletal integrity	Hypercalcitoninism
	The regulation of many enzymes	Enlarged joints, crooked long bones	Gastric ulcers
	Homeostasis		
P	Constituting 14-17 % equine bone	Rachitic-like and osteomalacia changes	Reduced calcium
	Required for energy transfer reactions		Chronic calcium deficiency
	Synthesis of phospholipid, nucleic acid, phosphoprotein		Secondary
Mg	Constituting 0.05 % of the body mass	Nervousness, muscle tremors, ataxia	
	Activator of many enzymes	The potential for collapse, hyperpnea	
	Participation in muscle contractions	Hypomagnesemia	
K	Body fluid regulation	Refuse to eat, loss weight	Hyperkalemia
	Muscle and nerve function	Unthrifty in appearance	
	Acid base balance	Hypokalemia	
Na	Body fluid regulation	Decreased skin turgor and water intake	Excretion in the urine
	Muscle and nerve function	Lick objects like sweat-contaminated bars	
	Acid base balance	Decreased serum Na and Cl concentration	
Cl	Body fluid regulation	Metabolic alkalosis, muscle weakness	
	Muscle and nerve function	Decreased food intake, milk yield, weight loss	
	Acid base balance	Dehydration, constipation, depraved appetite	

Table 3 (Continued)

Element	Normal function	Symptoms of deficiency	Symptoms of excess
S	Synthesis of S-containing amino acids, insulin In form of B vitamins, heparin, chondroitin slufate	Has not been described in horses	Lethargic, colic, labored Jaundiced mucous membranes
Co	Required for synthesis of vitamin B_{12}	Vitamin B_{12} deficiency	
Cu	Essential for several Cu-dependent enzymes Required for elastic connective tissue Mobilization of iron stores Detoxification of superoxide	Hypocupremia Lameness Fatal rupture of the uterine artery	
I	Required for thyroid hormone	Hypothyroidism and Goitre	Goiters in the newborn Abortions and foal mortality
Fe	Haemoglobin syntheses Oxygen transport and cellular respiration Enzyme systems	Anaemia, weakness, and fatigue Pale mucous membranes Mare's milk is low in Fe	Diarrhea, icterus, coma Dehydration, death
Mn	Essential for carbohydrate and lipid metabolism Synthesis of the chondroitin sulfate	Bone abnormalities Interferes with phosphorus absorption	Interfere with P absorption
Se	Component of Se-dependent glutathione peroxidase Control of thyroid hormone metabolism	Muscle disease and impaired cardiac function Respiratory problems and tying up	Blind staggers, alkali disease Hair loss and hooves change
Zn	Component of over 100 enzymes	Inappetence, lost weight, parakeratosis Reduced serum and tissue Zn concentrations Enlarged epiphyses, stiffness of gait, lameness	Secondary Cu deficiency

2.3.1. MACROMINERALS

Calcium

Calcium is a major constituent of bone and teeth, making up 35 % of the equine skeleton (El Shorafa *et al.*, 1979). It is also needed for muscle work and nerve function. As summarized in Table 3, Ca deficiencies bring about several health problems for horses.

The daily maintenance requirement of Ca for an adult horse is 0.043 g Ca/kg BW, based on estimated endogenous losses of 0.02 g Ca/kg BW/day (Table 4). Exercise increases the requirement of Ca. Calcium requirement of gestating horses is calculated according to the estimated Ca deposition in the fetus, especially during the last month of gestation (Table 4). Based on the Ca content of mare's milk, Ca requirement of the lactating horse has been calculated to 0.12 g Ca/kg of BW during early lactation (1-3 months) and slightly lower in late lactation (Table 4). The Ca requirement of the growing horse differs depending on age and growth rate (Table 4). Rapid growth requires slightly more Ca compared to a moderate growth (NRC, 2007).

For acceptability of the diet by the horse, a maximum tolerable concentration of Ca in horse feed has been given as 2 % of the diet (NRC, 2005).

Phosphorus

Phosphorous is important for building bones and for energy metabolism. Normal functions and deficiency symptoms are reported in Table 3.

Maintenance requirements of P are calculated according to estimated endogenous losses of P at 0.01 g/kg BW/day. The requirement increases slightly at higher work intensity. The P requirement increases during the final months of gestation due to rapid skeletal growth of the fetus. Thus, both Ca and P supply in the diet must be increased to the pregnant mare for optimal bone development in the foal. The P content of mares' milk varies between 0.75 g/kg of milk in early lactation and 0.5 g/kg of milk in late lactation. Thus, the P requirements differ as well (Table 4). The P requirement of the growing horse varies with age and growth rate (Table 4). Young foals with rapid growth usually require slightly more P compared to a moderate growth (NRC, 2007).

It has been suggested that a maximum tolerable concentration of dietary phosphorus in horses fed adequate dietary Ca is 1 % (NRC, 2005).

Magnesium

Mg constitutes about 0.05 % of the body mass. It is an activator of several enzymes and essential for muscle work (NRC, 2007). Clinical signs of Mg deficiency and normal functions are reported in Table 3.

Maintenance requirements are 0.015 g Mg/kg BW per day based on an absorption efficiency of 0.4 and an endogenous loss of 6 mg/kg BW per day. Magnesium requirement of gestating horses is given in Table 4. Based on the Mg content of mare's milk, Mg requirement of the lactating horse has been calculated to 0.022 g Mg/kg of BW during early lactation (1-3 months) and slightly lower in late lactation (Table 4). The requirement of Mg for growth and exercise was calculated from NRC (2007) and are reported in Table 4.

The estimated maximum tolerable concentration of Mg is 0.8 % of the diet (NRC, 2005).

Potassium

Potassium is the major intracellular cation involved in maintenance of acid-base balance and osmotic pressure (Kronfeld, 2001).

Assuming an absorption efficiency of 0.8, NRC (2007) estimated that the daily maintenance requirement of K is 0.05 g/kg BW to offset an endogenous loss of 40 mg K/kg BW daily. Detailed requirements of K for exercising horses are given in Table 4, as different exercise intensities result in different sweat loss of K. For pregnant mares, slightly more K is required during the final gestation period (months 9-11) due to rapid fetal growth. For lactation, NRC (2007) calculated the detailed K requirements from foaling to after 5 months based on the estimated K content of mare's milk. The requirements of K for growth are given in detail in Table 4.

The NRC (2005) has listed the maximum tolerable concentration of K as 1 % of the diet.

Sodium

As the major extracellular cation and electrolyte, sodium is important for the maintenance of acid-base balance and osmotic regulation of body fluids. Sodium is usually present in insufficient quantity in the natural diet of the horse and must be supplemented. The most common way is to add salt (NaCl) to the diet. Chronic Na depletion results in health problems are reported in Table 3.

Maintenance requirements are 0.02 g Na/kg BW per day based on an absorption efficiency of 0.9 and an endogenous loss of 18 mg/kg BW per day (NRC, 2007). The requirements increase gradually with increasing work intensity due to increased sweat loss (Table 4). For pregnant mares, a slightly higher requirement of Na for gestation during months 9-11 were estimated by NRC (2007) to meet needs of rapid fetal growth. The requirements of Na for lactating horses gradually decrease from foaling to the end of lactation (Table 4). The daily growth requirement for Na differs depending on age, growth rate and sweat loss (NRC, 2007). Detailed figures for Na requirements are shown in Table 4.

The NRC (2005) has set the maximum tolerable concentration of NaCl as 6 % of the diet.

Chlorine

Chlorine is an important extracellular anion involved in acid-base balance and osmotic regulation. It is an essential component of bile and of hydrochloric acid, which is necessary for digestion (Table 3). Chlorine deficiency is unlikely to occur, when the requirements for sodium are met with NaCl (NRC, 2007).

Assuming a 100% absorption efficiency, a minimum daily maintenance requirement of 0.08 g Cl/kg BW is recommended in order to offset obligatory losses (fecal, urinary and cutaneous endogenous losses) as well as to prevent changes in acid-base balance and hypochloremia (NRC, 2007). Detailed requirements of Cl for exercising horses are given in Table 4, as different exercise intensities result in different sweat loss of Cl. The Cl requirement increases slightly during the final months of gestation due to a rapid fetal growth (NRC, 2007). Lactation requirements are maintenance plus 11 mg Cl/kg BW daily (Table 4). The Cl requirement of the growing horse differs depending on age, growth rate and sweat loss (Table 4).

As mentioned for Na, the maximum tolerable concentration of NaCl has been set at 6 % of the diet (NRC, 2005).

Sulfur

Sulfur, in the form of sulfur containing amino acids, several water soluble vitamins, heparin, insulin, and chondroitin sulfate, constitutes about 0.15 % of the body weight (Table 3). Sulfur deficiency in horses has rarely been described. Since the S requirements of the horse needs to be verified by further studies, NRC (2007) suggested to retain the recommendations of NRC (1989) at 0.15 % S on a dietary DM basis. The maximum tolerable S concentration has been estimated at 0.5 % of the diet (NRC, 2005).

Table 4. The daily macromineral requirements of horses, based on NRC (2007) recommendations (g/100 kg BW/day)

Type	Ca	P	Mg	K	Na	Cl
Adult maintenance*	4.3	2.8	1.5	5.0	2.0	8.0
Working-exercise						
Light	6.0	3.6	1.9	5.7	2.8	11.2
Moderate	7.0	4.2	2.3	6.4[a]	5.1[b]	13.3[c]
Heavy	8.0	5.8	3.0	7.8[a]	6.6[b]	15.5[c]
Very heavy	8.0	5.8	3.0	10.5[a]	8.2[b]	18.6[c]
Stallion						
Nonbreeding	4.3	2.8	1.5	5.0	2.0	8.0
Breeding	6.0	3.6	1.9	5.7	2.8	8.0
Gestation						
1-6 months	4.0	2.9	1.5	5.0	2.0	8.0
7-8 months	5.6	4.1	1.5	5.0	2.0	8.0
9-11 months	7.2	5.3	1.5	5.2	2.2	8.2
Lactation						
1-3 months	12.0	7.6	2.2	9.5	2.6	9.1
4-5 months	8.5	5.1	2.1	7.1	2.4	9.1
≥6 months	7.5	4.4	1.7	6.7	2.3	9.1
Growth						
4 months	23.3	13.0	2.1	6.6	2.5	9.4
6 months	18.0	10.0	2.0	6.0	2.3	9.3
12 months	11.8	6.6	1.7	5.5	2.2	8.3
18 months	9.5	5.3	1.6	5.2	2.1	8.3
18 light exercise	9.5	5.3	3.0	5.9	2.8	9.5
18 moderate exercise	9.5	5.3	3.0	6.6[a]	3.6[b]	10.9[c]
24 months	8.5	4.7	1.6	5.1	2.0	8.3
24 light exercise	8.5	4.7	3.0	5.8	2.8	9.5
24 moderate exercise	8.5	4.7	3.0	6.5[a]	3.6[b]	10.9[c]
24 heavy exercise	8.5	4.7	3.0	7.9[a]	5.1[b]	13.5[c]
24 very heavy exercise	8.5	4.7	3.0	10.7[a]	8.2[b]	18.8[c]

* Maintenance is the dietary intake to achieve equilibrium, replacing endogenous (faecal, urinary and cutaneous) losses, and each requirement assumes an absorption efficiency of 0.5 for Ca and an efficiency of 0.35 or 0.45 for P (Frape, 2010).

[abc] These figures assume that 2.8 g K, 3.1 g Na and 5.3 g Cl respectively is required per kg BW loss as sweat loss during exercise, and that 10 g to 20 g BW is lost per kg BW during exercise.

2.3.2. MICROMINERALS

Cobalt

Cobalt is required by the gut microflora of horses in the synthesis of vitamin B_{12}, which is necessary for blood cell formation (Frape, 2010). Cobalt deficiency results in vitamin B_{12} deficiency and anemia as well as other health problems (Table 3). The NRC (2007) has set the minimum recommended amount of cobalt to 0.05 mg/kg dietary DM and day (Table 5), which should be acquired through consumption of normal feedstuffs. The maximum tolerable concentration of Co is 25 mg/kg DM intake (Table 5).

Copper

Copper is essential for several enzymes and plays an important role in the synthesis and maintenance of elastic connective tissue and the mobilization of iron reserves (Table 3). The NRC (2007) estimates the requirement of Cu to 10 mg/kg of dietary DM. This value is assumed for all categories of horses, apart from pregnant mares during late gestation (9-11 months) for whom the requirement is 12.5 mg/kg DM of diet (Table 5). Horses can tolerate relatively high dietary Cu content. The maximum tolerable concentration of copper has been estimated to 250 mg/kg DM intake (Table 5).

Iodine

Iodine is necessary for the synthesis of thyroid hormones (T_3 and T_4), which are involved in regulation of basal metabolism. Both excess and severe deficiency of I may result in hypothyroidism leading to thyroid gland hypertrophy or goiter (Table 3). Assuming a near 100 % absorption efficiency, the requirement is 0.35 mg I/kg DM diet. This value is assumed for all groups of horses, with the exception of pregnant mares during late gestation (9-11 months) for which the required concentration has been reported to be 0.4 mg I/kg DM of diet (NRC, 2007). The maximum tolerable concentration of I is 5 mg/kg DM of intake (Table 5).

Iron

Iron is contained in hemoglobin (60 %), myoglobin (20 %), storage and transport forms of cytochromes (20%) and many enzyme systems (0.2 %) within the equine body (Frape, 2010). It also plays a critical role in oxygen transport and cellular respiration (Table 3). Iron deficiency causes anemia, but dietary Fe deficiency is rare in horses unless heavily bleeding or parasitic infestation have occurred. The dietary Fe requirement proposed by NRC (2007) is 50 mg/kg DM for growing foals, pregnant mares during late gestation (9-11 months) and lactating mares (Table 5), and 40 mg/kg DM for other categories of horses (Table 6). The maximum tolerable concentration of Fe is 500 mg/kg DM intake (Table 5).

Manganese

Manganese is essential, not only for carbohydrate and lipid metabolism, but also in several stages of glycosaminoglycan chondroitin sulfate synthesis in cartilage formation (Frape, 2010). Manganese deficiency may be associated with bone abnormalities (Table 3). The Mn requirements of horses have been recommended to be 40 mg Mn/kg DM of diet (Table 5 and 6) (NRC, 2007). Underwood (1977) suggested that Mn is one of the least toxic trace elements. However, large amounts of Mn in the ration can interfere with phosphorus absorption (NRC, 2007). The maximum tolerable amount of dietary Mn has been estimated to 400 mg/kg of diet (Table 5).

Selenium

Selenium is an essential part of selenium dependent glutathione peroxidase which protects cell membranes (Rotruck *et al.*, 1973). Selenium also helps to control thyroid hormone metabolism. Deficiency of Se produces white muscle disease and other health problems (Table 3). NRC (2007) concluded that the recommended concentration of Se should be 0.1 mg/kg DM of diet in order to prevent classic deficiency disorders. However, a slightly higher Se intake is suggested for optimum immune function of foals to prevent deficiency symptoms (Tables 5 and 6). The maximum tolerable concentration of Se in horse diets has been estimated to 5 mg/kg DM (Table 5).

Zinc

Zinc is present in the body of animals as a cofactor for more than 100 enzymes, either as a component of the molecule or as an activating cofactor (Frape, 2010). Zinc deficiency depresses appetite and growth rate, and also is accompanied by skin lesions as well as reduced Zn concentrations in both serum and tissues of horses (Table 3). The dietary Zn requirement is 40 mg/kg DM of diet (NRC, 2007). Horses can tolerate a maximum Zn concentration of 500 mg/kg DM in the total ration (Table 5). Zn is one of the less toxic of the essential trace metals, and it generally does not accumulate in tissues with continued exposure (Casteel, 2001).

Table 5. The daily micromineral requirements of horses, based on NRC (2007) recommendations (mg/kg DM intake per day)

Element	Maintenance Work Gestation (1-8months)	Gestation (9-11) months	Lactation	Growth	Maximum tolerable concentration
Co	0.05	0.05	0.05	0.05	25
Cu	10	12.5	10	10	250
I	0.35	0.40	0.35	0.35	5
Fe	40	50	50	50	500
Mn	40	40	40	40	400
Se	0.1	0.1	0.1	0.1	5
Zn	40	40	40	40	500

For the above mentioned micromineral requirements of horses, the daily recommended intake was reported as a concentration of the diet. It could be converted to recommendations on body weight basis using assumptions of feed intake for different horse categories. Such a conversion is presented in Table 6.

Table 6. The daily micromineral requirements of horses, based on NRC (2007) recommendations (mg/100 kg BW/day)[a]

Type	Co	Cu	I	Fe	Mn	Se	Zn
Adult maintenance*	0.10	20.0	0.7	80	80	0.20	80
Working-exercise							
Light	0.10	20.0	0.7	80	80	0.20	80
Moderate	0.11	22.5	0.8	90	90	0.23	90
Heavy/very heavy	0.12	25.0	0.9	100	100	0.25	100
Stallion	0.10	20.0	0.7	80	80	0.20	80
Gestation							
1-8 months	0.10	20.0	0.7	80	80	0.20	80
9-11 months	0.10	25.0	0.8	100	80	0.20	80
Lactation	0.12	25.0	0.9	125	100	0.25	100
Growth	0.12	25.0	0.9	125	100	0.25	100

* Maintenance is the dietary intake to achieve equilibrium, replacing endogenous (faecal, urinary and cutaneous) losses, and each requirement assumes an absorption efficiency of 0.3 to 0.35 for Cu.

[a] The daily requirements listed in this table for Co, Cu, I, Fe, Mn, Se, and Zn are calculated using assumed feed intakes of 2.5% of BW for heavy and very heavy exercise, lactating mares, and growing horses; 2.25% of BW for moderate exercise; and 2% of BW for all other classes.

3. Own study

3.1. Materials and methods

3.1.1. General and sampling

Samples of haylage were taken from round and square bales of different sizes from 124 farms. Forty-nine Swedish farms were visited during the spring 2010 (April – June), and haylage bales produced on the farms were sampled following a standardized procedure. In 2011, fifty other farms in Sweden and twenty-five farms in Norway were also visited and haylage bales were sampled using the same procedure as in 2010. Figure 1 shows all the sampling points in Sweden and Norway from 2010 and 2011.

Figure 1. Sites where samples of haylage were taken at farms in Sweden and Norway during 2010 and 2011.

At each farm, three randomly chosen bales from the same harvest batch were selected for sampling. Samples were collected from each of the three bales at eight sites per bale using a cylindrical stainless steel core sampler (0.65 m × 40 mm ø) connected to an electric drilling machine. All sampling equipment used was sterilized using ethanol (0.995 w/w) and an open flame prior to sampling of each bale. In 2010, the eight core samples from the same bale were pooled to produce one sample per bale, resulting in three samples per farm. The triplicate samples were pooled to produce one sample per farm. In 2011, core samples (eight per bale) from all the three bales were pooled to produce one sample per farm. The pooled samples were divided into two portions, of which one was used for analysis of chemical composition (including minerals) of the haylage. At the farm visits, the forage producers were interviewed following a standardized questionnaire to retrieve information about production and management of the bales. The information was summarized and when computing the result, some of the questions that resulted in several different responses were categorized into fewer classes.

3.1.2. Analyses

Dry matter content was analysed in two steps. First, core samples (nominal length 4 cm) were dried for 18 h at 55 ℃. After air equilibration, the samples were weighed and ground to pass a 1.0 mm sieve and then dried again for 20 h at 103 ℃ for calculation of DM content. Ash was determined by incineration for 3 h at 550 ℃. Data on pH value in forage and contents of crude protein (CP), neutral detergent fibre (NDF_{om}) and metabolizable energy for horses (ME_h) were collected from a previous publication from the same study (Müller, 2013).

Analysis of mineral contents was performed as follows: Around 0.3 g of each ground and dried sample was dissolved by 5 ml nitric acid and 0.05 ml hydrogen fluoride in a microwave oven and then diluted to 10 ml with MQ water. Samples were further diluted 20 times to a matrix of 10% HNO_3 except for I, for which the analysis of the samples were diluted 20 more times to an alkaline matrix. The samples were then analyzed for contents of macrominerals (Ca, P, Mg, K, Na) by inductively coupled plasma optical emission spectroscopy (ICP-OES) (3 - ICP Märke AAS Spectro Germany) at Agrilab AB in Uppsala, Sweden. Microminerals (Co, Cu, I, Fe, Mn, Se, Zn) were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) (Thermo-Finnigan "Element 2" Bremen Germany) at ALS Scandinavia AB in Luleå, Sweden. The detection limits for microminerals (Co, Cu, I, Fe, Mn, Se, Zn) were listed in Table 7.

Table 7. Limits of detection and reporting for microminerals (Co, Cu, I, Fe, Mn, Se, Zn)

Element	Limit of detection (µg/kg)	Minimum reporting limit (µg/kg)	Maximum reporting limit (mg/kg)
Co	2.5	8	30
Cu	50	167	600
I	40	133	6
Fe	80	267	3000
Mn	20	67	1000
Se	10	33	10
Zn	100	333	1000

3.1.3. Calculations and statistical analysis

In the original dataset, values below the minimum reporting limits were transformed to a value corresponding to half the minimum reporting limits for the calculations of mineral contents on dry matter basis. Then the gained data were used for the final calculations of mean, standard deviation, and correlations. The mean, standard deviation, median, and range (minimum-maximum) of mineral contents in wrapped forages were computed using Microsoft Excel 2010 and SAS Means Procedure (SAS Institute 9.3 for Windows, SAS Inc., USA). The ranges and distributions of macro- and micromineral contents were calculated using Microsoft Excel 2010.

Correlation analysis was carried out using the SAS Correlation Procedure (SAS Institute 9.3 for Windows, SAS Inc., USA). Results where $P<0.05$ were considered as a statistically significant correlation. The Pearson correlation coefficient (ρ) between analyzed mineral contents and other nutrients (DM, ash, pH, CP, NDF_{om} and ME_h) was calculated according to Kaps and Lamberson (2009) as:

$$\rho = \frac{\sigma_{xy}}{\sqrt{\sigma_x^2 \sigma_y^2}}$$

where σ_y^2 = variance of y, σ_x^2 = variance of x, σ_{xy} = covariance between x and y. The Pearson partial correlation coefficient (γ) between each analyzed mineral content was calculated according to (Kaps and Lamberson, 2009) as:

$$\gamma_{xy.z} = \frac{\gamma_{xy} - \gamma_{xz}\gamma_{yz}}{\sqrt{(1-\gamma_{xz}^2)(1-\gamma_{yz}^2)}}$$

where γ_{xy}, γ_{xz}, and γ_{yz} were ‘ordinary’ correlations between variables x, y and z. The correlation coefficient (ρ) between mineral contents and management variables was computed using polyserial correlation procedures, which can calculate the correlation between numeric (mineral contents) and ordinal variables (management factors).

3.2. Results and discussion

The overall ranges, mean and median values, and distributions of tested macro- and micromineral contents in forage samples are presented in Table 8 and Table 9, respectively.

Table 8. Average macromineral concentrations of forages in g/kg DM collected from 124 farms (99 farms in Sweden 2010 and 2011, 25 farms in Norway 2011)

Element	Range (Min-Max)	Mean (SD)	Median	Distribution g/kg DM	Frequency (%)
				0.1 - 6.7	75.8
Ca	0.1 - 26.6	5.3 (3.41)	4.5	6.7 - 13.4	21.8
				13.4 - 20.0	1.6
				20.0 - 26.6	0.8
				0.1 - 1.7	4.0
P	0.1 - 6.5	2.7 (0.80)	2.5	1.7 - 3.3	77.4
				3.3 - 4.9	17.8
				4.9 - 6.5	0.8
				0.02 - 1.2	14.5
Mg	0.02 - 4.5	1.8 (0.76)	1.7	1.2 - 2.3	70.2
				2.3 - 3.4	10.5
				3.4 - 4.5	4.8
				1.0 - 13.2	8.9
K	1.0 - 49.7	21.7 (7.44)	21.1	13.2 - 25.4	66.1
				25.4 - 37.5	21.0
				37.5 - 49.7	4.0
				<0.1	62.1
Na	<0.1 - 3.5	0.3 (0.45)	<0.1	0.1 - 1.2	34.7
				1.2 - 2.3	2.4
				2.3 - 3.5	0.8

Table 9. Average micromineral concentrations of forages in mg/kg DM collected from 124 farms (99 farms in Sweden 2010 and 2011, 25 farms in Norway 2011)

Element	Range (Min-Max)	Mean (SD)	Median	Distribution mg/kg DM	Distribution Frequency (%)
				0.01 - 0.3	93.6
Co	0.01 - 1.2	0.09 (0.15)	0.05	0.3 - 0.6	4.0
				0.6 - 0.9	1.6
				0.9 - 1.2	0.8
				1.8 - 4.1	39.5
Cu	1.8 - 11.0	4.9 (1.61)	4.5	4.1 - 6.4	46.0
				6.4 - 8.7	10.5
				8.7 - 11.0	4.0
				<0.1	37.1
I	<0.1 - 3.9	0.2 (0.39)	0.2	0.1 - 1.4	61.3
				1.4 - 2.7	0.8
				2.7 - 3.9	0.8
				44 - 196	79.0
Fe	44 - 1990	194 (288.92)	92	196 - 348	9.7
				348 - 500	3.2
				>500	8.1
				12 - 100	75.0
Mn	12 - 364	85 (49.31)	72	100 - 188	21.0
				188 - 276	3.2
				276 - 364	0.8
				<0.03	83.9
Se	<0.03 - 0.28	0.02 (0.03)	<0.03	0.03 - 0.1	15.3
				0.1 - 0.2	0.0
				0.2 - 0.28	0.8
				13 - 34	91.9
Zn	13 - 96	23 (9.46)	21	34 - 54	7.3
				54 - 75	0.0
				75 - 96	0.8

Table 10. Correlation analysis (Pearson partial correlation coefficients) between mineral contents in 124 haylage samples collected from Swedish and Norwegian farms

Element	P	Mg	K	Na	Co	Cu	I	Fe	Mn	Se	Zn
Ca	ns	0.50***	ns	ns	ns	ns	ns	ns	-0.26**	ns	ns
P		0.30**	0.68***	ns	ns	ns	ns	ns	ns	ns	ns
Mg			-0.31***	ns	ns	0.35***	ns	ns	ns	ns	ns
K				ns	ns	0.19*	ns	ns	-0.20*	ns	ns
Na					ns	ns	0.20*	ns	ns	ns	ns
Co						ns	ns	0.61***	0.27**	ns	ns
Cu							ns	ns	0.25**	ns	0.24*
I								ns	ns	ns	ns
Fe									ns	ns	0.32***
Mn										ns	ns
Se											ns

* represents P<0.05; ** represents P<0.01; *** represents P<0.001; ns=not significant

Correlations between contents of different minerals were weak but some were statistically significant (Table 10). The three highest Pearson partial correlation coefficients (γ) were found between phosphorus and potassium (γ=0.68), cobalt and iron (γ=0.61) and calcium and magnesium (γ=0.50). In Table 11, the contents of calcium, phosphorus and magnesium were positively correlated with ash content and negatively correlated with NDF. The contents of copper and selenium were negatively correlated with DM content, pH and NDF and positively correlated with ash content. Otherwise, positive correlations were found between CP content and the contents of phosphorus and copper, and between the content of potassium and ME_h. The content of zinc was only negatively correlated with DM content.

Table 11. Correlation analysis (Pearson correlation coefficients) between content of each mineral and other nutrients

Element	Ca	P	Mg	K	Na	Co	Cu	I	Fe	Mn	Se	Zn
DM	ns	ns	ns	ns	ns	ns	-0.26**	ns	ns	ns	-0.19*	-0.18*
Ash	0.32***	0.29**	0.20*	0.21*	ns	ns	0.26**	ns	ns	ns	0.22*	ns
pH	ns	ns	ns	ns	ns	ns	-0.19*	ns	ns	ns	-0.24**	ns
CP	ns	0.24**	ns	ns	ns	ns	0.31***	ns	ns	ns	ns	ns
NDF	-0.41***	-0.22*	-0.31***	ns	ns	ns	-0.27**	ns	ns	ns	-0.23*	ns
ME_h	ns	ns	ns	0.21*	ns	ns	ns	ns	ns	ns	ns	ns

* represents $P<0.05$; ** represents $P<0.01$; *** represents $P<0.001$; ns=not significant

Table 12. Correlation analysis (polyserial correlation) between content of each mineral and variables describing forage production and management

Variables	Ca	P	Mg	K	Na	Co	Cu	I	Fe	Mn	Se	Zn
Year	ns	ns	ns	ns	ns	ns	ns	0.56***	ns	ns	ns	ns
Country[a]	-0.68***	ns	ns	ns	ns	0.23*	ns	0.17*	0.33**	ns	ns	ns
Latitude	ns	ns	0.24*	-0.25*	-0.34***	ns	ns	ns	ns	ns	ns	0.25*
Longitude	ns	ns	ns	ns	-0.25*	ns	ns	ns	ns	ns	ns	ns
Own production[b]	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Harvest numbers	0.28**	0.33***	0.27**	0.37***	0.20*	ns	0.36***	ns	ns	ns	ns	ns
Mowing date	ns	ns	ns	ns	-0.38**	ns	ns	-0.66***	ns	ns	ns	ns
Sward age	ns	ns	0.20*	-0.20*	ns	-0.22*	ns	ns	ns	ns	ns	ns
Fertilizers	0.20*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Botanical composition	ns	ns	ns	ns	ns	ns	0.24*	ns	ns	ns	ns	ns
Weeds	0.32*	ns	0.29*	ns	ns	0.47*	0.37*	ns	0.63**	ns	ns	ns
Visible soil in sward	ns	ns	ns	ns	ns	ns	ns	ns	0.23*	ns	ns	ns
Uneven ground	ns	ns	ns	ns	ns	0.51**	ns	ns	0.54***	ns	ns	ns
Gaps in the sward	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Old plant material left	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Use of sward last year	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Widespread during wilting	-0.28*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Stubble height	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Wilting time	-0.46***	-0.24*	-0.42***	ns	ns	ns	-0.28**	ns	ns	ns	ns	-0.25*
Swath turning during wilting	-0.38**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

* represents $P<0.05$; ** represents $P<0.01$; *** represents $P<0.001$. ns=not significant

[a] Country where the samples of haylage were taken. [b] Own production: forage produced on their own farms or not.

Management variables (categories): Year (2010, 2011); Country (Sweden, Norway); Latitude; Longitude; Own production (yes, no); Harvest numbers (1, 2, 3, 4); Mowing date (middle of May to middle of June, middle of June to middle of July, July: second cut, middle of July to middle of August, middle of August to middle of September, August or September: second or third cut); Sward age (direct cut=0 year, 1, 2, 3, 4, 5, over 5 years); Fertilizers (yes: NPK or N, yes: manure, no, yes: other organic, yes); Botanical composition (only grasses; mixture of grasses and legumes); Weeds (no, don't know, yes); Visible soil in sward (no, yes); Uneven ground (no, yes); Gaps in the sward (yes, no); Old plant material left (yes, no); Use of sward last year (harvest, newly sown, pasture, trimmed material left in field, nothing); Widespread during wilting (no=dried in swaths, yes); Stubble height (<3cm, 3-5cm, 5-8cm, 8-10cm, approximate 10cm, >10cm); Wilting time (<24h, 24h, 48h, 72h, 96h, 120h, 144h); Swath turning during wilting (no, putting swaths together, yes).

Calcium

Table 8 presents the range, mean, median and distributions of forage Ca concentrations. The mean forage Ca concentration was generally lower than corresponding concentrations found in hay from Ireland or in legume hay from Pennsylvania, USA but similar to the average Ca content of grass samples in Pennsylvania and perennial ryegrass pasture mixed with white clover in Wales (Table 1). In the present study, median forage Ca concentration was 4.5 g/kg DM and approximately 76% of the Ca concentrations were lower than 6.7 g/kg DM, which may be sufficient for the daily maintenance requirement (NRC, 2007) of horses but close to deficient for gestating, lactating, rapidly growing horses and horses under heavy exercise (Table 4).

Forage Ca content was positively correlated with the content of Mg but negatively correlated with the content of Mn in forages (Table 10). Forage Ca content was positively correlated with ash content of forages but negatively correlated with the forage NDF (Table 11).

Table 12 shows that forage Ca content was positively correlated with increased harvest number and use of fertilizers, but negatively correlated with increased wilting time, widespread during wilting and swath turning during wilting. The positive correlation between forage Ca content and increasing harvest number was probably due to the earlier plant maturity of forages with the increased harvest numbers. Forages were reported to have decreased Ca contents with advancing plant maturity (Powell *et al.*, 1978; Jumba *et al.*, 1995). Calcium concentration was lower in forages that were wilted for longer time as well as widespread and swath turning during wilting. The reason may be that there are likely more losses of plant leaves and a concomitant decline in leaf:stem ratios after wide spreading or turning swath especially after long wilting hours as leaves contain higher levels of Ca than stems (Minson, 1990; Pastrana *et al.*, 1990; Jumba *et al.*, 1995). The positive correlation between forage Ca content and use of fertilizer was significant but weak ($r=0.20$, $P<0.05$) in the present study. Some studies suggest that the application of N or K fertilizer could result in a depression of Ca concentration in forages (Brown et al., 1969; Kemp, 1971; Wilcox and Hoff, 1974). However, a study on ryegrass-white clover pastures in New Zealand found that the use of fertilizer N had little effect on the concentration of Ca in the mixed herbage (Molloy *et al.*, 1978). More research is needed to elucidate the influence of fertilizer application on forage Ca content. The polyserial correlation analysis (Table 12) also showed positive correlations of forage Ca concentration with presence of weeds and negative correlations with country. The forage samples collected in Norway tended to have lower concentrations of Ca than those collected in Sweden. However, the information on the influence of presence of weeds on forage Ca content is scarce. Correlations between forage Ca content with other management variables were not found (Table 12). More research is needed to elucidate the influence of these variables on forage Ca content.

Phosphorus

The range, mean, and median forage P concentrations are reported in Table 8. Mean and median values were similar and at the same level as corresponding P concentrations of forages in Pennsylvania and worldwide (Table 1). Among forages in the present study, 81% of the samples contained P concentrations less than 3.3 g/kg DM (Table 8), which may be deficient for many classes of horses (Table 4). Phosphorous deficiency is however rare in grazing horses with the exception of horses during the final period of gestation and the first period of lactation, those producing large amount of milk for rapidly growing foals (NRC, 2007). Thus, P supplementation could be considered to the pregnant and lactating mares for optimal bone development in the fetus and foal.

Forage P content was positively correlated with contents of Mg and K in the forages (Table 10). Forage P content was positively correlated with ash and crude protein contents of forages but negatively correlated with forage NDF content (Table 11).

In Table 12, forage P content is positively correlated with increased harvest number but negatively correlated with increased wilting time. The positive correlation between forage P content and increasing harvest number was probably due to the earlier plant maturity of forages with the increased harvest numbers. The concentration of P in forage plant species has been reported to decrease with advancing maturity (Powell *et al.*, 1978; Minson, 1990). Phosphorus content was lower in forage samples that were wilted for longer time. This may indicate that wrapped forages produced after short wilting time should provide better possibilities to preserve P content than long wilting hours. Correlations between forage P content with other management variables were not found (Table 12).

Magnesium

The range, mean and median forage Mg concentrations is presented in Table 8. The mean and median values were similar (Table 8). The average concentration of forage Mg in our study was higher than that of dry season herbage in Mount Elgon region of Western Kenya but lower than the corresponding concentrations of perennial ryegrass pasture mixed with white clover in Wales and of forages on a worldwide basis (Table 1). About 85% of the forage samples in the current study contained Mg concentrations over 1.2 g/kg DM (Table 8), which may be sufficient for most classes of horses (Table 4).

Forage Mg content was positively correlated with the contents of Ca, P and Cu in forages but negatively correlated with the forage K content (Table 10). The negative correlation between forage Mg and K contents in our study was in agreement with the findings by Powell et al. (1978), who reported the interfering effect of K on Mg in herbages. Forage Mg content was positively correlated with forage ash content but negatively correlated with the forage NDF content (Table 11).

In Table 12, forage Mg content was positively correlated with increased latitude, harvest number and sward age and presence of weeds, but negatively correlated with increased wilting time. However, most of these correlations were weak. Information on the influence of latitude, harvest number, sward age and weeds on Mg content in forages is rarely reported by other studies. More research is needed to elucidate the influence of these factors on forage Mg content. Magnesium content was lower in forage samples that were wilted for longer time. This may indicate that wrapped forages produced after short wilting hours should provide better possibilities to preserve Mg content than long wilting hours. No correlations between forage Mg content and other management variables were found (Table 12).

Potassium

In table 8, the range, mean, and median forage K concentrations are presented. The range was large starting at 1.0 and ending at 49.7 g/kg DM, but the mean and median values were similar. Both were around 21 g/kg DM, which was lower than the corresponding concentrations of forages on a worldwide basis and of perennial ryegrass pasture mixed with white clover with Na fertilizer in Wales, but higher than those of grasses at 4 and 36 weeks of age in Brazil (Table 1). According to the distribution of forage K contents in Table 8, almost all forage samples had sufficient K for the horses (Table 4).

The forage K content was positively correlated with the contents of P and Cu but negatively correlated with the contents of Mg and Mn in forages (Table 10). Table 11 showed forage K content was positively correlated with forage ash and ME_h contents.

The forage K content was positively correlated with increasing harvest number but negatively correlated with increasing latitude and sward age. Correlations between forage K content with other management variables were not found (Table 12). The positive influence of increasing harvest number on forage K content may be explained by the earlier plant maturity of forages with the increased harvest numbers, and forages in earlier maturity stage have higher proportion of leaves and higher concentration of K (Pastrana *et al.*, 1990). Temperate grasses were also reported to have declined apparent absorption of K with increased plant maturity (Powell *et al.*, 1978). However, information on the influence of latitude and sward age on forage K content is scarce. More research is needed to elucidate the influence of latitude and sward age on forage K content.

Sodium

The forage Na concentration was quite low in most farms, and approximately 62 % of the forage samples had Na concentrations below 0.1 g/kg DM (Table 8). Nearly 97% of the forage samples had Na concentrations between <0.1-1.2 g/kg DM (Table 8), which was similar to the range on a worldwide basis (Table 1). However, the mean concentration of forage Na in our study was lower than the corresponding concentration of perennial ryegrass pasture mixed with white clover with Na fertilizer in Wales (Table 1). Chiy and Phillips (1993) also reported that Na fertilizer increased herbage content and uptake of Na in perennial ryegrass. Almost all forage Na concentrations in this study were lower than the recommended daily requirements for horses (Table 4). Only one farm had a maximum forage Na concentration of 3.5 g/kg DM which could fulfill the daily Na requirements of horses. Based on these results and the fact that sodium is usually present in insufficient quantity in the natural diet of the horse (NRC, 2007), it is recommended that Na is supplemented to horses on farms in Sweden and Norway. The most common way is to add salt (NaCl) to the diet.

The content of forage Na was only positively correlated with forage I content (Table 10). No other correlations between forage Na concentration and other measured mineral contents were found (Table 11).

The forage Na content was positively correlated with increasing harvest number but negatively correlated with increasing latitude and longitude and delayed mowing date (Table 12). The correlations of forage Na content with harvest number and mowing date are probably explained by the stage of plant maturity. Generally, forages tend to have increased plant maturity with the delayed mowing date. Na concentration of rangeland pasture decreased from 0.5 to 0.2 g/kg DM as they matured between March and September in a study in California (Morris et al., 1980). The findings were in agreement with the present study. There were no correlations between forage Na contents and other management variables. This is probably due to the general low forage Na concentrations in most farms.

Cobalt

The range, mean, and median forage Co concentrations are shown in Table 9. The range of forage Co concentrations was 0.01-1.2 mg/kg DM, which was similar to the result (<0.01 to 1.26 mg/kg DM) given by Beeson (1950). However, approximately 93 % of all forage samples had forage Co concentrations less than 0.3 mg/kg DM. The median forage Co concentration (0.05 mg/kg DM) was in between median concentrations of first and second cut herbages in Norway (Table 2). The median forage Co concentration (0.05 mg/kg DM) indicated that 50 % of the farms had lower forage Co concentrations than the recommended daily Co requirements of horses (Table 5 and 6).

No significant correlation between forage Co concentration and other nutritive values were found in Table 11. Forage Co concentration was positively correlated with the concentrations of Fe and Mn in forages (Table 10).

As reported by Beeson (1950), the forage Co concentration is mainly related to soil type. Correlations between forage Co content with other management variables were few (Table 12). The forage Co concentration associated positively with country (Sweden and Norway) ($r=0.23$, $P<0.05$) and uneven ground ($r=0.51$, $P<0.01$). The forage samples collected in Norway tended to have higher concentrations of Co than those collected in Sweden. Forage Co concentration was higher in forage produced on uneven ground. Givens *et al.* (2000) reported that forage grown on poor drained soils can have up to 7-fold more Co than forage from well drained soils, because of increased Co concentration in soil solution released from the soil minerals due to waterlogging. This may be explained by increased Co concentration in soil solution released from the soil minerals due to waterlogging by the poor drainage of bumpy ground. This also probably explains why the forage Co concentration was positively correlated with uneven ground, as waterlogging may easily occur in these uneven locations after rains.

Copper

Forages in this study had Cu contents from 1.8 to 11.0 mg/kg DM (Table 9), which was a wider range than reported for grasses in UK and cool season pasture forages in North Florida (Table 2). Mean, median and range (min-max) forage Cu concentrations are reported in Table 9. The mean Cu concentration was comparable to the average Cu concentration of temperate grasses worldwide, but was lower than corresponding concentrations found in Norwegian herbages, herbs and weeds in UK, and temperate legumes on a worldwide basis (Table 2). Almost all forage Cu concentrations in this study were insufficient for the daily requirements of horses and especially those in gestation (Table 5 and 6) (NRC, 2007). Supplemental feeding with mineral mixtures or concentrates containing Cu could be applied to fortify this micronutrient and suitably prevent the risk of primary Cu deficiency in Sweden and Norway.

Forage Cu content was positively correlated with the contents of Mg, K, Mn and Zn in forages (Table 10). Forage Cu content was positively correlated with ash and crude protein contents of forages but negatively correlated with the forage dry matter content, pH, and NDF content (Table 11).

The content of forage Cu was positively associated with increasing harvest number, botanical composition (mixture of grasses and legumes) and presence of weeds and negatively correlated with increasing wilting time. Correlations between forage Cu content with other management variables were not found (Table 12). The positive correlation between forage Cu content and increasing harvest number was probably due to the earlier plant maturity of forages with the increased harvest numbers. Many forage plant species were also reported to have lower Cu contents with increased plant maturity (Minson, 1990). Copper concentration was lower in forage samples that were wilted for longer times. The reason may be that loss of leaves is likely to be higher when the crop is drier and more brittle, and leaves easily break and fall off after long wilting time and at high DM contents. Leaves of temperate grasses and legumes contain more Cu than stems (Davey and Mitchell, 1968; Hendricksen, 1980). Wrapped forages, produced after short wilting periods, should therefore provide better possibilities to preserve Cu than long wilting hours. Studies comparing the effect of different botanical composition/plant species on forage Cu content are more abundant. Copper contents are generally higher in forages containing grasses and legumes compared to only grasses. These results are in agreement with the positive correlation between forage Cu content and botanical composition (mixture of grasses and legumes) in the present study. The positive association between forage Cu concentration and presence of weeds was in accordance with the findings of many studies. It was shown that Cu content was highest in temperate herbs and weeds (10.8-16.6 mg/kg DM) (Thomas and Thompson, 1948), medium in temperate legumes (7.8 mg/kg DM) (Minson, 1990), and lowest in temperate grasses (4.0-4.7 mg/kg DM) (Thomas and Thompson, 1948; Minson, 1990). There was no difference in soil Cu content where the different plant species were cultivated.

Iodine

Table 9 presents the range, mean, median and distributions of forage I concentrations. The forage I concentrations in this study had a much wider range than that of pasture grasses in Wales, and the mean value was higher than that of forages in Netherland but lower than that of forages in New Zealand (Table 2). Approximately 80% of forage I concentrations in the present study were lower than the daily requirements (0.35-0.4 mg/kg DM intake per day) of horses (Table 5 and 6) and about 37% of forage samples had extremely low I concentrations (<0.1 mg/kg DM) indicating that some supplemental strategies should be taken into consideration.

In Table 10, forage I concentration was only positively correlated with forage Na concentration. No significant correlation between forage I concentration and other nutritive values of forages were found in Table 11.

The polyserial correlation analysis (Table 12) showed positive correlations of forage I concentration with year and country. However, the information of this study was not enough to draw any final conclusions about these two positive correlations. Forage samples in the present study from late harvests tended to have decreased I concentrations (Table 12). The negative association between forage I concentration and delayed mowing date (from middle of May to middle of September) was in accordance with the findings of many studies (Johnson and Butler, 1957; Alderman and Jones, 1967; Hartmans, 1974; Watkins and Ullrey, 1983; Groppel et al., 1989), which reported that I concentrations in most grasses and legumes were highest during spring (the early growing season), but decreased during summer with advancing plant maturity.

Iron

Table 9 presents the range, mean, median and distribution of forage Fe concentrations. The median forage Fe concentration was higher in our investigation than previous findings in herbages both from first and second cuts in Norway (Table 2), and the mean value of forage Fe contents was also higher than that of grasses in UK (Table 2). The range of forage Fe concentration in our study was quite large (44-1990 mg/kg DM) and showed large variations among different farms (Table 9). All forage samples in the study contained sufficient Fe for the daily requirement of horses (Table 5 and 6) and 8% of forage samples even had very high Fe concentrations (>500 mg/kg DM, the maximum tolerable Fe concentration of horses). However, Givens et al. (2000) suggested that Fe contents above 300 mg/kg DM reflect soil contamination of the sample, rather than intrinsic iron in the forage. Samples in our investigation were not washed before analysis and the large range and variation in the forage Fe concentration might have been due to soil contamination as well. This also might explain why the forage Fe concentration was positively correlated with visible soil on swards and with uneven ground (Table 12), as soil contamination may easily occur on these locations. Forage Fe concentrations were also positively correlated with presence of weeds and country of origin (Table 12). Information on the influence of country and weeds on Fe content in forages is rarely reported in other studies. More research is needed to elucidate the influence of country and weeds on forage Fe content.

In Table 10, forage Fe concentration was positively associated with forage Co and Zn concentrations. No significant correlation between forage Fe content and other nutritive values of forages were found (Table 11).

Manganese

Table 9 presents the range, mean, median and distribution of forage Mn concentrations. The median forage Mn concentration was higher in our investigation compared to in herbages both from first and second cuts in Norway (Govasmark, 2005) (Table 2). The mean value of forage Mn contents was similar to that of forages on a worldwide basis but lower than in grass-clover pastures in New Zealand (Table 2). The range of forage Mn concentrations in our study was large (12-364 mg/kg DM) and showed a large variation among farms (Table 9). Approximately 89% of forage samples in the study contained sufficient Mn content (>=40 mg/kg DM) for the daily requirement of horses (Table 5 and 6). Manganese supplementation in horse diets may therefore not be needed based on these results.

The content of forage Mn was negatively correlated with forage Ca and K contents and positively correlated with forage Co and Cu contents (Table 10). No correlations between forage Mn concentration and other nutritive values of forages were found (Table 11). No correlations between forage Mn content and management variables were found (Table 12).

Selenium

The forage Se concentration was quite low in all farms, and approximately 84 % of all haylage samples had Se concentrations below the detection limit of 0.03 mg Se/kg. The range, mean, and median forage Se concentrations are shown in Table 9. The forage Se concentrations in our investigation were at the same level as the corresponding concentrations in selected studies (Table 2). Almost all forage Se concentrations in this study were lower than the recommended daily requirements of 0.1 mg Se/kg DM intake per day for horses (Table 5 and 6) (NRC, 2007), except one farm where forage Se concentration was 0.28 mg/kg DM, which could fulfill the daily Se requirements of horses (Table 9). Based on these findings, Se supplementation is recommended to horse diets on farms in Sweden and Norway.

No correlations between forage Se concentration and other measured mineral contents were found (Table 10). The content of forage Se was negatively correlated with DM content, pH and NDF content and positively correlated with ash content (Table 11).

There were no correlations between forage Se contents and management variables (Table 12). This is probably due to the generally low forage Se concentrations in most farms. The large number of farms with forage Se content below detection level made it impossible to explain the variation with regard to various management factors, and it was only possible to associate the Se concentration to the geographical position. Many parts of continental (particularly northern) Europe have been identified as Se deficient areas (Givens et al., 2000). Most forages grown on soils with low Se content do not differ markedly in their Se concentrations, and similar Se contents were reported in subterranean clover and associated grasses in Australia (Caple et al., 1980), and in Danish lucerne and grasses (Gissel-Nielsen, 1975). The forage Se concentrations in our investigation were also similar to Se concentrations of cereals and pasture species in Denmark, herbages in Norway, cool season pasture forages in North Florida and conventional herbages worldwide (Table 2).

Zinc

Table 9 presents the range, mean, median and distribution of forage Zn concentrations. Approximately 92 % of forage samples had Zn concentrations from 12.9 to 33.6 mg/kg DM. This indicates that the forage Zn concentration was generally lower than the suggested requirement of 40 mg Zn/kg DM in the total ration for horses per day (Table 5 and 6). Feeding supplemental Zn in horse diets should therefore be taken into consideration. The median forage Zn concentration in our investigation was higher than the median concentration found in herbages from first cut but similar to Zn concentration of herbages from second cut in Norway (Table 2). The mean concentration of forage Zn in this study was similar to concentrations found in forages from British Columbia, but lower compared to Zn content in forages from Louisana, Pennsylvania and worldwide (Table 2).

The content of forage Zn was positively correlated with forage Cu and Fe contents (Table 10) and negatively correlated with DM content (Table 11).

The content of forage Zn was negatively correlated with increasing wilting time and positively correlated with increasing latitude (Table 12). The correlations were significant but weak. Information on the influence of latitude on forage Zn content is scarce. The negative correlation between forage Zn content and wilting time may be explained by a probably larger leaf loss after a long wilting time, since leaves easily breaks and fall off during handling of a dry crop. Zinc content has been found to be generally higher in the leaves of various forages compared to stems (Fleming, 1963). Thus, wrapped forages produced after short wilting hours should provide better possibilities to preserve Zn content than long wilting hours.

3.3. Conclusions

In our study, the contents of Mg, K, Fe and Mn in the forage samples were sufficient to fulfill the daily requirements of all classes of horses (NRC, 2007). Based on our results, Mg, K, Fe and Mn supplementation in horse feeding on farms in Sweden and Norway may therefore be unnecessary. The contents of Ca and P were often sufficient for the daily maintenance requirement of horses but close to deficient for heavily exercising, gestating, lactating, and rapidly growing horses (NRC, 2007). Thus, supplementation of Ca and P should be considered to these classes of horses. Almost all investigated forage samples were low in Na, Co, Cu, I, Se, and Zn content and could not fulfill the requirement of these minerals for any horse category, indicating that mineral feeds fortified with these minerals have to be supplied to horse diets.

Management practices in forage production influenced content of some macro- and microminerals in forage. Content of several minerals was positively correlated with increasing harvest number and negatively correlated with increasing wilting time. The content of forage Fe seemed to be influenced mostly by soil contamination. The content of Cu, Se and Zn decreased with increasing DM content, and Ca, P, Mg, Cu and Se content decreased with increasing NDF content of forages. Plant maturity and botanical composition also affected content of Ca, P, K, Na, I and Cu. As several factors influence content of minerals in forages, it is difficult to compare data from this study with literature values.

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References

Adams, S., Honeysett, J., Tiller, K., Norrish, K., 1969. Factors controlling the increase of cobalt in plants following the addition of a cobalt fertilizer. Aust. J. Soil Res. 7, 29–42.

Alderman, G., Jones, D.I.H., 1967. The iodine content of pastures. J. Sci. Food Agric. 18, 197–199.

Allman, R.T., Hamilton, T.S., 1948. Nutritional deficiencies in livestock, FAO agricultural studies, 5. Food and Agriculture Organization of the United Nations, Washington.

Alloway, B.J., Tills, A.R., 1984. Copper deficiency in world crops. Outlook Agric. 13: 32-42.

Andrews, E.D., 1966. Cobalt concentrations in some New Zealand fodder plants grown on cobalt-sufficient and cobalt-deficient soils. N. Z. J. Agric. Res. 9, 829–838.

Antanaitis, A., Lubyte, J., Antanaitis, S., Staugaitis, G., Viskelis, P., 2008. Selenium concentration dependence on soil properties. J. Food Agric. Environ. 6, 163–167.

Aumont, G., Xande, A., Bellanger, J., 1996. Macro mineral and trace element content of pangola grass and other forages in Guadeloupe (FWI). J. Agric. Univ. P. R. 80, 21–35.

Bahners, N., Hartfiel, W., 1987. Influence of selenium and nitrogen phosphorus potassium fertilization on the selenium content of farm-grown feeds. Wirtsch. Futter 33, 5–12.

Beeson, K.C., 1950. Cobalt - Occurrence in soils and forages in relation to a nutritional disorder in ruminants. Agriculture Information Bulletin, Publication 7, United States Department of Agriculture, Washington, DC.

Bolland, M., Jarvis, R., Coates, P., Harris, D., 1993. Effect of Phosphate Fertilizers on the Elemental Composition of Seed of Wheat, Lupin, and Triticale. Commun. Soil Sci. Plant Anal. 24, 1991–2014.

Brown, C.S., Carpenter, P.N., Belyea, P.R., 1969. Fertilization responses of hayland grasses in Maine. pp. 28.

Bryson, G.M., Barker, A.V., 2007. Effect of nitrogen fertilizers on zinc accumulation in fescue. Commun. Soil Sci. Plant Anal. 38, 217–228.

Butler, G.W., Bailey, R.W., 1973. Chemistry and biochemistry of herbage. Academic Press.

Butler, G.W., Barclay, P.C., Glenday, A.C., 1962. Genetic and environmental differences in the mineral composition of ryegrass herbage. Plant Soil 16, 214–228.

Campbell, A.G., Coup, M.R., Bishop, W.H., Wright, D.E., 1974. Effect of elevated iron intake on the copper status of grazing cattle. N. Z. J. Agric. Res. 17, 393–399.

Caple, I.W., Andrewartha, K.A., Edwards, S.J., Halpin, C.G., 1980. An examination of the selenium nutrition of sheep in Victoria. Aust. Vet. J. 56, 160–167.

Casteel, S.W., 2001. Metal toxicosis in horses. Vet. Clin. North Am. Equine Pract. 17, 517–527.

Chelliah, G., Myer, R.O., Carter, J.N., McDowell, L.R., Wilkinson, N.S., 2008. Mineral Concentrations of Cool Season Pasture Forages in North Florida During the Winter-Spring Grazing Season: II. Trace Minerals. J. Plant Nutr. 31, 1774–1788.

Chiy, P., Phillips, C., 1993. Sodium Fertilizer Application to Pasture .4. Effects on Mineral Uptake and the Sodium and Potassium Status of Steers. Grass Forage Sci. 48, 260–270.

Chiy, P.C., Avezinius, J.A., Phillips, C.J.C., 1999. Sodium fertilizer application to pasture. 9. The effects of combined or separate applications of sodium and sulphur fertilizers on herbage composition and dairy cow production. Grass Forage Sci. 54, 312–321.

Chiy, P.C., Phillips, C.J.C., 1996. Effects of Sodium Fertiliser on the Chemical Composition of Grass and Clover Leaves, Stems and Inflorescences. J. Sci. Food Agric. 72, 501–510.

Davey, B.G., Mitchell, R.L., 1968. The distribution of trace elements in cocksfoot (Dactylis glomerata) at flowering. J. Sci. Food Agric. 19, 425–431.

Davies, E.B., Watkinson, J.H., 1966. Uptake of native and applied selenium by pasture species. N. Z. J. Agric. Res. 9, 317–327.

Edmeades, D.C., O'Connor, M.B., 2003. Sodium requirements for temperate pastures in New Zealand: A review. N. Z. J. Agric. Res. 46, 37–47.

Ehlig, C.F., Allaway, W.H., Cary, E.E., Kubota, J., 1968. Differences among Plant Species in Selenium Accumulation from Soils Low in Available Selenium. Agron. J. 60, 43–47.

El Shorafa, W.M., Feaster, J.P., Ott, E.A., 1979. Horse metacarpal bone: age, ash content, cortical area and failure stress interrelationships. J. Anim. Sci. 49, 979–982.

Elkins, C.B., Haaland, R.L., Hoveland, C.S., Griffey, W.A., 1978. Grass Tetany Potential of Tall Fescue as

Affected by Soil O2. Agron. J. 70, 309.
Evans, D.R., Thomas, T.A., Williams, T.A., Davies, W.E., 1986. Effect of fertilizers on the yield and chemical composition of pure sown white clover and on soil nutrient status. Grass Forage Sci. 41, 295–302.
Fleming, G.A., 1963. Distribution of major and trace elements in some common pasture species. J. Sci. Food Agric. 14, 203–208.
Fleming, G.A., 1968. Seasonal changes in herbage mineral content. Agri Digest, 28–32.
Fleming, G.A., 1970. The influence of stage of maturity and season on trace element levels in perennial ryegrass. Agri Dig. 25–32.
Fleming, G.A., Murphy, W.E., 1968. The Uptake of Some Major and Trace Elements by Grasses as Affected by Season and Stage of Maturity*. Grass Forage Sci. 23, 174–185.
Frape, D. (Ed.), 2010. Equine Nutrition and Feeding, 4th ed. Wiley-Blackwell, Chichester, West Sussex, U.K.; Ames, Iowa, pp. 37-68 (Chapter 3).
Gissel-Nielsen, G., 1975. Selenium Concentration in Danish Forage Crops. Acta Agric. Scand. 25, 216–220.
Givens, D.I., Owen, E., Axford, R.F.E., Omed, H.M. (Eds.), 2000. Forage Evaluation in Ruminant Nutrition. CABI Publishing, Oxon, UK, pp. 345-397 (Chapter 17-18).
Gladstones, J., Loneragan, J., 1967. Mineral elements in temperate crop and pasture plants. I. Zinc. Aust. J. Agric. Res. 18, 427–446.
Gomide, J.A., Noller, C.H., Mott, G.O., Conrad, J.H., Hill, D.L., 1969. Mineral Composition of Six Tropical Grasses as Influenced by Plant Age and Nitrogen Fertilization1 2. Agron. J. 61, 120–123.
Govasmark, E., 2005. Trace element status of soil and organically grown herbage in relation to animal requirements (Thesis). Norwegian University of Life Sciences.
Gray, C.W., McLaren, R.G., 2005. The effect of ryegrass variety on trace metal uptake. N. Z. J. Agric. Res. 48, 285–292.
Groppel, B., M, A., B, K., E, S., 1989. Iodine Deficiency in Ruminants 1. the Iodine Content of Feedstuffs Plants and Drinking Water. Arch. Anim. Nutr. 39, 211–220.
Grunes, D.L., Welch, R.M., 1989. Plant contents of magnesium, calcium and potassium in relation to ruminant nutrition. J. Anim. Sci. 67, 3485–3494.
Gupta, U.C., 1969. Effect and Interaction of Molybdenum and Limestone on Growth and Molybdenum Content of Cauliflower, Alfalfa, and Bromegrass on Acid Soils. Soil Sci. Soc. Am. J. 33, 929–932.
Gupta, U.C., WU, K., LIANG, S., 2008. Micronutrients in Soils, Crops, and Livestock. Earth Sci. Front. 15, 110–125.
Hacker, J.B., 1984. Nutritional limits to animal production from pastures. Commonw. Agric. Bureaux.
Hall, J.A., Bobe, G., Hunter, J.K., Vorachek, W.R., Stewart, W.C., Vanegas, J.A., Estill, C.T., Mosher, W.D., Pirelli, G.J., 2013. Effect of Feeding Selenium-Fertilized Alfalfa Hay on Performance of Weaned Beef Calves. Plos One 8.
Halvorson, A.D., White, L.M., 1983. Seasonal Zn, Cu, Mn, and Fe Levels of Western Wheatgrass and Green Needlegrass as Affected by N Fertilization. Agron. J. 75, 225–229.
Hartmans, J., 1970. The detection of copper deficiency and other trace element deficiencies under field conditions, In: Mills, C.F. (ed.) Trace Element Metabolism in Animals: Proceedings of WAAP/IBP International Symposium, Aberdeen, Scotland. E. & S. Livingstone, Edinburgh and London, pp. 441-445.
Hartmans, J., 1974. Factors Affecting the Herbage Iodine Content. Netherlands Journal of Agricultural Science 195–206.
Hemingway, R.G., 1962. Copper, Molybdenum, Manganese and Iron Contents of Herbage as Influenced by Fertilizer Treatments Over a Three-Year Period. Grass Forage Sci. 17, 182–187.
Hill, R.R., Guss, S.B., 1976. Genetic Variability for Mineral Concentration in Plants Related to Mineral Requirements of Cattle1. Crop Sci. 16, 680.
Hopkins, A., Adamson, A.H., Bowling, P.J., 1994. Response of permanent and reseeded grassland to fertilizer nitrogen. 2. Effects on concentrations of Ca, Mg, K, Na, S, P, Mn, Zn, Cu, Co and Mo in herbage at a range of sites. Grass Forage Sci. 49, 9–20.
Jansson, A., Saastamoinen, M., Lindberg, J.E., 2012. Forage feeding systems, in: Saastamoinen, M., Fradinho, M.J., Santos, A.S., Miraglia, N. (Eds.), Forages and Grazing in Horse Nutrition, Forages and Grazing in Horse Nutrition. Wageningen Academic Publishers, pp. 289–303.
Johnson, J.M., Butler, G.W., 1957. Iodine Content of Pasture Plants. Physiol. Plant. 10, 100–111.

Jones, R.J., Loch, D.S., LeFeuvre, R.P., 1995. Differences in mineral concentration among diploid and tetraploid cultivars of rhodesgrass (Chloris gayana). Aust. J. Exp. Agric. 35, 1123–1129.
Jumba, I.O., Wandiga, S.O., Suttle, N.F., Hunter, E.A., 1995. Effects of soil origin and mineral composition and herbage species on the mineral composition of forages in the Mount Elgon region of Kenya, 1. Calcium, phosphorus, magnesium and sulphur. Trop. Grassl. 29.
Kaps, M., Lamberson, W. (Eds.), 2009. Biostatistics for animal science, 2nd ed. CABI, Cambridge, UK.
Karn, J.F., Frank, A.B., Berdahl, J.D., Poland, W.W., 2003. Water, nitrogen and ploidy effects on Russian wildrye mineral concentrations. J. Range Manag. 56, 534–541.
Kemp, A., 1971. The Effects of K and N Dressings on the Mineral Supply of Grazing Animals. Instituut voor Biologisch and Scheikundig Onderzoek van Landbouwgewassen.
Kemp, A., Deijs, W.B., Hemkes, O.J., Es, A.J.H.V., 1961. Hypomagnesaemia in milking cows: intake and utilization of magnesium from herbage by lactating cows. Neth. J. Agric. Sci. 9.
Klessa, D.A., Dixon, J., Voss, R.C., 1988. Soil and agronomic factors influencing the cobalt content of herbage. Res. Dev. Agric. 25–35.
Kronfeld, D.S., 2001. Body fluids and exercise: Replacement strategies. J. Equine Vet. Sci. 21, 368–375.
Latteur, J.P., 1962. Cobalt deficiencies and sub-deficiencies in ruminants. 48 pp.
Leaver, J.D., 1985. Milk production from grazed temperate grassland. J. Dairy Res. 52, 313–344.
Lindberg, P.E., Lannek, N., 1970. Amounts of selenium in Swedish forages, soils and animal tissues 421–426.
Loneragan, J., Gladstones, J., Simmons, W., 1968. Mineral elements in temperate crop and pasture plants. II. Calcium. Aust. J. Agric. Res. 19, 353–364.
Long, M.I.E., Marshall, B., 1973. The selenium status of pastures in Uganda. Trop. Agric. 121–128.
Matthews, H., Thornton, I., 1982. Seasonal and species variation in the content of cadmium and associated metals in pasture plants at Shipham. Plant Soil 66, 181–193.
Mcnaught, K.J., 1970. Diagnosis of mineral deficiencies in grass-legume pastures by plant analysis. pp. 334–8.
McNaught, K.J., 1970. Diagnosis of mineral deficiencies in grass-legume pastures by plant analysis. pp. 334–8.
McNaught, K.J., Dorofaeff, F.D., Karlovsky, J., 1968. Effect of magnesium fertilisers and season on levels of inorganic nutrients in a pasture on Hamilton clay loam. N. Z. J. Agric. Res. 11, 533–550.
Metson, A.J., Gibson, E.J., Hunt, J.L., Saunders, W.M.H., 1979. Seasonal variations in chemical composition of pasture. N. Z. J. Agric. Res. 22, 309–318.
Metson, A.J., Saunders, W.M.H., 1978. Seasonal variations in chemical composition of pasture. N. Z. J. Agric. Res. 21, 341–353.
Miller, W.J., Adams, W.E., McCreery, R.A., Perkins, H.F., 1964. Zinc Content of Coastal Bermudagrass as Influenced by Frequency and Season of Harvest, Location, and Level of N and Lime.
Mills, C.F., MacPherson, A., 1982. Trace Element Deficiency in Ruminants: Report of a Study Group, March 1982. Scottish Agricultural Colleges.
Minson, D., 1984. Digestibility and voluntary intake by sheep of five Digitaria species. Aust. J. Exp. Agric. 24, 494–500.
Minson, D., 1990. Forage in Ruminant Nutrition. Elsevier.
Mitchell, R.L., 1972. Trace Elements in Soils and Factors That Affect Their Availability. Geol. Soc. Am. Bull. 83, 1069–1076.
Molloy, L.F., Ball, R., Collie, T.W., Ross, D.J., 1978. Influence of fertiliser nitrogen on higher fatty acids and on Mg, Ca, K, and P in grazed grass-clover herbage. N. Z. J. Agric. Res. 21, 57–64.
Morris, J.G., Delmas, R.E., Hull, J.L., 1980. Salt (Sodium) Supplementation of Range Beef Cows in California. J. Anim. Sci. 51, 722–731.
Mudd, A.J., 1970. Trace mineral composition of heavily fertilized grass in relation to A.R.C. standards for the requirements of dairy cows. Br. Vet. J. 126, 38–44.
Müller, C.E., 2013. Slutrapport för projekt H1047026:Svampflora och förekomst av mykotoxiner i inplastat vallfoder för hästar. Stiftelsen Hästforskning, Stockholm.
Nielsen, J.M., 1969. On the potassium and sodium concentrations in plants. R Vet Agric Coll., 5–18.
Norrish, K., 1975. GEOCHEMISTRY AND MINERALOGY OF TRACE ELEMENTS, in: D. Nicholas (Ed.), Trace Elements in Soil-Plant-Animal Systems. Academic Press, pp. 55–81.
NRC, 2005. Mineral Tolerance of Animals, 2nd rev. ed. National Academies Press, Washington, DC, USA.

NRC, 2007. Nutrient Requirements of Horses, 6th rev. ed. National Academy Press, Washington, DC, USA, pp. 69-108.
Pastrana, R., Mcdowell, L., Conrad, J., Wilkinson, N., Martin, F., 1990. Mineral Concentrations in Leaves and Stems of Various Forages of the Colombian Paramo. Commun. Soil Sci. Plant Anal. 21, 2345–2360.
Perdomo, J.T., Shirley, R.L., Chicco, C.F., 1977. Availability of Nutrient Minerals in Four Tropical Forages Fed Freshly Chopped to Sheep. J. Anim. Sci. 45, 1114–1119.
Pfander, W.H., 1971. Animal Nutrition in the Tropics—Problems and Solutions. J. Anim. Sci. 33, 843–849.
Pott, E.B., de Brum, P.A.R., Pott, A., de Almeida, A.L., Comastri Filho, J.A., Tullio, R.R., 1989. Beef cattle mineral nutrition in the Brazilian Pantenal. 4. Micronutrient survey on the lower Piquiri River. Pesqui. Agropecuriaria Bras. 1369–1380.
Powell, K., Reid, R.L., Balasko, J.A., 1978. Performance of Lambs on Perennial Ryegrass, Smooth Bromegrass, Orchardgrass and Tall Fescue Pastures II. Mineral Utilization, in Vitro Digestibility and Chemical Composition of Herbage. J. Anim. Sci. 46, 1503–1514.
Price, N.O., Hardison, W.A., 1963. Minor element content of forage plants from the Central Piedmont Region of Virginia. 15 pp.
R. Hendricksen, D.J.M., 1980. The feed intake and grazing behaviour of cattle grazing a crop of Lablab purpureus cv. Rongai. J. Agric. Sci. 95, 547 – 554.
Ramírez, R.G., González-Rodríguez, H., Ramírez-Orduña, R., Cerrillo-Soto, M.A., Juárez-Reyes, A.S., 2006. Seasonal trends of macro and micro minerals in 10 browse species that grow in northeastern Mexico. Anim. Feed Sci. Technol. 128, 155–164.
Reay, P.F., Marsh, B., 1976. Element composition of ryegrass and red clover leaves during a growing season. N. Z. J. Agric. Res. 19, 469–472.
Reddy, G., Alston, A., Tiller, K., 1981. Effects of fertilizer on concentrations of copper, molybdenum, and sulfur in subterrranean clover (Trifolium subterraneum). Aust. J. Exp. Agric. 21, 491–497.
Reid, R.L. (Richard L., 1979. Chemical composition and quality of tropical forages. West Virginia University. Agricultural Experiment Station.
Reid, R.L., Horvath, D.J., 1980. Soil chemistry and mineral problems in farm livestock. A review. Anim. Feed Sci. Technol. 5, 95–167.
Reid, R.L., Jung, G.A., Kinsey, C.M., 1967a. Nutritive Value of Nitrogen-Fertilized Orchardgrass Pasture at Different Periods of the Year. Agron. J. 59, 519–525.
Reid, R.L., Odhuba, E.K., Jung, G.A., 1967b. Evaluation of Tall Fescue Pasture under Different Fertilization Treatments. Agron. J. 59, 265–271.
Reid, R.L., Post, A.J., Jung, G.A., 1970. Mineral composition of forages. 35 pp.
Reith, J.W.S., 1965. Mineral composition of crops.
Reith, J.W.S., Burridge, J.C., Berrow, M.L., Caldwell, K.S., 1983. Effects of the application of fertilisers and trace elements on the cobalt content of herbage cut for conservation. J. Sci. Food Agric. 34, 1163–1170.
Rotruck, J.T., Pope, A.L., Ganther, H.E., Swanson, A.B., Hafeman, D.G., Hoekstra, W.G., 1973. Selenium: biochemical role as a component of glutathione peroxidase. Science 179, 588–590.
Rudert, C.P., Oliver, J., 1978. . Rhod. J. Agric. Res. 23–29.
Rumball, W., Butler, G.W., Jackman, R.H., 1972. Variation in nitrogen and mineral composition in populations of prairie grass (Bromus unioloides H.B.K.). N. Z. J. Agric. Res. 15, 33–42.
Saunders, W.M.H., Metson, A.J., 1971. Seasonal variation of phosphorus in soil and pasture. N. Z. J. Agric. Res. 14, 307–328.
Sengul, S., Haliloglu, K., 2008. Determination of mineral concentration and cell-wall energy content of some alfalfa cultivars and genotypes (Medicago sativa L). Asian J. Chem. 20, 3231–3240.
Smith, D., 1970. Influence of Temperature on the Yield and Chemical Composition of Five Forage Legume Species1. Agron. J. 62, 520.
Smith, L.C., Morton, J.D., Catto, W.D., 1999. The effects of fertiliser iodine application on herbage iodine concentration and animal blood levels. N. Z. J. Agric. Res. 42, 433–440.
Spears, J.W., Burns, J.C., Hatch, P.A., 1985. Sulfur Fertilization of Cool Season Grasses and Effect on Utilization of Minerals, Nitrogen, and Fiber by Steers. J. Dairy Sci. 68, 347–355.
Spedding, C.R.W., 1972. Grasses and Legumes in British Agriculture. Commonwealth Agricultural Bureaux.

Spörndly, R., 2003. Fodertabeller för idisslare (Feed tables for ruminants). Report 257. Department of Animal Nutrition and Management, Swedish University of Agricultural Sciences, Uppsala, Sweden. pp. 68-69.

Stuart, D.M., Mayland, H.F., Grunes, D.L., 1973. Seasonal Changes in Trans-Aconitate and Mineral Composition of Crested Wheatgrass in Relation to Grass Tetany. J. Range Manag. 26, 113–116.

Suttle, N.F., 2010. Mineral nutrition of livestock, 4. ed. ed. CAB International, Wallingford, Oxfordshire, UK ; Cambridge, MA.

Taube, F., Wulfes, R., Sudekum, K.-H., 1995. Impact of nitrogen fertilization and growing period on the concentration of mineral element during growth of permanent grass swards. Wirtsch. Futter 41, 219–237.

Tergas, L.E., Blue, W.G., 1971. Nitrogen and Phosphorus in Jaraguagrass (Hyparrhenia rufa (Nees)Stapf) During the Dry Season in a Tropical Savanna as Affected by Nitrogen Fertilization1. Agron. J. 63, 6.

Thomas, B., Thompson, A., 1948. The ash-content of some grasses and herbs in the Palace Leas hay plots at Cockle Park. Emp. J. Exp. Agric. 16.

Underwood, E.J., 1977. Trace elements in human and animal nutrition. Academic Press, New York. Fourth Edition 1977. Biochem. Educ. 10, 36–36.

Underwood, E.J., 1999. The mineral nutrition of livestock, 3. ed. ed. CABI, Wallingford, Oxon.

Vitkus, A.A., Tamulis, P.T., 1977. Biological Characteristics and Chemical Composition of Yellow Flowered Alfalfa Part 6 Dynamics of Manganese Iron Zinc and Copper Content. Liet. TSR Mokslu Akad. Darb. Ser. C Biol. Moksl. 33–38.

Voss, R.C., MacPherson, A., 1977. Cobalt and Copper in Soils, Herbage and Ruminant Nutrition. Technical Note 5. West of Scotland Agricultural College, Ayr, Scotland. Herb. Rumin. Nutr. Technical Note 5.

Watkins, E.B., Ullrey, E.D., 1983. Iodine Concentration in Plants Used by White-Tailed Deer Odocoileus-Virginianus in Michigan Usa. J. Wildl. Manag. 47, 1220–1226.

West, T.S., 1981. Soil as the source of trace elements. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 294, 19–39.

Whitehead, D.C., 1966. Nutrient Minerals in Grassland Herbage. Commonwealth Bureau of Pastures and Field Crops, Hurley, No. 1, 1966. 83 Seiten. 24 × 18 cm, 15s. Z. Für Pflanzenernähr. Düng. Bodenkd. 114, 135–136.

Whitehead, D.C., 1970. The role of nitrogen in grassland productivity: a review of information from temperate regions. Commonwealth Agricultural Bureaux.

Whitehead, D.C., Jones, E.C., 1969. Nutrient elements in the herbage of white clover, red clover, lucerne and sainfoin. J. Sci. Food Agric. 20, 584–591.

Whitehead, D.C., Jones, L.H.P., Barnes, R.J., 1978. The influence of fertiliser N plus K on N, S and other mineral elements in perennial ryegrass at a range of sites. J. Sci. Food Agric. 29, 1–11.

Wilcox, G.E., Hoff, J.E., 1974. Grass Tetany: An Hypothesis Concerning its Relationship with Ammonium Nutrition of Spring Grasses. J. Dairy Sci. 57, 1085–1089.

Williams, R.D., 1959. Minor elements and their effects on the growth and chemical composition of herbage plants. Mimeo Publ 11959 Commonw Bur Past Fld Crops 68 pp.

Wu, F., Zhang, G., 2002. Genotypic Variation in Kernel Heavy Metal Concentrations in Barley and as Affected by Soil Factors. J. Plant Nutr. 25, 1163–1173.

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