Micronutrients in Grassland Production

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MICRONUTRIENTS IN GRASSLAND PRODUCTION

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Abstract

Micronutrients, also known as trace minerals, which chiefly include boron (B), molybdenum (Mo), copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe), are required in extremely small quantities by crops and livestock. Their name, however, is not meant to imply their role is minor. Their lack, e.g., can cause serious crop production problems in forages and health disorders in livestock. This presentation includes the response of forage legumes and grasses to micronutrients, their deficiency and sufficiency levels in forages and their sufficiency levels in livestock. Forage legumes are more responsive to micronutrients, particularly B and Mo, than grasses. There are fewer documented cases of Cu, Fe, Mn and Zn deficiencies than of B and Mo deficiencies in forages. Soil acidity is one of the primary factors affecting the availability of micronutrients to forages. Low soil pH, e.g., is the principal cause of Mo deficiency in soybeans in Brazil and in a variety of crops in eastern Canada. More often soil properties and environmental factors are more important than actual soil levels, in affecting micronutrient availability. Micronutrient deficiencies have been emerging as a major problem in intensively cultivated soils in many countries and have become one of the serious constraints to crop productivity. Deficiency symptoms for most micronutrients appear on the young leaves at the top of the plant, because most of these nutrients are not readily translocated. However, Mo is an exception in that it is readily translocated, and its deficiency symptoms generally appear on the whole plant. Toxicity symptoms, on the other hand, for most micronutrients appear on the older leaves of the plant which is very striking, e.g., for B. Soil, foliar and seed applied methods of micronutrient application to control their deficiency are discussed in detail. Frequently the Cu, Fe, Mn, Zn and Se levels in forages which are sufficient for optimum crop yields are not adequate to meet the needs of livestock. Selenium is a trace mineral which is not required by plants and maximum forage yields can be obtained on soils with very low amounts of soil Se. However, if animals are fed forage with low Se, they could suffer from serious muscular disorders and other diseases. White muscle disease caused due to Se deficiency is the most common disorder and is found in calves and lambs. Sufficiency levels of micronutrients for crops have been discussed in relation to the animal requirement.

Introduction

Micronutrients, also known as trace minerals, which chiefly include boron (B), molybdenum (Mo), copper (Cu), zinc (Zn), Manganese (Mn) and iron (Fe), are required in extremely small quantities by crops and livestock. This, however, in no way refers to their role being minor. Their lack, e.g., can cause serious crop production problems in forages and health disorders in livestock (Römheld and Marschner, 1991; Miller et al., 1991).

The increasing world population has created a serious need to increase food and feed production. For example, micronutrient deficiencies have been emerging as a major problem in many intensively cultivated soils of India and have become one of the serious constraints to productivity (Takkar et al.,1989). Review articles related to micronutrients on tropical forages as prepared by Mattos & Colozza (1986), Monteiro (1991) and Monteiro et al. (1999) provide additional information.

Forage yield responses to some micronutrients have been reported (Gupta and Lipsett, 1981; McFarlane et al., 1990; and Turner, 1993). Forage legumes are particularly responsive to B and Mo (Gupta, 1969,1984; Johansen et al., 1997). Copper concentrations in pasture legumes are often greater than in grasses grown under similar conditions (Robson and Reuter, 1981), while grasses under certain conditions, such as high pH, are sensitive to Mn and Cu deficiency.

In studies on the nutrient requirements of forages, more attention is focused on dry matter yield response and less to animal health. The nutrient requirement for plants and livestock can differ considerably. For example, the Mn concentration as low as 31 to 34 mg kg $^{-1}$ in forages is adequate for optimum dry matter yield (Gupta, 1986); however the animal requirement is reported to be higher at 40 to 50 mg kg (Underwood, 1981; NRC, 1988a). Miller et al. (1991) stated that non-ruminants grazing in pastures may develop Zn-deficiency and a marginal deficiency could occur even in grazing sheep and cattle. Since forages in many parts of the world constitute a major diet of livestock, it is necessary to know the sufficiency levels of micronutrients for animal health.

The objective of this investigation is to discuss forage yield responses to micronutrients and their deficiency and sufficiency levels in forages and livestock. Soil and plant factors affecting micronutrient uptake and their deficiency and toxicity symptoms in forages will also be discussed.

Response to Micronutrients on Forage Yields

It is recognized that plant species other than legumes and grasses are also important sources of livestock fodder worldwide, but this review is restricted to forage legumes and grasses.

Anions (B and Mo)

Legumes in general are more sensitive to B deficiency than grasses. Lack of B depressed white clover (*Trifolium repens* L.) dry matter yields in the third and fourth harvests on a sandy soil limed periodically (Blue and Malik, 1986). Boron applications increased herbage and seed yields of clover in a cereal-clover rotation (Dear and Lipsett, 1987) and liming further increased the magnitude of responses. Dry matter yield response to B has been found to be greater for red clover *(Trifolium pratense* L.) and lucern or alfalfa (*Medicago sativa* L.) than for white clover as reported in New Zealand by Sherrell (1983 a). Studies conducted in Canada showed higher response to B on alfalfa than on red clover (Gupta, 1984). Large dry matter yield responses to B on alfalfa have also been reported in Virginia, USA (Hutcheson and Cocke, 1941). For crimson clover (*Trifolium incarnatum* L.) and alfalfa, B was found to be very important for the growth of these legumes in Texas, USA. Significant responses to B on perennial soybean (*Neonotonia wightii*)dry matter yield and nodules number and weight were reported by Werner and Mattos (1974) in a Brazilian Latosol. Seed yield increases in red clover due to B fertilization have been reported in Sweden on a B-deficient soil (Ericksson, 1979). Liming of acid soils in India resulted in 38% increased dry matter yields in response to 4 kg B ha $^{-1}$ (Bhagat et al., 1985).

Grasses, e.g., perennial rye grass (*Lolium perenne* L.), Cocksfoot (*Dactylus glomerata* L.) and timothy (*Phleum pratense* L.) have not been found to respond to B, even when plant B levels are very low (Gupta, 1973; Sherrell, 1983 b). In a study on seven established stands of Bermuda grass (*Cynodon dactylon* (L.) Pers.), limited yield responses to B were reported (Monson and Gaines, 1986). However, the small dry matter yield increases were significant for only two cultivars.

Boron deficiency can be overcome by soil applications of 1 to 4 kg B ha $^{-1}$ or 0.25 to 1.0 kg B ha $^{-1}$ as a foliar spray as reviewed by Mortvedt and Woodruff (1993).

The first field response of a pasture species to Mo application was reported in 1942 in subterranean clover (*Trifolium subterraneum* L.) grown on acid soils in southern Australia (Anderson, 1956). Thereafter, Mo deficiency was found to be limiting the legume component of the temperate-legume-based ley pasture systems on the acid soils prevalent across southern Australia (Gladstones et al., 1977). Outside of Australia, there have been numerous reports of field-grown pasture and forage temperate legumes responding to Mo application at soil pH values less than 6.0 (Kubota and Allaway, 1972).

Because acid soils are common in the humid and sub-humid tropics, the pasture and forage legumes grown in tropical areas are particularly prone to Mo deficiency (Johansen et al., 1977; Ross and Calder, 1990). Elsewhere in the tropics, there are increasing reports of responses by legumes to Mo including tropical legumes in Brazil (Werner et al.,1983; Mattos and Colozza, 1986). Molybdenum was the most responsive micronutrient for perennial soybean, centrosema, siratro and galaxia grown in soils from several regions of the State of São Paulo, Brazil (Monteiro et al., 1983a; Colozza et al., 1986; Colozza et al., 1987; Monteiro et al., 1987). There are species differences in response to Mo, e.g., *Neonotonia wightii* was shown to be more responsive, in some cases, than *Centrosema pubescens* as found in Brazil (Monteiro et al., 1983,b,c; Colozza and Werner, 1984). On the other hand, Werner and Mattos (1974,1975) grew perennial soybean and centro in a Brazilian Latosol and found that responses to Mo (the most responsive micronutrient for both legumes) were nearly the same for nitrogen concentration and content in these forage legumes. In a 4-year field study with a Guinea grass-siratro mixed pasture Carriel et al. (1989) found positive effects from adding Mo with P and K fertilization at the forage establishment. Maximum forage mixture yield response occurred at 225 g Mo ha^{-1} (average of period).

Molybdenum has been supplied to legumes by pelleting seeds with Mo fertilizers. In Brazil, positive effects of Mo supply as pellet was reported for siratro dry matter yield, nitrogen concentration and nitrogen content by Monteiro et al. (1980) and for centro nitrogen concentration and content by Colozza and Werner (1982).

As trace amounts of Mo are required for nitrate reductase activity, Mo responses can be expected in grasses. Responses to Mo on temperate pasture grass (*Phalaris aquatica* L.) in Australia (Lipsett, 1975) and to *Brachiaria decumbens* (19% increase in dry matter) in Brazil (Miranda et al., 1985) have been found under field conditions. Rye grass (*Lolium multiflorum* Lam) and kikuyu grasses (*Pennisetum clandestinum*) have not been found to respond to Mo; while among tropical grasses, panic is more responsive to Mo than is Buffel or Setaria (Johansen, 1978b).

Molybdenum deficiency can be corrected by applying Mo fertilizers to the soil at 100 g Mo ha $^{-1}$, by treating seeds at 8 to 10 g Mo kg $^{-1}$; or by foliar applications of 50 to 100 g Mo ha $^{-1}$.

Details of Mo fertilization of crops can be found elsewhere (Mortvedt, 1997).

Cations (Cu, Fe, Mn and Zn)

Highly weathered and sandy soils are generally low in Cu. Responses to Cu have been found on a wide variety of cereals, such as, wheat, corn, rice (*Oryza sativa* L.) barley *(Hordeum* *vulgare* L.) and oats (*Avena sativa* L.) as well as on sugar beets (*Beta vulgaris* L.) and carrots (*Daucas carota* L.) as reviewed by Gupta (1997a). However, responses to Cu on forages have been reported only in few instances. Overdahl et al.(1976) in Minnesota, USA reported some positive effect of Cu on alfalfa yields. On peat soils, large increases of hay crops have been found in response to Cu fertilization (Sorteberg and Oijord, 1977). Studies conducted in Atlantic Canada failed to show any effect of Cu on alfalfa and timothy yield increases in spite of the tissue Cu concentrations as low as 3 to 4 mg Cu kg $^{-1}$ (Gupta, 1989a). A positive Cu x Mo interaction was reported by Werner and Mattos (1975) for dry matter yield and nitrogen content in Centro grown in a greenhouse experiment with a Latosol. These micronutrients were applied to the molasses grass + centro pasture (where the soil was collected for the pot experiment) and Werner et al. (1983) found significant responses to them for both legume herbage yield and nitrogen content, and also for the proportion of centro in the forages mixture.

Copper deficiency when suspected can be overcome by adding 2 to 8 kg Cu ha $^{-1}$ as a soil fertilizer or 0.25 kg Cu ha $^{-1}$ as a foliar spray.

Iron deficiency is generally accepted as a “physiologically induced disease” and it is only in specific cases that a lack of Fe in the soil itself is the cause. Iron deficiency is most common in the Mediterranean and in the middle east. (Shorrocks, 1984). Studies conducted on highly calcareous soils in Arizona indicated that Fe chlorosis in range grasses was overcome by soil acidification resulting in dry matter yield increases (Ryan et al., 1975). Such yield increases were obtained on five range grasses on Fe deficient soils with pH 8.3. Studies conducted on forages on sandy leached soils showed no response to Fe on alfalfa and timothy which contained as low as 20 and 30 mg Fe kg $^{-1}$ (Gupta, 1991b). Generally 10 to 30 mg Fe kg $^{-1}$ in young mature leaves is used as an indicator of Fe deficiency (Shorrocks, 1984).

The chelate Fe EDDHA has generally been considered to be the most effective soil applied material in alleviating chlorosis due to a lack of Fe (Hagstrom, 1984). Shorrocks (1984) recommends production and use of new Fe chelates that are stable in alkaline soils in the presence of free calcium carbonates. Progress has been made in the correction of Fe deficiency by the development of Fe-efficient genotypes (Fehr, 1984). Foliar applications of inorganic and chelated Fe sprays are ineffective unless repeated several times during the growing season and that they often fail to give a yield response (Shorrocks, 1984).

Manganese responses are most likely to occur on highly organic and high pH sandy soils. Although responses to Mn have been found on a variety of crops, Mn responses in forages are low. On acid sandy soils where forage plant tissue Mn levels were as low as 29 mg kg $^{-1}$, no responses to Mn were found. (Gupta, 1986). Responses to Mn have been reported on oats and soybeans (*Glycine max* (L.) Merr) when plant tissue Mn levels were as low as 15 to 18 mg kg $^{-1}$ (Martens et al., 1977; Parker et al., 1981). Martin and Matocha (1973) showed that responses to Mn on alfalfa occurred when Mn levels were less than 20 mg kg $^{-1}$. Manganese deficiencies are common in soybeans growing in soils with pH higher than 6.5 and soils with natural high water tables (Steckel, 1946).

In the case of suspected Mn deficiency, it can be corrected with 11 to 16 kg Mn ha^{-1} placed in bands or broadcast. A total of 2.2 kg Mn ha $^{-1}$ applied in 2 to 3 foliar sprays is also effective (Alley et al., 1978).

Zinc deficiency in agricultural crops is one of the most common micronutrient deficiencies. Zinc deficient soils have been found in India, USA, Canada, New Zealand, Africa, Europe and South America (Pedersen, 1966). A positive Zn x Cu x Mo interaction was found by Monteiro et al. (1983d) in two Brazilian soils for centro nitrogen content. Zinc resulted in significant benefits for this legume only when supplied together with molybdenum. Many soils do not contain sufficient Zn for livestock but responses to Zn on forage yields are not common. (Gupta, 1989b; Stout et al., 1987). No response to Zn occurred on alfalfa and timothy dry matter yields when plant tissue Zn levels were as low as 12 to 16 mg kg $^{-1}$ (Gupta, 1989b). These Zn levels are close to the borderline deficiency since Zn deficiency in alfalfa tops has been found to be associated with tissue levels of less than 11 mg kg $^{-1}$ (Martin and Matocha, 1973). Similar Zn levels of less than 15 mg kg $^{-1}$ in cereals have been considered to be low (Ward et al., 1973). However, Zn levels of 19 to 26 mg kg $^{-1}$ are considered deficient from the livestock nutrition viewpoint (Boila et al., 1985). In a field study, limed and sewage sludge treated soils showed rye grass response to Zn, which was attributed to tissue Zn level increases above the critical Zn tissue concentration (Smith, 1994).

Zinc deficiencies can be corrected by applying Zn to the soil at five to 15 kg Zn ha $^{-1}$or at 0.5 to 1.0 kg Zn ha $^{-1}$ applied as a foliar spray.

Dry matter yield responses to B, Mo and Cu for a few forage species are shown in Table1.

Micronutrient Sufficiency Levels in Forages for Yield vs. Animal Requirement

Often when one talks about sufficiency levels of nutrients in crops, there is a range in values rather than one definite number that could be considered "critical." Therefore, the term sufficient will be used where ever possible. When describing sufficient levels in forages, consideration must be given to the animals since the later will consume the forages.

So far B has not been proven essential for animals and therefore its levels in forages only will be considered. Generally, 20 to 40 mg B kg $^{-1}$ in the whole tops of alfalfa and red clover have been considered to be sufficient (Meyer and martin, 1976; Gupta, 1972a). Grasses generally require less B than forage legumes and hence their sufficiency levels are also low. For example, pasture grasses, rye grass and timothy containing as low as 3 to 10 mg B kg $^{-1}$ are considered sufficient as summarized in Table 2.

Molybdenum deficiency in animals is apparently relatively rare, and is usually produced by feeding its antagonists, tungsten, in amounts 1000-fold greater than Mo (Rajagopalan, 1987). However, Mo deficiency occurs occasionally as reported by Anke et al.(1985) in goats when rations contain 0.024 mg Mo kg $^{-1}$. This level is unusually small and does not occur frequently. Like B, forage legumes are more responsive to Mo than are grasses. Sufficient levels of Mo in forages are lower than for most other micronutrients. Often they are less than 1.0 mg kg $^{-1}$. Sufficiency levels of Mo in alfalfa and red clover range between 0.2 - 0.5 mg kg $^{-1}$ and in timothy and tropical and temperate pastures as low as 0.1 as summarized by Gupta (1997b). Sufficiency levels vary depending upon the age and part of the plant sampled. Detailed sufficiency levels in various forage species are described in Table 2.

The requirement for Cu by most animals is quite low when compared with the requirement for most other minerals. As evident from Table 3, sufficiency levels of Cu for cattle and sheep at 6 to 10 mg kg $^{-1}$ are small and most forages appear to contain sufficient Cu. Levels of Cu which are sufficient for forages are also adequate for cattle and sheep. However, the requirement of Cu for pigs at 50 to 60 mg kg $^{-1}$ and chickens at 60 to 80 (Suttle and Mills, 1966; Miller et al., 1991) is higher than 8 to 35 mg Cu kg $^{-1}$ considered sufficient for most forages (Table 2). Researchers from South Australia reported that Cu concentrations of less than 4 mg kg $^{-1}$ indicate deficiency in subterranean clover (McFarlane et al., 1990). They however concluded that Cu deficiency may occur in livestock even when Cu concentrations in pastures are 10 mg kg $^{-1}$.

It is important to consider forage Mo level when discussing Cu sufficiency for livestock.

Animals grazing on pastures high in Mo could develop Cu deficiency in spite of the fact that the Cu concentration in forages is adequate for maximum dry matter production. This is considered Mo induced Cu deficiency (Kubota and Allaway, 1972). In such cases high Cu supplementation with sulfates may be necessary to immobilize Mo (Suttle, 1975). A survey on Cu and Mo concentrations in forages and beef cattle liver, in the state of Mato Grosso, Brazil, high levels of Mo and Cu concentrations of less than 5 mg kg $^{-1}$ were found in forages. However, the levels of Cu in the liver wetre normal for the animal, because of Cu supplementation in the salt mixture (Sousa et al., 1980). Ratios of Cu:Mo in the range of 2:1 to 7:1 have been reported to be critical but Cu deficiency in animals does not occur if feed intakes of Cu are more than 5 mg kg $^{-1}$ (Gupta and Lipsett, 1981).

Studies conducted in P.E.I. showed that Mn levels as low as 31 to 34 mg kg $^{-1}$ were in the crop sufficiency range (Gupta, 1986). These Mn levels for poultry and ruminants are not sufficient whose requirements are higher at 50 ,e.g., for ruminants. The recommended level for ruminants is 50 but it cannot be given with any certainty.

Field studies in Prince Edward Island (P.E.I.), eastern Canada showed that Zn levels as low as 12 to 16 mg kg $^{-1}$ in alfalfa and rye grass were sufficient for maximum dry matter yield (Gupta, 1989b). However, these levels are far short of the sufficiency levels of 50 to 100 for pigs (NRC 1988b) and of 50 mg kg $^{-1}$ for dairy cows (NRC 1988a). Zinc is an indispensable component of a number of enzymes or other proteins in animals (Hambidge et al., 1987). It is essential for maintaining normal growth, reproduction, and lactation performance (Miller et al., 1979). Forages in the north eastern part of North America do not contain enough Zn to meet the recommended Zn allowance at 40 mg kg $^{-1}$ for dairy cattle (Stout et al., 1987). In the State of Mato Grosso, Brazil, low levels of Zn in the soil, forage (less than 30 mg kg^{-1}), and beef cattle liver were found by Sousa et al. (1982) in a survey on several farms. Hutton (1982) mentioned that at the beginning of the 70's the fotossensibilization in young animals grazing *Brachiaria decumbens* was a serious problem in Central Brazil and that such problem was linked to low levels of Zn in the forage.

Cobalt concentrations as low as 0.022 and 0.012 mg kg $^{-1}$ in alfalfa and timothy, respectively were sufficient for maximum dry matter yields (Gupta, 1993a). Generally the requirement of Co for crops is very low. Cobalt concentrations found adequate for forages are inadequate for a variety of animals. As summarized in Table 3, the Co requirement for various class of livestock is higher and ranges from 0.04 to 0.10 mg kg $^{-1}$ in the feed.

In the semiarid southern region of Puerto Rico, Mn, Cu, Co and Se levels in pastures have been found to be below the recommended levels for grazing ruminants (Santana and MacDowell, 1994). Their research indicates the need for livestock supplementation even under conditions of high pasture fertilization with NPK. Selenium is a trace mineral which is not required by crops and maximum forage yields can be obtained on soils with amounts of Se as low as 0.01 mg Se kg$^{-1.}$ However, if animals are fed forages with less than 0.1 mg Se kg^{-1}, they could suffer from serious physical disorders as summarized by Gupta and Gupta (2000).

Factors Affecting Micronutrient Uptake by Forages

Soil acidity is one of the primary factor affecting the availability of micronutrients to crops (Corey and Schulte, 1973). With the exception of Mo, the plant availability of other micronutrients, e.g., Mn, B and Fe decreases with liming (Gupta, 1972a,b; Gupta, 1979,1992). Manganese and Zn concentrations in forage legumes decreased as lime rates (and consequently soil pH) increased as found in several Brazilian studies (Monteiro et al., 1983b,c; Gontarsky, 1991; Premazzi, 1991; Colozza et al., 1998). Similar effect was observed for Guinea grass and Marandu grass by Premazzi (1991). It should be pointed out that special care need be taken to avoid overliming the soil that would result in Mn and/or Zn deficiency.

Forage legumes are responsive to Mo as summarized by Adams (1997). Forage legumes are, in general, more susceptible to B deficiency than grasses (Gupta, 1984). Grasses along with cereals are the least responsive to B. Continuous use of some fertilizers such as nitrogenous has caused widespread Zn deficiency particularly in light-textured soils (Kumar et al., 1985).

High uptake of B can occur from the use of high B irrigation water or due to accidental applications of too much B. For example, addition of compost with high B can result in significantly higher B uptake by crops (Gupta et al., 1973; Purves and MacKenzie, 1973). Molybdenum in forages can be significantly increased by liming soils containing sufficient total Mo (Gupta, 1969). As shown in Table 4, Mo increases due to liming were much higher in the silty clay loam soil than in the sandy loam soil low in total Mo. In the absence of Mo fertilization, plant tissue Mo increases in the sandy loam were in traces only. Sulfur can also seriously decrease Mo in forage crops on podsol soils (Gupta and MacLeod, 1975) and in white clover grown on a Florida spodosol (Monteiro, 1986). Molybdenum toxicosis (molybdenosis) is a serious problem in grazing ruminants in those areas of the world where the soils and resulting herbage have relatively high levels of Mo. Molybdenum content of such pastures may range from 20 to 200 mg Mo kg^{-1} (dry basis) (Underwood, 1977). The critical Cu:Mo ratio in cattle diets in western Canada was considered to be 2:1 (Miltimore and Mason, 1971). Alloway (1973) suggested that Cu/Mo ratio nearer to 4:1 was required on some pastures in England to prevent Cu deficiency in sheep. Molybdenum can also interact with other nutrients such as Mn, Fe and Zn (NRC, 1980).

Copper uptake in crops is difficult to increase. Toxic Cu uptake can occur only at very high rates of applied Cu (Baker, 1974).

Iron uptake by plants is pH related and is often called as lime-induced chlorosis when grown on alkaline calcareous soils. Application of lime reduced the Fe uptake in a variety of crops (Gupta, 1991b,1992). Iron uptake in lupins (*Lupinus* spp.) on calcareous soils was seriously reduced when the pH of the soil solution was close to 7.5 (Bertoni et al., 1992). Soils with a pH range of 5.1 to 7.0 showed no effect on Fe concentration in several plant species (Gupta, 1992).

Decrease in plant Mn in response to liming is most dramatic (Gupta and MacLeod 1973; Gupta, 1972b; Vitosh et al., 1981). Moraghan (1979) reported that Mn uptake is enhanced with high levels of water soluble or salt extractable Mn. Manganese availability to crops is enhanced by reducing conditions in poorly aerated or submerged soils (Vlamis and Williams, 1964). In new South Wales, Australia, liming suppressed Mn toxicity by reducing its concentration in pastures (Holford and Crocker, 1994). Applications of Linz-Donawitz (LD) slag, a by-product of the Fe and steel making industry, used as a dolomitic agent for pastures has been found to decrease Mn concentration in herbage (Besga et al., 1996). Studies in Atlantic Region of Canada showed that on a strongly acid soil, the Mn levels in timothy decreased from 175 mg kg^{-1} at soil pH 4.5 to 50 mg kg^{-1} at pH 6.7 and in bromegrass from 225 to 65, respectively (Umesh C. Gupta, AAFC, Charlottetown, Canada, unpublished data).

Zinc uptake is reduced in crops grown on high pH, organic and sandy textured soils. Potential phytotoxicity due to high Zn uptake from excess Zn application exists because only small amounts of Zn leach, and because reversion of applied Zn to unavailable forms is relatively slow in soils (Payne et al., 1988). On a sludge treated soil, liming from pH 4.2 to 7.0 reduced the plant Zn concentration and to a lesser extent, Cu concentration (Smith, 1994).

Crops are highly tolerant to Zn. Large applications of Zn are required to raise its concentration significantly to cause phytotoxicity (Dudka et al., 1994). A pH of 6.5 or above must be maintained to significantly decrease Zn availability to plants (USPEA,1983).

Levels of most micronutrients are higher in leaves than in stem or whole plants (Gupta, 1990,1991a). Copper and Zn, in general are higher in root portions than in the aerial parts (Wong and Chu, 1985). Jarvis and whitehead (1983) reported that clover absorbed more Cu and, in general, had higher concentration in shoots than did the ryegrass. Interaction with other nutrients can be an important factor. The most conspicuous interaction between Mo and other nutrients is the three-way interaction of Mo, Cu and S.

Other factors affecting micronutrient uptake include, e.g., method of application, temperature, moisture supply and plant genotypes.

Deficiency levels and Toxicity Symptoms in Forages

a. Symptoms

Deficiency symptoms for most micronutrients appear on the young leaves at the top of the plant, because most of these nutrients are not readily translocated. However Mo is an exception in that it is readily translocated, and its deficiency symptoms generally appear on the whole plant as summarized by Gupta (1997c). Relative sensitivity of a few forages to micronutrient deficinecy is reported in Table 5. Toxicity symptoms for most micronutrients appear on the older leaves of the plant which is very striking ,e.g., for B (Gupta,1993b).

Anions (B and Mo)

Under B deficiency, flowers fail to form in alfalfa and buds appear as white or light-brown tissue (Nelson and Barber, 1964). Internodes are short, blossoms drop or do not form, and stems are short (Berger, 1962). Younger leaves turn red or yellow in color (Gupta, 1972a,1984), and “top yellowing” of alfalfa occurs (Bergman, 1976). Clover plants are weak with thick stems that are swollen close to the growing point, and leaf margins often look burnt (Janos, 1963). It results in poor clover plants with cupped and shriveled leaves, which are small and reddish or yellowish in color (Gupta, 1984). Leaves develop a leathery texture and become extremely brittle (Sherrell, 1983a). Grasses are not sensitive to B and B deficiency is generally not observed.

Boron toxicity in alfalfa and red clover includes burning and yellowing of older leaf edges (Gupta 1972a,1984). In birdsfoot trefoil *(Multiflorum corniculatus* L.), growth is poor and leaves are small and dark with thin stems (Gupta, 1972a). Boron toxicity in timothy appears in the form of burning of the older leaf edges (Gupta, 1984), and yellowing and drying of leaf tips in *Stylosanthes guyanensis* (Werner et al.,1975) and in *Stylosanthes hamata* (Werner, 1979).

Symptoms of Mo deficiency are common in certain soil and climatic conditions. Deficiency is manifested as general yellowing of the whole plant in alfalfa (Bergman, 1983). Root nodules weight is considerably lower (Robinson, et al., 1957). In severe cases, symptoms of Mo deficiency appear as incurled leaves and marginal scorching (Climax molybdenum company, 1956). In perennial rye grass, growth is reduced and the foliage turns pale green, suggestive of nitrogen deficiency, although some interveinal chlorosis may also occur (Turner, 1993). Molybdenum deficiency in *Phalaris tuberosa* is manifested as pale and stunted plants with scorched and necrotic leaves, similar to those seen after frost damage (Lipsett, 1975).

Molybdenum toxicity in forages and in most crops is uncommon and found only when unusually high concentrations are present. In lucerne, Mo toxicity produces light-colored leaves that turn golden yellow and then bronze (Falke, 1983) or as intense yellowing of leaves (Bergman, 1992). Excess Mo in plants generally is not known to adversely affect plant growth. However, high Mo concentrations (10 to 20 mg kg^{-1}) can induce Cu deficiency in ruminants that consume such material (Scott, 1972). High Mo applications can also be detrimental to *Rhizobia* in the seed inoculum (Sedberry et al., 1973).

Cations (Cu, Fe, Mn and Zn)

Copper deficiency in alfalfa results in reduced plant growth, leaves faded green with a grayish cast, shortened internodes and bushy plants (Nelson and Barber, 1964). Plants are much like those produced under drought conditions. In red clover, leaves become light green and die suddenly. Deficiency in Kenya white clover is characterized by wilting and drooping, followed by leaf malformation and cup like shape (Wapakala, 1972). Copper deficiency results in delayed flowering causing depressed seed production (Reuter et al., 1981). In subterranean clover, Cu deficiency results in delayed flowering and depressed seed production (Reuter et al., 1981).

Copper has generally not been known to be toxic even when applied in large quantities. Field experiments conducted on maize (*Zea mays L.*) over 17 years using a high rate of 280 kg Cu ha^{-1} did not cause any harmful effect and yield was unaffected (INCRA: Shorocks et al., 1984). In general, Cu toxicity causes reduced branching, thickened and abnormally dark coloration of the rootlets of many plants (Reuther and Labanauskas, 1966).

Iron deficiency in grasses, e.g., in turf grass leaves is first manifested in younger leaves as interveinal chlorosis (Turner, 1993). Iron toxicity symptoms usually are blackening of leaf tissue without permanent damage to the turf grass plant (Yust et al., 1984). Symptoms in alfalfa include general yellowing of leaf lamina with light-colored veins (Bergman, 1983). Iron chlorosis due to Fe deficiency is generally found on calcareous soils. A direct Fe toxicity in crops from an application of Fe fertilizer would not be expected because of the relatively rapid conversion of soluble Fe compounds in soil systems (Martens and Westermann, 1991). Iron supply at 2 kg ha^{-1} with macronutrients (except N) depressed both centro dry matter yield and nitrogen content when this legume was grown in a Podzolic soil (Fancelli et al., 1981).

Manganese deficiency in crops generally occurs on poorly drained and/or on high pH soils. On acid soils, Mn toxicity is most common. Among the forages, alfalfa and clovers are more sensitive to Mn toxicity than grasses and other forages. For a group of forage legumes, Andrew (1978), suggested that the tolerance to excess Mn should be in the following order: Lotononis bainesii = Centrosema pubescens> Stylosanthes humilis = Desmodium uncinatum > Desmodium intortum = Leucaena leucocephala > Macroptilium lathyroides > Neonotonia wigthii = Macroptilium atropurpureum. In lucerne, Mn toxicity results in yellow brown leaf margins which change to light and deep purple on both sides (Siman et al., 1974). In subterranean clover, faint yellow margins developed interveinally and on the tips of the leaves. These margins extended and darkened becoming reddish and finally purple. In perennial soybean, Mn toxicity results in yellow new leaflets which change to yellow leaf margins with brown spots mainly in leaflet margins (Werner et al., 1975; Monteiro et al., 1983b). Such symptoms were associated with Mn concentration of 947 mg kg^{-1} in perennial soybean plant tops (54 days plant growth) (Monteiro et al., 1983b). Souto and Dobereiner (1969) found Mn concentrations in the range of 3720 to 6160 mg kg^{-1} for stylo, centro and perennial soybean at 22 days after sowing, when they supplied Mn at 200 mg kg^{-1} soil. They also reported very low or no-nodulation in these legumes + siratro when Mn rate was 100 mg kg^{-1} , and concluded that the most and least tolerant species to Mn excess were centro and siratro, respectively.

Zinc deficiencies are prevalent in crops grown on high pH, organic and sandy textured soils than on heavier soils and are generally more pronounced under a cool, wet spring and often disappear by mid season. Zinc deficiency led to the accumulation of amino acids due to the impairment of protein synthesis and increased activity of peroxides and decreased auxin levels (Srivastava and Gupta, 1996). Grasses are highly tolerant to Zn ,e.g., no deleterious effects from tissue Zn levels of 3000 mg kg $^{-1}$ were found in bent grass (Christians, 1984). Zinc deficiency in turf grass results in stunted leaves with chlorotic margins (Turner, 1993). A Zn deficiency markedly retarded the growth of *Crotalaria anagyroides* (a leguminous plant grown for green manuring). Plants were chlorotic and reduced in size and number of leaves (Widdowson, 1966).

b. Levels

The deficiency and toxicity levels of micronutrients as reported are associated with plant disorders and/or crop yield reductions. Differences in the various levels to a certain extent are attributed to the differences in the analytical techniques used and the location of the various laboratories. Selection of plant part and stage of plant growth (Gupta, 1990,1991a,1992) are some of the factors which can affect the various values.

The deficient and toxic levels of micronutrients in forage legumes and grasses are summarized in Tables 6 and 7. Such levels are discussed in terms of their effect on crop quality and yields. In an earlier section it has been discussed that some of the micronutrient levels which are sufficient for optimum crop dry matter yield may be deficient from the animal nutrition point of view.

Toxicity of Mo in crops is seldom observed under normal conditions. However, on alkaline soils and other high Mo soils, the plant Mo concentrations could be high. Although such levels will be of no detriment to the crop but if such crops are fed to livestock, the later could develop severe Mo toxicity resulting in Cu deficiency.

Data on deficiency and toxicity levels of Cu, Zn, and Fe, particularly for Cu (Baker, 1974), in forages is scanty because of a lack of response to these micronutrients. Furthermore, the plants appear to have a cut off mechanism for theses micronutrients and high degree of tolerance. Consequently it is difficult to increase their concentration in crops (Marsh and Waters, 1985; Dudka et al., 1984; Dragun and Baker, 1976). In general, legumes are more sensitive to Mn toxicity, as high Mn levels may affect root nodulation (Kluge et al., 1985). Pasture Mn concentrations of 2000 mg kg $^{-1}$ are considered detrimental to grazing sheep (Black et al., 1985).

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Table 1 – Effect of B, Mo and Cu on Forage Dry Matter Yield

Species	Country	Degree of response over control	Reference
		Boron	
Alfalfa	New Zealand	43 - 49%	Sherrell (1983a)
	Canada	8 - 32%	Gupta (1984)
Red Clover	Canada	15%	Gupta (1984)
White Clover	New Zealand	14 - 40%	Sherrell (1983a)
Bermuda Grass	USA	Positive response	Summarized by Shorrocks (1987)
		Molybdenum	
Alfalfa	Canada	Soil pH 6.5 silty clay loam <5% sandy loam 45%	Gupta (1969)
Bromegrass	Canada	silty clay loam Nil sandy loam 50%	Gupta (1969)
		Koper	
Brachiaria decumbers	Brazil	6%	Miranda et al. (1985)
Alfalfa	USA	Positive response	Overdahl et al. (1976)
Red Clover	Norway	10%	Sorteberg and Oijord (1977)
Timothy		30%	Sorteberg and Oijord (1977)

Table 2 – Sufficiency Levels of B and Mo in Forages

Crop	Part of Plant Tissue	Sufficiency levels	Reference
		B, mg kg^{-1}	
Alfalfa	Whole tops at early bloom	20 - 40	Meyer & Martin (1976)
	Whole tops at 10% bloom	39 - 52	Gupta (1972a)
	Top rd plant before flowering	31 - 80	Neubert et al. (1970)
Red Clover	Whole tops at bud stage	21 - 45	Gupta (1972a)
	Top rd plant at bloom	20 - 60	Neubert et al. (1970)
Birdsfoot Trefoil (*Lotus Coniculatus* L.)	Whole tops at bud stage	30 - 45	Gupta (1972a)
Pasture grass (*Gramineae)*	Vegetative tops at first bloom	10 - 50	Neubert et al. (1970)
Ryegrass	Whole plants at rapid growth	6 - 12	Sherrell (1983b)
Timothy	Whole plants at rapid growth	6- 12	Sherrell (1983b)
		Mo, mg kg $^{-1}$	
Alfalfa	Leaves at 10% bloom	0.34	Reisenauer (1956)
	Whole plants at harvest	0.55 - 1.15	Evans & Purvis (1951)
	Whole tops at 10% bloom	0.12 - 1.3	Gupta (1970)
Red Clover	Above ground parts at bloom	0.3 - 1.6	Neubert et al. (1970)
	whole tops at 10% bloom	0.27	Gupta & LeBlanc (1990)
Subterranean Clover	Leaflets and petioles	0.1	Petrie & Jackson (1982)
Temperate pasture legumes	Plant Shoots	>0.1	Johansen (1978a)
Timothy	Whole plant at blossom	0.15 - 0.50	Bergmann (1992)

Table 3 – Sufficiency Levels of Micronutrients in Forages and Animals

Nutrient	Sufficiency Levels, mg kg^{-1}	
	Forages	Animals
Copper†	Alfalfa 8 - 12 (Gupta 1989a)	Cattle 4 - 10 (NRC, 1988a)
	Timothy 5-8 (Gupta 1989a)	Sheep 6 - 10 (Underwood, 1981)
	Red Clover 8 - 17 (Neubert et al., 1970)	Pigs (post weaning) 60 (NRC, 1988b)
	Pasture grasses 5 - 12 (Neubert et al., 1970)	Pigs when fed high Cu diet 50 (Suttle and Mills, 1966)
Iron	Alfalfa 35 - 50 (Gupta 1991b)	21 mg Fe‡/kg body weight (baby pigs) (ARC, 1981)
	Timothy 23 - 47 (Gupta 1991b)	Leghorn chicken 60 - 80; Broiler chicks 80 (Miller et al., 1991)
Manganese	Alfalfa 31 to 49; Timothy 34 to 53 (Gupta, 1986);	Poultry and chicks 50 (Underwood, 1981); Ruminants 40 (NRC,1988a)
Zinc	*Crotolana anagryoides* 10 (Widdowson, 1966)	Pigs at various stages of growth 50 to 100 (NRC, 1988b); Dairy calves, dairy cows and
	Alfalfa 16 - 28; Ryegrass 12 to 22 (Gupta, 1989b)	bulls 50 (NRC, 1988a); Swine at various growth stage 35 to 65 (NRC, 1984)
Cobalt	Alfalfa 0.030 - 0.42; Timothy .012 - 0.24 (Gupta, 1993a)	Ruminants 0.1 mg kg $^{-1}$ (Smith, 1987); (NRC, 1988a); >0.07 for sheep ,>0.04 for cattle (ARC, 1965)

†Copper concentrations in relation to Mo and S in the ration
‡Based on body weight, all other values are in forage dry matter

Table 4 – Effect of soil pH (liming) on the Mo concentration in Forages Grown on two Soils

Soil texture	Alfalfa		Bromegrass	
pH	No Mo	With Mo	No Mo	With Mo
	Mo Concentration, mg kg $^{-1}$			
Silty Clay Loam				
5	Trace	0.43	0.11	0.95
5.5	0.51	4.4	0.3	1.8
6	0.91	4.63	0.27	1.67
6.5	1.48	4.93	0.62	2.3
Culloden Sandy Loam				
5	Trace	0.11	0.02	0.35
5.5	Trace	2.04	0.02	1.09
6	Trace	2.01	0.04	3.59
6.5	Trace	3.32	0.05	3.77

Table 5 – Relative Sensitivities of a Few Forage Species to Micronutrients Deficiencies

Nutrient	Crop		
	Alfalfa	Clover	Grasses
B	H*	M	L
Cu	M	M	L
Fe	M	M	H
Mn	M	M	M
Mo	M	M	L
Zn	L	L	L

*H = High. M =Medium. L = Low.

Table 6 – Deficiency and Toxicity Levels of B and Mo in Forages

Crop	Plant part sampled	Deficient	Toxic	References
		B, mg kg $^{-1}$		
Alfalfa	Whole tops at early bloom	<15	200	Meyer and Martin (1976)
	Top rd of plants	<20	>100	Neubert et al. (1970)
	Whole tops at 10% bloom	8 to 12	>99	Gupta (1972a)
Red Clover	Whole tops at bud stage	12 to 20	>59	Gupta (1972 a)
	Top rd of plants		>60	Neubert et al. (1970)
Pasture grass	Above ground part at first bloom at first cut		>800	Neubert et al. (1970)
Ryegrass	Whole plant at rapid growth		>39-42	Sherrell (1983b)
Timothy	Whole plants at heading stage		>102	Gupta and MacLeod (1973)
	Whole plants at rapid growth		47	Sherrell (1983b)
		Mo, mg kg $^{-1}$		
Alfalfa	Leaves at 10% bloom	0.26 - 0.28		Reisenauer (1956)
	Top rd of plants	<0.2		Neubert et al. (1979)
	Whole tops at 10% bloom	<0.12		Gupta (1970)
Red Clover	Total above ground part at bloom	<0.15		Neubert et al. (1970)
	Plants at 10% bloom	0.03		Gupta and LeBlanc (1990)
Timothy	Whole tops at prebloom	0.11		Gupta and MacKay (1968)

Table 7 – Deficiency and Toxicity Levels of Cu, Mn, Zn, and Fe in Forages

Crop	Plant Part Sampled	Deficient	Toxic	References
		Cu, mg kg^{-1}		
Alfalfa	Top 15 cm plant before flowering	<5	>50	Jones (1967)
	Top rd plant before flowering	<2	>60	Neubert et al. (1970)
Red Clover	Top of plants at bloom	<3	>17 *	Neubert et al. (1970)
Pasture grasses	Above ground parts at first cut	<5	>12 *	Neubert et al. (1970)
Rye grass	Plants when leaves 12 to 15 cm long		21	Davis & Beckett (1978)
		Zn, mg kg^{-1}		
Alfalfa	Top 15 cm growth	<11		Martin & Matocha (1973)
	Whole tops at 10% bloom		123*	Gupta (1989b)
Rye grass	Whole plants at heading		87*	Gupta (1989b)
	Whole plants at heading		210	Dudka et al. (1994)
Cow peas			>145	Marsh and Waters (1985)
		Mn, mg kg^{-1}		
Alfalfa	Top 15 cm growth	<20	77*	Martin & Matocha (1973)
	Whole tops at 10% bloom			Gupta (1986)
Timothy	Whole tops at pre bloom		66*	Gupta (1986)
		Fe, mg kg^{-1}		
Alfalfa	Top 15cm plants before flowering		>400	Jones (1967)
Timothy	Whole plants at pre bloom		87*	Gupta (1991b)
Variety of Crops	Whole plants		>400	Brown (1982)
Most crops	Plant tissue	<25	>500	Srivastava and Gupta (1996)

*Considered high but not toxic