Distribution of Micronutrients Available to Plants in Different Ecological Regions of Nepal

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Abstract

An attempt is made to present the status of micronutrients available for plant growth in different agro-ecological regions of Nepal. The amount of micronutrient elements present in plants and soil, such as copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn), are given and discussed. Scattered studies of boron (B) and molybdenum (Mo) are also interpreted. In the High Himalayan region, diethylene triamine pentaacetic acid (DTPA) extracted soil contained greater amounts of Mn (4.36 mg kg^{-1}) and Zn (3.43 mg kg^{-1}), whereas Cu (0.28 mg kg^{-1}), Fe (8.86 mg kg^{-1}), and B (0.16 mg kg^{-1}) contents were low. In the mid hills of the Western region all of these elements were low except Fe, which was present in medium amounts. The central hills had similar characteristics. In the Kathmandu Valley, however, where soil is formed by lacustrine deposits, the content of trace elements varied. Zinc content ranged from 2.7 mg kg^{-1} to 26.8 mg kg^{-1}, Cu from 9.12 to 10.93 mg kg^{-1}, Fe from 290.9 to 1101.9 mg kg^{-1}, and Mn from 27.94 to 128.83 mg kg^{-1}. These elements in the Valley are categorised as being in the medium to high range. The higher content of these elements was due to the heavy application of compost formed from city waste. In contrast, B and Mo are low even in the Valley soils and crops responded well to B and Mo applications. In the Inner Terai (Chitwan), B and Zn contents are low whereas Cu, Fe, Mn are high. In the Terai, Cu, Zn, and Mn content are low to medium, but Fe content is high. All of these elements responded well to experiments in all five physiographic regions. In the eastern Terai, boron has been found to create deficiencies in wheat.

Background

The increasing population of Nepal (2.3% pa) demands greater productivity of food crops. This has led to adoption of high-yielding crop varieties combined with greater cropping density than heretofore; and in turn to greater amounts of plant nutrient use. Even increasing the amounts of compost (some farmers apply 60t of compost per ha), it has proved to be insufficient to replenish the losses (Ghani and Brown 1997). The consequence is widespread deficiency in both major and micro elements (Hobbs et al. 1988). One of the results of urbanisation is that animal husbandry decreases and there is insufficient compost (Joshi and Karki 1993), hence in the Kathmandu Valley farmers traditionally use fresh night soil and sewage and this has been taken up elsewhere too. Compost from municipal waste is also applied in high doses where drainage irrigation is not possible. These waste compost materials and sewage water have sufficient plant nutrients but are also a source of contamination (Cameron et al. 1997), especially the compost from the city waste of the Kathmandu Valley (Karki 1995).

The importance of micronutrients for Nepalese agriculture was recognised in 1971, but at the time there were no analytical facilities available. Micronutrient analysis began when a project funded by FAO (UNDP/FAO Nep-12) provided an atomic absorption spectrophotometer (AAS), but this only lasted for a few years. At that time, analysis concentrated on Zn, although sporadic symptoms of other micronutrient deficiencies were also observed in some areas where higher crop yields were expected. High-yielding wheat varieties which used up greater amounts of nutrients from the soil were introduced in Nepal, but balanced application of fertiliser was seldom practised (Joshi and Karki 1993). Some high-yielding crop varieties (e.g., wheat) did not yield well in Nepalese soils, and in some cases in the eastern Terai sterility was also observed (Mishra et al. 1992). In the beginning, foggy conditions at the time of fertilisation, together with moisture stress, were blamed for the sterility; later B deficiency was included as a cause. Whatever studies were carried out and written up were based on the agronomical characteristics of the crops, especially wheat and barley and some vegetables such as radishes, cauliflowers, and cabbages.

Cropping intensification coupled with intensive vegetable cultivation during winter and spring, especially of micronutrient-sensitive crops, such as radishes for B, cole crops for B and Mo, and rice grown in calcareous soils for Zn, resulted in deficiency symptoms in plants. Even when sufficient amounts of total micronutrients are available in the soil, crops, or even succeeding crops, may exhibit deficient symptoms as a result of pH fluctuations during different seasons. Studies of micronutrients were not carried out for some years due to the lack of efficient laboratory facilities for analysis. It was only when Professor Sillanpää of Finland carried out a soil and plant survey for his 'Global Assessment of Micronutrients' for FAO (Sillanpää 1982) that Nepalese scientists became aware of the status of various micronutrients in Nepalese soils. Recently, analytical facilities have been developed for most micronutrients with the exception of Mo, for which analysis has so far not been successful.

This paper aims to provide an overview of the distribution of micronutrients in the five different physiographic regions of Nepal (Figure 1): the High Himalayan region (5000 to 8848 masl), the High Mountains (3000 to 5000 masl), the Middle Mountains (1000 to 3000 masl, in some cases including low valleys down to 200 m), the Siwaliks (300 to 1000 m), and the Terai (66 to 300 m).

Review of Past Work on Micronutrients in Nepalese Soils

Work has been carried out in field and greenhouse experiments on micronutrients important in agriculture such as boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). Most of this work concentrated on B and Zn, as deficiency of these two elements is significant in Nepalese soils; although chlorine (Cl) is equally important. However since chlorine is supplied as potassium fertiliser in the form of muriate of potash (KCl), its deficiency is not often observed. Silicon (Si), another important mineral element needed for plants and animals, is the second most abundant element next to oxygen and occurs in almost all minerals. Silicon is available through weathering of rocks and minerals, and so far its deficiency has not been noticed in plants.

Boron (B)

The distribution and levels of boron elements in the districts surveyed are shown in Figure 2. Boron is an important element needed by plants for building cell walls, tissue development, and germination and growth of pollen. Its deficiency and toxicity range is very narrow. B has a direct impact on pollen development so its deficiency leads to sterility of crops. Boron levels in soil are related to the organic C (carbon) and clay content, including oxides of

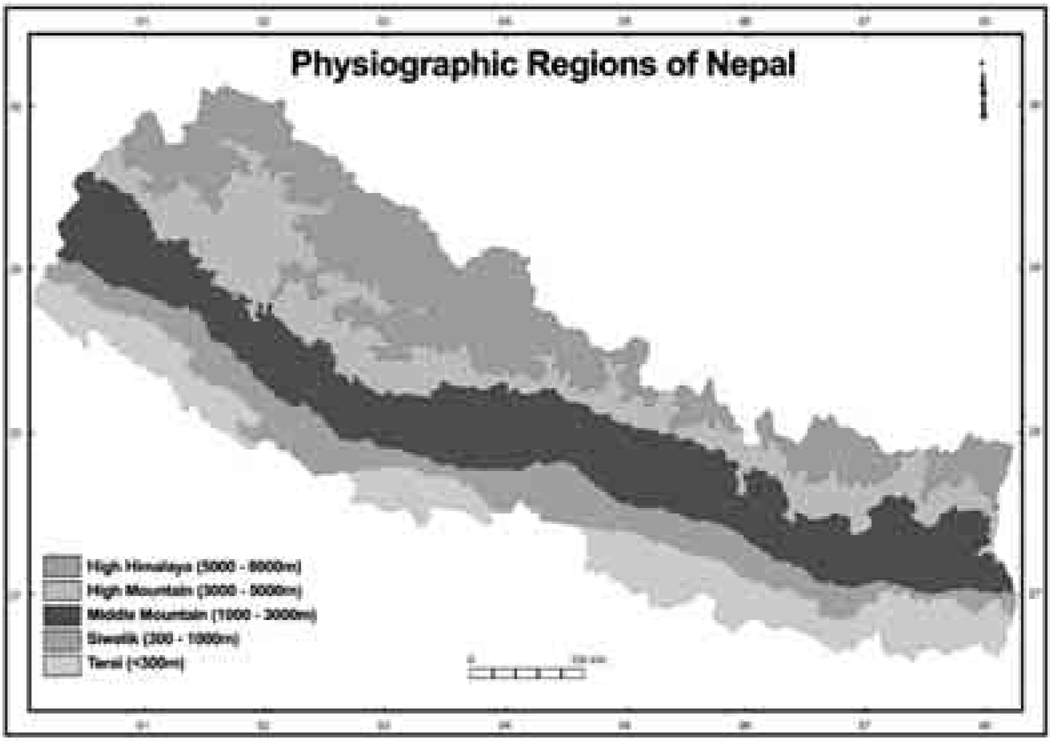

Figure 1: **Physiographic regions of Nepal** (Source: LRMP 1986)

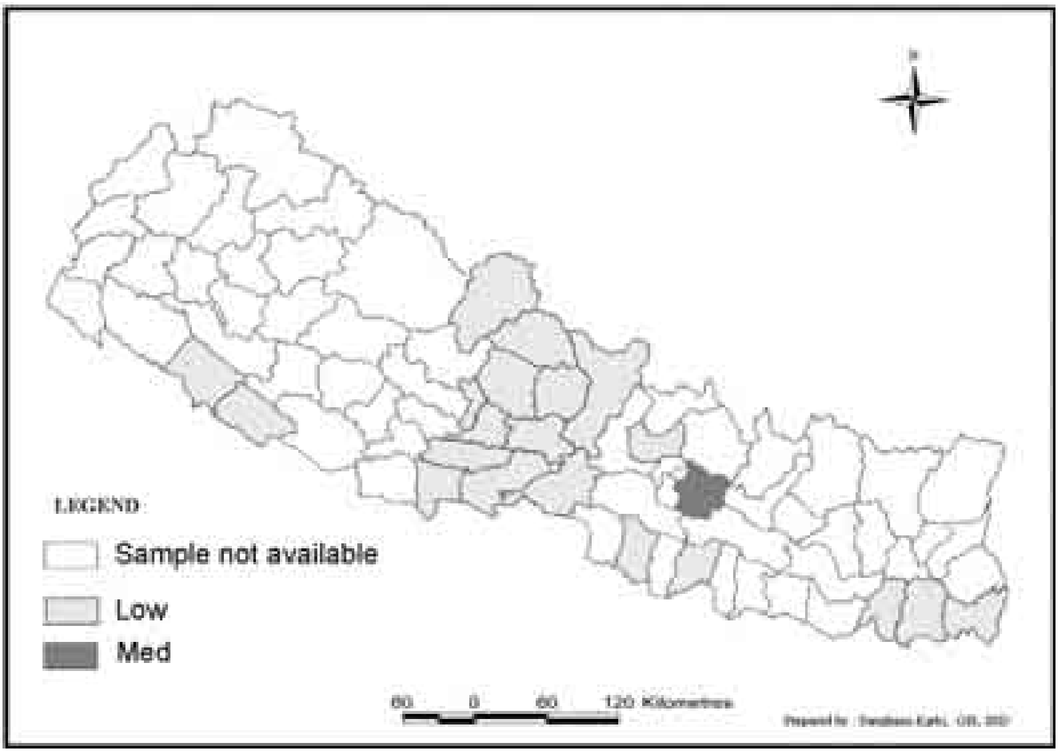

Figure 2: **Boron levels in soil in selected districts of Nepal**

aluminium (Al) and iron (Fe) in soil (Goldberg et al. 2002). Some high-yielding wheat varieties are very susceptible to B deficiency and wide-scale deficiency has been reported in different ecological regions of Nepal. Subedi et al. (1995) reported that boron deficiency and cold tolerance were two major factors causing wheat sterility in western Nepal.

Availability of B is also related to the temperature and the availability of moisture (Mishra et al. 1992; Pandey 1995). Since Nepalese soils are light in texture (low clay content) and low in organic carbon (Joshi and Karki 1993), B content is generally low (Sillanpää 1982; Sillanpää 1990; Sipola and Lindset 1994). Acharya et al. (1998) studied the B content in selected soils in Baglung, Parbat, Tanahun, and Syangja in the Middle Mountain region and reported very low contents of B.

Several experiments showed that crops responded well to B application. Adhikari and Pathak (1999) reported that application of 20 kg ha^{-1} borax increased radish yields by 26% over the control. In another study, boron application in poorly-drained soils was not encouraging, whereas application of 2.5 kg ha^{-1} B produced significantly higher yields of wheat over crops without B application (Karki 1995). Munakarmi and Tuladhar (1998) correlated hot-water extracted B and colour developed by Azomethane-H and curcumin and found a positive correlation between these two methods of colour development and B contents in soil. They concluded that soil with hot-water extractable B of 0.7 µg g^{-1} is sufficient for normal plant growth, whereas addition of B is important for additional yield. Increase of soil pH by liming and application of B was more effective in low pH soils than application of the same amount of B only (Chaudhary and Jaisi 1984).

Shrivasta et al. (1996, 1997) studied the relationship of B and Mo in chickpeas. Problems of flower/pod drop decreased significantly following the application of 0.5 kg ha^{-1} B in Chitwan soils (Inner Terai). Application of Mo along with B helped to reduce the problem, but the results were not significant. Similar results were also reported for lentils (Shrivastav et al. 2000). B deficiency was observed in mandarin leaves in the Middle Mountains region in addition to B deficiency in cereals and vegetables (Tripathi et al. 1998). Importance of B was also observed for citrus fruit.

Zinc (Zn)

The content of microelements such as Cu, Zn, Mn, and Mo are medium to low in Nepalese soils, whereas Fe content is high. Several agronomic studies carried out in different parts of the country show that the response of these elements to experiments is encouraging. Responses of different crops have been positive, indicating deficiency or unavailability in the untreated soil. In general, the average content of Zn in soil is 80 ppm. The amount of Zn required by plants is low, but it can be as high as 100 ppm. Maximum yield is obtained with an uptake of 10-20 ng per g of root per day. Zn in plants helps to form a number of enzymes and coenzymes. The Zn level for Nepalese soils is shown in Figure 3. Most of the districts surveyed had soils low in Zn. If the Zn content in rice crops falls below 15 ppm, crops exhibit symptoms of deficiency. Clay loam soil contained higher amounts of Zn (0.96mg/kg) and Fe (2.3mg/kg) in the areas surveyed, whereas Mn content was higher in silt clay soils than in others. In soils with high pH values, addition of Zn gave positive responses (Chaudhary and Jaisi 1984); addition of 20 kg Zn ha^{-1} produced the highest yield of rice (3.71 t ha^{-1}) in soil with low pH values (Jaisi et al. 1989).

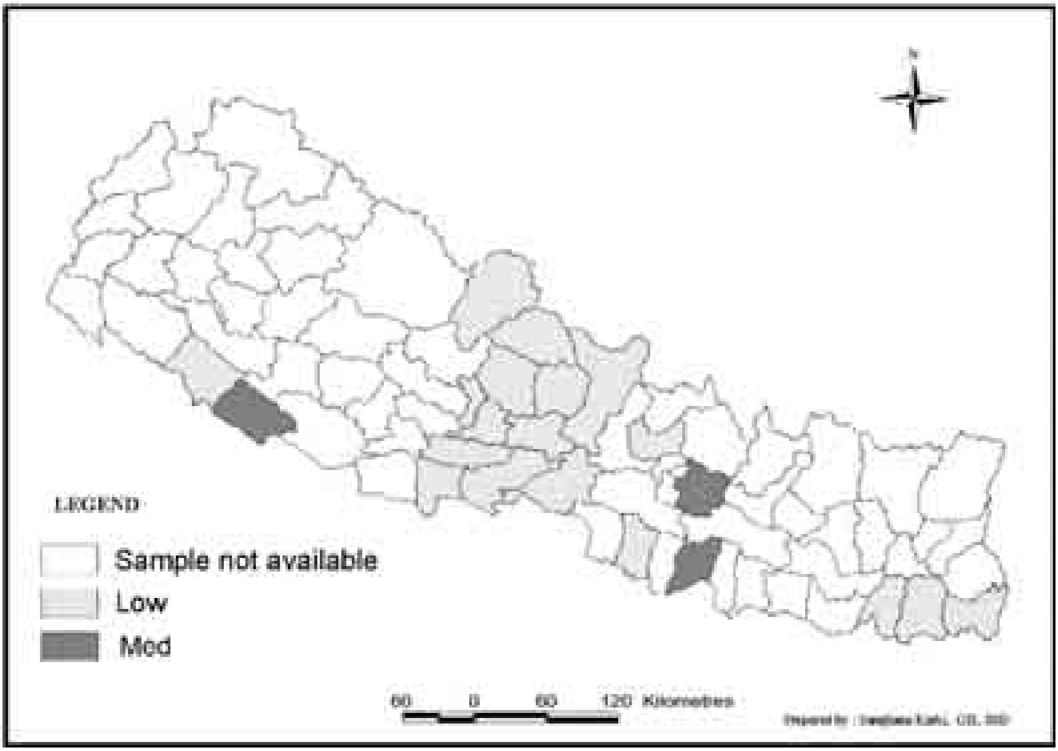

Figure 3: **Zinc levels in soil in selected districts of Nepal**

Sherchan and Gurung (1998) reported the importance of micronutrients in rice-wheat in eastern Nepal and Tripathi and Shah (1982) and Tripathi (1984) observed a positive response to applied micronutrients in rice crops in the central region. Tripathi (1989) described positive responses of wheat and barley to boron and molybdenum, and Shrivasta (1988) and Shrivastava et al. (1996) reported the effects of these elements in maize and chick peas. Tripathi et al. (1998) reported the results of a survey of mandarin leaves in western Nepal where it was found that Zn and B contents in the leaves of the mandarin were below sufficiency level.

Copper (Cu) and Iron (Fe)

The levels of copper and iron in the districts surveyed are shown in Figures 4 and 5. Plants need copper in very minute quantities. Cu is a component in the enzyme facilitating part of the chloroplast pigment (Mengel and Kirkby 1987). It influences the carbohydrate and nitrogen metabolisms and plays a role in photosynthesis. It is also an important element in pollen grain viability. Since the plant requirement is only 10 ppm, Cu deficiency is not normally observed in Nepal. Copper fungicide is used widely to control fungal diseases in cereals and vegetables and is added to the soil every year, thus there is only limited information available on the natural levels of Cu in Nepalese soil. Its importance in crop production along with the importance of other micronutrients has been reported by Tripathi and Shah (1982) and Tripathi et al. (1989). This element is one of the DTPA-extractable micronutrients. The levels of copper in the districts surveyed were mostly medium (Figure 4).

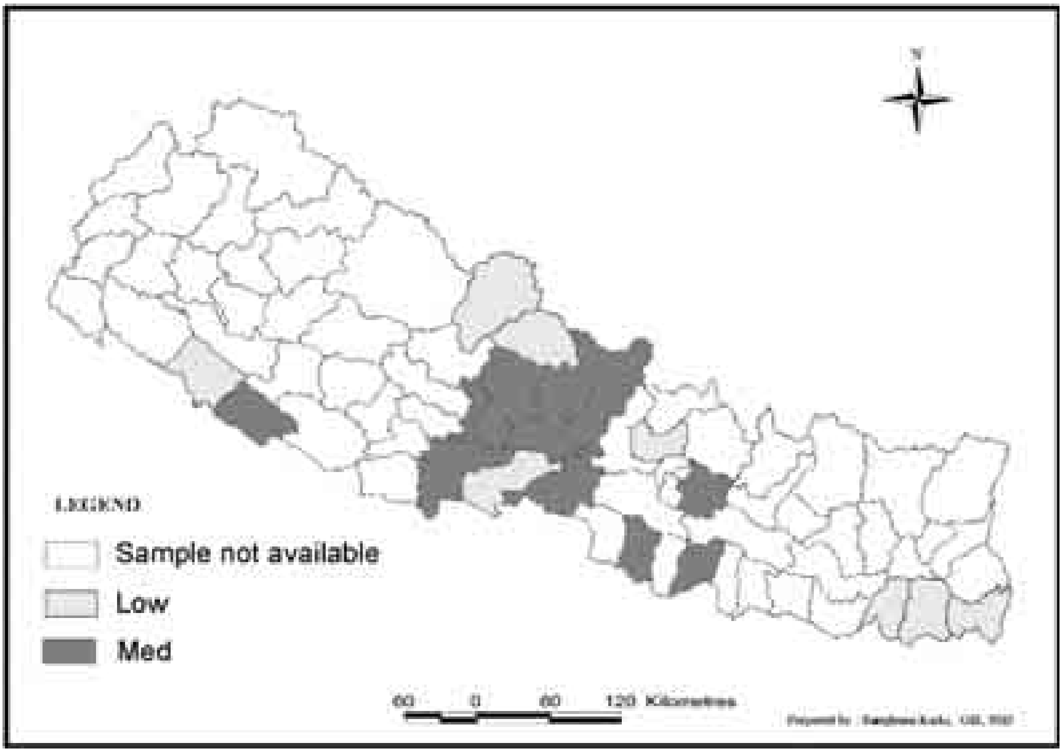

Figure 4: **Copper levels in soil in selected districts of Nepal**

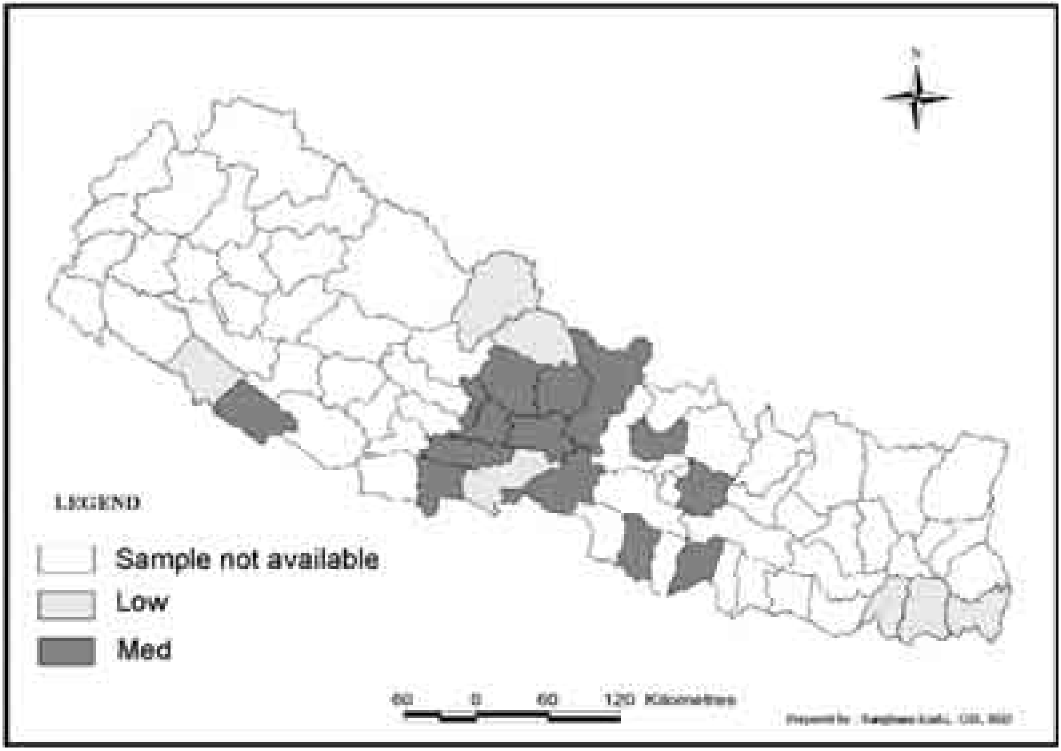

Figure 5: **Iron levels in soil in selected districts of Nepal**

Iron (Fe) forms 5% of the earth's crust, so it is rare to find shortages of iron in soil. Its function in the plant system is one of enzyme formation. The element is available to plants in soils with low pH values. However, formation of hydroxide in reduced conditions results in high soil pH values and plants cannot take up iron under such conditions. In normal conditions, Fe content in Nepalese soil is high (Sipola and Lindstedt 1994). Its impact on crop response has not been studied individually, but there have been several studies in-group with other micronutrients.

Manganese (Mn)

Manganese (Mn) is abundant in soil. Plant uptake of Mn is only 500 to 1000g ha^{-1}, and hence its application is unnecessary. Its activity in the plant system is similar to that of magnesium and it is required in chlorophyll and enzyme formation. Mn availability is based on soil reaction, it is mostly available in soils with low pH values. Information regarding its individual effects on crop production in Nepal is limited. In the light soils of Chitwan (Inner Terai), Mn content was found to be low (Khatri-Chhetri and Schulte 1985), but the reason for this is thought to be the waterlogged conditions in eastern Chitwan (Bhattarai 2004). Survey results from districts such as Chitwan, Nawalparasi, Palpa, Jhapa, and Bardiya showed soils with a high level of Mn (Figure 6). In light soils this element is mobile under dry conditions and can be leached easily, thus causing a shortage for plants. Excess of other micro-elements such as Zn and Fe inhibits its uptake by plants and it competes with Mg (Mengel and Kirkby 1987).

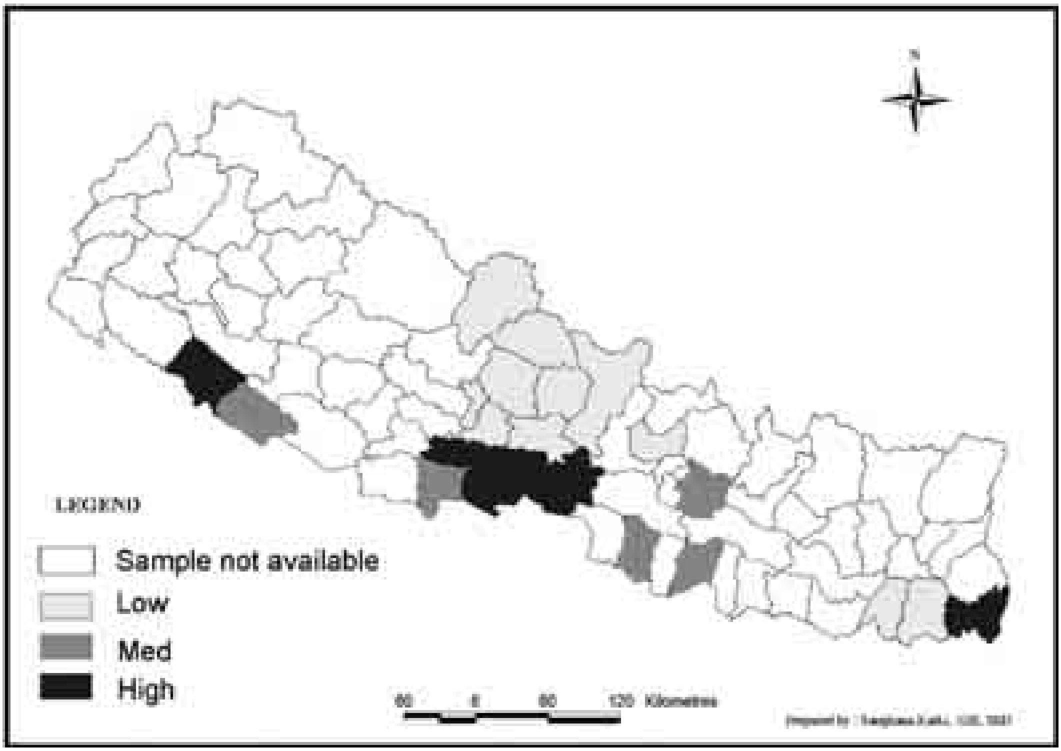

Figure 6: **Manganese levels in soil in selected districts of Nepal**

Molybdenum (Mo)

The average content of Mo in soil is 2 ppm, but availability is less than 0.2 ppm. Unlike other micronutrients, its availability decreases as soil pH values decrease. It competes with SO_4^{2-}. Phosphorous (P) application enhances the availability of Mo (Mengel and Kirkby 1987). Plants generally contain less than 1 ppm, but it can comprise up to 2000 ppm dry-matter weight of plants without having any adverse effects. Nitrogenase and nitrate reductase are the two enzymes formed by this element; they help nitrogen assimilation in plants. Application of NO_3-N and NH_4-N increases Mo uptake.

Nepalese soils are acidic, thus plant availability of Mo is limited, in fact it is low (Sippola and Lindstedt 1994; Karki 1995). Figure 7 shows that districts like Palpa, Nawalparasi, and Bardiya have high levels of Mo in the soils, as soils in these Terai regions are not as acidic as those in the hill regions. Under certain limited conditions, Mo applied as ammonium molybdate at 2 kg ha^{-1} provides sufficient Mo as residue, even after harvesting a third crop (Karki 1995). Tripathi and Shah (1982) suggested that the upper limits of Mo in rice plants is 2 ppm. Two barley varieties were tested and evaluated with the determined levels of B and Mo; the variety Ibion 171 was found to be more susceptible to sterility than the Bonus variety (Tripathi1989).

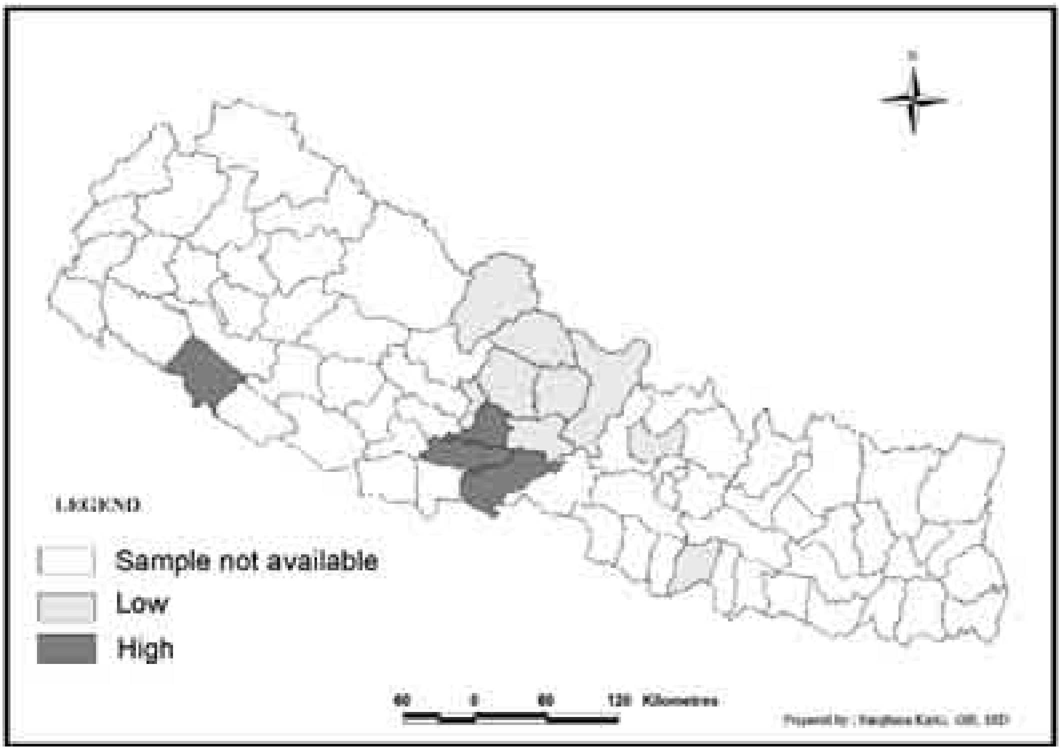

Figure 7: **Mo levels in soil in selected districts of Nepal**

Results of Soil Analysis and Interpretation of Findings on Micronutrients

Table 1: **Elements of micronutrients extracted by aqua regia from Nepalese soil profiles (n = 20) (1994)**

Soil depth (cm)	Micronutrients in ppm		
	Cu	Mn	Zn
0-30	35.5	628	105
30-60	9.1	222	62
60-90	7.9	207	40
0-90*	8.8-33.5	252-594	50-103

* n = 60, Source: SSD Khumaltar 1998

Soil samples were collected from different depths at 20 different sites, and Cu, Mn, and Zn analysed as extracted by aqua regia (royal water – a mixture of hydrochloric and nitric acid); the results are shown in Table 1.

The amount of micronutrient elements in surface soil as shown after aqua regia extraction, seems to be sufficient, but it is difficult to state how much of the total is available to plants. Despite crop removal and other losses, the surface soil contains higher amounts of micronutrients, and the contents decrease with depth. Karki (1995) reported similar results. This could be due to the addition of heavy organic manure, especially farm-yard manure (FYM) at the surface. Equally the reason that there are lower amounts of micronutrients in subsoil could be that the geological materials are just not rich in these micronutrients. The same type of result was obtained even in the young alluvial soil (Ochric Fluvaquents) in Dhading district (Karki 1995), indicating that even the fresh sediment deposited by water does not contain higher amounts of micronutrients. Acid ammonium-extracted micronutrients in soil profiles of the two soils, Rhodic Ustochrept and Ochric Fluvaquents, also showed greater amounts of micronutrients in surface soils and less below the surface, indicating that the organic manure that farmers apply added micronutrients to the surface soil. DTPA-extracted Zn was also low in these soils (Karki and Blum 1994) and application of municipal compost containing higher amounts of Zn did not improve the situation. Application of Zn with municipal compost correlated positively with wheat crops (Karki and Blum 1994).

Testing for contents of DTPA-extractable Zn in five different soil types of the Kathmandu Valley, namely Typic Ustocrepts, Dystrict Ustochrept, Typic Fluvaquents, Fluvic Ustochrept, and Aquic Ustochrept, showed them all to contain low to very low amounts (Karki et al. 2000; Karki et al. 2002). Khatri-Chhetri and Schlute (1985) studied the response of maize to secondary and micronutrients and found a general trend in the increase of maize yields due to addition of micronutrients. Prasad (1989), with results of the 8th year harvest in a long-term fertility experiment, concluded that application of organic matter with zinc sulphate ($ZnSO_4$) along with the recommended dose of chemical fertiliser is imperative for sustaining crop yields. The content of DTPA extractable micronutrients (Cu, Fe, Mn, and Zn) remained almost the same even after five years of continuous harvest of rice-wheat crops. Application of compost only increased the availability of Fe (Sherchan and Gurung 1995, 1998).

The soil science division receives samples from different locations for laboratory analysis. Between 1994 and 2003, the soil laboratory at Khumaltar analysed and reviewed samples from the districts listed in Table 2. The results are shown in Table 3.

The micronutrient contents found in the soils of Chitwan district from a farmers' field soil survey in 2000 are shown in Table 4. All elements were found to be above the critical level except for B. Khatri-Chhetri and Schulte (1984) reported similar results for the content of B

Table 2: **Districts supplying soil samples for analysis**

Physiographic Region	Eastern	Central	Western	Mid-Western
Terai	Jhapa, Morang, Sunsari	Bara, Chitwan, Sarlahi	Nawalparasi, Rupandehi,	Banke, Bardiya
Hills		Kavre, Nuwakot,	Gorkha, Kaski, Lamjung, Manang, Mustang, Palpa, Parbat, Shyangja, Tanahun	

Table 3 : **Status of DTPA e xtractable micronutrients from soil samples received for analysis (1995 -2003)**

Districts and Regions	B	Cu	Fe	Mn	Mo	Zn
Terai						
Jhapa	Low	Low	Low	High	Trace	Low
Morang	Low	Low	Low	Low	Trace	Low
Sunsari	Low	Low	Low	Low	Trace	Low
Sarlahi	Low	Med	Med	Med	Low	Med
Bara	Low	Med	Med	Med	Trace	Low
Chitwan	Low	Med	Med	High	Trace	Low
Nawalparasi	Low	Low	Low	High	High	Low
Rupandehi	Low	Med	Med	Med	Trace	Low
Banke	Low	Med	Med	Med	Trace	Med
Bardiya	Low	Low	Low	High	High	Low
Mid mountain						
Kavrepalanchok	Med	Med	Med	Med	Trace	Med
Nuwakot	Low	Low	Med	Low	Low	Low
Lamjung	Low	Med	Med	Low	Low	Low
Gorkha	Low	Med	Med	Low	Low	Low
Kaski	Low	Med	Med	Low	Low	Low
Tanahun	Low	Med	Med	Low	Low	Low
Shyangja	Low	Med	Med	Low	High	Low
Parbat	Low	Med	Med	Low	Low	Low
Palpa	Low	Med	Med	High	High	Low
High Mountain						
Manang	Low	Low	Low	Low	Low	Low
Mustang	Low	Low	Low	Low	Low	Low

Table 4: **Micronutrient status of soils in Chitwan district (2000)**

Nutrient	Variables (ppm)		Critical level (ppm)	Nutritional status (% samples)		
	Mean± SE	Range		Low	Medium	High
B	0.3±0.03	0-2	2.00	100	-	-
Cu	2.41±0.19	0-23	0.1-2.5	2	48	50
Mn	11.05±0.61	0-40	1-5	25	18	57
Zn	0.86±0.08	0-7	0/2-2.0	5	90	5
Fe	70.22±1.76	8-124	2.5-5.0	-	-	100
Source: Tuladhar et al. 2001						

and Mn in Chitwan. Khatri Chhetri and Shulte (1984) reported that 83% of the samples were low in Zn, whereas Tuladhar et al. (2001) reported 90% of samples to be medium for Zn.

All the results presented here are from soil samples either collected or surveyed by soil scientists, but none of the samples was analysed nor any interest displayed by farmers. Awareness about micronutrient deficiency in the soils of fields is still lacking among farmers.

Conclusions and Recommendations

In general, the results show that micronutrients are deficient in the soils of Nepal. Mn and Fe are sufficient in most soils, but other micronutrients need proper attention, especially in areas where intensive cropping is practised. Boron and molybdenum are problems for vegetables, especially where hybrid varieties are grown. Boron is also a problem for wheat, and Mo is a problem for legumes. Because of flooding, Zn has become a serious problem for rice. Fruit crops such as citrus have also shown sporadic symptoms of Zn and to some extent B deficiency. Soils in the districts surveyed are low in B and Zn, low to medium in Cu and Fe, and low, medium, and high in Mo. However, Nepalese soils respond well to the application of all these micronutrients.

The limited results available from soil analyses with respect to micronutrients in Nepalese soils indicates that the quantity of these elements is low. However, there is no information available on their actual content in different crops from different soils and agro-climatic conditions. Manpower and sufficient analytical facilities, including appropriate equipment, need to be made available for systematic and detailed study of micronutrients including plant analysis. At present, there is a limitation in trained manpower in this field and the analytical facilities are not sufficient for precise analysis. Quality control of soil and plant analyses, and maintenance of equipment, are among the major problems encountered. Scientists are unable to carry out repeat analyses in order to have reproducible, precise, and well-analysed data. Further experiments are needed to quantify the recommended levels of micronutrient fertiliser application with response to crop yields.

The importance of micronutrients such as Zn in rice, B in wheat, Mo in legumes, and B in vegetables as well as in other sensitive crops, should be conveyed to local farmers where deficiency is more prominent. Farmers should be trained to test their soil and plants so that they can correct micronutrient deficiencies.

References

Acharaya, G.P.; Tripathi B.P.; Bhattarai, S. P. (1998) 'Plant nutrient survey on tomato crop in the western hills of Nepal'. In *Proc. Second National Horticulture Research Workshop*, May 13-14, NARC, Lalitpur, Nepal. Kathmandu: NARC

Adhikari, B.H.; Pathak H.P. (1999) 'Effect of boron levels on radish (*Raphanus sativus L)* production in Pokhara'. Paper presented at the Third National Conference on Science and Technology, 1999, Pokhara, Nepal

Bhattarai, E.M. (2004) *Soil analysis results of Eastern Chitwan.* Personal communication

Cameron, K.C.; Di, H.J.; McLaren R.G. (1997) 'Is soil an appropriate dumping ground for our waste'? In *Aust. J Soil Res.*, 35:995-1036

Chaudhary, S.L.; Jaisi S.N. (1984) 'Research note on the effect of N, P, K, Zn and Azolla on yield, content and quality of forage sorghum'. In *Nep. J. Agri.,* 15:27-32

Ghani, A.; Brown. M.W. (1997) *Improvement of soil fertility in Nepal through balanced application of fertiliser*, Ag Research, Hamilton, New Zealand. A Study Report for the Ministry of Foreign Affairs and Trade, Govt. of New Zealand

Goldberg, S.; Shouse, P.J; Lesh, P.J.; Grieve, S.M.; Poss; C.M.; Forster, J.A.; Saurez, D.L. (2002) 'Soil boron extractions as indicators of boron content and field-grown crops'. In *Soil Sc*. 167:720-728

Hobbs, P.R.; Mann C.E.; Butler, L. (1988) 'Wheat production constraints in tropical environment'. In Klat, A.R. (ed) *Proceedings of an international conference*, pp.197-211. El Batan (Mexico): CYMMIT

Jaisy, S.N.; Shrestha, K.K.; Baral, K.P. (1989) *Effect of zinc on grain yield of rice*. Paper presented at the 14^{th} Summer Crop Workshop, January 1989, Parwanipur, Nepal

Joshi, D.; Karki, K.B. (1993) 'Soil fertility and fertiliser use in Nepal'. In Tondon, H.L.S. (ed) *Soil fertility and fertiliser use in Asia.* New Delhi: Development and Consulting Service

Karki, K.B. (1995) *Influence of organic and inorganic fertiliser in sustaining crop productivity in the central hills of Nepal.* A Ph D. Dissertation, Universitaet fuer Bodenkultur, Vienna, Austria (unpublished)

Karki, K.B.; Blum, W.E.H. (1994) 'Uptake of zinc in a wheat-mungbean-rice cropping system on a dystric fluvisol of Nepal'. In *Transactions, 15th World Congress of Soil Science, Acapulco, Mexico,* 5b:60-61. Mexico City: International Society of Soil Science, Mexico Chapter

Karki, K.B.; Mentler, A.; Blum, W.E.H. (2000) 'Food security and crop productivity situation in the Kathmandu Valley'. In *International seminar and workshop on food security in urban and peri-urban areas of developing countries*, November 15-18, 2000, Extended Abstracts, pp. 28-30. Vienna: University of Agriculture

Karki, K.B.; Mentler, A.; Blum, W.E.H. (2002) 'Distribution of plant available trace elements in soils developed on lacustrine deposit of Kathmandu Valley, Nepal'. In *International Congress of Soil Science Bangkok,* 24:(2135) 908

Khatri-Chhetri, T.B.; Schlute, E.E. (1985) 'Response of maize to the application of secondary and micronutrients in the soils of Chitawan Valley, Nepal'. In *Nep.J.Agri*. 16

LRMP (1986) *Land Resources Mapping Project.* Kathmandu: His Majesty's Government of Nepal, and Government of Canada, Kenting Earth Sciences Limited

Mengel, K.; Kirkby, E.A. (1987) *Principles of Plant Nutrition* (4th edn). Bern: International Potash Institute

Mishra, R.; Munakarmy, R ; Pandey S.P.; Hobbs, P.R. (1992) 'Sterility on [sic] wheat at Tarahara in the eastern Terai of Nepal'. In Mann, C.E.; Rerkasem, B. (eds) *Boron deficiency in wheat, Wheat special report No. 11:* 62-74. El Batan (Mexico): CIMMYT

Munakarmy, R.C.; Tuladhar, J. (1989) 'Response of wheat to boron application in Sipaghat soil'. In *Nep. Agri.Res. J.,* 3:36-41

Pandey, S. P. (1995) 'Historical highlights of wheat sterility research in Nepal'. In *Proc. international workshop on identification of causes of wheat sterility in sub-tropical Asia*, Lumle Agricultural Research Centre, Sept. 18-21, 1995. Lumle (Nepal): LARC

Prasad, R.C. (1989) *Long term fertility experiment.* Paper presented at the Summer Crop Working Group meeting held at Rampur Agricultural Station, 17-24 June 1989, Rampur, Nepal

Sherchan, D.P.; Gurung, G.B. (1995) 'Effect of long term application of chemical fertiliser and organic manure on soil fertility and crop yields under rice-wheat system in the hills'. In *Nep. Agri. Res. J.,* 2:35-41

Sherchan, D.P.; Gurung, G.B. (1998) *Effect of long term application of chemical fertiliser and manure on crop yields and soil chemical properties under rice-wheat cropping pattern (the results of 8 cropping cycles),* PAC Technical Paper No. 183. Pakhribas (Nepal): Pakhribas Agricultural Research Centre

Shrivasta, S.P. (1988) *Micronutrients trial on maize.* Paper presented at 14^{th} Summer Crops Workshop (working group meeting on maize oilseed and legume), Rampur Agricultural Research Station, April 17-19, 1988, Rampur, Nepal

Shrivasta, S.P; Yadav, C.R.; Rego T.J; Johansen, C; Saxena, N.P. (1996) *Effect of molybdenum on the problem of flowerpod and grain yield of chickpeas in Nepal* . Paper presented at the Summer and Winter Grain and Legume Crops workshop, Rampur Agricultural Research Station, held on 12-15 Sep. 1996, Bhairawa, Nepal

Shrivasta, S.P; Yadav; C.R. Rego; T.J.; Johansen, C.; Saxena, N.P. (1997) 'Diagnosis and alleviation of boron deficiency causing flowers and pods abortion in chickpeas *(Cicer aretinum L)* in Nepal. In Bell, R. W.; Rerkasem, B. (eds) *Boron in soil and plants*, pp 95-99. Dordrecht: Kluwer Academic Publisher

Shrivasta, S.P; Bhandari, TMS; Yadav, C.R.; Joshy, M.; Erskine, W. (2000) 'Boron deficiency in lentil: yield loss and geographic distribution in a germplasm collection, December 3, 1998 – November 15, 1999'. In *Plant and Soil*, 219:147-151

Sillanpää, M. (1982) 'Micronutrients and nutrients status of soil: a global study'. In *FAO Soils Bulletin,* 48:242-250

Sillanpää, M. (1990) 'Micronutrient assessment at the country level: an international study'. In *FAO Soils Bulletin,* 63:94-106b

Sipola, J.; Lindstedt, L. (1994) 'Report on soil test results for samples from Nepal',' unpublished report for the Agricultural Research Centre for Finland

Subedi, K.D.; Budhathoki, C.B.; Subedi, M.; GC, Y.G. (1995) 'Effect of boron and sowing time to cause sterility in four genotypes of wheat in the western hills of Nepal'. In *Proceedings of study on the causes of wheat sterility in sub-tropical Asia*, LARC, Sept. 18-21, 1995. Lumle (Nepal): LARC

Tripathi, B.P. (1984) *Report of micronutrients trials on rice in farmers field*. Paper presented at a summer workshop, National Rice Research Program, 30 Jan – 2 Feb, 1984, Parwanipur, Nepal

Tripathi, B.P. (1989) *Effect of agricultural lime* ($CaCO_3$)*, boron and molybdenum in controlling the sterility of barley*. Paper presented at the Third Working Group Meeting of Soil Scientists, 11-15, Sept. 1989, Bhairawa, Nepal

Tripathi, B.P.; Shah, R. (1982) 'Status and effect of micronutrients on the yield of paddy in different agroecological regions of Nepal'. In *Nepal Himalaya: geological perspectives*. Talital (Nanital, India): Himalaya Research Group

Tripathi, B.P.; Suwal B.N.; Joshy, D; et al. (1989) *Soil fertility and plant nutrition study on barley in Khumaltar during 1989/90 (2046/47)*. Paper presented at the 13th Winter Crop Workshop, National Wheat Research Centre, 10-14, September 1989, Bhairawa, Nepal

Tripathi, B.P.; Harding A.H.; Subedi, P.P. (1998) 'Plant nutrient status in mandarin trees in some mandarin growing pockets in Lamjung and Gorkha districts of Nepal'. In *Proceedings of the Second National Horticulture Research Workshop*, 13-15 May, 1998, pp 194-201. Kathmandu: Nepal Agricultural Research Council

Tuladhar, J.K.; Sah, K.; Lauren J.G.; Duxbury, J.D. (2001) *Soil nutrient status of Chitawan soil.* Paper presented at the 23rd National Summer Crops Workshop, NARC, 2-4 July 2001, Khumaltar (Kathmandu), Nepal