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A Review of Micronutrient Problems in the Cultivated Soil of Nepal

An Issue with Implications for Agriculture and Human Health

Micronutrient problems in the food systems of the Himalaya are widespread due to bedrock with low nutrient content, high erosion rates, poverty, subsistence agriculture, and increasing cropping intensity. Agriculturally based strategies for the reduction of micronutrient malnutrition will require knowledge of the scale and spatial patterns of soil deficiencies or excesses of some elements. The present article documents current knowledge about the micronutrient status of cultivated soil in Nepal. Most studies have recorded largely the same magnitude of deficiencies in this country. Some 80 to 90% of soil samples were deficient in boron (B), 20 to 50% in zinc (Zn), and 10 to 15% in molybdenum (Mo). These are important micronutrient deficiencies because they limit agricultural production and affect human nutrition directly or indirectly.

Keywords: *Micronutrients; zinc; boron; molybdenum; soil; nutrition; Nepal.*

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Introduction

Hidden hunger—malnutrition due to a lack of micronutrients—is a major threat to human health in Nepal (Anonymous 1998; Andersen et al 2005). Presently, the focus of national policy is on iodine (I), vitamin A, and iron (Fe) (Anonymous 1998). However, micronutrient deficiencies in the context of soil–crop relations are increasingly being recognized, not least Zn deficiency, which affects the immune system and hence resistance to diarrhea and other infectious diseases (WHO 1996; Bhan et al 2001). There are no good indices of Zn deficiency in humans (WHO 1996), but on the basis of food balance sheets, Brown and Wuehler (2000) estimated that 95.4 ±2.1% of the South Asian population is at risk of low Zn intake. *Stunting*—height-for-age being less than 2 standard deviations below the median—is a common measure of malnutrition. Among rural pre-school children in Nepal in 1996–1997, 56.3% were stunted; in Western Mountain regions the figure was as high as 72.2% (Anonymous 1998).

Environmental factors, such as geology and soil type and condition, affect supplies of micronutrients such as selenium (Se) and Zn, for instance, and can decrease their concentrations in crops or depress crop yields. Zinc, Mo, and B deficiencies affect the yields of pulse crops, for example, and reduce the availability of protein, Fe, folate, and other nutrients. Subsistence agriculture and lack of technical knowledge or inputs can lead to improper soil nutrient management. Cropping intensity can result in depletion of nutrients, while socioeconomic and cultural factors lead to diets poor in nutrient concentration.

Many natural factors contribute to micronutrient deficiency in soil. The Himalaya is a region where high erosion rates and leaching conditions can lead to low concentrations of some elements. Pedologically, most of the soil in the Hill areas derives from phyllite and schist (leading to modestly inherent soil fertility) or sandstones, quartzite, and granite (leading to infertile sandy soil [Carson 1992]). Nutrient-rich bedrocks such as basalts, shale, and limestone do occur but are less widespread.

Knowledge of the scale and distribution of the problems is essential to develop strategies for more sustainable agricultural systems and food that is more nutritious. It is often assumed (eg IFA 2000) that soil conditions in mountain areas are too complex for blanket recommendations of fertilizer use to farmers. Accordingly, many recommend more extension officers and more intensive soil testing (ibid). However, little extension service is available to Hill farmers (Andersen 2001). The Nepal Agricultural Research Council (NARC) has issued only few recommendations on micronutrients and none in particular for Hill crops. The purpose of this review is to summarize current knowledge about soil micronutrients in cultivated soil in Nepal and to analyze whether there are patterns that can be used for development of general policies.

Limitations of the study

Most of the research reviewed here has not been published in peer-reviewed publications, but in technical reports or conference papers. Many of the studies are based on small numbers of samples. Sampling techniques and methods of extraction and estimation differ between authors. Some papers are not explicit about the use of border values. A serious question is whether the laboratories provide reliable results with given analytical standards. Data from different laboratories in Nepal have shown differences so large—even with subsamples taken from the same bag—that analyses became inconclusive. Laboratories throughout the world suffer from inconsistencies, but few Nepalese ones have been accredited, and so the quality of analyses is subject to economic resources. The Nepalese state laboratories have problems with staff turnover, outdated equipment, impure chemicals, etc. The consequences of dubious results are substantial for policymaking as well as for agricultural extension programs.

Iodine deficiency is not dealt with here because it is not tested in soil analyses in Nepal. However, the iodization of salt has reduced I deficiency, which used to lead to large incidences of cretinism and goiter in Nepal. The Nepal Micronutrient Status Survey (Anonymous 1998) determined that 82.7% of all salt tested contained some iodine and the number of adult women and children with low urinary iodine excretion (UIE) had decreased to 39.1% compared to 52% in 1985.

Soil concentrations

The most authoritative source on micronutrient concentrations in Nepalese soils is *FAO Soils Bulletin* No 48 (Sillanpää 1982). Its aim was a global overview of soil micronutrients with the collection of 3744 soil samples from several countries across the world. Plant available micronutrients in soil samples were measured and wheat was grown in pots to measure plant uptake. The size of the study enabled statistical treatment of the data to analyze the relationship with pH, texture and other soil properties, and also assess the best methods of extraction and determination for each element. The study has become a standard reference. A drawback of the exercise was a lack of joint sampling strategy seen from a mapping perspective. In the case of Nepal, no map of the sampling sites is provided. Among the findings on Nepal was that calcium (Ca) and magnesium (Mg) were low. The soil samples had the lowest average B content of all countries included in the study and it was concluded that "widespread B deficiency, acute or hidden, is likely to exist in Nepal, limiting yields especially of those crops with a high B requirement" (p 245). Zinc values placed the Nepalese samples at the lowest end of the scale of concentration, although not quite as low as in countries with alkaline soil (India, Turkey, Iraq). The conclusion was that "Zn deficiency should be expected at many locations in Nepal" (p 247). In addition, "Mo deficiency is likely to occur in Nepal, most probably in the soil of the Bagmati area but also elsewhere" (ibid). Among the other elements that were studied, the status of copper (Cu), Fe, and manganese (Mn) were not considered to be a problem (ibid).

The project was followed by field trials (Sillanpää 1990). The field trials used the "minus-one" strategy. This means that the crop is fertilized with the full range of elements except for one, to test for yield responses. One control plot is given no fertilizer and one is fertilized with all elements. The crop tested at 16 sites was paddy rice, but the varieties were different. One trial was done with mustard and another with wheat. The trials indicated considerable variation between locations with respect to the response to different micronutrients, and there were also many instances of negative yield response to the application of the full micronutrient treatment, or to specific elements. Omission of B increased the yields in many cases; this can be attributed to the sensitivity of rice to B toxicity. The use of different varieties of rice has probably added to the variation in growth responses as varieties differ in their response to nutrients. Sillanpää (1990) included studies in 15 countries and gives standard values for 5 fertility classes ranging from very low to very high for several micronutrients, assessed by different methods of determination. The report also suggested tentative ranges of deficiency and excess. In the international data set, it was found that fertilizer with Zn increased the plant content in 97% of the samples, proving that the use of Zn fertilizers can result in more nutrient-rich food.

A report by Sippola and Lindstedt (1994) was based on 150 soil samples collected from cultivated fields. The samples were from areas considered representative of the central Middle Hills of Nepal. The use of a recognized laboratory gives this report credibility. The soil samples were analyzed for pH, OM, electrical conductivity, Ca, Mg, P, K, S, Sr, Cu, Zn, Mn, Fe, Mo, Cd, B, and Pb, and compared to the international standards given by Sillanpää (1990). Paddy–paddy rotations had the lowest concentrations of all nutrients, especially phosphate (P), potassium (K), sulphur (S), Mn and Zn. Heavy metal content—cadmium (Cd) and lead (Pb)—was not elevated at the sites investigated. Sulphur, Ca, and Mg content was generally low, and pH was generally low (average 5.8, minimum 4.4). The main deficiency was B; 58% of the samples were very low, and 36% were low. Zinc was very low in 14% of the samples, and low in 42%. Only a few samples were very low in Mo, but half the samples were in the low category.

Gupta et al (1989) analyzed the soil of citrus growing areas in Dhankuta District in the Eastern Hills of Nepal for its content of N, P, K, Mg, Mn, Cu, Zn, and B. The soil samples were tested for total element concentration and not the bio-available content, and so the figures are not directly comparable to those in other papers reviewed here. Leaf samples were analyzed and cross-correlated with soil values. The results were that Zn deficiency was widespread, followed by B, N, Mg, and Cu, whereas P, K, and Mn were sufficient.

In the Western Hills of Nepal, Tripathi (1999) found that 87% of samples were deficient (< 1 mg/kg) in B, and 10–20% of samples were low in Zn (< 0.5 mg/kg), Mn (< 10 mg/kg) and Cu (< 0.5 mg/kg).

Reports from the Terai plains show similar problems. One report from the Chitwan District in central Terai by Khatri-Chhetri and Ghimire (1992) found that 100% of 70 soil samples were "very low to low" in B, 83% were "very low to low" in Zn, and 23% were "very low to low"' in Mn. The trends were confirmed by plant tissue analysis, and by yield responses in trials. The methods of measurement were not noted in this publication. It is said that farmers in Terai are applying Zn sulphate at a rate of 20–25 kg/ha or other Zn fertilizers to paddy rice (TB Scherchan, personal communication 2006), but there is no evidence of the extent of the practice. In the Hill areas in Nepal, Zn fertilizers are rarely applied. A small quantity of micronutrient mixtures is used in horticultural production.

A paper by Karki et al (2005) included maps of the district-wide distribution of B, Zn, Cu, Fe, and Mn shown in classes of low, medium, and high concentrations. Of the 75 Nepalese districts, 21 were represented in the survey. It was concluded that Fe and Mn are sufficient in most soil, and that B, Zn, and Mo are commonly deficient in soil. The paper summarized mapping done by NARC, but it was not explicit about the sampling strategy, sample numbers, analytical methods, or classification limits. The notions of low soil nutrient values for the high mountain districts are surprising in light of the large amounts of compost applied by farmers in these farming systems, and they are not in line with findings by the author.

Rai et al (2005) presented a statistical analysis of Zn in the soil of Rupandehi district in Terai with a mean of 0.29 mg/kg (0.002–1.641), another confirmation of Zn deficiencies not only in Middle Hill, but also Terai soil.

Bhatta et al (2005) give a map of areas in Nepal affected by wheat sterility, where the largest areas clearly were found in Terai and in the districts surrounding the Kathmandu Valley. Trials with and without supplying boron at a rate of 2 kg/ha proved that sterility was caused by boron, but the susceptibility of wheat varieties varied greatly, from 0 to almost 100% sterility. Micronutrient studies from neighboring countries, such as India (Singh et al 1987; White and Zasoski 1999; Narwal et al 2005; Takkar and Jalali 2005) and Bangladesh (Bodruzzaman et al 2005) show problems similar to those in Nepal, with B, Zn, and Mo being the most deficient. Micronutrients often vary in relation to soil types. For example, Zn is less available in sandy and alkaline soils, whereas Mo deficiency is only a problem in acid soil.

Relation to landscape and farming system

Tripathi (2003) presented data from the Western Hills, correlating nutrient content, altitude, and land type. The main division of land types in Nepal is between *khet* (paddy fields) and *bari* (dryland terraces). On altitudes ranging from 600–2200 m, the mean values of available Zn were 0,92 mg/kg, Fe 180.6 mg/kg, Mn 58 mg/kg, Cu 1.50 mg/kg, and B 0.59 mg/kg. In this study, altitude did not affect micronutrient concentrations except for B, which increased with altitude. Comparing *khet* with *bari* there were larger Zn values on *khet*, whereas all other micronutrients were lower in *khet* soil than in *bari*. This was a surprising finding considering the small amount of compost normally applied on *khet* land.

Andersen and Sandvold (2000) studied 102 samples from altitudes of 300–2200 m. In the Arun Valley, Eastern Nepal, B was deficient in 86 samples and Zn was deficient in 34, using deficiency limits of 0.5 and 0.6 mg/kg, respectively. Zinc values were larger under maize–potato and horticulture at high altitude, whereas B was deficient everywhere. The Zn values were largely deficient in *khet* fields.

Sapkota and Andersen (2005) presented a case study of intensive horticulture from the Kathmandu Valley. Despite continuous cultivation, 75 soil samples had sufficient macro- and micronutrients, except for B. The 2 studies mentioned above may be used to modify the assumption that agricultural intensification leads to the depletion of nutrients. High-value crops may enable farmers to purchase fertilizers and chicken manure and to spend more labor on compost management, leading to improved nutrient balance. Farmers prioritize high-value crops with extra compost.

Other elements of concern

Shrestha et al (2005) showed a significant increase in the fertility of goats given Se supplements in Dhanusha district. The goats showed reduced kid mortality, less disease, and greater weight gain. This is the only study known by the author with results on Se in Nepal. Considering the widespread Se deficiency in neighboring Tibet and the soil leaching conditions in Nepal, it is likely that Se deficiency in Nepal is common. Cobalt (Co) deficiency affects nitrogen fixation in legumes (Srivastava and Gupta 1996) and is required for rumen bacteria for vitamin B_{12} formation in ruminants. No Co values are known for Nepal.

Most micronutrient problems in the Nepal region are due to soil deficiencies, but excess can also be a problem. For example, considerable interest has arisen over drinking water contaminated with arsenic (As), which has reached dramatic proportions in Bangladesh. In Nepal, the problems seem to be concentrated in Terai. Analyses of tube wells show that 6.78% are above the 50 μg/kg safety limit, and an estimated 0.5 million people in Terai live with the threat of As poisoning (Sijapati et al 2004). Other elements in excess that could be of concern include fluoride (F), and heavy metals such as Pb and Cu that are linked to mining operations or mineralization. Heavy metal pollution from industry and urban waste contaminates soil especially in the Kathmandu Valley (Krishna B. Karki, personal communication 2006). Selenium toxicity occurs in some dry zones of South Asia but is unlikely to be a problem in most of Nepal.

Conclusions

Most of the studies reviewed point in the same direction regarding the nature of micronutrient disorders in Nepal. The main deficiencies in the soil of relevance to crop production are those of B, Zn, and Mo. Other elements, for instance Cu and Mn, can play a role locally. Boron is a universal problem in Nepal and affects 80 to 90% of agricultural soil. The primary effect of B deficiency is reduced crop yields, and the pattern of this deficiency suggests that blanket recommendations are possible and that the use of B-added fertilizers may be feasible. Zinc deficiency is widespread, and appears to affect 20 to 50% of the cultivated lands, and even more in Terai, where the major part of the country's rice production takes place. Since low Zn content of soil affects the content in the rice grain, the low Zn soil values in Terai present a matter of concern for human nutrition on a national scale. However, a small proportion of soil samples have quite large Zn values, and this may restrict blanket recommendations of Zn fertilizers. Molybdenum is a frequent problem in acid soil and reduces yields of pulse crops. Arsenic should be a matter of further investigation.

For future research, more mapping of soil micronutrients should be a priority, in particular of Se and Co, for which no data exist. Monitoring over time is essential to understand the rate of depletion of soils. Research on the availability of micronutrients in inundated paddy soil is of particular interest to Nepal. With respect to agricultural extension, fertilizer formulas and recommendations are only a small part of the need for micronutrient strategies. The pathways of technology diffusion to farmers, including the role of the private sector, need to be addressed. The development of technically feasible and cost-effective nutrient management methods is important. Much research is still needed on micronutrient status of the population of Nepal, across socioeconomic and ethnic groups, gender, and age. Finally, interdisciplinary work to understand the pathways of nutrients from soil to human nutrition is needed.

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