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Geographical approaches to micronutrient deficiencies in Himalaya.

Summary

Research carried out under the NUFU (Norwegian Committee for Development Research and Education) programme has shown that micronutrient deficiencies in Himalayan soils are widespread, and also that there are links from the plant-soil system and agricultural productivity to livestock nutrition and human nutrition. The most important micronutrient deficiency to plants is boron, whereas zinc deficiency is a serious problem to both plant production and human nutrition in large areas in Himalaya. Deficiencies of selenium, iodine and molybdenum are also recognised in several regions. The explanations are complex, and the causal links from 'soil-to-health' are complicated by farming systems, socio-economic and cultural factors. However, the chains of explanation are plausible, and the main purpose of the paper is to demonstrate how models and methods commonly applied by geographers can contribute to micronutrient research. Analysis of spatial distribution of nutrient concentrations in soils provides insights in landscape processes. Adding a farming systems approach adds causal factors connected to markets, economy and labour. Analyses of the interface between local and scientific knowledge leads to institutional analysis questions, where quality control of agricultural inputs and international trade is at stake. Metalevel discussions of the Green Revolution show how HYV crops lead to 'empty calories'.

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Introduction: why micronutrients?

My incentive to start research on micronutrient problems in Nepal is related to human nutrition. I was introduced to a medical intervention programme in Bhaktapur, carried out by a Nepalese/Norwegian team. Zinc is regarded as one of the most important minor elements in human nutrition, being part of several enzymes and taking part in the formation of many more, and in synthesis of the biological building block RNA. The best general source of zinc is red meat, while fats and fruit are poor. Fish, poultry and dairy produce are reasonable zinc sources. Pulses – poor peoples' proteins - have a relatively zinc content, but the high content of phytate acid and fibres in pulses and whole grain flour is inhibiting its bioavailability. White rice has the lowest zinc content of major cereal crops (Brown & Wuehler 2000). In theory, the majority of Nepalese are not vegetarians. In practice, poverty is making many of them predominantly vegetarians except for festival occasions. The two meals of *dal bhat* a day provide a marginal diet regarding zinc as well as many other nutrients. Although no authoritative data exist on zinc in the Nepalese diet, nutritionists assume that deficiency is a major problem. Brown & Wuehler 2000 have assessed the zinc supply situation globally, using FAO data from 1998, and calculate the available zinc on the basis of energy, zinc density and zinc-phytate molar ratio. They estimate that 95.4 % (+/- 2.1) of the population in South Asia are at risk of low zinc intake, compared to 71.2 % (+/- 14.2) for Southeast Asia. In USA and Canada, 0.9 % (+/- 0.2) are found in this category.

The effects of milder zinc deficiency can be difficult to assess. With more pronounced deficiencies it has been demonstrated that the principal effects of zinc are growth retardation, delay in skeletal and sexual maturation, orificial and acral dermatitis and other skin diseases, diarrhoea, alopecia (hair loss), failure of appetite and – in severe cases – behavioural changes. More important in the general picture, zinc deficiency seems to lead to *increased susceptibility to infections due to defects in the immune system* (WHO 1996). Results from other countries have already demonstrated quite dramatic reductions of "the big baby killers" - persistent diarrhoea and pneumonia - through supplements of vitamins and zinc to deficient children (Black & Sazawal 2001), and the preliminary results from Bhaktapur go in the same direction. The links from soil to diet are far from straightforward, especially with an increasingly globalised food trade (White & Zasoski 1999; Combs et al. 1997). Still, Nepal provides a good case for studying these links, due to the close dependency on local food produce.

The answer to my initial research question: 'are there any relevant micronutrient deficiencies in Nepalese soils' was positive (Andersen & Sandvold 2000). The questions which logically derive from this question could be 'where', 'why' and 'what are the effects' and not least 'what could be done about it'?

In this paper I have chosen to demonstrate how approaches commonly applied by geographers can contribute to an understanding of micronutrient problems in a broader perspective. The intention is not to make any claim that geography is a solution. After all, geographers do borrow methods and theories from neighbouring disciplines, and the individual geographer is often specialised in his or her own little niche. However, the combined strength of various geographically related approaches may contribute to a better understanding of the complex problems. Some general issues were given a good treatment by Deckers et al. 2000. The present paper is aimed at some of the perspectives that are specifically related to Nepal, but some findings can probably be generalised to a larger regional perspective. The most essential micronutrients for humans are Zn, Se, Fe, I, F, Cr, B, Cu, Mn and Mo (Deckers et al. 2000). I have mainly concentrated the discussion on boron and zinc, but I have also encountered indications of severe deficits of selenium and molybdenum through fieldwork.

Mapping: Where?

The 'where?' question has attained surprisingly little attention in the research on micronutrients in Nepal (and elsewhere). For instance, none of the FAO Soil Bulletin studies on micronutrients (Sillanpää 1982, 1990) contained a map of where the soil samples were taken. Among the dozen of reports and publications on micronutrients in Nepal which I have been able to trace, only the unpublished report by Sippola & Lindstedt 1994 contains maps of the sample locations, but these maps were not subject to spatial analysis. A number of possible hypotheses could be formulated about the spatial distribution of nutrients. Intuitively, *catena* processes - erosion from upper parts of a slope and deposition in lower parts, especially in paddy rice fields - are likely. Equally, it might be expected that market orientation and intensification of cropping cycles and increased reliance on chemical (macronutrient) fertilisers could lead to depletion of micronutrients (Andersen 1999). My field study from Arun Valley showed that neither of these hypotheses held.

Figure 1 presents the pattern of zinc concentrations in the study area. Surprisingly, the values found in the paddy fields at Manmaya in the valley bottom were either low or deficient (with deficiency expressed as DTPA extractable Zn < 0.6 ppm). Around

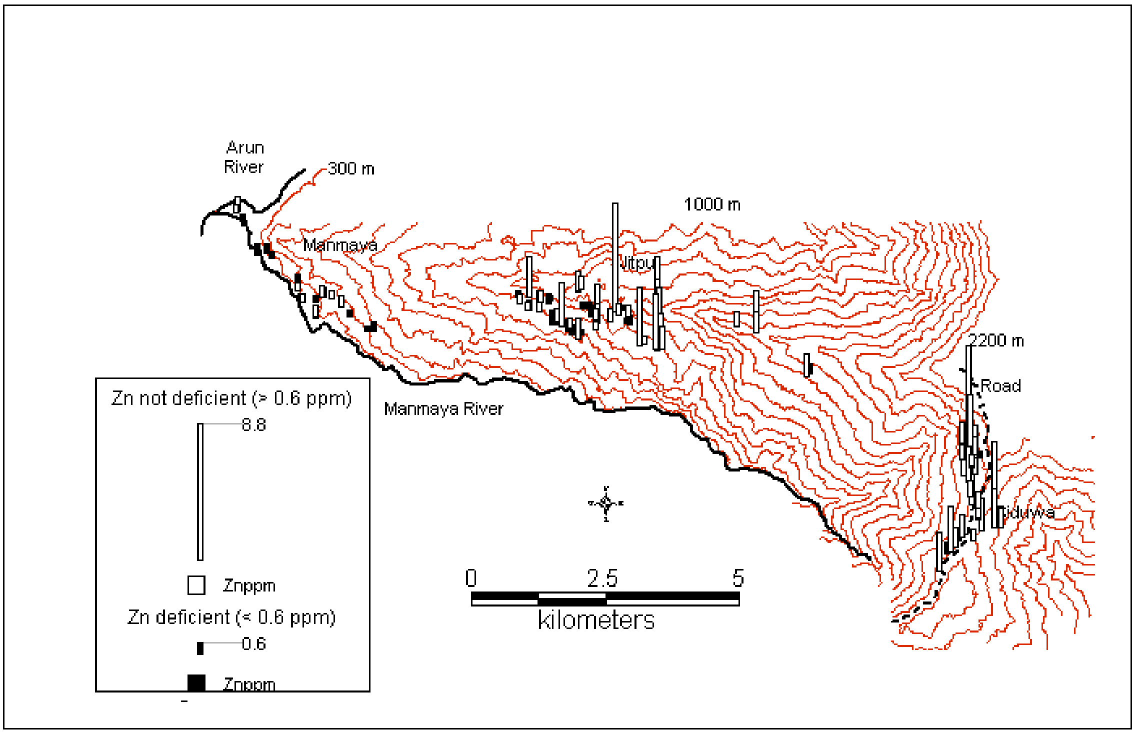

Figure 1. DTPA extractable zinc content of soil samples in a study area in Arun Valley, Eastern Nepal. The spatial patterns can be used for causal explanations as well as development of strategies.

On the top of the ridges, at Siduwa, one could have expected very low values due to catena processes, and to the intensive production of off-season vegetables undertaken in the vicinity of the road. The zinc values showed the opposite. Analysis of nitrogen and phosphate followed exactly the same pattern. For boron, there is no spatial pattern; the values are very low everywhere, and there is certainly a regional deficit of this element. Only copper did 'follow gravity' and was found concentrated in the lower samples. The copper values were not found deficient or excessive, and are not discussed further.

Farming systems analysis and economy: why and what to do?
Some explanations could certainly be related to *farming systems*. I interviewed 63 farmers in the study area about farming practices. A major difference was found in the production method and the amount of compost/farmyard manure produced. The farmers around the top-ridge village Siduwa all collect weeds such as *Banmara* (Lantana camera) and *Titepati* (Artemisia vulgaris) and use it for bedding for their animals. Around the low-lying villages Jitpur Bazaar and Manmaya, the farmers are using bedding only during the monsoon period, or - in a few cases: not at all. This striking difference may be related to resource distribution (availability of weeds at different altitudes). The maize-potato system in higher altitudes generally receives considerably more compost/FYM than the rice-wheat system in low altitudes. I will suggest that the variations best can be explained with reference to economics and market access. The Siduwa farmers have quite successfully entered in a market production. The increased earnings in turn justify the use of more labour in farm production. The Siduwa farmers are using significantly higher amounts of chemical fertilisers (46:0 urea or the 18:36 NP compound DAP), and some are purchasing chicken manure from large producers in the Terai plains. The use of animal bedding has several effects on the compost production. One is a reduction of losses of urine, another the higher amount of total biomass entering the system. It should be noted that the Siduwa farmers with fewer animals produce more compost than their neighbouring villages downstream.

The farming systems perspective is also useful in the discussion of different solutions to micronutrient problems. Any solution in the 'food chain' has its limitations: medical intervention is at times the most targetted, but requires health personnel resources, and is still in a R & D phase with regards to zinc (Bhan et al. 2001). Information campaigns are often biased towards urban areas, and affected by social as well as cultural questions. Fortification of foods or modified milling practices requires control over the processing of foods. Strategies that seek to correct micronutrient problems at the farm level have the advantage of raising productivity of plants and animals, and give the farmer a direct economic incentive to deal with micronutrients. In theory, adding a little borax and zinc sulphate to a deficient soil will be more cost-effective than adding large amounts of NPK fertiliser. Numerous agricultural intervention strategies may be considered.

Due to the central role of animal production in the mixed farming systems, the mineral flow through the animals is worthwhile to consider. The animals are generally fed with grass, leaves and crop residues. The gradual conversion of common grazing to arable leads to a change from transhumance and infield-outfield systems to mixed farming with stallfed animals. This increases the dependence of on-farm fodder production, and makes the farms more sensitive to local nutrient deficiencies.

Although purchase of commercial fodder is beyond the economic capacity of most farmers at the present level of commercialisation, mineral blocks or salt licks could be an option for improving the local nutrient flow.

The Arun Valley example indicated that the all year application of animal bedding might be enough to eradicate zinc deficiency problems in this area. However, it was not enough to cope with the regional deficit of boron. This element has to be added from outside. Adding boron and zinc to chemical fertiliser on a general basis may be considered.

This brings me back to the usefulness of mapping. The FAO/IFA 2000 guide assumes that farmers in large, relatively uniform plain areas can be given rather generalised advice. In such a situation there is not need for more than one extension worker per 2-3 000 farmers (Ibid.). In mountain areas where the soil conditions are more complex, extensive soil testing and one extension worker per 500 farmers is needed. In reality, the resource situation is probably rather the contrary between marginal mountain areas and densely populated plains. It is therefore necessary to find out if the FAO/IFA assumptions about mountain complexity are correct.

A comparison of my own study from Arun Valley, the Finnish from a larger area E and W of Kathmandu (Sippola & Lindstedt 1994) and the work of Singh et al. 1987 suggests similarities in the Himalayan Hills (**Table 1**). The data indicate that at least half the farmers could increase their production by using Zn added fertilisers. In addition the zinc content of grains and of plant residues would increase.

Table 1. Micronutrient content in soil samples in three studies from Himalaya.

	Zn deficit	Zn high	B Deficit	B high
Andersen & Sandvold 2000 Arun Valley	34 %	3-5 %	86 %	0
Sippola & Lindstedt 1994 Hills W + E of Kathmandu	56 %	3-5 %	94 %	0
Singh et al. 1987 Himachal Pradesh India	28 %	3-5 %	56-87%	0

However, there is a risk of inducing zinc toxicity in small areas where high soil zinc occurs. Zinc toxicity is normally only found in the vicinity of mine dumps and metal industries. The consequences of toxicity are normally not serious to human beings, animals and plants, but still the question should be considered. Adding boron to fertiliser appears to be less risky and more promising economically, since none of the three reports have found soils that are high in boron. The use of boron blended fertiliser has an advantage over the use of concentrated borax, if boron toxicity is to be avoided. This is especially important with boron, because the difference between deficiency and toxicity is very narrow. The optimal solution for the rice-wheat system is probably to use one boron-added fertiliser for the winter wheat crop to reduce the sterility problems, and a different fertiliser without boron for the boron-sensitive rice crop. This method, however, requires a precision in the use of agricultural inputs which is far beyond the present practises and knowledge of the majority of hill farmers. Strategies have to be seen in the context of knowledge and institutions, as will be discussed below.

Knowledge and institutions.

Issues on institutions and knowledge have been discussed in a previous paper (Andersen 2000). The following paragraph summarises those findings. 'Local knowledge' is a very imprecise term for many variations of sets of knowledge. It is dynamic in time, and is also able to absorb 'local knowledge' from elsewhere (which is how it is reproduced) as well as 'scientific knowledge'. The farmers I interviewed in Arun Valley used three 'Nepali' terms related to fertilisation of soil: *Maal* is compost/farmyard manure and is regarded as the real thing, which is improving the soil and the plants like. *Fertiliser* is chemical fertiliser and is used depending on price and availability but is seen as inferior to maal and is known to acidify the soil. The balance between urea and DAP fertiliser is normally based on availability and pure guesswork rather than soil analysis or extension advice. Finally, the term *vitamin* is employed for a broader range of other growth conditioners, plant hormones etc., containing nutrients or not. The micronutrient mixture Multiplex and products like borax, zinc sulphate and even zinc chelates are available to Nepalese farmers through the Agricultural Inputs Corporation and private traders, but the vast majority are not demanding them because *they do not know what they are*. Although the farmers were sceptical to overuse of chemical fertiliser because of the experienced problems with 'sour' soil getting cloddy and hardened, it did not mean that they were refusing 'scientific knowledge' at all. On the contrary, the farmers were highly interested in soil testing and very concerned about getting results and recommendations on fertilisation. Hybrid vegetable seeds are accepted, and pesticides are used rather indiscriminately.

The Nepal Agricultural Research Council (NARC) has a rigorous state centric and technocratic attitude to the development of recommendations to farmers. First, the issues must be subject to research trials under the auspices of NARC (e.g. recommending specific fertilisation for specific cultivars). Then, on the basis of the trials, recommendations are transmitted to the farmers through the extension system, NARC publications, radio programmes (and even internet). This system presents two problems. *Firstly*, although the scientists employed under the NARC are aware of micronutrient problems, it does not guarantee that research is carried out, and recommendations issued. Presently, fertilisation with zinc is only recommended for HYV rice in Terai, although it is likely that most crops grown on zinc poor soils would benefit, such as chickpea, sorghum and maize which are among the more sensitive (Srivastava & Gupta 1996). Traditional research trials, focusing on variations over how one crop is responding to one element, has little to do with the mixed cropping/mixed farming systems applied by most Nepalese farmers. *Secondly*, the majority of the hill farmers are not in regular contact with the agricultural extension system under the Department of Agriculture. In Arun Valley I asked 63 farmers about their affiliation to the extension system, and *none* of them had regular contact with the state extension system, despite the prevalence of extension officers in the area, as well as the Pakhribas Agricultural Research Centre and its outreach stations. In Siduwa, the local farmers' co-operative played a central role in knowledge exchange. Otherwise the personal networks of 'local knowledge' were predominant. Discussions with the farmers revealed that the VDC's (Village Development Committees) may be considered a credible and useful body for exchange of knowledge on farming.

Especially in connection with the deregulation of fertiliser trade, private fertiliser traders could also be considered a target group for information on balanced fertilisation. The Fertiliser Unit at Ministry of Agriculture was established in 1997 with the aim of providing and monitoring the control and strategic measures under an increasingly deregulated fertiliser market. A major challenge for the FU has been to set up a credible control system to cope with the vast amounts of spurious and substandard phosphate fertilisers, which have flooded the Nepalese market (Basnyat 1999).

To sum up, the farmers largely find themselves in a knowledge gap where the formal institutions so far have been unable to formulate and implement strategies to deal with micronutrient problems. Although the Ministry of Agriculture has begun working on establishing a legal framework for micronutrients, it will take a long time before this legislation also is reflected in the supply and extension system. With the deregulation of the fertiliser market in mind, work must be carried out in several fields at the same time. On the one hand, the state institutions must develop credible quality control systems for the farm inputs, and on the other hand, knowledge dissemination must be decentralised and also aim at the non-state actors (fertiliser traders, co-operatives etc.).

The Green Revolution – empty calories.

The Green Revolution was based on the development of new high yielding varieties (HYV) of grain crops. HYV are generally characterised by maximum response to N and P fertilisation. In addition, they may permit intensification of cropping cycles, leading to an increased off-take of micronutrients in the soil. The HYV crops are often more vulnerable to micronutrient deficiencies than 'local varieties'. Therefore, millions of farmers in the plain areas of Asia are giving their land supplements of zinc sulphate or zinc chelates, and various other mineral supplies. Still, some of the very few analyses of grain content ('micronutrient density') of HYV grains show that they are inferior to local varieties. Welch 2000 presents values for iron and zinc content of HYV and local, aromatic rice, where the HYV samples roughly contain 30 % less nutrients than the traditional varieties.

This can lead to some meta-level considerations: The Green Revolution has provided more food to be produced, and the majority of people in the affected regions have not only got more adequate calorie supplies, but also an increase in purchase power which has enabled them to diversify their diets. In some cases increased earnings may lead to less nutritive but more prestigious or tasty foods (e.g. from millet to white rice or excessive fat intake), but by and large the consumption of foods richer in protein and minerals (meat, dairy produce, vegetables) will increase. Also, in the general picture: despite some 'dilution effect', the vastly increased production after the Green Revolution has meant that more micronutrients are brought into circulation. The losers are, as always, the poorest of the poor in Asia, living from a diet which predominantly consists of white rice. Once they switch their diet to micronutrient poor varieties, their daily nutrient intake deteriorates severely.

Micronutrients and GIS.

Geography and neighbouring disciplines have rapidly increased the use of GIS in mapping and analysis, and also in the analysis of micronutrient problems, GIS offers advantages over previous techniques (White & Zasoski 1999). In the present work, GIS has been used in the analysis of the data from Arun Valley, and an example is given in figure 1. In epidemiology, GIS is also used in to study regional medical problems, and it may under certain circumstances reveal soil related health issues (Deckers et al. 2000). However, GIS studies of local environmental factors provide only a part of the analysis of the long and complex way in the 'soil to food' chain of explanation, because social and cultural factors and international food trade overrules the local food systems. In the medical intervention study mentioned earlier in this paper, the children taking part in the study have been registered with GPS for GIS analysis. Here, the purpose is not to find variations in nutrients (as they are controlled in a double-blind intervention trial), but to check for spatial variations of disease which may be attributed to other environmental factors. The results have not yet been analysed, but so far the exercise has provided two results. Firstly, it has been demonstrated that the children are randomly distributed over the area. Secondly, the use of GPS registration has proved an extremely useful tool for keeping control over the approximately 1800 children and their whereabouts, so that the researchers can follow up on the study in time.

Conclusion.

This paper has only scratched the surface of micronutrient problems. But it demonstrates that: 1) there are still unsolved problems related to micronutrients in the Himalayan region, and 2) that geographical approaches have a potential to identify causes and effects at levels which go from the single farm, and to the global Green Revolution level. Mapping and spatial analysis of soil nutrients does not only answer the *where?* questions, but also establish foundations for strategy development. However, the biological and soil science approaches are useful only when related to the social science aspects of the problems, and in particular the knowledge gap between farmers and the formal institutions.

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