Micronutrients in South and South East Asia

Proceedings of an International Workshop held 8-11 September, 2004, Kathmandu, Nepal

Editors
Peter Andersen, Junoo K. Tuladhar, Krishna B. Karki, and Surya L. Maskey

About the Organisations

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December 2005

ISBN 92 9115 210 2

Cover photos
Front – growing vegetables in the Phulchowki watershed, Nepal, *Ujol Sherchan*
Background – rice terraces in Nepal, ICIMOD File photo

Published by
International Centre for Integrated Mountain Development
G.P.O. Box 3226
Kathmandu, Nepal

Editorial Team
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Dharma R. Maharjan (Technical Support and Layout Design)

Printed and bound in Nepal by
Quality Printers (P) (Pvt.)
Kathmandu, Nepal

Foreword

Plant nutrients are essential for producing sufficient and healthy food for the world's expanding population, especially in South and South East Asia. Unbalanced use of mineral fertilisers and a decrease in the use of organic manure are the main causes of nutrient deficiency in this region. Moreover, agricultural intensification requires an increased flow of plant nutrients to crops and greater uptake of those nutrients by crops. Until now, micronutrients have mostly been addressed as a soil problem. But micronutrient deficiency complexities have now been observed abundantly in crops produced from micronutrient deficient soils; and these in turn produce nutrient deficient food. People depending on these foods then also display deficiency symptoms (malnutrition and certain inborn deformities in human beings). With this recognition of the importance of soil micronutrients for human well-being, the time has come to focus on a multidisciplinary and integrated approach to addressing the micronutrient problem.

The Soil Science Division of the Nepal Agricultural Research Council and the University of Bergen, Norway, organised a workshop on 'Micronutrients in South and South East Asia' in Kathmandu from 8th-10th September 2004. This was the first time in Nepal that experts in health, nutrition, plant nutrition, soil science, and other agricultural sciences had gathered together to discuss the micronutrient problem and to find a common solution for the benefit of the poorer areas of the world. The survey and research results showed widespread deficiencies of micronutrients in soils of South Asia, and also recommended some measures to correct them. Bio-fortification – breeding of varieties efficient in concentrating micronutrients from deficient soils – is one strategy. Other interesting agricultural strategies include use of improved fertilisers, seed priming with micronutrients, seedbed preparation, and improved compost management. Improved food preparation, food fortification and promotion of more nutritious food are other promising strategies. However, the problem is complex and any strategy must be evaluated in relation to the local context.

This workshop provided an international arena for micronutrient research using an integrated approach, and provided a valuable platform for sharing ideas and experiences related to addressing micronutrient problems in soil, plants, and humans. With this publication, we hope to share this knowledge with a wider audience, particularly with the many people concerned with soils, agriculture, and human nutrition in developing countries across the world, and thus to stimulate further integrated activities towards a long-term solution of micronutrient problems.

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Editor's Preface

This book is the proceedings of a workshop on micronutrient related research which was held in Kathmandu from 8-10 September 2004. The idea for the workshop was developed by Junoo K. Tuladhar, Krishna Karki, and Surya Maskey of the Soil Science Division of the Nepal Agricultural Research Council, and Peter Andersen of the Department of Geography, University of Bergen, Norway. The purpose was to establish the status of current knowledge and identify future research needs related to micronutrients in South and South East Asia. The main focus of the meeting was on agricultural strategies, but the participation of researchers concerned with human nutrition and other disciplines beyond plant-soil interactions served to make the workshop a truly interdisciplinary event. The participants covered a broad range of themes which together illuminate a comprehensive picture of the complexities of micronutrient issues, ranging from soil processes through plant nutrition to agricultural extension, fertiliser quality control, and the effects on human nutrition.

Several of the papers are based on relatively small collections of data or field plots, and clearly more research is needed to raise some statements from the status of 'indicative' to more strictly verified. However, the scale of the problems in agricultural productivity and human nutrition is beyond doubt. The majority of agricultural land in South Asia is severely affected by one or more micronutrient imbalances, and the majority of people in the region are suffering from micronutrient deficiencies. Insufficient supplies of iodine, iron, zinc, and vitamin A have adversely affected the health of literally hundreds of millions of people.

It is important to raise micronutrient problems much higher on the agenda, not only in terms of scientific research, but also in terms of public awareness. Agricultural research is much needed, but must be complemented with interdisciplinary research and development. There is a need to develop enabling strategies that can help farmers to carry out their own experiments and improve their soil management, as well as help people improve their own nutrition. The editors believe and hope that the quality of the papers contained in this publication can help to get research and development in the field moving ahead. The workshop was sponsored by grants from the University of Bergen, the International Centre for Integrated Mountain Development (ICIMOD), and Hill Agriculture Research Project (HARP), and ICIMOD kindly offered to publish the proceedings.

The workshop was not unaffected by the security problems and political unrest that have affected Nepal in recent years. Two keynote speakers had to cancel their participation as a result of travel restrictions imposed by their home countries. Nevertheless, the workshop was attended by some 55 researchers from 9 different countries, and several initiatives developed since it was held have shown that the undertaking was worthwhile.

It is the sincere hope of the organisers that the content of this book will provide a humble contribution to improving the livelihoods and wellbeing of the people in this region.

Note:

the papers in this volume have been edited into the current form, in some cases without further review by the authors.

Acknowledgements

The 'International Workshop on Micronutrients in South and South-East Asia' was organised jointly by the University of Bergen (UoB) and Nepal Agricultural Research Council (NARC). The workshop was funded by UoB, for which the organising committee would like to express its sincere thanks; without this support the workshop would not have been possible. Funding from ICIMOD for two candidates from the Himalayan region to attend the workshop is gratefully acknowledged and logistics support of Hill Agriculture Research Project (HARP) also acknowledged. The organising committee thanks Professor Dr. Ross Welch for his very important Key Note speech. Likewise, although Professor Rosalind Gibson of the University of Otago in New Zealand was unable to attend the workshop in person, the paper that she sent for the workshop considerably extended the participants' knowledge on human nutrition and was sincerely appreciated. Thanks are also extended to the participants whose active participation and sharing of knowledge and experience with fellow participants helped to make the workshop such a success. The help and cooperation rendered by the staff of the Soil Science Division (NARC) is gratefully acknowledged. Many thanks are also expressed to the Mountain Hotel for its warm hospitality. Finally, the organisers wish to thank the publishing unit at ICIMOD for their kind and professional contribution in turning the proceedings of the workshop into the present publication.

Executive Summary

A workshop on 'Micronutrients in South and South East Asia' was held in Kathmandu from 8th - 10th September 2004. Fifty-five scientists from nine countries discussed problems related to micronutrient disorders in human nutrition and agriculture, and strategies and methods to address the issues. These problems are more common in South and South East Asia than in any other region in the world owing to poverty, plant-based diets with low micronutrient density and availability, and widespread soil deficiencies.

Keynote presentations
Professor Rosalind Gibson from Otago University, New Zealand, explained that the prevalence of protein deficiency in a number of poor countries is very small compared to deficiencies of iron and zinc. The adverse effects of a poor supply of iron, zinc, iodine, selenium, vitamin A, and vitamin B_{12} include productivity, cognition, morbidity, and mortality, in other words not only human health, but also socioeconomic conditions at large. A case study by Gibson showed the potential impact of food processing at local level, including soaking and fermentation of cereals in order to increase bioavailability of micronutrients, increased intake of locally available foods with higher content of micronutrients, and nutrient rich porridges for child feeding. The study showed that changing cooking processes and local diets has a potential to increase the nutritive value significantly, but not enough to bring all people out of a deficient status. Therefore, dietary interventions should be supplemented with other strategies encompassing a larger part of the food system, for example food fortification and bio-fortification.

Professor Ross Welch from Cornell University, USA, addressed the connection between farming systems and food systems. Between 1965 and 1999, there was a dramatic decrease in the density of micronutrients in the diets of the average population in developing nations in general, and in South Asia in particular. One important reason was the change in balance between population, cereal production, and pulse production. Whereas the increase in cereal production was bigger than the population growth, the per capita availability of pulses – the nutrient rich part of the diets – declined to less than half as a result of deficiencies of boron, zinc, and molybdenum. This in turn effects the provision of iron and zinc in human diets, and in particular among people with rice-pulse based diets. Welch proposed a number of different strategies to make agriculture more sustainable in terms of provision of healthy food to people including improved fertilisation, promotion of crops with higher nutrient density and availability, breeding for micronutrient efficient crops, and diversification of cropping systems. CGIAR's Harvest Plus programme is one of the efforts being undertaken in this direction.

The final keynote presentation by Dr. Krishna B. Karki and colleagues from the Nepal Agricultural Research Council's Soil Science Division (NARC-SSD) summarised the status of soil micronutrient problems in Nepal. Visual symptoms of micronutrient deficiencies in indicator crops have been recognised for a long time. Studies of soil micronutrients have been undertaken in the country since 1971. There was a big step forward when Nepal was included in Mikko Sillanpää's Global Assessment of Micronutrients (FAO 1982), which raised awareness among Nepalese researchers of the scale of micronutrient deficiencies. In the high Himalayan region, available zinc and manganese is relatively abundant, and only boron presents a problem to agriculture. In the western and central hills, boron, zinc, manganese, and copper are frequently low. However, some studies show that soil content of iron, zinc, copper, and manganese can be high in the Kathmandu Valley owing to the use of city waste as compost. Trials in the Valley have shown a positive response to application of boron and molybdenum. Boron and zinc are low in the inner Terai (Chitwan), and boron, zinc, manganese, and copper, elsewhere in the Terai. There has been less mapping of molybdenum status than of other elements, but deficiency in this element is a common reason for reduced yields of vegetables and legumes. Boron deficiency is very widespread and strikes wheat, vegetables and fruit crops. Zinc deficiency is a major problem in rice cultivation.

Human nutrition

According to Chandyo, in 2001 the World Health Organisation finally recognised the efficacy of zinc supplementation in the treatment of acute diarrhoea. In a double blind intervention trial from Bhaktapur in the Kathmandu Valley, zinc supplementation shortened the duration of acute diarrhoea by 19-26% and reduced the risk of prolonged diarrhoea by 43-47%. Zinc intervention has potential impacts on other infectious diseases as well. Preliminary findings from studies in Bhaktapur on the effects of zinc supplementation on pneumonia were promising but more research is needed. Valentiner-Branth (not in this publication) has discussed the reasons for these effects. Zinc deficiency is known to affect development of the immune system, but he hypothesised that zinc also has a pharmacological effect on infection.

Attaluri and Ilangantileke presented research from the International Potato Center (CIP) on vitamin A rich orange fleshed sweet potatoes which have been bred in order to reduce vitamin A deficiency. Because sweet potatoes are a common food item in some areas in Asia, the improved varieties have a potential to improve nutrition without dietary changes or altered cropping patterns.

Problems in agriculture

Rai and colleagues presented the results of studies on the spatial variation of soil zinc status in Rupandehi district, Nepal. The area has low to medium zinc content in the soils (0.013-1.402 ppm DTPA extractable), making zinc deficiency the most widespread micronutrient disorder in the district. It was not possible to establish statistically significant associations with other soil variables. The study showed the usefulness of GIS and geo-statistics for analysing soil status.

Narwal et al. presented findings on the status of micronutrients in soils in different agro-climatic zones in Haryana, India. Imbalanced fertilisation with macronutrients together with intensive agriculture has led to depletion of micronutrients, especially of zinc, iron and manganese. The copper status was not critical. Overall, soils in the southwestern zone were more deficient in micronutrients than soils in the northeastern zone. In the southwestern zone, between 32 and 88% of the soils sampled in different districts were deficient in zinc, in the northeastern zone it varied from 30 to 78%. Although increasingly farmers are using zinc and other micronutrient fertilisers, the overall balance between supply and crop removal losses was negative for all micronutrients. The increase in production has led to larger removals by crops. Between 1966/67 and 2001/02, removal of zinc increased from 20 to 80 grams per hectare. Thus Haryana is in urgent need of improved nutrient balance management.

Takkar and Jalali presented a review of soil micronutrient problems from India. In most zones, zinc deficiency is a major problem, affecting grain crops as well as pulses and fruit orchards. Deficiencies of copper, iron, and manganese are less frequent. Intensification worsens the status: in Uttar Pradesh, zinc in foothill soils went down from 2.77 ppm to <1 ppm over 12 years of rice-wheat-cowpea cultivation. Boron deficiency is also widespread in many soils. Applications of micronutrients have shown good results in many places in India.

Bhatta et al. examined a number of genotypes of wheat for susceptibility to sterility (no grain formation). Grain sterility in wheat in Nepal (and neighbouring countries) is largely induced by boron deficiency, although other environmental factors also play a role. Sterility may at times reach 100%, and soil application has produced very significant results. The susceptibility is largely genetically controlled. A screening of 200 genotypes in 2002/03 and 317 genotypes in 2003/04 showed sterility rates varying from 1 to 100%, typically either very low or very high. Application of boron in control fields indicated that deficiency of this element was the main cause.

Shrestha et al. tested the effects of supplements of selenium on goats in Nepal and observed substantially increased fertility and reduced kidding interval, reduced kid mortality, and less disease occurrence in the flock. This highlights two issues: that livestock in Nepal is also affected by micronutrient deficiencies, and that there is selenium deficiency in the environment in Nepal. This may also have implications for human health. Both issues are in need of further research.

Sapkota and Andersen studied a peri-urban farming area in the Kathmandu Valley where traditional farming has been replaced by highly intensive horticulture. The effect of commercialisation has been that the farmers have improved their soil nutrient management substantially, using compost, purchased chicken manure, and chemical fertilisers, as well as micronutrient fertilisers. The soils were found to be acid and deficient in boron, but otherwise to have good nutritional status. However, farmers use the nutrients in a haphazard manner without soil testing and, and their knowledge of plant nutrition is not sufficient to deal with micronutrient problems in a cost-effective manner.

The social science context

Andersen discussed the gap between local knowledge systems and scientific knowledge, and suggested that addressing the knowledge gap on micronutrients was a major strategic problem. Although some traditional farming practices are having effects, local knowledge does not contain concepts that are able to comprehend micronutrient issues. On the other hand, the present traditions in scientific research and agricultural extension have developed little information in terms of strategies and recommendations that has relevance to marginal farmers. Mapping of soil nutrients is a prerequisite for issuing recommendations: uniform deficiencies can be addressed with blanket recommendations, but spatial variations require other extension models. Andersen suggested that alternative pathways of knowledge dissemination should be addressed, including provision of knowledge on visual symptoms and micronutrient disorders to fertiliser traders, farmers, and schools.

Manandhar and Khanal gave an overview of the legal system for quality control of fertilisers in Nepal. After deregulation of the fertiliser trade in 1997, the government issued a Fertiliser (Control) Order. In accordance with the Guidelines issued in 1999, 75 fertiliser inspectors have been appointed under the District Agriculture Development Offices (DADO). Soil testing laboratories have been authorised, and fertiliser test kits developed for testing adulteration of fertilisers, which is a major problem. So far, 27 inorganic fertilisers have been approved and the rules for specification of major element fertilisers are well developed. However, there is as yet no system for specification or control of micronutrient fertilisers, and these products are largely applied haphazardly by farmers.

Analysis using soil applications

Srivastava et al. showed how boron is a severely limiting factor for grain legume production in the inner Terai. Omission experiments at a field station had shown that boron and molybdenum were major limiting factors for chickpea. On-farm trials were conducted to determine the effects of different levels of micronutrient supplies to chickpea, lentil and mustard. The maximum yield appeared to be reached with applications of 0.5 kg/ha boron; more than 3 kg/ha appeared to approach the toxic range. The yield response of lentils was about tenfold. There was also a significant response to zinc applications of 2 kg/ha, but a decrease when the amount was increased to 4 kg/ha. The small amount of boron needed suggests that field application of this element could be economically viable and relevant for resource poor farmers.

Sherchan et al. carried out a study at Rampur, Chitwan, to identify the limiting micronutrients and their effect on maize productivity and quality. The study used omission of boron, zinc, sulphur, manganese, iron, copper, and molybdenum, compared to control fields with full 120:60:40 NPK treatment, and without organic manure and chemical fertilisers. Soil and plant samples were analysed. Although boron is a known problem in the area, there was no significant effect of boron on maize. Likewise, although soil and plant zinc concentrations were below normal critical values, zinc did not have any significant impact on yields, but there was a significant correlation between soil content of zinc and manganese, and the concentration in leaves.

Shivay & Kumar reported in a review that the extent of zinc deficiency in Indian soils is almost 50%, and that it is increasing. In their experiments, they studied interactions between phosphorous and zinc in aromatic rice. Both elements significantly influenced grain, straw and biological yields, and harvest index. The yields increased significantly up to applications of 40 kg/ha P_2O_5. The optimum dose of zinc was found to be 5 kg/ha Zn, whereas lower applications did not have any significant impact on yield. Although it is known from the literature that interactions can occur between zinc and phosphorous, no significant interaction effects were found at the moderate levels studied.

Adhikary et al. described the results of a study of different micronutrients on grain production of toria (*Brassica campestris*) in Chitwan under farmers' field conditions. Soil application of a combination of boron, zinc, and sulphur produced the highest grain yield, 1115 kg/ha compared to 605 kg/ha in a control field. However, considerable differences were found when a research field was brought into comparison, indicating that soil type plays an important role in response to fertilisation.

Other agricultural methods

Soil applications will inevitably incur losses. As commercial micronutrients are often costly, it is important to consider other methods, especially for resource poor farmers.

Bodruzzaman et al. studied the impact of micronutrient enrichment of seeds of wheat and rice in Bangladesh. Salts of zinc, molybdenum, nickel, copper, manganese, and boron were applied to crops in on-farm trials by foliar spraying. The enriched seeds showed substantially increased yield, wheat by 25% in twelve of forty-seven trials, and rice by 22% in twelve of seventeen trials. The authors believe that some of the effect was the result of increased resistance to disease. The study suggests that micronutrient enrichment of seeds can improve yields of wheat and rice in areas where soil testing is unavailable. However, the researchers were cautious about recommending foliar spraying of micronutrients because it is laborious and not necessarily practical for resource poor farmers.

In a study on alkaline soils from the North West Frontier zone in Pakistan, Harris et al. tested priming (soaking seeds in water) of wheat and chickpea with solutions of zinc sulphate. The safe, optimum solution for wheat was found to be 0.4% zinc, which led to a mean increase in yield of 615 kg/ha compared to non-primed seeds. For chickpea, the safe, optimum concentration was 0.05% zinc, which gave a mean yield increase of 48% over non-primed seeds. The benefit:cost ratio for priming wheat with zinc was calculated to be about 360, of which 160 could be contributed to zinc alone and the remainder to the effect of priming in water. This compares to a benefit:cost ratio of 8 for soil application of zinc. The benefit:cost ratio for priming chickpea with zinc was about 1500, of which 750 was a response to zinc. Thus, it appears that seed priming is a much more appropriate method for resource poor farmers than soil application.

In another priming study, Johansen et al. studied micronutrient problems in chickpeas grown on acid soils in the High Barind Tract, Bangladesh. Molybdenum was found to be the only limiting micronutrient, giving a yield response of 73%. Trials were held to test the effects of soil application of molybdenum and *Rhizobium* inoculation. In addition, trials were carried out with seed priming in water containing molybdenum and *Rhizobium*. It was found that all treatments gave substantial increases compared to control fields. Adding molybdenum and *Rhizobium* to priming water reduced the amount of molybdenum needed, and had several features which suggest that it is a favourable method for resource poor farmers. Feasibility studies are planned to determine whether this is really the case.

Chaudary and Narwal presented data on the effects of long-term application of farmyard manure (FYM) on soil micronutrient status in a pearl millet-wheat cropping system in Hisar, India. FYM was applied at rates of 15, 30, and 45 tonnes per hectare; the soils contained significantly higher amounts of all micronutrients than a control field. The content of micronutrients correlated significantly with soil organic matter, with the highest increase in the upper soil layers and with winter application of FYM.

Regmi et al. focused on experiences from research into integrated plant nutrient management systems (IPNS) in the mid hills. IPNS aims at enhancing local knowledge to develop holistic soil management at farm level. Organisation of farmer-field schools is an important element. A long list of methods includes improved FYM production, legume integration, and avoiding excessive use of chemical fertiliser. Experiments in farmers' fields showed that application of boron and molybdenum had a positive impact on cauliflower production, and applications of boron on wheat. Maize responded to zinc application. Many of the techniques gave positive results, but there was a need for location specific analysis of problems, as well as for institutions for building and maintaining knowledge.

Khanal et al. studied various methods of micronutrient supplementation to a number of crops in hill areas and the Terai plains in Nepal. Priming water, soil applications, and foliar sprays of cattle urine and stinging nettle extract were compared. The soils were generally constrained by boron and zinc, and molybdenum affected yields of pulses. All treatments gave positive yield results compared to controls, indicating that there is vast scope for developing and testing different methods of micronutrient applications based on locally available resources for resource poor farmers.

Acronyms and Abbreviations

AAS	atomic absorption spectrophotometer
AIC	Agricultural Inputs Corporation
BINA	Bangladesh Institute of Nuclear Agriculture
BpLB	*Bipolaris* leaf blight
CEC	cation exchange capacity
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
cv	co-efficient of variation
DADO	district agricultural development office
DAS	days after sowing
FAO	Food and Agriculture Organization (UN)
FYM	farmyard manure
GLRP	Grain Legumes Research Programme
GPS	global positioning system
GR	Green Revolution
GRW	grain weight
ha	hectare
HBT	High Barind Tract (Bangladesh)
HMGN	His Majesty's Government of Nepal
HP	Himachal Pradesh
IAAS	Institute of Agriculture and Animal Sciences (Nepal)
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICP	inductively-coupled plasma
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics
IFA	International Fertilizer Industry Association
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
IPNM	integrated plant nutrient management
IPNS	integrated plant nutrient system
IRRI	International Rice Research Institute
ISNRMP	Indo Swiss Natural Resource Management Programme
IU	international unit
JRP	Jute Research Programme
JT	junior technician
JTA	junior technical assistant

LARC	Lumle Agricultural Research Centre
LBW	low birth weight
LKS	local knowledge system
LSD	least square deviation
MOA	Ministry of Agriculture
MPN	most probable number
NARC	Nepal Agricultural Research Council
NWRP	National Wheat Research Programme
NY	New York
OFSP	orange-fleshed sweet potato
OM	organic matter
PAC	Pakhribas Agricultural Research Centre
ppm	parts per million
PPR	'pestes des petits ruminantes' (diseases of small ruminants)
PRDF	Participatory Rural Developmental Foundation
PVS	participatory variety selection
PZMR	phytate-zinc molar ratio
RARS	Rampur Agricultural Research Station
RCB	randomised complete block
sed	standard error deviation
SKS	scientific knowledge system
SOC	soil organic carbon
SOM	soil organic manure
SRDI	Soil Resources Development Institute (Shyampur)
SSD	Soil Science Division
STSS	Soil Testing and Service Section
STV	stover yield
SWCA	South, West and Central Asia
THW	thousand-grain weight
TOT	transfer-of-technology
UNICEF	United Nations Children's Emergency Fund
UP	Uttar Pradesh
USAID	US Agency for International Development
USDA	United States Department of Agriculture
USDA-ARS	United States Department of Agriculture, Agricultural Research Service
VAD	vitamin A deficiency
WHO	World Health Organization
WORLP	Western Orissa Rural Livelihood Project

Chemicals

AAAC-EDTA	acid ammonium acetate – ethylenediaminetetracetic acid
AB	ammonium bicarbonate
ACC	accumulated flow
Al	aluminium
As	arsenic
B	boron
C	carbon
Cd	cadmium
Cl	chlorine
Co	cobalt
Cr	chromium
Cu	copper
DAP	diammonium phosphate
DTPA	diethylenetriaminepentaacetic acid
F	fluorine
Fe	iron
Hg	mercury
HNPV	Helicoverpa nuclear polyhedrosis virus
I	iodine
K	potassium
Li	lithium
Mg	magnesium
Mn	manganese
Mo	molybdenum
MOP	muriate of potassium
N	nitrogen
Na	sodium
Ni	nickel
P	phosphorous
P_2O_5	phosphorous pentoxide
Pb	lead
PYR	pyrene
S	sulphur
Se	selenium
Si	silicon
Sn	stannous (tin)
TSP	triple superphosphate
V	vanadium
Zn	zinc

Note: In Nepal, the calendar year is based on the Vikram Sambhat system and runs from mid April to mid-April. Yearly data are presented in the form '2004/05' meaning the calendar year from mid April 2004 to mid April 2005. In some cases, particularly data from India, the form '2004/05' refers to a cropping year – from late spring/early summer to late spring/early summer.

Glossary

aqua regia	also known as royal water, a mixture of hydrochloric and nitric acids
bagar khet	sandy/gravelly lowland
bari	rainfed upland (usually terraces)
bhed	shallow lake
kandi	high altitude soils
karewa	Hapludalfs soil type
kharif	summer (rainy) season
khet	irrigated (flooded) lowland used to grow rice
kriged	an indicator, kriging is a geostatistical method which estimates the distribution of grades within a block
pH	derived from the German word, 'potenz hydrogen' meaning power of hydrogen. The pH of a solution is related to its hydrogen ion concentration and indicates the acidity /alkalinity.
rabi	winter (dry) season
sim khet	wet lowland
toria	rapeseed/oilseed
upazilla	A rural administrative subdivision of a district in Bangladesh
zizufus	jujube/ Chinese date

Contents

Keynote Presentations

Dietary Strategies to Enhance Micronutrient Adequacy: Experiences in Developing Countries

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Introduction

There is increasing recognition that in developing countries, where diets are mainly plant-based, dietary inadequacies of several micronutrients are likely. These inadequacies have been identified from FAO food balance sheet data as well as national and regional food consumption surveys, and confirmed by biochemical and clinical studies of micronutrient deficiencies, often involving randomised, double-blind clinical trials. Several factors are associated with the etiology of micronutrient deficiencies. Dietary factors are linked with low intakes of micronutrients arising from a low content of the same in the soil and crops, low energy intakes, and poor food selection patterns, as well as poor bioavailability of certain micronutrients. The latter is especially a problem among population groups consuming diets in which a high proportion of the energy and micronutrients is provided by cereals, and intakes of food from animal sources are low. Diets low in expensive foods from animal sources are also low in dietary components known to enhance micronutrient absorption, whereas those containing high amounts of unrefined cereals and legumes are high in inhibitors such as phytate and polyphenols. One useful measure of the bioavailability of zinc (Zn) in diets is the phytate-zinc molar ratio (PZMR). A PZMR value of less than 15 is associated with good zinc bioavailability, whereas a ratio above 15 is associated with poor zinc bioavailability. The diet of Canadian children has a PZMR of 5, whereas in countries such as Kenya and Malawi the PZMR of the habitual diet is often about 30. As a result, their zinc content is likely to be poor in terms of bioavailability. The Nepalese rice/lentil diet is also likely to have very poor bioavailability of Zn.

Increased losses of micronutrients due to diarrhoea and parasitic infections are common in developing countries and exacerbate micronutrient deficiencies. Risk of micronutrient deficiencies is also high during periods of the life cycle when physiological requirements are high such as infancy, childhood, pregnancy, and lactation. Low birth weight (LBW) and malnourished infants also have high physiological requirements, and hence are at risk in terms of micronutrient deficiencies.

As a result of the low content and/or poor bioavailability of micronutrients in the plant-based diets of developing countries, the prevalence of inadequate intakes of micronutrients is much higher than that of inadequate intakes of protein, as shown in Figure 1.

The consequences of micronutrient deficiencies to society are grave. They may include impairments in growth, development, cognitive function, immune function, and adverse outcomes of pregnancy. Such adverse health effects also have an economic impact, affecting productivity and cognitive development, and increasing the risk of morbidity and mortality among the population, as summarised below (Table 1).

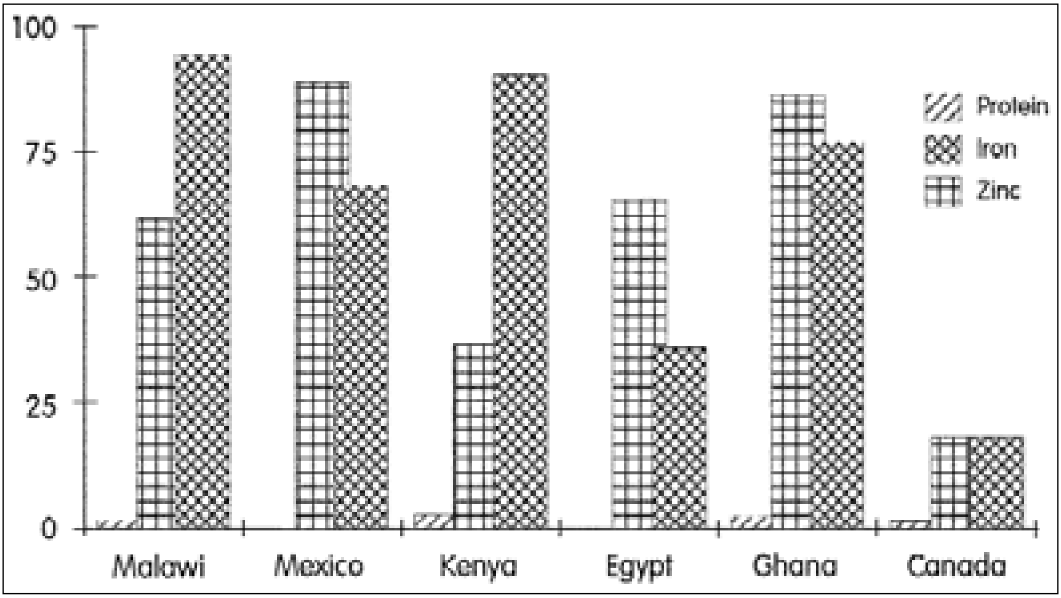

Figure 1: **Predicted prevalence of inadequate intakes**

Table 1: Adverse effects of micronutrient deficiencies	
Adverse effect	**Micronutrients**
• Productivity	Fe, Zn, I, Vit A
• Cognition	Fe, Zn, I, B-12
• Morbidity	Fe, Zn, Vit A, Se
• Mortality	Fe, Zn, I, Vit A
Key: Fe=iron; Zn=zinc; I=iodine; B=boron; Se=selenium; Vit=vitamin	

Nutrition interventions to combat micronutrient deficiencies can be divided into four strategies: supplementation, fortification, dietary diversification/modification and bio-fortification. Dietary strategies have several advantages over supplementation. They are culturally acceptable and can be designed so that they are likely to be sustainable and can reduce the risk of concurrent micronutrient deficiencies with a minimal risk of antagonistic interactions. They are also community-based, and thereby can empower communities to help themselves.

Case Study from Rural Southern Malawi

In the following, a case study from rural Southern Malawi is presented to illustrate the application of dietary diversification/modification; more details are given in Gibson et al. (2000, 2003). The strategies aimed to change food selection patterns and traditional household methods for preparing and processing indigenous foods, with the overall goal being to enhance the availability, access, and use of foods with a high content and bioavailability of micronutrients. The study applied both formative and laboratory-based research to develop appropriate dietary strategies, and these were later tested in the community to assess their feasibility and acceptability before implementing them. Nutrition education and interventions to promote behavioural change, such as social marketing, were used to implement and disseminate the dietary strategies. Finally, their efficacy was evaluated using a knowledge and practices' survey, and data on nutrient adequacy, biochemical status, and functional outcomes such as growth and morbidity. The study included weanlings aged 6-23 months and children aged 36-84 months, with a median age of 48 months.

Staple diets in Malawi are maize-based (>50% of energy) and hence contain high levels of phytic acid, a potent inhibitor of Zn, Fe, and calcium (Ca) absorption (Ferguson et al. 1993); consumption of foods from animals is low (3-7% of energy). In certain regions of Malawi there is a high prevalence of stunting (>50%), anaemia (>50%), and vitamin A and iodine deficiency in young children. As a result, four dietary strategies were tested, as outlined below.

1. Reduction of phytate content of cereal-based staples at the household level to enhance Zn, Fe, and Ca absorption
2. Increase in the intake of foods that enhance Zn, non-heme Fe, and vitamin A absorption
3. Increase in production and consumption of foods with a high content and bioavailability of micronutrients
4. Increase in the dry-matter content of porridges used for feeding young children to enhance energy and micronutrient density

Strategy 1 was based on changes in practices of food preparation such as soaking cereal and legume flours to allow passive diffusion of water soluble phytates, fermentation of cereal porridges to hydrolyse phytate acid via microbial phytase, and the addition of germinated cereal flours to provide a source of endogenous phytase for hydrolysis of phytate. Different methods of soaking were shown to reduce the phytate content of maize porridge from 11-36% compared to the unsoaked control preparation, resulting in a marked reduction in the PZMR (19 for the soaked porridge vs. 29 for the unsoaked porridge). Different methods of lactic fermentation can reduce the phytate content of maize porridge by 27 to 73%, depending on the fermentation treatment used.

Strategy 2 was based on encouraging the community to increase small livestock production and develop fish ponds to increase the intake of flesh foods such as meat; poultry; eggs; and dried, whole powdered fish with bones, and thus increase intakes of readily available sources of Zn, Ca, and Fe, as well as B-12, B-2, niacin, fat, and, in certain cases, preformed vitamin A. Consumption of indigenous foods rich in micronutrients, such as grubs/locusts and legumes, and the solar-drying of papaya and mangoes (sources of precursors of vitamin A) and fish were also encouraged.

Strategy 3 aimed to increase the dry matter content of porridges for feeding young children from 6 to 16% dry matter for weanlings and from 10 to 25% dry matter for young children. These trials were carried out with or without addition of amylase-rich germinated flour (ARF). ARF reduces the viscosity of porridges to a semi-liquid consistency suitable for feeding infants and young children without diluting with water, thus enhancing the energy and nutrient density of the porridges consumed.

Figure 2 shows the results of the dietary intervention study for weanlings.

Results confirmed that intakes of the complementary food (g/day), energy density of the complementary food, and intakes of Ca, Fe, available iron, Zn, and available Zn, all identified as 'problem nutrients' by the World Health Organization (WHO), were significantly higher, whereas the average PZMR of the diet was lower in the intervention compared to the control group. Nevertheless, these changes were still not enough to achieve the needs estimated by WHO due to poor access to nutrient-rich foods. Therefore, fortified complementary foods may still be needed in such subsistence settings.

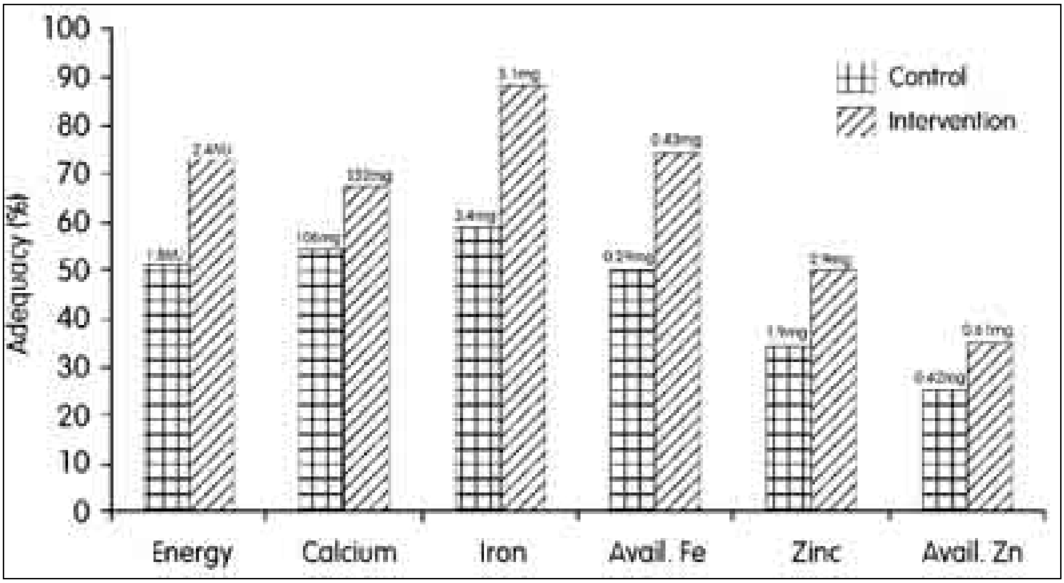

Figure 2: **Weanlings (12-23 months): Adequacy of energy, Ca, Fe, and Zn intakes from cereal foods**

Similar results were obtained in the dietary intervention for the children aged between 3 and 7 years old (Gibson et al. 2003). In this study, the quality of the diets in the intervention compared to the control group increased significantly, most notably as a result of an increase in intake of animal protein, fat, and hemi iron, and a significant reduction in the PZMR in the intervention compared to the control diets. These high-quality diets were accompanied by a significant reduction in the prevalence of inadequate intakes of several important nutrients, especially protein, vitamin B-12, Ca, and Zn (Table 2).

In addition, in this study, the intervention group had a higher haemoglobin concentration than the controls (107 vs. 102 g/l), and a significantly lower prevalence of anaemia (62 vs. 80%). No significant difference was found in hair Zn concentrations between the two groups, but there was a significant reduction in morbidity in the intervention compared to the control group. No effect on linear growth was found, but a higher lean body mass (via anthropometry) was also noted in the intervention compared to the control group.

Table 2: **Prevalence of inadequate intakes (as %) post-intervention: children 3 -7 years**

Nutrient	intervention	control
Protein	1	7*
Vitamin A	15	17
Vitamin B-12	23	41*
Calcium	34	54*
Iron	19	20
Zinc**	26	44*

** adjusted for 50% reduction in phytate; p<0.01

Other Strategies

The results suggest that alternative strategies must also be pursued. Strategies that are currently under investigation employ bio-fortification. These strategies may include the use of Zn, I, and Se fertilisers to increase the content of these micronutrients in grain, as practiced in Turkey for Zn and Finland for Se. Plant-breeding to produce efficient varieties with a higher content of grain micronutrients is another field of research carried out at the Consultative Group on International Agricultural Research (CGIAR) institutions. Breeding for a higher content of S-amino acids in cereal staples, which in turn act as promoters of Fe/Zn absorption, is another strategy. Genetic modification can be used to obtain the same results. A third R&D effort aims at reducing the effects of inhibitors through a decrease of phytic acid per se in the grain, or by increasing the content of heat-resistant phytase to break down phytic acid in grains during cooking.

The present research has documented that there are substantial differences between existing varieties in terms of efficiency of uptake and content of promoters and inhibitors. However, breeding should not stand alone. Even efficient varieties of wheat respond positively to fertilisation with Zn, both in terms of yield as well as content (Graham & Welch 1996).

Fortification of staple foods is also feasible in some countries. Sprinkles fortified with micronutrients which can be mixed with cooked cereal porridges used for feeding infants and young children have been developed and packaged in serving-sized packets. Nevertheless, they have some limitations. The micronutrient dose must be tailored to the infant's age, and the sachets are expensive for consumers of low socioeconomic status. Sustainability may also be a problem when donor agencies withdraw the supplies and the consumer is forced to pay the market price. UNICEF has also developed a 'foodlet': a micronutrient tablet to be mixed with cereal food. The foodlet is crushed into dispersible powder and may be suitable for emergency situations. Nutriset, France, has developed fat-based supplements in spreads fortified with micronutrients. They have low water content, and this reduces the potential for both micronutrient interactions and bacterial growth. Moreover, as a result of their high fat content, they have a high energy density and enhance absorption of fat soluble nutrients, addressing another common problem in the diets of population groups in developing countries. Other fortified products suitable for feeding infants and children include the broken-rice developed by the Institute of Nutrition, Mahidol University, Thailand, at a low cost.

Acknowledgements

Postgraduate students: PhD – Fiona Yeudall; Christine Hotz; Carolyn MacDonald; Nancy Drost; MSc: Lara Temple; Leah Perlas. Collaborators: Dr B Mtitimuni, University of Malawi; Professor T Cullinan, College of Medicine, University of Malawi, Emmanual International, Lewonde, Malawi

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Harvesting Health: Agricultural Linkages for Improving Human Nutrition

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Introduction

Agricultural technologies can be directed at improving the 'healthiness' of foods to meet human needs, but this requires the use of holistic perspectives of food systems to ensure sustainable impact. Global food systems are failing to provide adequate quantities of essential nutrients and other factors needed for good health, productivity, and well-being for vast numbers of people in many developing nations. Cropping systems promoted by the Green Revolution (GR) have resulted in reduced food-crop diversity and a decrease in the availability of micronutrients. Nutrition transitions are causing increased rates of chronic diseases (cancer, heart disease, stroke, diabetes, and osteoporosis) in many developing nations.

Holistic, sustainable improvements in the entire food system are required to solve the massive problem of malnutrition and increasing chronic disease rates in developed and developing countries. The question is how can agriculture contribute to sustainable solutions?

Global Food Systems' Problems

Agriculture's primary focus is on production alone, with little concern for nutritional or health-promoting qualities. Nutritionists tend to emphasise unsustainable medical approaches to solve problems of malnutrition by using supplements and fortification of food. Simplistic views are the norm – looking for 'the silver bullet' approaches to solutions. However, there are 50 essential nutrients for sustaining human life (Table 1).

All regions of the world have experienced a worsening of nutritional status during the last decade. High levels of chronic malnutrition exist in food-deficient and food-surplus regions alike. The primary focus has been on protein-energy malnutrition and not on micronutrients, although micronutrient malnutrition is severe. Global micronutrient deficiency is shown in Figure 1.

Over half of the human population is deficient in micronutrients, and a further 15% have inadequate energy supplies, most of these people being in resource-poor countries. The food systems of these people can be said to be dysfunctional since they fail to deliver all the nutrients needed for healthy lives. The problem can be viewed from a food-system perspective, and solutions developed for the food system to ensure that the changes we advocate are agriculturally, environmentally, economically, and socially sound and sustainable. There have been changes in the food production systems of the developing nations in the last 35 years which correspond to the increases in population (Figure 2). There is a drastic decrease in the pulse production compared to the cereal production, but the

Table 1: **The 50 essential nutrients known for sustaining human life** *					
Water & Energy (2)	**Protein (amino acids) (9)**	**Lipids/Fat (fatty acids) (2)**	**Macro-minerals (7)**	**Micro-elements (17)**	**Vitamins (13)**
Water Carbohydrates	histidine isoleucine leucine lysine methionine phenylalanine threonine tryptophan valine	linoleic acid linolenic acid	Na K Ca Mg S P Cl	Fe Zn Cu Mn I F B Se Mo Ni Cr V Si As Li Sn Co (in B_{12})	A D E K C (ascorbic acid) B_1 (thiamin) B_2 (riboflavin) B_3 (pantothenic acid) niacin B_6 (pyridoxal) folate biotin B_{12} (cobalamin)
Key: Macro-minerals (as per order in table) – Na = sodium; K = potassium; Ca = calcium; Mg = magnesium; S = sulphur; P = phosphorous; Cl = chlorine Micro-minerals (as per order in table) V = vanadium; Si = silicon; As = arsenic; Li = lithium; Sn = stannous; Co = cobalt; Fe = iron; Zn = zinc; Cu = copper; Mn = manganese; I = iodine; F = fluorine; B = boron; Se = selenium; Mo = molybdenum; Ni = nickel; Cr = chromium					

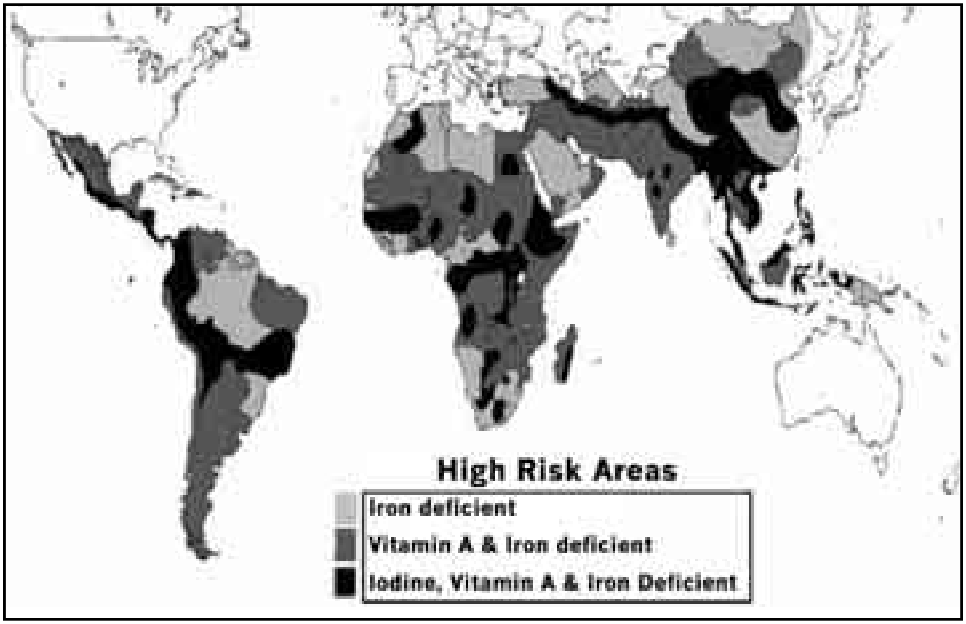

Figure 1: **Global micronutrient deficiencies**
(Source: Map from USAID)

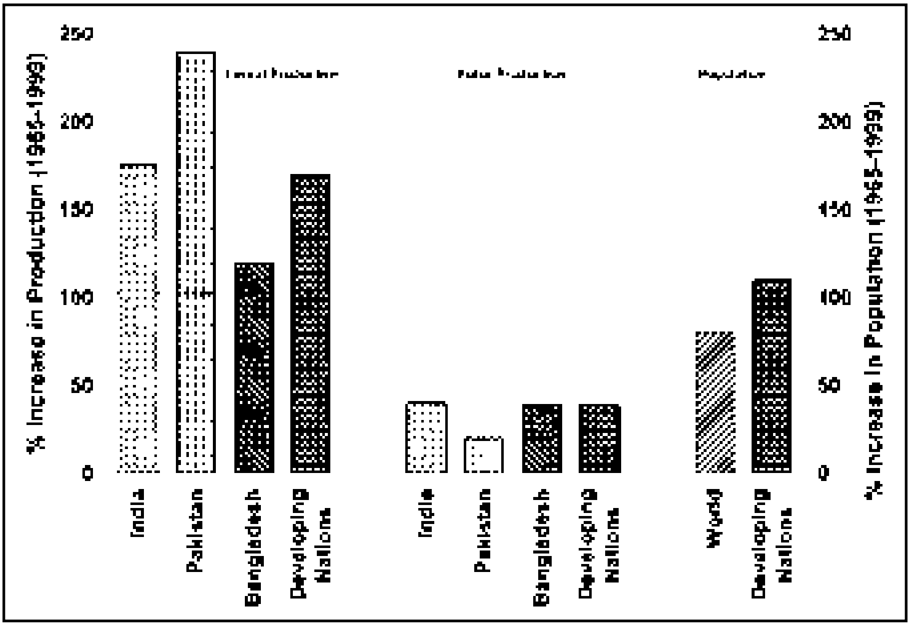

Figure 2: **Percentage changes in cereal and pulse production and in population between 1965 and 1999**

micronutrient content is higher in pulses than in cereals. However, the population increment demanded higher cereal production.

Food systems are generally identified by the main staple or staple food eaten. The rice-based food system in which rice is supplemented with a few vegetables, green leaves, and/or small fish feeds much of China and South and South East Asia. Other major food systems are based on rice-wheat, rice-pulses, maize, bean, maize-bean/cassava, and in Africa, sorghum/millet systems. Polished rice is very low in iron, low in zinc and calcium, and contains almost no pro-vitamin A carotenoids. Deficiencies of these nutrients are common in rice-eating populations. Adding these nutrients back into the food system agriculturally is difficult as the at-risk population in these areas is typically dense and much land must be devoted to rice cultivation to supply caloric needs. Moreover, rice is higher yielding and more tolerant of stresses such as typhoons, disease, pests, and drought than alternative staples that may be more nutritious. Milling of rice has an effect on the micronutrient concentration (Table 2).

Agricultural approaches to 'healthier' plant foods

There are several approaches to producing healthier plants; the simple methods are given below.

- Suitable field site selection and appropriate agronomic practices
- Macronutrient fertiliser applications: nitrogen, phosphorous, potassium, sulphur, calcium, magnesium; affects protein, fats, vitamins, anti-nutrients, etc.
- Micronutrient and trace element fertiliser application
  Zn, Se, Co, Ni, I, Mo, Li, Cl – effective in increasing amounts in plant seeds and grains
  Fe, Cu, Mn, B, Cr, V, Si – not effective in increasing seed or grain levels

Table 2: **Effects of polishing and milling on rice grain micronutrient concentration** [A]			
Micronutrients	**Brown rice**	**Polished rice**	**% Removed**
Iron (mg kg^{-1})	20	5	75
Copper (mg kg^{-1})	3.3	2.9	12
Manganese (mg kg^{-1})	17.6	10.9	62
Zinc (mg kg^{-1})	18	13	30
Biotin (ug kg^{-1})	120	50	58
Folic acid (ug kg^{-1})	200	160	20
Niacin (mg kg^{-1})	47	16	66
Pantothenic acid (mg kg^{-1})	20	10	50
Riboflavin (mg kg^{-1})	0.5	0.3	40
Thiamin (mg kg^{-1})	3.4	0.7	80
Vitamin B_6 (mg kg^{-1})	6.2	0.4	94
Vitamin E (IU kg^{-1}) [B]	20	10	50

A - Dry weight basis
B - IU = International unit

- Cropping systems' diversification: legume-cereal rotations – affects micronutrient content
- Use micronutrient-dense varieties of food crops
- Increase production of vegetables, fruits, and legumes
- Use indigenous plant foods and diversify food systems
- Genetically modify food crops to improve nutrient output of farming systems

Current supplementation and food fortification programmes are plagued with poor compliance and low long-term efficacy and are sustainable only with long-term external support. Further they do not reach many of the people who are most in need.

Supplying more iron and pro-vitamin A to the diet via the rice crop itself requires breeding of nutrient-dense varieties. Breeding can help to deliver more zinc too, but zinc in rice can also be raised effectively by adding zinc to the system as fertiliser, and this is often done in some areas as rice yield is also sensitive to soils low in zinc. Because of population pressure on the land, it is not easy to add more nutrients to the diet by growing more nutrient-dense secondary staples and viands unless the yield of rice can be increased by fertiliser use. Fertilisation is one method of enrichment of micronutrients in crops. Fertilisation with Zn does have an effect on increasing the yield of wheat grain and Zn concentration in the grain (Table 3).

Table 3: **Effects of zinc fertilisation on yield and zinc concentration of wheat grain**		
Zinc treatment (mg kg^{-1})	**Grain yield (g/plant)**	**Zinc concentration (mg kg^{-1})**
0.00	1.00	9.1
0.05	2.20	9.9
0.20	2.24	14
0.80	2.51	83
3.20	1.70	145

Genetic potential to improve the micronutrient efficiency of crops

Historically, plant breeders did not select for micronutrient efficient traits in food crops. Generally they used more fertile soils in selection processes, and this resulted in high-yielding varieties that require high inputs to maximise yield. Within wild relatives and land races of crop plants, a wide variation exists to improve micronutrient efficiencies in crop plants. The ability to screen genotypes for micronutrient efficiency traits is a limitation to breeders. The CGIAR-Harvest Plus programme has launched some projects on this line of breeding for micronutrient-dense staple plant foods. The following organisations are involved in breeding for micronutrients.

Consultative Group on International Agricultural Research (CGIAR) cooperators
International Food Policy Research Institute (IFPRI) – coordination of project
International Rice Research Institute (IRRI) – rice breeding
International Centre for Tropical Agriculture (CIAT) – beans and cassava breeding
International Maize and Wheat Improvement Centre (CIMMYT) – wheat and maize breeding
International Institute of Tropical Agriculture (IITA) – maize and sweet potato breeding International Potato Center (CIP) – sweet potato
International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) – phase 2 crops
International Centre for Agricultural Research in the Dry Areas (ICARDA) – phase 2 crops
University of Adelaide, Waite Campus
United States Department of Agriculture, Agricultural Research Service (USDA-ARS) – US Plant, Soil & Nutrition Laboratory, Cornell University, Ithaca, New York (NY); Children's Nutrition Research Center at Baylor College, Houston, Texas; Grand Forks Human Nutrition Research Center, Grand Forks, USA
Other international centres
Other universities in developed and developing countries
National agricultural research services
Non-government organisations

Issues in bio-fortifying staple food crops

There are several issues that could challenge the bio-fortification of crops. They include the magnitude of change possible and potential impact on health; effects on crop yields; farmer acceptance; environment vs. genetic effects on micronutrients; consumer acceptance and safety; bio-availability – anti-nutrients, promoters, diet/meal sustainability (soil-mining, farm inputs, environmental concerns); effects of processing and preparation on micronutrients; and cost and benefit considerations. But there are agronomic benefits from enrichment of micronutrients in seeds, as for example, zinc enrichment that could increase seed viability and seedling vigour and lead to denser stands (less soil erosion), lower seeding rates (lower cost to farmers), larger absorptive surface of roots (better efficiency of water and nutrient use), better resistance to disease, better plant survival, and increased plant and seed yield.

The importance of bio-availability

One important issue is that of bio-availability. Bioavailability is the amount of a nutrient in a food that can be absorbed from a typical diet and used in the body. Bioavailable amount of a micronutrient in a meal, not the total amount, is the critical factor for human health. Most staple plant foods (cereal grains and legume seeds) eaten alone contain very low levels of bioavailable Fe and Zn (e.g., about 5%) because of the anti-nutrients they contain (like phytate and polyphenols). Increasing the bioavailability of micronutrients from 5 to 30% would have the same effect as increasing their total amounts in staples 6-fold. The complexity of the factors that effect bioavailability are shown in Figure 3. The anti-nutrients in food plants affect the bioavailability of micronutrients. Examples of some antinutrients are given in Table 4.

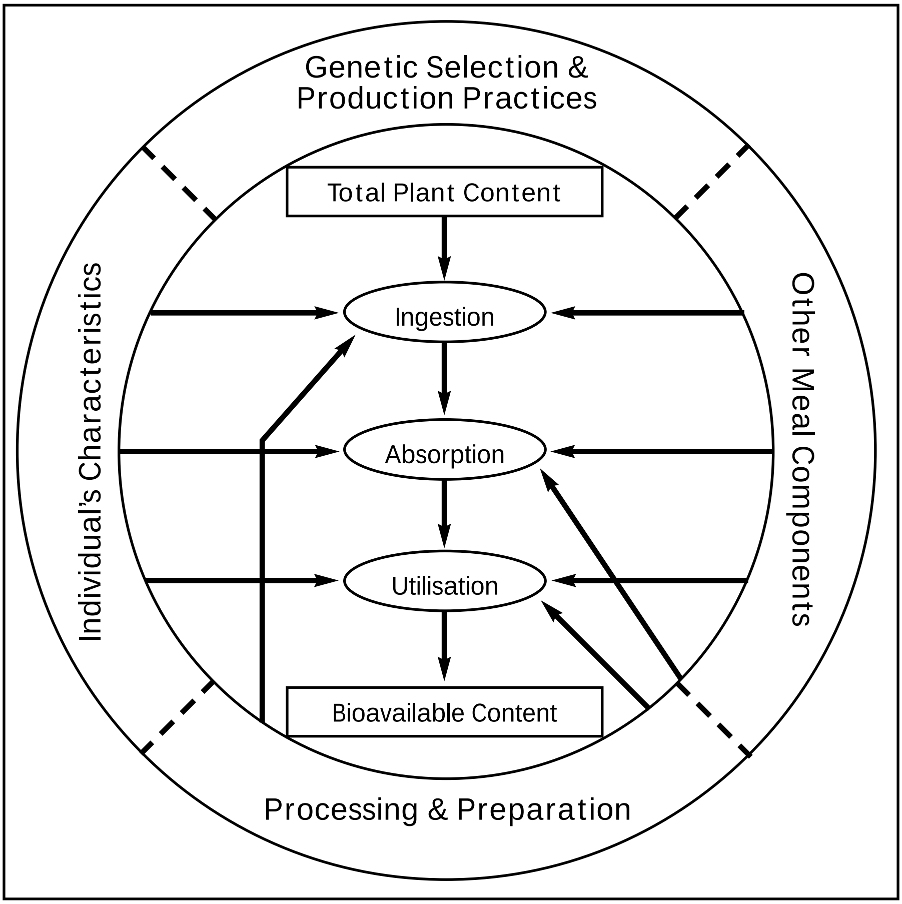

Figure 3: **Complexities of bioavailability**

Agronomic concerns in changing anti-nutrients in food crops

Anti-nutrients are major plant metabolites. They perform beneficial functions in plant growth and development (e.g., disease and insect resistance, nutrient stores). For example, phytate plays a role in inhibiting fungal infection of seeds and the production of aflatoxin B1, a potent carcinogen. Phytic acid is a major storage site of P and other mineral elements (e.g., Fe, Zn, Cu, Mn, K, Mg, Ca). High levels of anti-nutrients may affect seed vigour and viability. Crop production could be negatively affected when crops are sown in nutrient-poor soils.

Human health concerns in lowering phytic acid in food crops

If phytic acid is lowered in the food of humans it appears to decrease the risk of cancer (human cells tested: colon adenocarcinoma, erythoroleukaemia, mammary

Table 4: **Examples of antinutrients in plant food affecting bioavailability of micronutrients**	
Antinutrient	**Major dietary sources**
Phytic acid	Whole seeds and grain
Certain types of fibre (e.g., cellulose, hemicellulose, lignin, cutin, suberin)	Whole grain products (e.g., wheat, rice, maize, oats, barley
Tannins, polyphenolics	Tea, coffee, beans, sorghum
Hemaglutinins	Most legumes, wheat
Goitrogens	*Brassicas* and *Alliums*
Heavy metals (e.g., Cd, Hg, Pb)	Plant foods from crops grown on polluted soi ls (e.g., Cd in rice)
Key: Cd = cadmium; Hg = mercury; Pb = lead	

adenocarcinoma, and prostate adenocarcinoma); up-regulates tumour suppressor genes p53 and p21 (WAF1CIP1) in HT-29 human colon carcinoma cells; appears to be involved in signal transduction pathways, cell cycle regulatory genes, differentiation genes, oncogenes and tumor suppressor genes; inhibits the production of carcinogenic aflatoxins in cereal grain; possibly plays a role in preventing heart disease; lowers serum cholesterol and triglycerides; may prevent renal calculi (kidney stones); and greatly decreases heavy metal bioavailability (e.g., Cd). Dietary phytate can accumulate in the brain and in plasma (Grases et al. 2002). There are also interactions between micronutrients themselves that affect bioavailability (Figure 4).

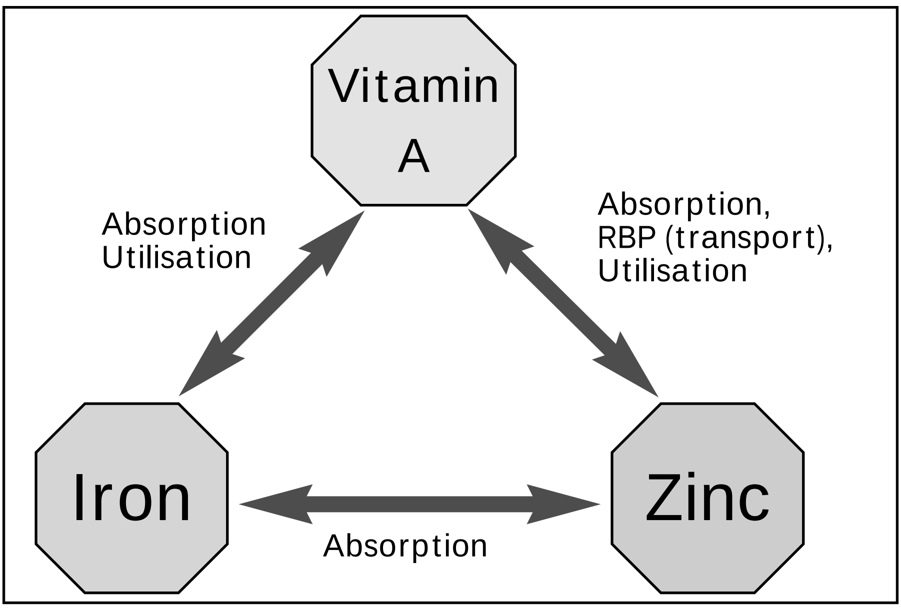

Figure 4 : **Interactions between Fe, Zn, and vitamin A, affecting bioavailability**

Agricultural agenda for better health

One major agricultural agenda for better human health includes making human health and well-being an explicit goal of agricultural systems in addition to productivity and environmental goals, re-diversifying cropping systems, and designing for maximum nutrient output. It is important to make more use of indigenous edible plant species that have a dense micronutrient content, in addition to small livestock and fish. Other strategies might be: use of agricultural practices (e.g., fertilisers) that increase the bioavailable micronutrient output of farming systems; breeding and selection for bioavailable micronutrient-dense staple food crops with micronutrient efficiencies; and genetically modifying plants to increase nutritional and health-promoting factors. Redefining sustainable agriculture to include adequate nutrient output for healthy and productive lives is a sine qua non for improving human health .

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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

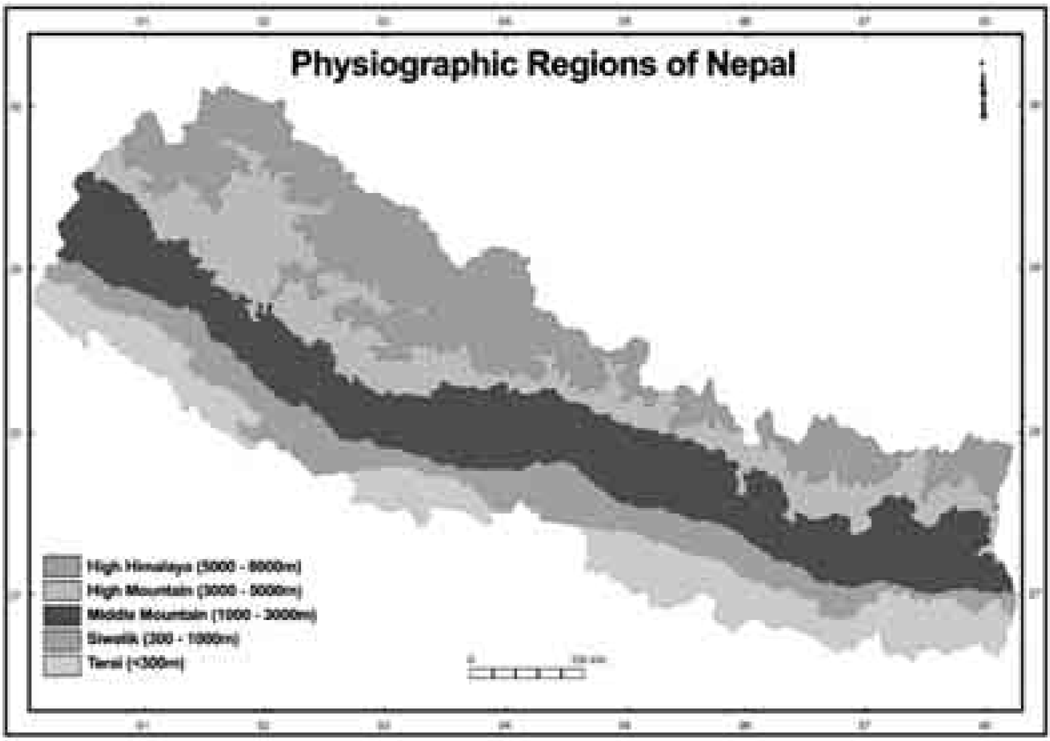

Figure 1: **Physiographic regions of Nepal** (Source: LRMP 1986)

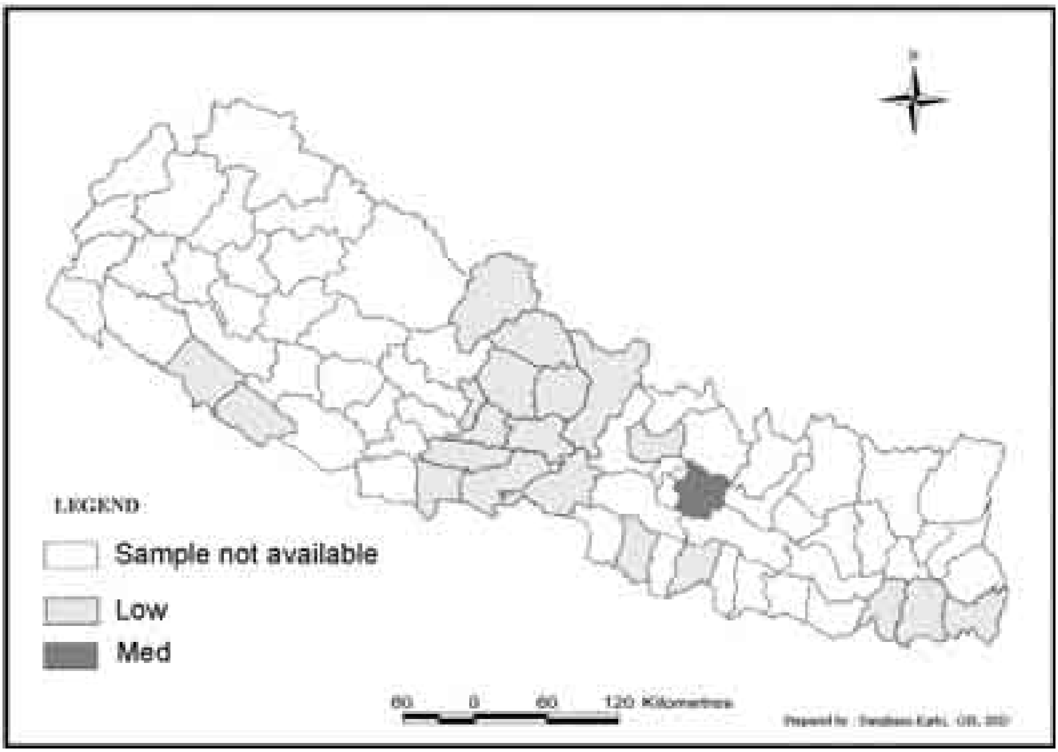

Figure 2: **Boron levels in soil in selected districts of Nepal**

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).

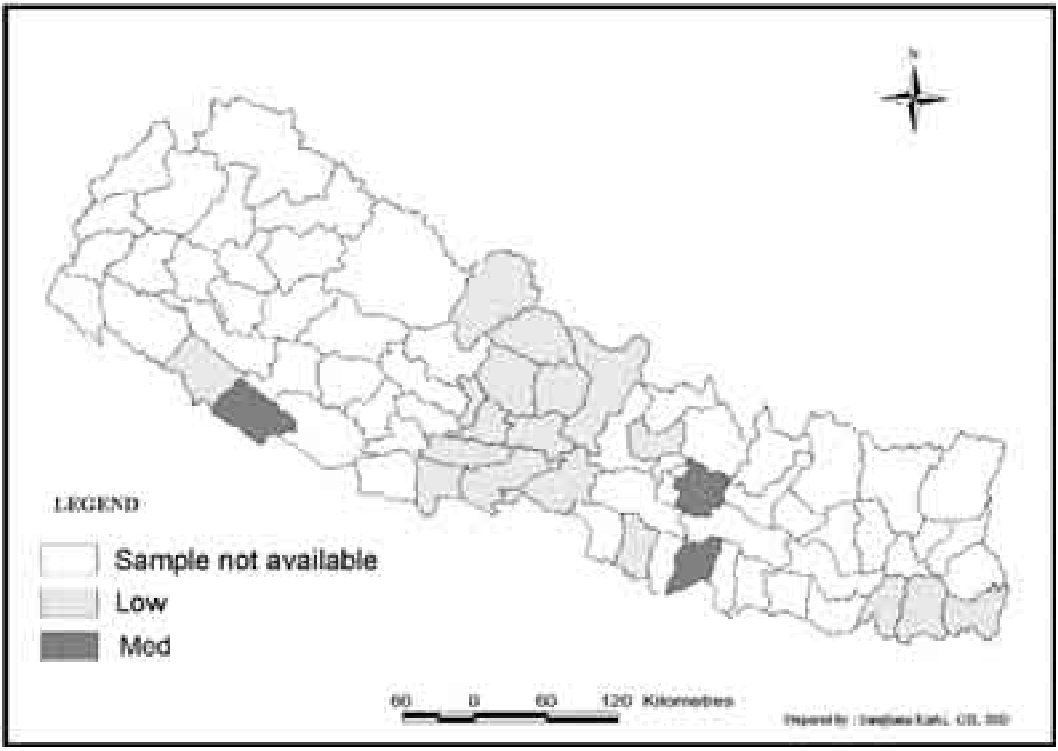

Figure 3: **Zinc levels in soil in selected districts of Nepal**

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).

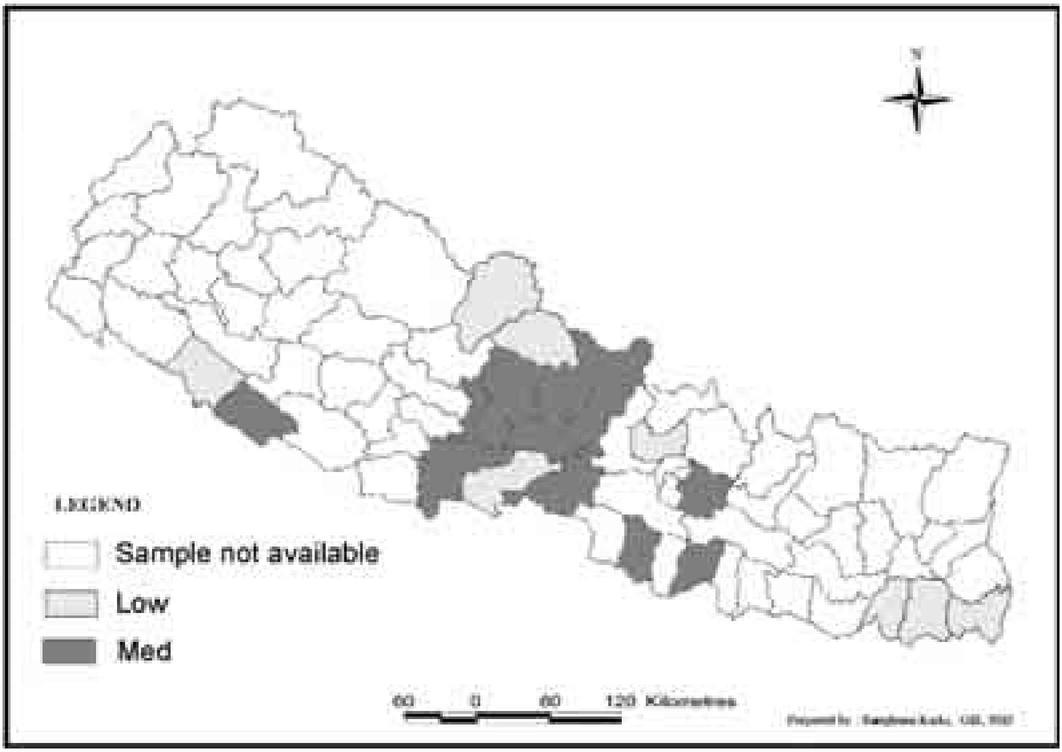

Figure 4: **Copper levels in soil in selected districts of Nepal**

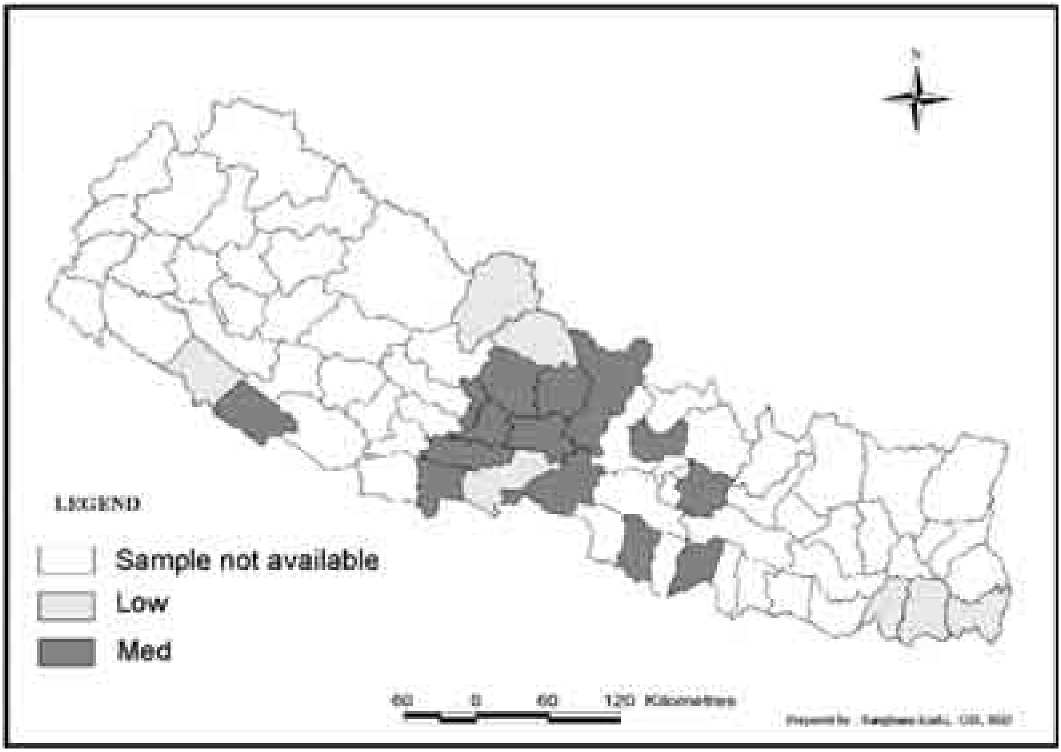

Figure 5: **Iron levels in soil in selected districts of Nepal**

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).

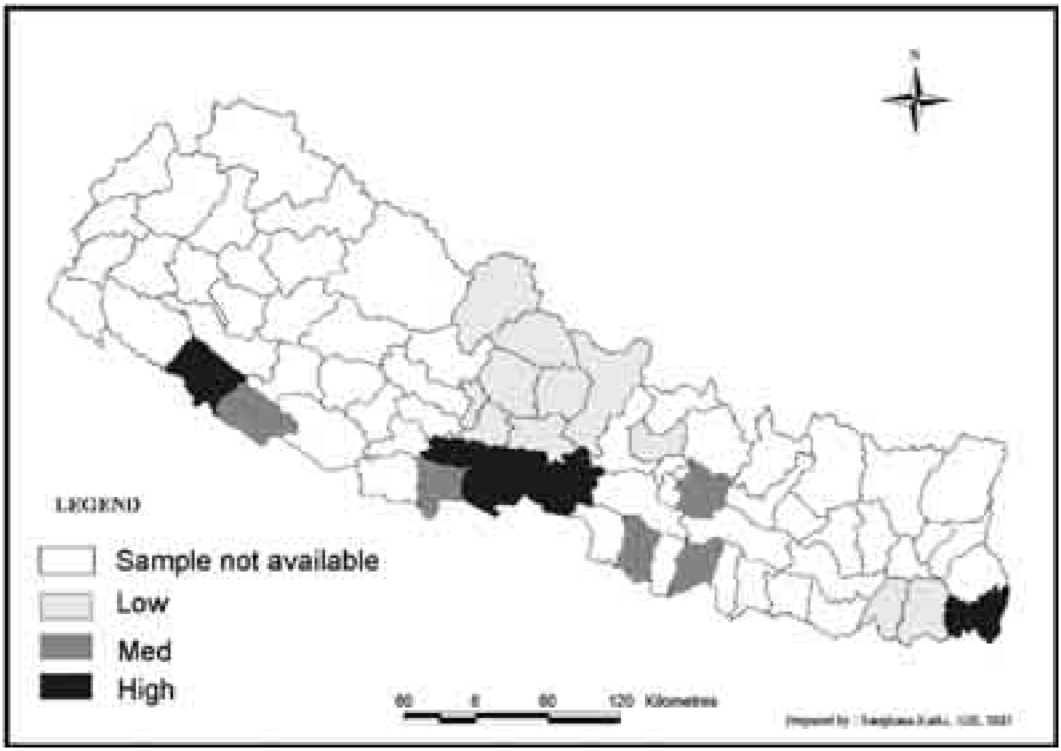

Figure 6: **Manganese levels in soil in selected districts of Nepal**

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).

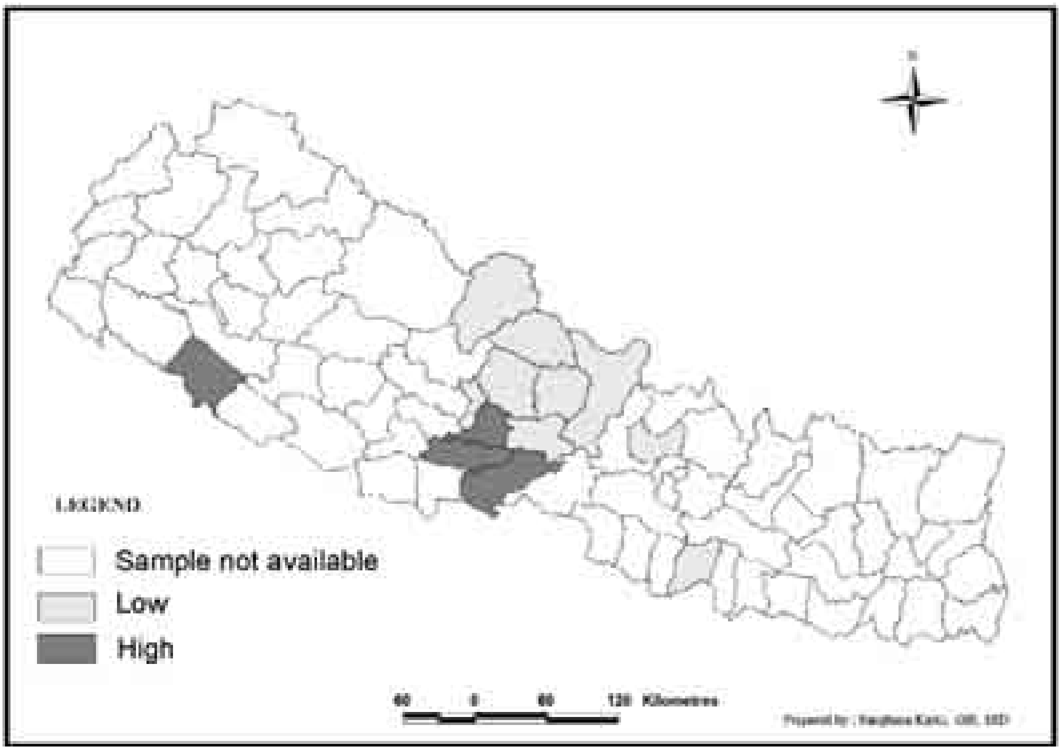

Figure 7: **Mo levels in soil in selected districts of Nepal**

Results of Soil Analysis and Interpretation of Findings on Micronutrients

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.

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

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 8^{th} 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.

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Session 1

Human Nutrition and Health

Zinc and Childhood Infections

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Background

Zinc deficiency is estimated to be widespread in developing countries, with the result that children are more vulnerable to illness and death from infectious diseases (Black 2003; Bahl 1998, 2002). The low intake of food rich in zinc, consumption of foods containing high phytate levels which impair the absorption of zinc, and frequent episodes of infection might be responsible for the high prevalence of zinc deficiency (Baqui 2003; Bhatnagar, 2004). Zinc is an essential mineral important for proper functioning of the immune system, growth and development, cell division, and differentiation of skin and epithelial cells in the body (Dutta 2000; Ellis 1987). Intervention through clinical trials directed at the correction of zinc deficiency has been demonstrated to lead to a substantial reduction in the severity and duration of acute diarrhoea and a potential for a lowered prevalence of pneumonia in children in developing countries.

Zinc in an acute diarrhoea trial in Bhaktapur, Nepal

Method

A total of 1792 cases of acute diarrhoea in Nepalese children were randomised into four study groups. The first three groups were blinded: one placebo group, one zinc syrup group, and one zinc syrup plus vitamin A group; placebo syrup and zinc syrup were given daily by field workers; vitamin A was given as a single dose at enrolment. The fourth group was open and also received zinc syrup daily, but administered by the child's care giver. The study period was 1997-2000.

Results

The prevalence of zinc deficiency in the study was 84% (plasma zinc <10 µmol/L). The relative hazards for termination of diarrhoea were 26% (95%, confidence interval [CI]: 8%, 46%), 21% (95%, CI: 4%, 38%), and 19% (95%, CI: 2%, 40%) higher in zinc, zinc-vitamin A, and zinc-caretaker groups, respectively, than in the placebo group. The relative risks of prolonged diarrhoea (duration >7 days) in these groups was 0.55 (0.37, 0.84). Thus zinc shortened the duration of acute diarrhoea by 19-26% and reduced the risk of prolonged diarrhoea by 43-47%. Five per cent and 5.1% of all syrup administrations were followed by regurgitation in the zinc and zinc-vitamin A groups, respectively, whereas this occurred after only 1.3% of placebo administrations.

A World Health Organization (WHO) meeting in 2001 (New Delhi) reviewed all the studies evaluating the effects of zinc on the clinical course of acute diarrhoea, including the study carried out in Bhaktapur, Nepal. The report concluded that "there is now enough evidence demonstrating the efficacy of zinc supplementation on the clinical course of acute diarrhoea" (Faruque et. al., 1999). The results of published studies by others on therapeutic effects of zinc on acute and prolonged diahorrea are summarised in Tables 1 and 2.

Table 1: Other studies evaluating the therapeutic effects of zinc supplementation in acute diarrhoea			
Author, year	**No. of subjects zinc/placebo**	**Dose of zinc (elemental)**	**Difference in mean duration of diarrhoea in days (95% CI)**
Sachdev, 1988	25/25	40 mg	-0.4 (-1.4, 0.6)
Faruque, 1999	341/340	14.2 or 40 mg	-1.0 (-1.8, -0.2)
Dutta, 2000	44/36	40 mg	-1.4 (-1.6, -1.1)
Sazawal, 2001	547/547	5 or 10 mg	0.1 (-0.2, 0.3)
			Relative Hazard (95% CI)
Hidayat, 1998	739/659	4.5 mg/kg	0.92 (0.83, 1.02)
Sazawal, 1997	456/481	20 mg	0.79 (0.69, 0.90)
Roy, 1997	57/54	20 mg	0.85 (0.57, 1.28)
Bhatnagar, 2004	132/134	15 or 30 mg	0.77 (0.59, 0.99)
Bahl, 2002	404/401	15 or 30 mg	0.89 (0.80, 0.99)
Strand, 2002	442/449	15 or 30 mg	0.79 (0.68, 0.93)

Table 2: Other studies evaluating the therapeutic effects of zinc supplementation on episodes of prolonged diarrhoea			
Author, year	**No. of subjects zinc/placebo**	**Dose of zinc (elemental)**	**Odds ratio (95% CI)**
Hidayat, 1998	739/659	4.5 mg/kg	0.72 (0.48, 1.07)
Sazawal, 1997	456/481	20 mg	0.85 (0.60, 1.19)
Roy, 1997	57/54	20 mg	0.77 (0.33, 1.79)
Bahl, 2002	404/401	15 or 30 mg	0.61 (0.33, 1.12)
Strand, 2002	442/449	15 or 30 mg	0.57 (0.38, 0.86)

Zinc supplementation as an adjuvant therapy for the treatment of childhood pneumonia

Pneumonia is a major cause of death among children under five years of age in developing countries. Treatment of pneumonia still remains a major challenge in Nepal as elsewhere. A pooled analysis of the results of routine zinc supplementation in the prevention of pneumonia showed a reduction of 41% (95% CI: 17, 69%) (Sazawal, 1997; Strand, 2002). However, the data on zinc as an adjuvant therapy for the treatment of pneumonia are limited. Two small studies that have been published showed no substantial effect of zinc on the prevention of pneumonia. From November 2003, we have been undertaking a clinical trial in Bhaktapur, Nepal, to measure the efficacy of zinc as an adjuvant therapy along with antibiotics on childhood pneumonia.

Effect of zinc supplementation on child mortality

As studies have shown promising results of zinc supplementation for prevention of childhood pneumonia and diarrhoea, the two most common causes of death among children in developing countries, scientists are now evaluating its effect on overall reduction of child mortality. A clinical trial of zinc supplementation among infants born small for gestational age found a substantial reduction in mortality (Hidayat et al. 1998). Currently, large clinical trials in India, Nepal, and Zanzibar are underway to evaluate the effect of zinc on child mortality and hospitalisation for infectious diseases.

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Growing orange-fleshed sweet potatoes to combat Vitamin A deficiency in Eastern India: experience of the International Potato Center (CIP)

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Abstract

Vitamin A deficiency is a serious problem among children in the eastern Indian region. The deficiency could be prevented in children by a regular daily intake of about 100g of orange-fleshed sweet potato (OFSP). OFSP is a ready and cheap source of high counts of beta-carotene, which is largely responsible for the orange colour of the flesh. OFSP is gaining importance as a dietary food product in eastern India, especially in the states of Orissa and eastern Uttar Pradesh (UP); and this popularity is promoted with the active participation of different international and national organisations. The International Potato Center (CIP), through its Regional Office for South, West, and Central Asia (SWCA), is playing a pivotal role in promoting OFSP in eastern India, especially in the state of Orissa. Organisations such as UNDP-Orissa, Western Orissa Rural Livelihood Project (WORLP), Indo Swiss Natural Resource Management Programme (ISNRMP) Orissa, the Central Tuber Crops Research Regional Station in Bubaneshwar, and the Participatory Rural Developmental Foundation (PRDF) in Gorakhpur, eastern Uttar Pradesh have partnered CIP to promote OFSP for food and nutritional security in their respective operating areas. CIP and its partners are evaluating over twenty germplasms in farmers' fields in different districts. The OFSP germplasms that help in food and nutritional security and which are successful in yield and dry matter in Orissa and eastern UP are IB-97-2/5, IB-97-6/15, CIP-SWA-2, and CIP-SWA-1, all of which are red skinned. White and yellow fleshed germplasms, which mainly serve food security and are successful in high yield and dry matter in drought prone areas of western Orissa are CIP-SWA-7, IB-91-26, and IB-97-12/24. The promotion of OFSP is being taken up on a large scale by different organisations in partnership with CIP to reduce vitamin A deficiency amongst the rural population, mostly the children, of eastern India.

Introduction

Dietary vitamin A deficiency is the world's most common cause of childhood blindness. The World Health Organization (WHO) estimated that as many as 228 million children are affected sub-clinically at a severe to moderate level by vitamin A deficiency (VAD), placing their health at risk. About three million of these children have some form of eye disease related to VAD, ranging from night blindness to irreversible partial or total blindness. Every year, at least 500,000 children become partially or totally blind as a result of VAD. Nearly half of the world's micronutrient deficient people can be found in India; vitamin A deficiency (VAD) is thought to cause an estimated 30,000 to 40,000 children to go blind each year in the country. VAD rates vary greatly among the states from 2.2% in Andhra Pradesh to 9.0% in Bihar; the overall prevalence of VAD is a significant public health problem.

In India, sweet potato is generally used as a food product and as a food base. In the states of Orissa, Uttar Pradesh (UP), and Bihar, sweet potato is used for consumption and for commercial use. The three states also have an acute VAD problem. The use of orange fleshed sweet potato (OFSP) in the three states could provide a solution to vitamin A deficiency since the vegetable is a ready and cheap source of beta-carotene, which is largely responsible for the orange colour of the flesh (Simonne et al. 1993; Takahata et al. 1993). White and yellow fleshed sweet potatoes contain only very low or minute quantitities of beta-carotene. OFSPs contain 6-8 mg of beta-carotene per 100g, which is sufficient for the recommended vitamin A requirement. Thus regular intake of 100g per day of orange-fleshed sweet potato roots would provide the recommended daily amount of vitamin A for children and should be sufficient to protect them from blindness. OFSPs could be taken on a sustainable basis in those states where sweet potato is generally consumed for food and health. OFSPs could be used in Orissa, eastern UP, and Bihar to combat VAD. At present, promotion of OFSPs is done in a big way in these states. International, government, and non-government organisations are interested in introducing larger quantities of OFSPs in the VAD areas. Seed multiplication and distribution of OFSP to poor communities is the prime task for all these organisations. Out of the many readily available food sources, sweet potato is an important food crop that could meet the needs of farmers for both food and nutritional security in Orissa, UP, and Bihar.

Sweet potato is grown on an area of 6.91 million hectares in Asia, with a total production of 119 million metric tons (t) and productivity of 17.26 t/ha. Asia as a whole accounts for 78% of the world's sweet potatoes in terms of area cultivated and 92% of the world production, but nearly 85% of this is contributed by China which is the largest producer and consumer of sweet potatoes in the world with 68% of the area cultivated and 86% of the production. In contrast Africa, thought by many to be the home of sweet potato, has less than 18% of the area and 5.5% of the world production. (FAO 1998)

The total sweet potato production in South Asia is about 1.6 million tonnes on 0.2 million hectares. India accounts for 68% of the total production followed by 27% in Bangladesh and about 5% in Sri Lanka. In India, sweet potato is cultivated mainly in the states of Orissa, Bihar, and Uttar Pradesh. It is the most important root crop in Bihar and Orissa, covering 17,900 and 47,900 ha of land with a production of 170,700t and 364,900t, respectively. It is also an important root crop in Uttar Pradesh, covering 30,600 ha of land with a production of 285,900t (Table 1). Sweet potato is usually raised as a rainfed crop from June-September ('kharif' crop); supplementary irrigation is provided from October-January for winter planting ('rabi' crop)

CIP activities with partner organisations

The International Potato Center (CIP) commenced collaborative work and popularisation of OFSPs in India from 2001 with organisations like the Central Tuber Crops' Research Regional Station in Bhubaneswar, UNDP Orissa, Western Orissa Rural Livelihood Project (WORLP), Indo Swiss Natural Resource Management Programme (ISNRMP) Orissa, and the Participatory Rural Developmental Foundation (PRDF) in Gorakhpur eastern Uttar Pradesh. The collaborating organisations have partnered CIP to promote orange fleshed sweet potatoes for food and nutritional security in their respective operating areas in eastern India. Over the past two years, approximately twenty germplasms have been evaluated in different parts of the country. Sweet potato germplasms were evaluated in participatory farmers' field trials. Most of the germplasms preferred by the farmers were those of orange-fleshed sweet potatoes.

Table 1: **Area, production and productivity* of sweet potato in leading states in India**

State	Area ('000 ha)	Production ('000t)	Productivity (t ha^{-1})
Orissa	43.9	361.2	8.2
Bihar	9.9	135.2	13.7
Uttar Pradesh	25.6	302.1	11.8
Assam	8.9	31.0	3.5
Karnataka	3.1	23.3	7.5
Kerala	1.1	11.9	10.8
Tamil Nadu	1.9	32.2	16.9
India total	114	1007	8.8

* Source: Indian Horticultural Database (2001)

Materials and Methods

Sweet potato germplasm was introduced in batches to all areas selected after initial evaluation at the CIP research farm. The places chosen for participatory field evaluation were in Ganjam and Gajapathi districts (monitored by ISNRMP), Nuapada and Kalahandi districts (UNDP), Bolangir and Nuapada districts (WORLP), and certain districts of eastern Uttar Pradesh (PRDF). Details of the number of germplasms monitored by each organisation are given in the sections below. The trials consisted of three replications of 30 plants each.

Evaluation trials

Multi-locational trials were carried out in all areas over two seasons on farmers' fields. In all, from 10 to 14 germplasms were evaluated under the supervision of different organisations in different places. The highest marketable root yields from the trials were recorded in all areas. Five to six germplasms were short-listed on the basis of marketable root yield and taste as identified in the results of the multi-locational trials.

Results and Discussion

Indo Swiss Natural Resource Management Programme (ISNRMP), Orissa

Collaborative work to promote sweet potatoes, especially orange-fleshed sweet potatoes, started in 2002 in the Ganjam and Gajapati districts of Orissa. Large numbers of children in the tribal areas of both districts suffer from malnutrition. CIP and ISNRMP together identified the places where orange-fleshed sweet potatoes were to be promoted. After initial evaluation at the CIP research farm, the farmers were given high-yielding germplasms to be tried and tested in their fields with the support of local NGOs. Out of ten germplasms (Table 2), three orange-fleshed germplasms with high contents of dry matter were particularly successful: IB-97-6/15, CIP-SWA–1, and CIP-SWA-2; as were two yellow/white varieties: IB-91-26 and CIP-SWA-7. Orange-fleshed sweet potatoes were distributed and sold at market after the harvest. Farmers were convinced of the germplasms being able to meet their needs from the perspectives of food and nutritional security.

UNDP Orissa, Western Orissa Rural Livelihood Project (WORLP)

Both UNDP and WORLP were working in the western part of Orissa, which is drought prone; the farmers' field trials were held in three districts, namely, Bolangir, Nuapada, and Kalahandi. Farmers' enthusiasm to plant the newly-introduced, orange-fleshed sweet

Table 2: Germplasms evaluated in the Ganjam and Gajapathi districts by ISNRMP with marketable yield and taste			
Name	**Flesh colour**	**Marketable yield t haÎ¹**	**Taste**
CIP-SWA-1	Orange	23.6	Very Good
CIP-SWA-2	Orange	21.2	Excellent
CIP-SWA-3	White	18.2	Good
CIP-SWA-4	Yellow	16.6	Good
CIP-SWA-7	Yellow	24.2	Very Good
IB-97-13/11	Yellow	17.6	Good
IB-97-6/15	Orange	22.8	Very Good
IB-97-2/5	Orange	19.8	Good
IB-91-26	White	23.1	Very Good
IB-96-7/25/16/26	yellow	15.2	Good
Mean		20.23	
CV (coefficient of var iation)		15.85	

potatoes in their fields has been increasing since 2003. Of the twelve germplasms tested (Table 3), four orange-fleshed varieties demonstrated better marketable root yields, taste, and a high-level of acceptability among farmers: CIP-SWA-1, CIP-SWA-2, IB-97-6/15, and IB-97-2/5; as did three white-fleshed varieties: CIP-SWA-7, IB-91-26, and IB-97-12/24. The promotion of orange-fleshed sweet potatoes is being taken up on a large scale by the two organisations in collaboration with CIP. Vitamin A deficiency is prevalent in Western Orissa and farmers came forward to receive high carotene vines to plant in their fields. Some women farmers took the vine cuttings to plant in their backyards to be used to feed their children.

Participatory Rural Development Foundation (PRDF)

Sweet potato is widely cultivated in the eastern part of Uttar Pradesh, and through PRDF's collaboration with CIP the opportunity was given to the farmers in this region to introduce orange-fleshed sweet-potato germplasms for trials on farmers' fields. Fourteen germplasms were introduced (Table 4), of which six (four orange-fleshed, two yellow-fleshed) have thrived well as indicated by marketable root yield and taste: CIP 440074, IB-97-12/7, CIP-SWA-2, CIP-SWA-1, IB-90-12-29 and IB-97-7/2. Uttar Pradesh is one of the states in India where acute vitamin A deficiency prevails.

Conclusions

The partner organisations of CIP spearheaded the promotion of orange-fleshed sweet potatoes in Orissa and in eastern UP especially to help children suffering from malnutrition and vitamin A deficiency. The germplasms of orange-fleshed sweet potato were found to be the best in terms of both food and nutritional security. The multi-locational trials followed after selection, and some farmers expressed an interest in growing the plants commercially on a large scale.

Table 3: Germplasms evaluated in the Bolangir, Nuapada and Kalahandi districts by UNDP and WORLP, with marketable yield and taste			
Name	**Flesh colour**	**Marketable yield t haÎ ¹**	**Taste**
CIP-SWA-1	Orange	21.2	Very Good
CIP-SWA-2	Orange	23.6	Excellent
CIP-SWA-3	White	14.7	Average
CIPS-WA-4	Yellow	12.5	Average
CIPS-WA-7	Yellow	23.1	Very Good
IB-97-13/11	Yellow	15.2	Good
IB-97-6/15	Orange	24.3	Very Good
IB-97-2/5	Orange	20.7	Good
IB-91-26	White	24.1	Very good
IB-96-7/25/16/26	Yellow	13.7	Good
IB-97-12/24	White	20.8	Good
IB-97-12/7	Orange	18.8	Good
Mean		19.39	
CV (co-efficient of variation)		22.23	

Table 4: Germplasms evaluated in Gorakhpur and adjoining districts of Eastern UP by PRDF, with marketable yield and taste			
Name	**Flesh colour**	**Marketable yield t haÎ ¹**	**Taste**
CIP-SWA-2	Orange	24.2	Very Good
CIP-440074	Orange	20.1	Very Good
IB-97-12/7	Orange	16.4	Very Good
IB-97-12/24	White	19.6	Average
IB-91-26	White	22.4	Good
IB-90-10-20	Orange	18.0	Very Good
IB-97-7/2	Yellow	17.5	Very Good
IB-97-6/7	Yellow	12.2	Good
CIP-SWA-1	Orange	22.9	Excellent
IB-97-2/5	Orange	14.9	Good
IB-97-6/15	Orange	14.3	Very Good
IB-90-12-29	Yellow	20.8	Very Good
IB-90-5/5	Orange	11.1	Average
IB-97-5/7	White	16.3	Good
Mean		17.90	
CV (coefficient of variation)		22.27	

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Supplementation of Selenium: A Strategy to Increase Fertility in Goats

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Abstract

This study was carried out in four villages in Dhanusha district to test the possibility of increasing the fertility rate in goats by administering 500 µg of vitamin E containing 200 ppm of selenium. The results so far indicate that this might be a suitable technique for increasing fertility in does. The usefulness of selenium and the farmers' evaluation are described.

Introduction

Goats are an important component in the livelihoods of resource-poor livestock keepers in Nepal, since they serve as ready cash to meet household needs, especially in times of crisis. There are number of constraints in the production performance of goats. One such constraint is the problem of infertility, longer breeding intervals, and late puberty. Taking these physiological constraints into consideration, supplementation of selenium along with vitamin E (E Care Se, Vet Care) was considered. Selenium is an essential mineral which works closely together with vitamin E. Organic, and inorganic forms of selenium may have different properties. Organic forms include selenomethionine, selenocysteine, amino acid chelates, yeast, and kept-bound selenium. Inorganic forms include sodium selenite and sodium selenate. Selenium is naturally found in vegetables like garlic, mushrooms, and asparagus. Natural selenium levels in the soil are highly variable throughout the world. A daily intake of 50 to 300 µg of selenium is 'safe and adequate' (Chakrabarti 1999).

Therapeutic doses often range from 200 to 500 µg daily. Selenium is absorbed fairly easily in the upper portion of the gastro-intestinal tract (Blood and Radostits 1989). Selenium and other antioxidants play an essential role in the formation of certain proteins found in sperm, and deficiencies of selenium can have a detrimental effect on sperm mortality. Does who have miscarried tend to have lower levels of selenium than does who carry a pregnancy to full-term. Whether selenium supplementation helps prevent miscarriage, however, is not clear (Van Vleet 1975). Supplementation of selenium along with vitamin E in does was studied for overall improvement in flock productivity, which could help to improve fertility, to reduce breeding intervals, and to attain early puberty. The study was carried out as one component of a larger project entitled 'Strategies to increase the contribution goats make to the livelihoods of resource-poor livestock keepers in Nepal'.

Materials and Methods

Four villages were selected in the Dhanusha district of Nepal, namely Jamunibas, Baluwa Biman, Birendra Bazaar, and Kemalipur. Within each village, 20 households were selected representing poor (average monthly income <US $27) and less poor households (average

monthly income >US $27). In each village, the flocks belonging to seven of the households were randomly allocated the selenium plus vitamin E supplementation, while the flocks of other households were kept as control groups (fed maize only). The does in the households in which khasi (castrated male goats) were given maize were also treated as a control group. These control does were not given maize or selenium.

All the goats from the four villages were administered an anthelmintic (Fenbendazole) in July and September and vaccinated against 'pestes des petits numinantes' (PPR). Goats and households were monitored at fortnightly internals for ten months from May 2003 to February 2004.

Out of 80 households, 28 households were selected for selenium treatment, seven from each of the villages. The does from other treatment groups (does without Se, and without either maize or Se) were taken as the control group for this treatment. A dose rate of 500 µg of vitamin E containing 200 ppm of selenium was administered approximately two weeks prior to parturition and six weeks after delivery. Altogether, selenium was administered for eight weeks to the does.

Results

The structure of the flock is summarised in Table 1 and the flock dynamics in an average farm household in Table 2. Altogether 66 does were administered with selenium for eight weeks. The performance of the does that received selenium is summarised in Table 3. All the does that received selenium had kids once or twice in the study period of 10 months. Selenium deficiency causes reproductive failure and infertility in animals (Ammerman and Miller 1975). Figure 1 shows the comparison of the three treatment groups. The results clearly show that, in the particular area where selenium is deficient in soil, giving does selenium along with vitamin E greatly improved fertility. It is thought that in the does treated with selenium plus vitamin E, the treatment acted as an antioxidant and protected tissues from pre-oxidation, and increased the body's immune mechanism, thus creating a suitable physiological environment for fertile ovas and leading to conception. In the does treated with 100 gm maize per day for six weeks, only 90% of the does gave birth, and in the control group only 60% gave birth. From the results, it can be seen clearly that the fertility of the does administered with

Table 1: **Mean flock structure in a household**

Adult males	0.9
Adult females	2.8
Male kids	1.4
Female kids	1.0

Table 2: **Flock dynamics in the household**

Entries	
* Births	3.0
* Purchases	0.4
* Other	0.6
Exits	
* Death	0.9
* Sales & slaughter	2.1
* Other	0.9

Table 3: **Doe performance**

	Treatment		
	DC	DM	DS
Kid LWG (kg)	1.08	1.52	1.15
Doe LWG (kg)	1.29	2.15	1.35
Kiddings/Doe	0.6	0.9	1.0

DC = control; DM = does given maize; DS = does given selenium; LWG = live weight gain

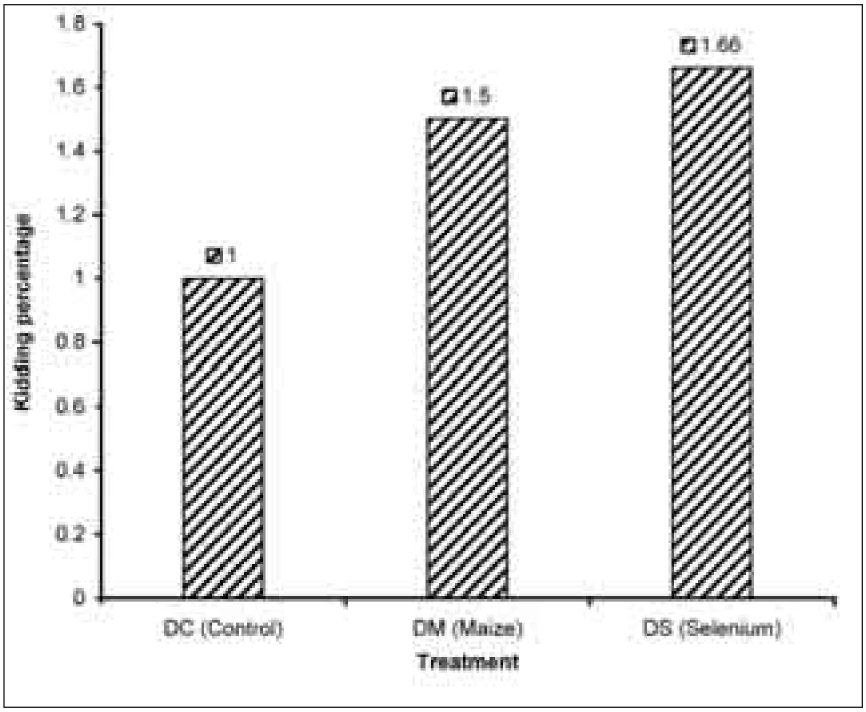

Figure 1: **Effect of selenium and vitamin E supplementation on fertility**

selenium improved, hence, the changes inducing reproductive failure are minimised. It seems that administration of selenium before and after parturition is beneficial for goat fertility.

At the end of the treatment, the farmers' evaluation was recorded. The overall observations made by the farmers on selenium treatment were as follows.

- Very effective in increasing fertility rate, reducing birth intervals and kid mortality
- Improved general body condition and live weight gains
- Health of animals improved as less disease occurred during the study period compared to previous years.
- Does sold for a good price because of their glossy coats and healthy appearance.

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Session 2

Mapping and Soil Micronutrient Status

Mapping Spatial Zinc Distribution in Rupandehi District, Nepal

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Abstract

Soil zinc is an important micronutrient for agriculture and for human health. The zinc content in Nepalese soils is lower than the optimum. Soil is the primary source of zinc for plants, animals, and human nutrition. This study attempted to investigate the spatial pattern of soil zinc distribution in the soils of Rupandehi District of the Terai plains of Nepal. A total of two hundred and ninety-seven samples were collected at random intersections of a 1 by 1 km square grid. The data indicated a strong variability in soil zinc content within the study area. The predicted (kriged) map showed the zinc content in the soil of the study area to be within the low to medium range (0.013-1.402 mg kg^{-1}). The study did not identify any association of available zinc in the soil with other soil factors such as pH, organic matter, and available phosphorous. This study should contribute to better understanding of the nature and extent of zinc deficiency and to the improvement and sustainability of agricultural production.

Introduction

Soils are the primary source of zinc for plants, animals, and humans. Total zinc content in the soil generally ranges between 10 and 300 ppm (Silllanpää 1982). Zinc availability, however, is greatly affected by a number of factors: mainly soil pH, organic matter, available P, and soil textural conditions. Soils with acidic conditions are less affected by zinc deficiency problems, as zinc is more available in such soils (Dvarák et al. 2003). However, zinc disorders are common in calcareous soils (Katyal 1972). More available phosphorous in the soil or a substantial level of phosphatic fertiliser application also induces soil zinc deficiency (Olsen 1972). Soil organic matter content also inactivates soil zinc and makes it deficient in rice plants (IRRI 1972; Yoshida et al. 1973). Extractable soil zinc decreases as the organic carbon content starts to increase over 0.4% (Silllanpää 1982). Zinc deficiency is also associated with soil moisture and is more common in wetland conditions than in dryland soils (Castro 1977; Randhawa et al. 1978). Zinc is more readily available in upland soils than in submerged soils. Unlike other micronutrients, the concentration of zinc decreases as the soil becomes submerged. In soils with a pH greater than 7.0 in wetland conditions, deficiency of zinc becomes common.

Zinc deficiency is the most widespread micro-nutritional disorder in food crops. Zinc problems are common in areas where lowland rice is grown, especially in soils that are near neutral to alkaline (Jaishy et al. 1989), causing considerable decrease in yield. The Terai is a major rice growing area in Nepal, and rice is grown on 32% of the total Terai area of 1,099,277 ha (MOAC 2002).

As zinc in soil and its availability are related to many other factors and other nutrients, its management requires an understanding of how other nutrients vary across the land (White et al. 1997). This study attempted to establish the spatial distribution pattern of soil nutrients and other parameters of some importance for zinc availability in the soil. Organic matter, soil pH, available phosphorous, and soil texture were studied and estimated for their spatial distribution pattern in the study area. These soil properties were also evaluated in terms of their relationship to zinc. The output of the research was intended to contribute to the improvement and sustainability of agricultural and livestock production, to improvement in the quality of the human diet, and to a better understanding of the nature and extent of plant, human, and animal zinc deficiencies.

Materials and Methods

The study area was in Rupandehi district in the Western Development Region of Nepal, which lies between 83°10' and 83°30' E and 27°20' to 27° 45' N, covering an area of approximately 133,596 ha. It has a subtropical climate with a mean annual rainfall of 1600 mm with a uni-modular structure. The mean monthly temperature varies from 8.5°C in January to 36°C in May. The altitude increases from south to north from approximately 100 to 200 masl (Harrington et al. 1989).

Soil samples collected during soil surveys in the past (Dec/Jan 1999) were used in the study. Samples were collected at random intersections of 1 by 1 km from a depth of 0-30 cm and analysed at the laboratory of the Soil Science Division, Khumaltar. Soil properties were determined using standard methods: organic matter by Walkley and Black (1934); available phosphorous by modified Olsen (1972) (USDA); zinc extracted following methods explained by Lindsay and Norvell (1978); pH by pH-meter; and texture (clay, sand, and silt %) by the hydrometric method.

Statistical analysis

Descriptive statistics were computed for sample mean, median, minimum, maximum, standard deviation, and coefficient of variation (CV). Multivariate regression analysis was performed to identify the most influential parameters that affect the available zinc content. For mapping the spatial variability of the soil properties, isotropic semi-variograms were calculated using GS+ Version 3.11.20 (Gamma Design Software 2000). The extreme outliers were excluded from the subsequent analysis and estimation. The best-fitted model with the maximum r^2 value was used in kriging for the estimation of soil properties at unknown locations (Yanai et. al. 2002). The punctual kriging interpolation method was carried out on Surfer Version 7.0 (Golden Software Inc. 1999) using the geostatistical model parameters. The spatial structure of the samples on the sampling scale was determined by the Q value as described by Yanai et al. (2002): $Q = (S-N)/S$, where S and N are the sill and nugget variance respectively. The spatial analytical work was done in ArcView 3.1 (Environmental Systems Research Institute Inc. 1999).

Results and Discussions

Descriptive statistics

The descriptive statistics for the measured soil variables over the entire study area are presented in Table 1. All the soil properties, except for soil reaction and silt, showed a great extent of variability with high coefficient of variation (CV) values (Wilding 1985; Yanai et al. 2002; Miao et al. 2000). Phosphorous exhibited the greatest spatial variability with a CV of

116% from values ranging from 0.487 to 137.62 mg kg^{-1}, followed by zinc and organic matter with CVs of 72.6 and 59.0% respectively. Soil reaction exhibited the least spatial variability (CV = 13.0%) of all the parameters tested.

Table 1: **Descriptive statistics for soil properties**

Variables	Minimum	Maximum	Mean	Median	SD	CV %	Variance	Skew
OM (%)	0.130	2.950	1.20	1.340	0.709	59.0	0.502	0.064
pH	3.600	8.000	6.02	6.100	0.781	13.0	0.610	-0.548
Clay (%)	9.000	66.000	24.99	23.000	10.768	43.1	115.960	0.893
P (mg kg^{-1})	0.487	137.620	17.05	11.549	19.789	116.0	391.600	3.006
Sand (%)	1.000	57.000	22.51	21.000	11.877	52.8	141.060	0.573
Silt (%)	24.000	79.000	52.51	53.000	8.504	16.2	72.325	-0.263
Zn (mg kg^{-1})	0.002	1.641	0.29	0.232	0.212	72.6	0.045	2.196

Zn = zinc, P = Av. phosphorous, OM = organic matter

Spatial variability of soil properties

Table 2 shows the geostatistical parameters such as nugget, sill, Q value, range, and model. Sill represents the overall variance of the sample data which was observed to be higher in P. The range indicates the limit of spatial dependence beyond which the samples become spatially independent and uncorrelated (Nayak et al. 2002). The higher value of range for pH might indicate that soil properties other than those tested might have an influence on pH. The nugget variance provides an indication of short distance variation. The variable P shows the highest nugget value, which might have caused higher CV.

Table 2: **Geostatistical parameters of the soil properties**

Variables	Nugget (Co)	Sill (Co+C)	Range Ao	Q (C/Co+c)	r^2	Model
OM (%)	0.168	0.522	10550	0.68	0.962	Sph
pH	0.172	0.769	27960	0.78	0.987	Sph
P (mg kg^{-1})	2.19	4.239	18780	0.48	0.85	Exp
Zn (mg kg^{-1})	0.009	0.035	12990	0.74	0.713	Exp

Sph = spherical, Exp = exponential

The isotropic semi-variogram for pH and OM is best fitted to a spherical model, and for zinc and P, to an exponential model. Models were selected for interpolating the soil properties over the study area based on the maximum r^2 value. The degree of spatial dependence of the soil properties varied among the properties taken into consideration. The Q value ranged from 0.48 to 0.68 for available phosphorous and organic matter, suggesting a moderately developed structure which was also confirmed by the higher nugget value (Mueller et al. 2000). Soil reaction and available zinc demonstrated a highly developed spatial structure with Q values of more than 0.74 (Yanai et al. 2002). Soil variables exhibiting strong spatial dependence may be controlled by intrinsic variability, and if there is less strong spatial dependence by extrinsic variability (Miao et al. 2000). Using the measured data and the models, estimates were computed by punctual kriging. The model used for zinc estimation seems satisfactory since the differences in mean and standard deviation between measured and estimated zinc values were not much different compared to P (Table 3 and Figure 1).

Table 3: Comparison of statistical parameters for measured and estimated zinc		
Variable	Mean	Standard deviation
Measured zinc (mg kg^{-1})	0.29	0.21
Estimated zinc (mg kg^{-1})	0.28	0.13
Measured P (mg kg^{-1})	17.05	19.79
Estimated P (mg kg^{-1})	17.50	11.22

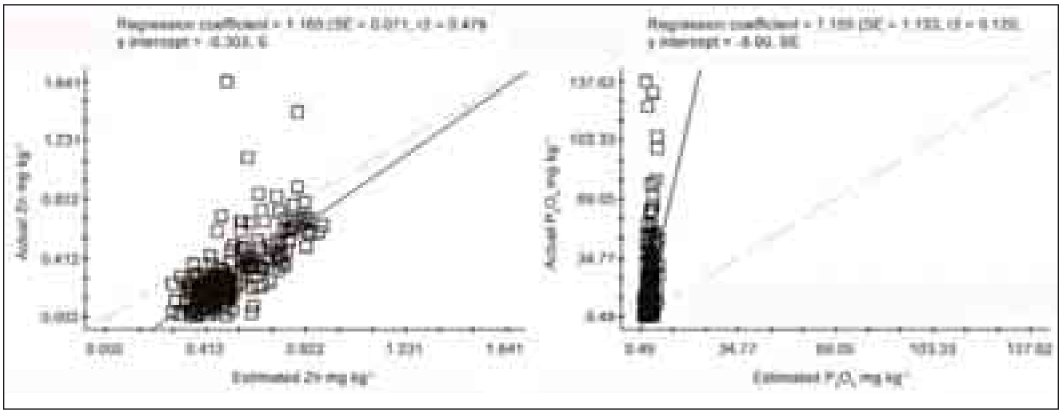

Figure 1: **Relationship of measured and predicted values of zinc and P**

The available zinc in the study area was quite low, ranging from 0.013 to 1.402 mg kg^{-1} (Table 4). Organic matter was also low. Most of the area has a slightly acidic to neutral soil reaction.

Figure 2 presents the map of the spatial distribution of the soil properties. Kriged maps showed considerable spatial variability for soil properties. Phosphorous and zinc portray a higher spatial variability than pH and organic matter.

Correlation analysis of OM, pH, P, clay, sand, and silt with zinc was not significant (Table 5) and could be attributed to experimental error and short distance variation (Kuzyakova et al. 2001).

Table 4: **Area and percentage area of the soil properties with classes and ranges**

Soil Property	Range	Class and range		Area (ha)	Area (%)
Zinc[a]	0.013-1.402 mg kg^{-1}	Low	<0.17 mg kg^{-1}	23,596	17.7
		Medium	0.17 – 11.5 mg kg^{-1}	110,000	82.3
OM[b]	0.019-2.84%	Low	< 2.5%	133,264	99.8
		Medium	2.5-5.0%	332	0.2
P[b]	3.02-115.34 mg kg^{-1}	Low	<13.39 mg kg^{-1}	59,868	44.8
		Medium	13.39-24.55 mg kg^{-1}	45,536	34.1
		High	>24.55 mg kg^{-1}	28,192	21.1
pH[b]	3.7-7.7	Acidic	<5.0	15,304	11.5
		Slightly Acidic	5.0-6.0	55,740	41.7
		Neutral	6.0-7.0	59,572	44.6
		Slightly Alkaline	7.0-8.0	2,980	2.2

[a] = Lindsay and Norvell 1978; [b] = SSD 1999

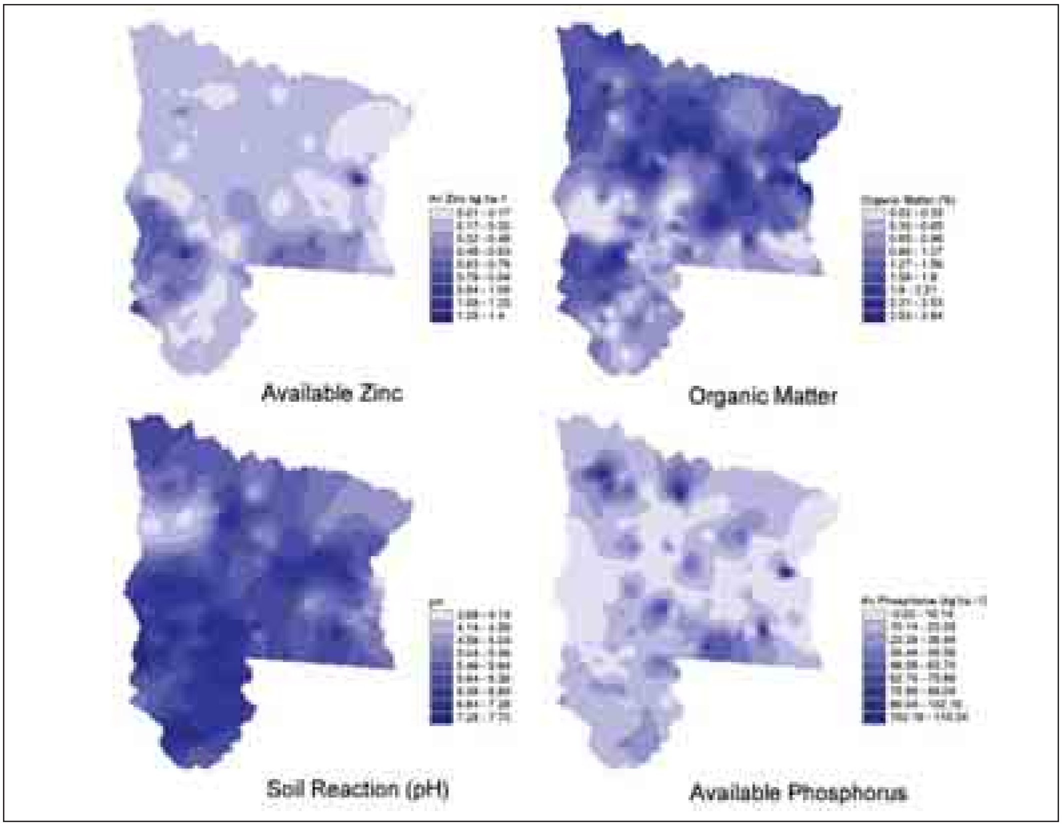

Figure 2: **Maps of soil properties**

Multivariate analysis of measured zinc, phosphorous, OM, pH, clay, silt, and sand were carried out to elucidate the factors that affect available zinc quantitatively, and the relationships among the properties investigated using stepwise multiple regression analysis. The most appropriate model obtained with the significance levels of $\alpha = 0.2$ (Gomez and Gomez 1984) was:

$$Zn = 0.07115 + 0.04627 (pH) + 0.00147 (P) - 0.00285 (Clay)$$

The r^2 value of 0.0237 indicates that the model using only soil factors explains 2% of the total variance of the measured zinc. Thus, a major part of the variation in the zinc could not be explained from the effects of the investigated factors.

Table 5: **Correlation of z inc with other soil properties**

Soil property	Zinc (mg kg^{-1})	P value
OM	-0.03	0.61
pH	0.07	0.21
P	0.09	0.12
Clay	-0.08	0.20
Sand	0.02	0.76
Silt	0.07	0.24

Conclusions

Available soil zinc and the other elements studied are generally low to medium in the soils of Rupandehi district. No specific associations were observed between zinc and other soil properties, this might be due to the low quantity of the tested soil properties. Soil properties with stronger spatial dependence make it easier to use kriging or other interpolation methods to predict soil properties at unsampled locations. Geostatistics and geographical information systems (GIS) are essential tools for analysing geo-referenced information and for advancing our understanding of spatial variability at different scales.

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Micronutrient Status in Different Agro-climatic Zones of Haryana, India

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Abstract

Indian Agriculture has undergone a revolution in the last 40 years and self-sufficiency in food-grain production has been attained. The increase in food-grain production has simultaneously created a problem of nutrient imbalance in soils due to extra mining of macro- and micronutrients. These imbalances have not only adversely affected the growth of agricultural production but also affected the chemical and physical conditions of soils. In addition the deficiency of micronutrients in soils has also resulted in food of poor nutritive quality. A widespread incidence of iron deficiency anaemia among young children and pregnant women in India has been reported in many studies. A number of authors revealed that 49% of Indian soils are deficient in Zn, 12% in Fe, 5% in Mn and 3% in Cu.

In India, Haryana is the second most important state contributing to the central food grain pool. A case study was carried out on mining of micronutrients from soils in the two agro-climatic zones of the state: the southwestern (SW) zone and the northeastern (NE) zone. The main crops in the SW zone are pear millet, cotton, gram, raya, and wheat, and in the NE zone rice, wheat, and sugar cane. The food-grain production in Haryana increased from 2.59t in 1966/67 to 13.30t in 2001/02, with projected estimates of 14.15t and 15.60t in 2005 and 2010, respectively. This increase has led to extra mining of nutrients from the soil. Farmers in Haryana generally apply fertilisers containing major nutrients only, as a result of which every year more areas are becoming deficient in micronutrients such as zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu). The soils in the SW zone are more deficient in micronutrients than the soils in the NE zone. Zn deficiency in SW-zone soils varied from 32 to 88% and in NE-zone soils from 30 to 78%. Fe deficiency in SW-zone soils ranged from 12 to 57%, and in NE zone soils from 7 to 29%. Manganese deficiency was only found in the SW zone (3 to 19%). Cu deficiency was not serious. Overall, 54% soils of soils in the state were deficient in Zn, 21% in Fe, 4.4% in Mn, and 2.6% in Cu. The negative balance was greater in the NE zone than in the SW zone, as a result of intensive cropping of high-yielding varieties of rice and wheat. Among micronutrients, the maximum negative balance in both zones was of Fe, followed by Mn, Cu, and Zn. Future research should be oriented towards improving soil fertility and arresting further mining of micronutrients.

Introduction

Soil is an exhaustible storehouse of plant nutrients. In a tropical country like India, the inherent soil fertility is low because of the loss of nutrients for climatic reasons. Before the green revolution, pressure to produce food was far less than it is today. In 1951/52, food-grain production was a mere 52 million tonnes with a fertiliser consumption of only 70 thousand tonnes; food-grain production increased to 212 million tonnes in 2001/02 with a fertiliser consumption of about 18 million tonnes – to feed a billion people. Use of chemically pure fertilisers together with intensive cropping accelerated the exhaustion of finite available micronutrient reserves in the soils. As a result, the deficiencies of these nutrients in present-day exploitative agricultural practices have assumed an alarming importance. It has become imperative to use matching doses of required micronutrients together with nitrogen (N), phosphorous (P), and potassium (K) to sustain high and profitable crop production. A hidden deficit of micronutrients has now emanated from many factors including interaction among nutrients, sub-optimal levels of particular nutrients, and irrigation water quality among others.

Haryana is an agriculturally important state in India. With only about 1.33% of the nation's geographical area, the state contributes 6.27% of the national food-grain production and about 30% of the food grain in the national food pool. It is considered to be the granary of the country. Food-grain production in Haryana rose from 2.6 million tonnes in 1966-67, to 13.3 million tonnes in 2001/02 (Figure 1; Table 1); fertiliser consumption rose from 13.4 to 984 thousand tonnes in the same period (Table 2). Rice and wheat crops accounted for a share of 49% in 1966/67 and 91% in 2001/2002 of the total food-grain production of the state. The area under these crops was 3.6 times more in 2001/02 than in the 1960s and their average yields had risen more than 2.6 times (Table 1). Apart from rice and wheat, average yield and production of other crops, such as pearl millet, maize, barley, cotton, sugar cane, and oilseeds, also increased, in spite of the fact that the area under some of these crops decreased (Table 1). Overall the average annual increase in food grain production was 0.297 million tonnes (Figure 2). It is estimated that total production will reach 14.2 million tonnes by 2005 and 15.6 million tonnes by 2010, requiring 980 and 1130 thousand tonnes of fertiliser, respectively (Antil et al. 2001).

The five-fold increase in food-grain production in the state over the last 36 years was mainly due to the diversion of areas from low productivity crops to rice and wheat which have higher productivity. This shift in cropping pattern was accompanied by increased nutrient mining from the soil at an alarming rate. In Haryana, only N, P, and Zn are usually applied, and this has led to widespread deficiency in nutrients like P, K, sulphur (S), Fe, Mn, and Cu. During the last few years, widespread deficiencies in S and Fe have been found in crops like pearl

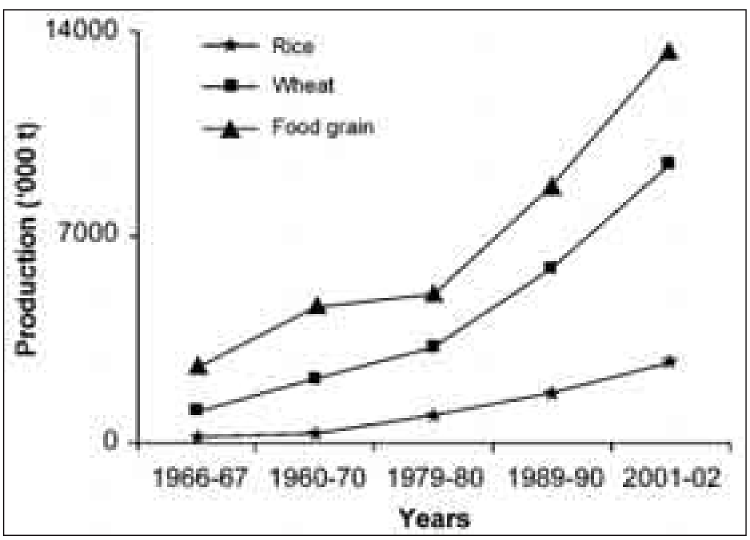

Figure 1: **Production of rice, wheat, and food grain in Haryana**

Table 1: **Area, production and average yield of different crops in Haryana**

Crops	Area ('000 ha)		Production ('000 t)		Average yield (kg ha^{-1})	
	1966/67	2001/02	1966/67	2001/02	1966/67	2001/02
Rice	192	1027	223	2724	1161	2652
Sorghum	270	104	49	22	181	212
Pearl millet	893	586	373	834	418	1423
Maize	87	18	86	47	989	2611
Wheat	743	2300	1059	9437	1425	4103
Barley	182	30	239	87	1313	2900
Cereals (T)	*2370*	*4065*	*2029*	*13151*	*856*	*3235*
Pulses (T)	1150	189	563	150	490	796
Food grain crops (pulses+cereals)	*3520*	*4254*	*2592*	*13301*	*1346*	*3127*
Cotton (L)	183	630	288	722	1572	2397
Sugarcane (G)	150	162	510	933	3400	5759
Oilseed (T)	212	546	92	807	434	1477

L = lint (in thousand bales of 170 kg each), G = gur, T = total
Source: Government of Haryana (2003)

Table 2: **Fertiliser consumption in Haryana ('000 t)**

Nutrients	Years				
	1966-67	1969-70	1979-80	1989-90	2001/02
N	12.63	47.00	174.54	402.59	742.05
P_2O_5	0.57	5.12	30.24	129.07	232.16
K_2O	0.15	1.80	10.66	3.82	9.74
S	1.28	1.92	0.55	10.20	7.59
Zn	0.0	0.0	0.065	1.05	1.80
Mn	0.0	0.0	0.0	0.0	0.0
Fe	0.0	0.0	0.0	0.0	0.0
Cu	0.0	0.0	0.0	0.0	0.0
$N+P_2O_5+K_2O$	13.35	53.92	215.44	535.48	983.95

Source: Government of Haryana (2003)

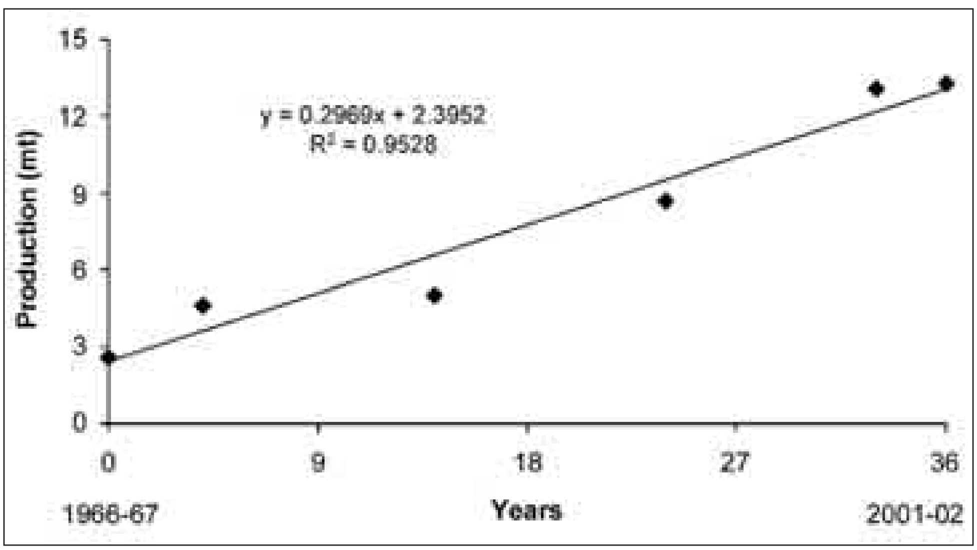

Figure 2: **Trend of food grain production in Haryana**

millet, sugar cane, wheat, and legumes. If this trend of nutrient depletion continues, then in future more areas will become deficient in nutrients like P, K, S, Fe, and Mn. Therefore, it is essential to limit extra mining of those nutrients which are either not being applied today, or are being applied in very limited quantities, in order to check further decline in soil fertility. The gap in nutrient removal and addition needs to be bridged.

The aim of this paper is to assess nutrient mining and addition through fertilisers and organic manure in different agro-climatic zones, and to construct a balance sheet for micronutrients in Haryana. This micronutrient balance sheet will be helpful for future planning of nutrient management strategies to maintain crop productivity for different cropping systems in different zones.

Agroclimatic Zones

Haryana State has nineteen administrative districts and is situated between 27°39' and 30°55'N and 74°27'8" and 77°36'5"E. It occupies a total geographical area of about 44,212 sq. km. The state slopes imperceptibly from north to south with heights ranging from 200 to 900 masl, but the slopes reverse further south and southwest due to the presence of the Aravalli hills in the south. The normal annual rainfall is about 300 mm in the southwest and this increases towards the north and eastern areas up to 600 to 1100 mm, with about a 25 to 45% coefficient of variation. The annual potential evapotranspiration in the region is quite high, exceeding 1200 mm all over the state. The mean temperature in the kharif (rainy) season is 32°C in the southwestern part, decreasing to 20-28°C in the northeastern part. The soils are light to medium textured.

The state can be divided into two main agro-climatic zones: namely, the southwestern (SW) zone and the northeastern (NE) zone.

The northeastern zone

The northeastern zone covers the semi-arid and sub-humid areas of Ambala, Yamuna, Nagar, Panchkula, Kaithal, Karnal, Panipat, Sonipat, Gurgaon, Faridabad, Jhajjar, Rohtak, and Jind districts. It lies between 30° and 31°N and 76°50' to 77°30'E. It receives more than 800 mm of annual rainfall with a coefficient of variation of 25%. Mean seasonal temperatures are around 29 to 16°C during the kharif and rabi (winter) seasons, respectively. The mean maximum temperature ranges from 37 to 47°C and the minimum temperature ranges from 3 to 25°C. This region has an average annual potential evapotranspiration of 1482 mm. The main crops are rice, wheat, and sugar cane with small areas of other crops like pearl millet, oilseeds, pulses, maize, and cotton. In general, the quality of water is good except in the central and southern parts of the zone. The soils are Typic Hapllustrept, Uchani, and loamy to clay loam.

The southwestern zone

The southwestern zone mainly consists of arid tracts. It lies between 27°50' and 30°N and 74°30' and 76°45'E. This zone covers the Sirsa, Fatehabad, Hisar, Bhiwani, Rewari, and Mohindergarh districts. Annual rainfall ranges from 200 to 500 mm during less than 25 rainy days with a coefficient of variation of more than 45%. Mean seasonal temperatures during the kharif and rabi seasons vary from 31 to 32°C and 11 to 16.5°C, respectively. Mean relative humidity is 60 and 50% during the kharif and rabi seasons, respectively.

Temperature variations are quite high, touching 47 to 48°C during the kharif and occasionally dropping below 0°C in the rabi season. Annual potential evapotranspiration is 1600 to 1700 mm. Most of the underground waters are brackish. The main crops are pearl millet, cotton, gram, raya, and wheat. The soils are sandy to sandy loam and classified as Typic Hapllustrept, Ladwa.

Micronutrient Status in the Agroclimatic Zones

The soil is a reservoir for the supply of all essential micronutrients to plants. This reservoir is depleted continuously and has been under stress since the introduction of high-yielding varieties. On average, 54% of the soils in Haryana were found to be deficient in Zn, 21% in Fe, 4.4% in Mn, and 2.6% in Cu (Gupta and Dahiya 2003).

In the northeastern zone, 65 to 84% of samples in Jind, Faridabad, Gurgaon, Rohtak, and Sonepat districts were deficient in available Zn, and less than 42% in other districts. The highest rate of Fe deficiency was found in Sonepat (29% of samples), followed by Faridabad, Ambala, Karnal, Kurukshetra, and Rohtak districts (Table 3). There was almost no deficiency of either Mn or Cu.

In the southwestern zone, Zn deficiency rates were highest in Bhiwani district (88% of samples), followed by Rewari and Mohindergarh (77%) (Table 3). About 12 to 57% of samples were deficient in available Fe with the highest rates in Bhiwani district, followed by Sirsa and Hisar. In Bhiwani district, 12 and 19% of samples were deficient in available Cu and Mn, respectively. But Cu and Mn deficiency was not serious in other districts.

Table 3: **Extent of micronutrient deficiency (% samples deficient) in soils of different districts of Haryana**

District	Zn	Fe	Mn	Cu
Northeastern zone				
Ambala	35	17	0	2
Panchkula	35	17	0	2
Yamunanagar	35	17	0	2
Kurukshetra	30	8	0	0
Kaithal	30	8	0	0
Karnal	42	17	0	0
Panipat	42	17	0	0
Sonepat	65	29	0	0
Rohtak	71	7	0	2
Jhajjar	71	7	0	2
Gurgoan	78	17	3	5
Faridabad	70	17	0	1
Jind	84	10	0	0
Southwestern zone				
Sirsa	32	29	3	0
Fatehabad	55	25	10	3
Hisar	55	25	10	3
Bhiwani	88	57	19	12
Mohindergarh	77	12	0	1
Rewari	77	12	3	1
Overall	54	21	4.4	2.6

Source: Gupta and Dahiya (2003)

Calculation of Nutrient Mining

Nutrient mining and balance in soils were calculated in different agro-climatic zones of Haryana for the micronutrients Zn, Mn, Fe, and Cu as reported by Antil et al. (2001) taking into account the following.

- Production of different crops
- Per ton nutrient requirement of crops
- Fertiliser consumption
- Contribution of dung
- Gross cropped area in different years
- Efficiency in nutrient use

Crop removal of nutrients

The removal of Zn, Cu, Fe, and Mn was calculated by multiplying the total crop production of different crops in different zones by the per tonne requirement for these nutrients as reported by FAO (1982) and Singh (1984). Nutrient removal by different crops was calculated for different years for each zone to give the total removal of nutrients.

Fertiliser consumption

Micronutrient fertiliser (Zn, Mn, Fe and Cu) consumption for the districts in each zone was calculated. The crops covered by this study occupied about 89% of the gross cropped area of the state during different years. The remaining area (11%) is used to grow vegetables, fruit, and forage crops which were not taken into consideration due to the lack of date on their yields and requirements. It was assumed that 11% of fertiliser nutrients were used by these crops, and this amount was subtracted from total fertiliser consumption. The value obtained was used to calculate nutrient removal and balance in kg ha^{-1}. Total dung production in Haryana in each year was calculated from livestock population figures and multiplied by the nutrient contents of dung to arrive at the potential contribution of dung to nutrient recycling in soils. It was estimated that only one third of dung is recycled in soil, the rest being burned as fuel or drained off during the rainy season and this value (one-third of total produced) was used in the calculations. The nutrients supplied through dung and fertilisers were added together to arrive at the total input of nutrients in each zone.

Nutrient balance

The nutrients obtained through fertiliser application and dung were multiplied by the efficiency factors of different nutrients. The efficiency of all the micronutrients (Zn, Mn, Fe and Cu) was taken as 20%. The amount of nutrients obtained after multiplying by nutrient efficiency factors was subtracted from total crop removal figures, and this gave a plus or minus nutrient balance for different nutrients in different years. The amount of nutrients obtained was divided by actual crop area occupied by these crops to give a nutrient balance in kg ha^{-1} in each zone.

Nutrient removal by different crops

The removal of micronutrients for each zone was calculated for different crops in different years (Table 4) by multiplying the total production of different crops with the per tonne requirement of the crops.

Table 4: Micronutrient removal in Haryana				
Micronutrient	1966/67		2001/02	
	Total removal tonnes	Average removal g ha^{-1}	Total removal tonnes	Average removal g ha^{-1}
Haryana state				
Zn	79.5	20.0	428.2	76.6
Mn	271.8	70.0	2217.7	396.9
Fe	851.8	210.0	4002.3	716.2
Cu	35.9	10.0	159.3	28.5
Northeastern zone				
Zn	57.8	20.0	264.4	80.0
Mn	218.9	90.0	1806.4	550.0
Fe	594.7	240.0	2268.9	640.0
Cu	27.0	10.0	107.7	30.0
Southwestern zone				
Zn	21.8	10.0	163.8	64.7
Mn	52.9	30.0	411.3	162.5
Fe	257.1	60.0	1733.4	684.9
Cu	8.9	10.0	51.6	20.4

The total calculated removal of micronutrients was much higher in the northeastern zone than in the southwestern zone (Table 4). In the northeastern zone, total Zn removal increased from 57.8 to 264.4 tonnes between 1966/67 and 2001/02, and in the southwestern zone from 21.8 tonnes to 163.8 tonnes. In terms of g ha^{-1} the rates increased from 20 to 76.6g ha^{-1} in the northeastern zone and from 10 to 64.7g ha^{-1} in the southwestern zone (Table 4). In Haryana overall, the rate of removal of Zn increased from 20 to 76.6g ha^{-1} and of Fe from 210 to 716.2g ha^{-1}. Cu had the lowest rates of removal of all the micronutrients studied in all years in both zones.

The share of each crop in micronutrient removal was calculated. In 1966/67, cereals removed 60% of total Zn removed, 73% of Mn, 54% of Fe, and 57% of Cu, the proportion increased to 77% of Zn, 95% of Mn, 71% of Fe, and 84% of Cu in 2001/02 (Table 5). Among the cereals, rice and wheat removed the maximum amounts. The share in nutrient removal by pulses, oilseeds, cotton, and sugar cane decreased over the years, as a result of the increase in yields of rice and wheat crops resulting from the increase in their area and average yields.

Nutrient balance in soils

In both zones, there was a negative balance of Zn, Fe, Mn, and Cu in all years, except for 2001/02, when Zn balance (7.4 g ha^{-1}) was positive in the northeastern zone (Table 6). The negative balance of Fe, Mn, and Cu was greater in the northeastern zone than in the southwestern zone (Table 6). In Haryana State, the negative balance of Zn, Fe, Mn, and Cu in 1966/67 was -66.7, -265.5, -504.1, and -30.6 tonnes which increased to -59.4, -2205.2, -3307.8 and -148.6 tonnes in 2001/02 (Table 6). The negative balance of all micronutrients increased in both zones separately except for Zn in the northeastern zone, where the balance became positive as a result of the application of Zn to rice and wheat crops.

Table 5: **Percentage micronutrient removal by different crops in Haryana**				
Crop	**Micronutrient**			
	Zn	**Mn**	**Fe**	**Cu**
1966/67				
Cereals	60.37	73.43	54.09	56.56
Cotton	5.79	1.48	3.68	6.40
Sugarcane	9.62	3.19	11.98	14.19
Pulses	12.03	18.44	17.19	17.23
Oilseed	11.57	3.22	12.13	4.22
2001/02				
Cereals	76.90	95.17	71.48	84.20
Cotton	0.46	0.08	0.33	0.62
Sugarcane	3.25	0.71	4.63	5.82
Pulses	0.59	0.60	0.96	1.02
Oilseed	18.81	3.45	22.60	8.34

Table 6: **Micronutrient balance in Haryana**				
Micronutrient	**1966/67**		**2001/2**	
	Total balance tonnes	**Average balance g ha^{-1}**	**Total balance tonnes**	**Average balance g ha^{-1}**
Haryana state				
Zn	-66.7	-16.4	-59.4	-10.6
Mn	-265.5	-65.3	-2205.2	-394.6
Fe	-504.1	-123.9	-3307.8	-592.0
Cu	-30.6	-7.52	-148.6	-26.6
Northeastern zone				
Zn	-49.0	-19.9	22.5	7.4
Mn	-214.7	-87.1	-1798.4	-588.2
Fe	-357.4	-145.0	-1826.8	-597.6
Cu	-23.4	-9.5	-100.9	-33.0
Southwestern zone				
Zn	-17.7	-11.1	-81.9	-32.3
Mn	-50.9	-31.7	-406.8	-160.7
Fe	-146.7	-91.5	-1481.0	-585.2
Cu	-7.2	-4.5	-47.7	-18.9

These studies indicate that the negative balance of nutrients such as Fe, Mn, and Cu will continue to increase in future. In the case of Zn, the situation is almost satisfactory. The more serious threat is for Fe, Mn, and Cu the deficiency of which has increased during the last two decades.

Suggestions to Limit Nutrient Mining from Soils

The increase in food-grain production in the state has led to a simultaneous increase in the removal of nutrients from soils. Except for Zn, there is more mining of all micronutrients from soils in both zones. The gap between nutrient addition and nutrient removal is increasing every year for nutrients like Mn, Fe, and Cu. Although it is not possible to replenish 100% of nutrients removed by crops every year, attempts should be made to maximise recycling of those nutrients likely to be deficient in future. The only way to check further nutrient mining and narrow the gap between nutrient removal and fertiliser consumption is through strategies such as:

- integrated nutrient management (INM),
- balanced use of fertilisers,
- emphasis on the use of organic manure, crop residues, and industrial waste,
- use of green manure, and
- crop diversification.

Conclusions and Future Research Needs

- Food-grain production in Haryana increased about five-fold between 1966/67 and 2001/02. Rice and wheat crops contributed the maximum in terms of grain production with annual rice production increasing from 223 to 2724 thousand tonnes and annual wheat production from 1094 to 9437 thousand tonnes. This was mainly due to the increases in area and average yields of these crops. In spite of a decrease in the cultivated area of pearl millet in the same period, the production of pearl millet also increased. There was an increase in average yields of sorghum, pearl millet, barley, cotton, sugar cane, pulses, and oilseeds.
- On average, 54% of soils in the state were deficient in available Zn and 21% in available Fe, whereas only 4.4 were deficient in Mn and 2.4% in Cu.
- Nutrients added through dung also increased over the same period in the state, as did micronutrient addition: Zn addition increased from 64 to 128 tonnes, Mn from 31.4 to 62.7 tonnes, Fe from 1738.3 to 3472.1 tonnes, and Cu from 26.8 to 53.5 tonnes.
- Nutrient removal by all crops increased from 1966/67 onwards. In 2001/02, rice and wheat crops removed the maximum nutrients. The average removal of Zn, Cu, Mn, and Fe increased over the years in both zones. The removal of all nutrients was greater in the northeastern zone than the southwestern zone.
- In Haryana overall there was a negative balance of micronutrients; the maximum negative balance overall and in both zones separately was of Fe followed by Mn, Cu, and Zn. In the northeastern zone there was a positive balance of Zn (7.4 g ha^{-1}). The negative balance of Fe, Mn, and Cu increased from 1966/67 onwards in both zones.

Future research should be oriented towards improving soil fertility and arresting further mining of nutrients like Fe, Mn, and Cu. Research emphasis should be on the following.

- Research on the balanced use of fertilisers should be carried out on important crops such as rice, wheat, oilseeds, pulses, cotton, and sugar cane.
- The critical levels of available Zn, Cu, Fe, and Mn for cereals, oilseeds, pulses, and other crops should be worked out for different zones.
- The highest priority should be given to research on integrated nutrient management in cropping systems based on rice, wheat, cotton, oilseeds, and sugar cane. The contribution of organic manure and crop rotation should be studied for various cropping systems.
- Emphasis should be given to safe use of industrial and farm wastes to assess their contribution to crop production.

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Severe Boron Deficiency limiting Grain Legumes in the Inner Terai of Nepal

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Abstract

Lentils, chickpeas, and pigeon peas are important grain legumes grown in Nepal. They provide staple components of Nepalese diets by supplying vegetable protein, vitamins, and minerals that are otherwise only available in sparse amounts. Their cultivation also improves soil health through additions of fixed nitrogen and organic matter and by breaking cereal pest and disease cycles. However, their yields are generally low and unstable due to an array of biotic and abiotic constraints. Symptoms suggestive of micronutrient limitations had been observed prior to the 1990s, but it was difficult to differentiate these symptoms from those caused by other factors. For example, the poor podding of chickpea was usually attributed to Botrytis grey mould disease, until it was shown that boron (B) deficiency had a similar effect.

In order to establish if any, and if so which, micronutrients were limiting chickpea, an omission trial was conducted in the field at the Research Station of the Grain Legume Research Programme, Rampur, Chitwan District, inner Terai in the 1993/94 season. In the absence of applied B, there was no yield as no pods formed, in comparison to a yield of 300 kg ha^{-1} in the full nutrient treatment. There was yellowing of younger leaves and typical 'little leaf' symptoms when B was omitted. Molybdenum (Mo) was also shown to be deficient for chickpeas at this site. Subsequent field trials established that the optimum rate of B to apply to the soil to correct the deficiency at this location was 0.5 kg ha^{-1}. Further studies at this location confirmed positive responses of lentils and pigeonpea in terms of yield to B application. In lentil variety ILL-4605, absence of B reduced yield to 6% of the treatment with B; in the pigeonpea variety, Bageswari, the reduction was to 10% of the treatment with B. Lentils also responded to zinc. For all of these legumes, there were large genotypic differences in response to B, with exotic germplasm (e.g., lentil genotypes from the International Centre for Agricultural Research in Dry Areas [ICARDA] and chickpea and pigeonpea genotypes from the International Crop Research Institute for the Semi-Arid Tropics [ICRISAT]) being more susceptible to B deficiency than locally-derived ones. This indicates evolution of local genotypes to B-deficient conditions and scope for genetic enhancement to alleviate B deficiency.

In the 1997/98 and 1998/99 seasons, on-farm trials were conducted to evaluate the extent of B deficiency in the inner Terai. Chickpea and mustard, crops known to be particularly susceptible to B deficiency, were used as test crops. Yield responses were widespread but variable, with responses of up to 560% in chickpea and 360% in mustard crops being recorded. Responsiveness decreased with increasing soil organic matter content. A critical concentration range of 15-20 ppm B was found for the shoot tips of chickpeas.

The large responses to B obtained in these grain legumes, and appearance of symptoms likely to be due to B-deficiency in these and other crops in the central and eastern Terai, indicate a need for systematic

assessment of the spatial and temporal distribution of the extent of limitation of grain legumes by micronutrient deficiencies (primarily B, but also other micronutrients) in Nepal. Optimum methods of diagnosis of micronutrient deficiencies and remedial measures most appropriate for small-holder farmers need to be evaluated on-farm and widely disseminated if the potential levels of yield of grain legumes are to be achieved.

Introduction

Lentil (*Lens culinaris* L.), chickpea (*Cicer arietinum* L.), and pigeonpea (*Cajanus cajan* L. Millsp.) are important grain legumes in Nepal (Johansen et al. 2000). They contribute to the staple diet of Nepalese people by providing vegetable protein, vitamins, and minerals that are otherwise only available in sparse amounts. Being legumes, their cultivation improves soil health through additions of fixed nitrogen and organic matter and by breaking cereal pest and disease cycles. However, their yields are generally low and unstable due to a range of biotic and abiotic constraints (Johansen et al. 2000). Among the abiotic constraints, micronutrient deficiencies appear to be important but these effects have only been quantified recently. Symptoms suggestive of micronutrient deficiencies had been observed prior to the 1990s, but it was difficult to specify which particular micronutrients were involved and, indeed, to differentiate these symptoms from those caused by other factors. For example, the poor podding of chickpeas was usually attributed to *Botrytis* grey mould (BGM) disease, until it was shown that boron (B) deficiency had a similar effect (Srivastava et al. 1997). Soil analyses conducted by Khatri-Chhetri (1982) indicated wide occurrence of micronutrient deficiencies in the Chitwan Valley in the inner Terai: a region of acid soils.

In this paper we summarise earlier attempts to diagnose micronutrient deficiencies, firstly in chickpeas, and to determine the extent of limitation in the major grain legumes grown in the inner Terai, namely chickpeas, lentils, and pigeonpeas. Appropriate means of diagnosing micronutrient limitations across regions, and methods of alleviating them suitable for adoption by resource-poor farmers, are then proposed.

Materials and Methods

Chickpea

To diagnose which nutrient elements were deficient for chickpeas, an omission experiment was carried out at the field station of the Grain Legumes Research Programme (GLRP), Nepal Agricultural Research Council (NARC), Rampur, Chitwan, during the 1994/95 season. Treatments consisted of the following: 1) control with no nutrients added; 2) complete supply of all nutrients likely to be deficient: phosphorous (P), potassium (K), sulphur (S), boron (B), zinc (Zn), molybdenum (Mo), copper (Cu), manganese (Mn), iron (Fe); 3) complete minus B; 4) complete minus Zn; 5) complete minus Mo; 6) complete minus Fe; 7) complete minus Cu + Mn; 8) complete minus K + S; and 9) complete + lime. Cultural details are given in Srivastava et al. (1997).

In 1995/96, a field experiment with four levels of B (0, 0.5, 1.0 and 3.0 kg ha^{-1}) and three levels of Mo (0, 0.15 and 0.3 kg ha^{-1}) was conducted at the Rampur station. Details are given in Srivastava et al. (1997). The chickpea cultivar Kalika was used in both seasons' trials. In 1994/95, there was no rainfall during the winter growing period and the crop suffered terminal drought stress. However, in 1995/96, there was adequate soil moisture throughout the growing season, as stored soil moisture from the monsoon rains was supplemented by light winter rainfall. In both experiments, *Botrytis* grey mould (BGM) was controlled by spraying fungicide and pod borer (*Helicoverpa armigera*) by insecticide.

In the 1997/98 and 1998/99 seasons, on-farm trials were held in Chitwan and Nawalparasi Districts of the Chitwan Valley, inner Terai, to determine the spatial distribution of B responses of chickpeas. In 1997/98, seven on-farm trials, designed by researchers but managed by farmers, were conducted as indicated in Table 1. Five treatments (0, 0.5, 1.0 B, 0.5 B + 0.15 Mo, and 1.0 B + 0.15 Mo kg ha^{-1}) were tested in plots of 3 x 3.6m in a randomised complete block design replicated three times at all seven locations. Boron was applied as boric acid and Mo as sodium molybdate mixed with some dry soil and then broadcast over the plots. Triple superphosphate (TSP) at 40 kg ha^{-1} P_2O_5 and muriate of potash (MP) at 20 kg ha^{-1} K_2O were then broadcast and all fertilisers mixed into the top 10 cm of soil with a spade. Seeds of the Sita variety of chickpea were sown at a spacing of 30 x 15 cm and the crops grown rainfed. The crops were weeded as necessary. Dates of sowing, application of insecticide (Endocel) for pod borer control, and harvest are indicated in Table 1. Tip samples of chickpeas, comprising the apical 6-8 cm with 4-5 pinnules, were taken from each replication of the 0, 0.5 and 1.0 kg ha^{-1} B treatments in the field of Khagendra Pathak at 117 days after sowing (DAS). The samples were oven dried at 72°C to constant weight and analysed for B by optical emission spectrometry (Zarcinas and Cartwright 1983) at Analabs, Ashoknagar, Hyderabad, India. The net area of each plot harvested for yield was 7.2m^2.

Table 1: Site details and timing of operations of successful [1] on-farm trials with chickpeas in 1997/98, Chitwan Valley, Nepal

Farmer	Village	District	Site elevation	Date of sowing (1997)	Sprays endocel (DAS[2])	Date of harvest (DAS[2])
Vishnu Hare Ghimi re	Shukranagar	Chitwan	upland	20 Nov	112, 129	144
Chandra Singh Chaudhary	Shukranagar	Chitwan	lowland	5 Nov	78, 124, 141	154
Khagendra Pathak	Rajahar	Nawalparasi	upland	6 Nov	119, 131	155
Dhruba Lamichhane	Rajahar	Nawalparasi	lowland	30 Nov	107, 121	139

[1] Three of the seven on -farm trials failed. [2] DAS = days after sowing

In 1998/99, seven researcher-designed, farmer-managed on-farm trials were conducted in different farmers' fields (all upland) in the village of Rajahar, Nawalparasi District (Table 2). Both chickpea (var. Kalika) and mustard (*Brassica campestris* L. var. Vikas) were used as test crops, as mustard is known to be particularly sensitive to B deficiency. Two levels of B, 0 and 1.0 kg ha^{-1}, were tested in paired plots of 3 x 3.6m replicated either three or four times (Table 2). Boric acid, TSP, and MP were applied to chickpeas and mustard as described for chickpeas in the previous season, but 60 kg ha^{-1} N as urea was also applied to mustard. The crops were grown rainfed (but there was no rainfall during the growing period) and weeded as required. Details of sowing time, chemical application, and harvest are given in Table 2. The net plot area at harvest for both crops was 6.48m^2, except for the crops of Bhawani Pathak and Dandapani Pathak who harvested their entire plots of mustard.

Lentil

A field experiment with four levels of B (0, 0.5, 1.0, 2.0 kg ha^{-1}) as boric acid and three levels of Zn (0, 2.0, 4.0 kg ha^{-1}) as zinc chloride, in factorial combination, was conducted at the

Table 2: **Timing of operations of successful [1] on-farm trials with chickpeas and mustard in 1998/99, Rajahar, Nawalparasi District, Nepal**

Farmer	Replications per farm	Date of sowing (1998)	Sprays to chickpea (DAS[2,3])	Sprays to mustard (DAS[2,4])	Harvest of chickpea (DAS[2])	Harvest of mustard (DAS[2])
Khagendra Pathak	3	23 Oct	95, 113	75	129	98
Ramakant Pathak	3	11 Nov	73, 81	73	107	98
Bhawani Pathak	3	13 Nov	75, 81	75	121	89
Narayan Dutta Lamichane	4	13 Nov	75, 93	75	116	91
Dandapani Pathak	4	6 Nov	68, 86	68	136	97

[1] Two of the seven on -farm trials failed ; [2] DAS = days after sowing ; [3] Bavistin and Endosulphan ; [4] Endosulphan

GLRP Rampur station in 1997/98. Lentil variety ILL-4605 was grown. Cultural details are given in Srivastava et al. (1999). At 107 DAS, apical shoot samples, including the top five pinnules, were sampled from selected treatments and oven dried at 70 °C to constant weight. The plant samples were analysed for B by optical emission spectrometry (Zarcinas and Cartwright 1983).

Pigeonpea

A field experiment was conducted at the GLRP Station, Rampur, in 1998/99. The experiment was conducted using a split plot design replicated four times with three pigeonpea varieties in main plots and three B treatments in sub-plots. The pigeonpea varieties were: ICPL 87 (short duration), Rampur Rahar 1 (RR1: medium duration), and Bageswari (long duration). The B treatments were: no B applied, 1 kg B ha^{-1} soil applied; and 1 kg B ha^{-1} soil application with an additional foliar application of 0.03% B solution at flowering time of each variety.

The experimental field was harrowed twice and levelled by tractor-drawn implements. Basal fertiliser was applied to all experimental plots as 40 kg ha^{-1} P_2O_5 and 20 kg ha^{-1} K_2O, as TSP and MP respectively. Soil applied B, as borax, was mixed with friable soil and evenly broadcast over designated plots. After hand broadcasting of TSP and MP on all plots, all fertilisers were mixed in the soil to a depth of 10 cm with a spade. The plot size was 3 x 4m and plant spacings were 50 x 40 cm for ICPL 87 and RR1 and 75 x 40 cm for Bageswari. Seed was sown in furrows 50 cm apart, for ICPL 87 and RR1, and 75 cm apart for Bageswari. Two seeds were sown per hill at 40 cm spacing on 25 July 1998, and seedlings were later thinned to one plant per hill. The plots were hand weeded at 46 DAS. A spray of 0.03% B, to give an additional 1.0 kg B ha^{-1} above the basal soil application, was applied to ICPL 87 and RR1 at 90 DAS and Bageswari at 189 DAS. At these times, Thiodan was also sprayed to protect against pod-boring insects. Plants were harvested at maturity of ICPL 87 (after several flushes of flowers and pods); RR1 at 165 DAS (16 January 1999); and Bageswari at 251 DAS (2 April 1999). The two central rows were taken for grain-yield determination. Where plants were missing from these inner rows, mainly as a result of waterlogging at the seedling stage, plants from border rows were used so that an even number of plants was sampled per plot.

Results and Discussion

In treatments omitting B at the GLRP Rampur station, chickpea plants showed B deficiency symptoms of 'little leaf' and tip yellowing from about 30 DAS and persisting to maturity. Absence of B also induced flower drop and, subsequently, poor podding (Srivastava et al. 1997). There were positive responses of chickpea to B in terms of yield increases in both seasons at Rampur, with maximum yield being reached in 1995/96 at 0.5 kg ha^{-1} B (Figure 1). There was also a significant Mo response in the first year, but no Mo response in the second year (Srivastava et al. 1997). Boron response appeared stronger in the first year than in the second year. Plants were limited by terminal drought stress in the first year, perhaps exacerbating the effect of B deficiency in limiting pod set. Other factors may also have been involved such as possible differences in availability of soil B between the experimental sites of different years (soil B levels not measured in 1995/96), and suppressive effects of other nutrients on B in the omission experiment (Srivastava et al. 1997). With the application of 3 kg ha^{-1} B, there was greater flower drop than at lower B application rates, suggesting a narrow range of B sufficiency and the danger of B toxicity at rates of 3 kg ha^{-1} B or above.

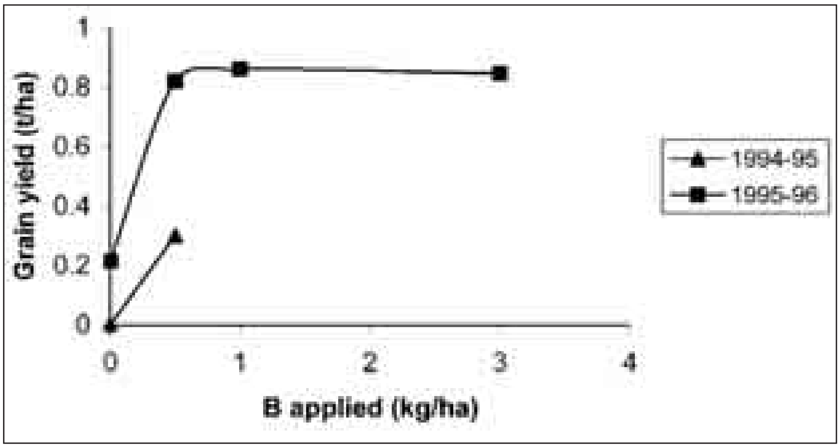

Figure 1: **Effect of application of B on grain yield of chickpeas in 1994/95 and 1995/96, Rampur, Chitwan Valley, Nepal**. Notes: in 1994/95 least significant difference (LSD) between treatments = 0.016 t/ha; in 1995/96 LSD for all treatments = 0.22 t/ha (mean value of 0, 0.15 and 0.3 kg ha^{-1} Mo treatments, as there was no significant effect of Mo treatment). Data derived from Srivastava et al. (1997).

In plots without applied B, there was clear development of B deficiency symptoms in lentils in 1997/98, from about 30 DAS (Srivastava et al. 1999). Chlorosis developed from the shoot tips, with a progressive reduction in sizes of younger leaves ('little leaf' symptoms). Eventually terminal buds died and the number of lateral branches increased, resulting in stunting of plants. These symptoms were most severe in introduced varieties, mainly 'ILL' introductions from ICARDA. Such symptoms were much less severe in local landraces of lentils such as Simul, Sindur, and Simrik (Srivastava et al. 1999). A similar effect was observed in chickpeas at the Rampur station, introduced chickpea lines, such as those from ICRISAT, had more severe B deficiency symptoms than 'local' varieties. Thus local varieties of chickpeas and lentils appear to have adapted to situations of low available soil B. According to the manifestations of symptoms, it appears that there are substantial genotypic differences in susceptibility to B deficiency, and thus scope for genetic improvement in ability to acquire B.

There was a more than ten-fold response of lentil grain yield to B, but with maximum yield reached at 0.5 kg ha^{-1} B (Figure 2). Grain yield also responded significantly to Zn application from 0 to 2 kg ha^{-1}, however, at the higher B rates there was a decrease in yield with increasing Zn from 2 to 4 kg ha^{-1} (Figure 2).

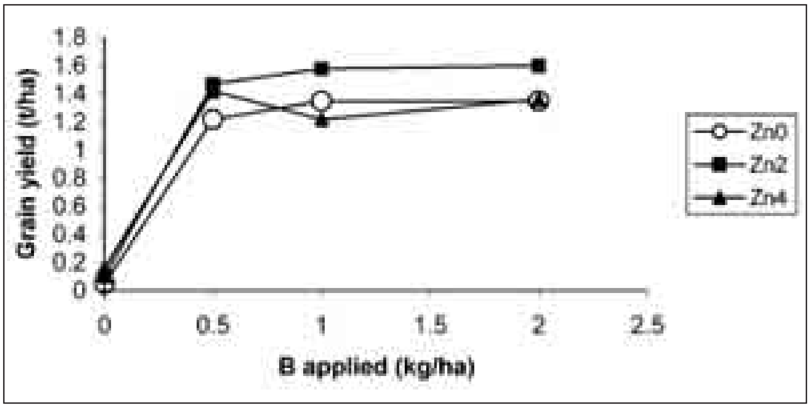

Figure 2: **Effect of application of B and Zn on grain yield of the lentil cultivar ILL-4605 in 1997/98, Rampur, Chitwan Valley, Nepal**. Note: Zn0, Zn2 and Zn4 = 0, 2 and 4 kg/ha Zn, respectively, LSD for all treatments = 0.20 t/ha. Data derived from Srivastava et al. (1999)

Significant responses in grain yield to B application were found in all genotypes of pigeonpea tested, and there was an additional response to foliar application of B (Table 3). However, even with maximum B application, yields were well below the potential yields of these varieties. This was because of poor physiological adaptation to this environment (ICPL 87), loss of plant stands through early waterlogging, and insect damage to flowers and pods. Nevertheless, despite the other constraints affecting yield, a clear response to B was apparent. The further increase in yield with foliar B application suggests that the optimum B level may not have been reached, and higher rates and frequencies of B application might

Table 3: **Grain yield (kg ha^{-1}) of three varieties of pigeonpea at three levels of B application, Rampur, Nepal, 1998 -99**

Variety	**B level (kg ha^{-1})**			
	0	**1 (soil applied)**	**1 (soil) + foliar spray**	**Mean**
ICPL 87	0	87	151	79
RR1	84	319	417	273
Bageswari	34	270	324	209
Mean	*39*	*225*	*297*	
	SE	LSD (0.05)		
Variety**	19.6	73.4		
Boron**	9.5	48.8		
Variety x boron**	23.8	68.1 across boron levels		
		28.2 across varieties		
CV (%) (main plot)	36.2			
CV (%) (sub-plot)	17.6			
** Significant at P < 0.01				

have increased yield levels beyond those presently obtained. In Bageswari, pod numbers per plant were also recorded and these increased with B treatment to the extent of 87, 140, and 154 pods/plant. Thus the impact of B deficiency on pod numbers is consistent with its general effect in legumes in causing flower and pod abortion.

At all B levels, RR1 had higher yields, consistent with its better adaptation to the Rampur environment, with respect to environmental factors in general and perhaps also with its ability to acquire B from B-deficient soil. Without B application, ICPL 87 could not form any pods. Despite low yield levels, these results show that B deficiency is limiting pigeonpea yield at this location. Further studies are needed to determine optimum rates, timing, and methods of B application to achieve maximum yields in different pigeonpea varieties. Further studies are also needed to understand the extent of genotypic differences in the response of pigeonpea crops to B.

In the on-farm trials with chickpeas in 1997/98, a significant response to B was only recorded in the fields of Khagendra Pathak (Table 4). There were indications of a B response in the fields of the other three farmers who harvested the trials but these did not reach statistical significance. However, it was noted that Vishnu Hari Ghimire applied compost and manure to the crop preceding the chickpea crop, and this may have contributed to the high yields but lack of B response. The chickpea yields of the other two farmers were low, indicating that other constraints to chickpea growth, such as excessive soil moisture for much of the growing period, may have masked any B response. No response to Mo was recorded in these trials (Table 4).

Large positive responses of both chickpea and mustard to B application were found in farmers' fields in 1998/99 (Table 5). The extent of the response was slightly larger in mustard, a crop known to be sensitive to B deficiency. It is clear that B deficiency is widespread across this region. The variation in response between farmers' fields may have been influenced by previous applications of organic manure, a common practice in the region. Soils with more organic matter appeared to be less prone to B deficiency, although a comprehensive analysis of this aspect was not undertaken in the present studies.

Initial soil analyses did not indicate any clear relationship between hot water soluble soil B levels and response of legumes to B application, although all soil analyses carried out indicated levels well below the reported critical level of 0.5 mg kg^{-1} B (Tandon 1993). The possibility of using plant tissue analysis to diagnose B deficiency was assessed. Figure 3 indicates the relationship between relative grain yield and B concentration in shoot tips of chickpeas at the vegetative stage. The B concentration at 80-100% yield is in the range of 15-20 ppm B, which can be considered to be the critical range of B concentration. This value corresponds with the critical value of 20 ppm B found in chickpea shoots at the pre-flowering stage by Sakal et al. (1990). Thus it appears possible to diagnose deficient, marginal, and adequate B concentrations in chickpeas. In lentils, the B concentration in shoot tips from plots without B was 5.7 ± 0.3 ppm. In plots with 0.5 kg ha^{-1} B but no Zn it was 26.7 ± 3.5 ppm and in plots with 0.5 kg ha^{-1} B and 2 kg ha^{-1} Zn it was 23.7 ± 1.2 ppm. Thus the critical value for B in shoot tips of the lentil cultivar ILL-4605 lies within the range 5-25 ppm. More detailed studies than provided by these preliminary analyses would be required to define critical B values of lentils definitively (Srivastava et al. 1999).

Table 4: **Effect of B and Mo application on grain yield (kg ha^{-1}) of chickpeas in farmers' fields in the Chitwan Valley, 1997/98 season**

Treatment	Farmer			
	Khagendra Pathak	Vishnu Hari Ghimire	Chandra Singh Chaudhary	Dhruba Lamichhane
Control	213	842	244	556
O.5 B	1,080	1,213	383	700
1.0 B	1,192	1,190	283	519
0.5 B + 0.15 Mo	1,148	1,289	297	517
1.0 B + 0.15 Mo	1,144	935	287	703
Significance [1]	P < 0.01	ns	ns	ns
LSD (0.05) [2]	189	-	-	-
CV (%) [3]	10.5	22.3	21.3	21.3

[1] Statistical significance of difference s between means , ns = not significant ; [2] least significant difference at P = 0.05; [3] coefficient of variation

Table 5: **Effect of B application on grain yields (kg ha^{-1}) of chickpeas and mustard in farmers' fields in the Chitwan Valley, 1998/99 season**

Farmer	Chickpea			Mustard		
	B applied (kg ha^{-1})		*% increase due to B[1]*	B applied (kg ha^{-1})		*% increase due to B[1]*
	0	1.0		0	1.0	
Khagendra Pathak	287	849	*196**	285	664	*133***
Ramakant Pathak	448	702	*57**	99	257	*160**
Bhawani Pathak	441	615	*39 ns*	46	181	*293 ns*
Narayan Dutta Lamichane	525	1,168	*122***	60	276	*361***
Dandapane Pathak	764	1,364	*79**	201	443	*120***

[1] Statistical significance of difference , ns = not significant; * = P < 0.05; ** = P < 0.01

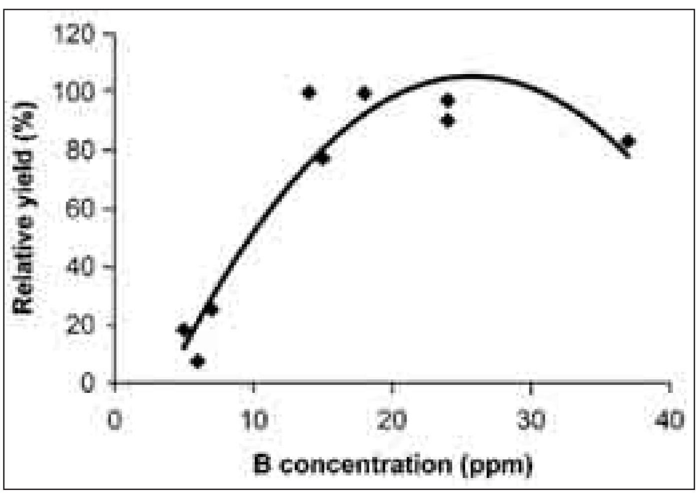

Figure 3: **Relationship between relative grain yield and B concentration in shoot tips of chickpeas grown at different B application rates in the field of Khagendra Pathak, Rajahar, Nawalparasi District, Chitwan Valley, Nepal, 1997/98**

To date, we have sporadic information, in time and space, that B is a major limitation to grain legumes, as well as other crops such as *Brassica* spp., in the Chitwan Valley. A systematic spatial analysis through geographic information system (GIS) analysis is required to determine the extent of B deficiency across Nepal. Plotting of soil extractable B levels is not enough, as we are unsure of the critical soil B levels as they apply to each crop and under different soil and climatic conditions. Relationships between extent of B response and the various soil and climatic factors that could affect B response need to be examined. Soil factors would, of course, not only include soil B level, but also other factors such as pH, soil organic matter, cation exchange capacity, and so on. To achieve this, more on-farm B response data are needed across representative soil and climatic zones. Outputs of such an exercise would allow mapping of probability and likely extent of a response to B for a range of crops (Bell 2004). This would then provide a basis for planning and implementing corrective measures.

Other micronutrients, such as Mo and Zn, also limit yield of grain legumes in Nepal, and thus the proposed GIS study should be comprehensive for all micronutrients suspected to be limiting. Further, the interaction between B and other nutrients, and various soil and climatic factors, needs better understanding in order to interpret the likelihood of B response.

Once the likelihood of B response is known, there are various options for overcoming the deficiency which are suitable for implementation by resource-poor farmers. These are primarily soil and foliar applications (Murphy and Walsh 1972) with the B application rates required (e.g., 0.5 kg ha^{-1} B for chickpeas and lentils, but perhaps more for pigeonpeas) being low enough not to commit resource-poor farmers to substantial investments in B fertiliser. The large genotypic differences in B response apparent in chickpeas and lentils at least suggest that breeding of B-efficient varieties is a longer-term option.

To extend this knowledge to farmers, a series of farmer-managed evaluations of B response is advocated. It is suggested that these be conducted in plots at an operational scale (similar plot sizes to those the farmer normally cultivates) divided between a B application treatment and no B application. This would have the effect of allowing farmers to assess for themselves whether B application is efficacious and demonstrate the effect to neighbouring farmers. It would also provide further feedback on B responsiveness for risk analysis of B response and on constraints to adopting methods of alleviating B deficiency.

If the value of grain legume cultivation is to be realised in Nepal, it is necessary to address systematically the micronutrient constraints to these legumes, which in the case of B at least can be severe. Increased legume cultivation is required to improve both soil health and human health. Adequate uptake of micronutrients by legumes is needed, not only to meet plant requirements but also to meet the consumption requirements of humans and their domestic animals (Welch and Graham 2002).

Acknowledgements

The authors thank the technical staff of the GLRP Rampur station for their assistance in carrying out field experiments at that location. We appreciate the cooperation of farmers in conducting on-farm trials during 1997/98 and 1998/99. This work was supported by the collaborative research programmes of the Nepal Agricultural Research Council (NARC) and the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT).

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Session 3

Soil Nutrient Management

Micronutrient Status of Soil and Response to Long-term Application of Farmyard Manure (FYM)

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Summary

In a long-term experiment carried out between 1967 and 2001 at Hisar, India, pearl millet (Pennisetum typhoides) and wheat (Triticum aestivum) were grown during summer and winter in sequence. The treatments consisted of application of farmyard manure (FYM) at rates of 15, 30, or 45 mg ha^{-1} during both seasons or either of the seasons. In addition to these treatments, an absolute control was maintained without any FYM in any of the seasons to give a total of 10 treatments. In addition two levels of nitrogen (N), 0 and 120 kg ha^{-1}, were added through urea (46% N) to both crops in 2000. Soil samples were collected from depths of 0-15, 15-30, and 30-45 cm and analysed for diethylene triamine pentaacetic acid (DTPA) extractable and total content of zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) as per standard procedures. Application of farmyard manure (FYM) significantly increased the DTPA extractable and total content of all the micronutrients studied at all soil depths. However, the rate of increase was greater in the surface layer than at lower depths. The time of application of FYM also influenced the content of micronutrients in the soil. The rate of increase of DTPA extractable and total content of all micronutrients was higher when FYM was applied in the winter season compared to the summer. Application of nitrogen (N) did not show any significant effect either on DTPA extractable or on total content of the micronutrients.

Introduction

The unabated use of high analysis chemical fertilisers together with high-yielding varieties of crops and intensive agricultural practices have led to a decline in the capacity of soils to supply micronutrients, resulting in sporadic appearances of deficiency. Furthermore, overdependence on chemical fertilisers and extensive tillage practices have led to deterioration of the soil's physico-chemical properties (Haynes et al. 1991). Thus there is an emerging need to revive the age-old practice of application of farmyard manure to retain the productive nature of soil and also to supplement many essential plant nutrients, especially micronutrients. The periodic application of farmyard manure (FYM) has been reported to improve many physico-chemical properties of the soil, viz., improvement in soil structure, increased water-holding capacity, and enhanced biological activity (Schjønning et al. 1994; Maheswarappa et al. 1999). Farmyard manure is also a good reservoir of nutrients, adding to fertility build up in the soil. It is known to improve soil productivity on a sustainable basis over a long period (Flaig 1975). The application of FYM to enhance micronutrient availability is of special significance for intensive agriculture with high analysis fertilisers, as it is closely associated with the dynamics of nutrient availability in soil (Stevenson 1982; Bhadoria et al. 2003). However, with all these known benefits of FYM, information on its long-term effects on soil micronutrient content is rather limited. The objective of this experiment was to study the impact of dose and time of FYM application in combination with N levels on extractable and total content of micronutrients in the soil after long-term FYM application to a pearl millet-wheat cropping sequence grown on a coarse loamy (Typic Ustochrepts) soil at the experimental farm of the Haryana Agricultural University, Hisar, India.

Materials and Methods

Field experiment

A long-term field experiment on the application of FYM and N to a pearl millet-wheat cropping sequence was established in 1967 at the research farm of the Department of Soil Science, Haryana Agricultural University, Hisar, India. The experiment is still continuing. The experimental site is located at 29°16' N latitude and 75°7' E longitude in northwest India. The climate of the area is semi-arid with a mean annual rainfall of 443 mm and mean annual temperature of 23.9°C. All agronomic practices were followed and weeding carried out manually. Treatments for this study consisted of three doses of FYM – 15, 30 and 45 mg ha^{-1} (Table 1); and three modes of application – in every summer season (June), in every winter season (October), or in both seasons. In addition to these treatments, an absolute control was maintained without any FYM in any of the seasons. This made the total number of treatments 10. These ten treatments (3 FYM levels each with 3 modes of application + 1 FYM control) were assigned in main plots and each main plot was divided into two sub-plots (10 x 6m) receiving 0 or 120 kg N ha^{-1} applied through urea to both crops.

Table 1: **Average micronutrient composition of FYM applied during the experiment**

Element	Range (mg g^{-1})	Mean
Zn	50 - 66	57
Fe	2128 - 2385	2214
Mn	25 - 32	28
Cu	200 - 267	239

Soil sampling

The experiment was carried out in a split-plot design with four replications. Soil samples were collected from depths of 0-15, 15-30, and 30-45 cm after harvesting the wheat crop in May 2001. Five cores collected from each treatment plot were mixed thoroughly and a composite sample was taken. Soil samples were air dried and passed through a two mm sieve for further analysis.

Analysis of soil samples

Total micronutrients in soil

For total concentration of micronutrient cations, 2g of soil was digested in aqua regia (HNO_3 and $HClO_4$ in 3:1 ratio), diluted with double deionised water, and then filtered through a Whatman No.40 filter paper. The total concentrations of zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) were measured using an atomic absorption spectrophotometer (Model-Varian Spectra AA 20 Plus).

DTPA extractable fractions of micronutrients

Soil samples were also analysed for extractable contents of micronutrients in soil according to the DTPA extractable procedure (Lindsay and Norvell 1978). The DTPA extractable fractions of Zn, Fe, Mn, and Cu were measured using an atomic absorption spectrophotometer (Model-Varian Spectra AA 20 Plus).

Statistical Analysis

Analysis of variance (ANOVA) was carried out using the split plot design method and critical difference (CD) was calculated on soil data for treatment means at 0.05 probability.

Results and Discussion

Effect of rate of farmyard manure application

There was a significant increase in DTPA extractable Zn in the soil with increasing dose of FYM application (Table 2). The increase in DTPA extractable Zn may be attributed to slow release of Zn from FYM after mineralisation and its chelating effect in maintaining a regular supply of Zn (Gupta et al. 2000). Compared to the control treatment, the increase in DTPA extractable Zn was also noticed in the sub-surface layers, i.e., 15-30cm and 30-45cm, indicating that some Zn released from FYM may have leached down to the lower layers along with dissolved carbon. At every successive dose of FYM, the total Zn content of the soil increased significantly. Kher (1983) also reported that the total Zn content of soil increased with the addition of FYM as a result of the mineralisation of organic forms of Zn present in the FYM. The total Zn content exhibited the same general trend as DTPA extractable Zn at all soil depths (Table 3).

Application of increasing doses of FYM also increased the DTPA extractable Fe in the soil significantly (Table 2). As with Zn, the highest content of DTPA extractable Fe was recorded with 45 mg FYM ha^{-1} and it was significantly higher than with the application rates of 15 and 30 mg ha^{-1}. The increase in Fe content at the highest rate of FYM application was more than twice that of the control treatment. A similar effect was observed on the total Fe content in the soil (Table 3). Although the DTPA extractable Fe and total Fe exhibited similar trends at all soil depths, both forms of Fe showed a greater increase in the surface layer than at lower soil depths. Hegde (1996) also reported a significant increase in availability of extractable Fe content in soil apparently due to the supply of additional Fe through organic matter sources (Nambiar and Abrol 1989).

Total and DTPA extractable Mn and Cu (Tables 2 and 3) in soil showed the same trend as Zn and Fe. The highest DTPA extractable Mn and Cu were observed at the highest rate of FYM application. Sub-surface layers (15-30cm and 30-45cm) of soil also showed an increase in total and DTPA extractable Mn and Cu, but the rate of increase was less pronounced than in the surface layer. Build up of organic matter under continuous manuring may result in higher DTPA extractable and total micronutrient content in soil. Swarup (1984) reported that incorporation of manures brought about a marked improvement in the availability of native and applied micronutrient cations (Zn, Fe, and Mn) in soil. These elements are known to form stable complexes with organic ligands that decrease their susceptibility to adsorption, fixation, and/or precipitation in soil; addition of FYM may have resulted in the formation of such metal-organic complexes of higher availability.

Time of application of farmyard manure (FYM)

The time of application of FYM also influenced the extractable content of micronutrients in the soil. The rate of increase in total and DTPA extractable Zn, Fe, Mn, and Cu contents (Tables 2 and 3) was higher when FYM was applied in winter than when it was applied in summer. This could be because when FYM was applied only in summer two crops were grown

Table 2: **Effect of different doses and time of FYM application with and without nitrogen fertiliser on DTPA extractable fractions (mg kg^{-1}) of micronutrients at different soil depths**

	Soil depth (cm)											
	Zn			**Fe**			**Mn**			**Cu**		
Treatments	**0-15**	**15-30**	**30-45**	**0-15**	**15-30**	**30-45**	**0-15**	**15-30**	**30-45**	**0-15**	**15-30**	**30-45**
Time of application												
Summer	2.05	0.85	0.52	8.70	6.18	5.79	6.25	5.26	4.57	0.76	0.66	0.55
Winter	2.04	0.92	0.71	9.90	6.31	5.85	6.97	5.58	4.45	0.76	0.56	0.59
Both	2.60	0.97	0.73	11.67	8.52	7.88	10.0	6.45	5.20	0.85	0.75	0.65
CD (P=0.05)	0.04	0.02	0.03	0.03	0.04	0.03	0.04	0.09	0.05	0.02	0.01	0.02
Rate of FYM (mg ha^{-1})												
0 (Absolute	0.63	0.51	0.49	5.31	4.60	3.95	3.31	3.25	3.19	0.42	0.39	0.38
15	2.05	0.83	0.59	8.19	5.79	5.63	5.50	4.69	4.24	0.74	0.60	0.54
30	2.20	0.93	0.63	9.83	7.25	6.51	7.87	5.91	4.61	0.79	0.63	0.59
45	2.46	0.98	0.74	12.25	8.10	7.38	9.85	6.69	5.38	0.85	0.74	0.67
CD (P=0.05)	0.04	0.02	0.03	0.03	0.04	0.03	0.04	0.09	0.05	0.02	0.01	0.02
N Dose (kg ha^{-1})												
0	2.43	0.81	0.62	8.81	6.38	5.82	6.59	5.12	4.29	0.70	0.59	0.54
120	2.44	0.81	0.61	8.97	6.42	5.91	6.67	5.16	4.42	0.70	0.59	0.55
CD (P=0.05)	ns	ns	ns	0.03	0.02	0.02	0.04	ns	0.03	ns	ns	ns

Table 3: **Effect of different doses and time of FYM application with and without nitrogen fertiliser on total micronutrient status (mg kg^{-1}) at different soil depths**

	Soil depth (cm)											
	Zn			Fe			Mn			Cu		
Treatments	**0-15**	**15-30**	**30-45**	**0-15**	**15-30**	**30-45**	**0-15**	**15-30**	**30-45**	**0-15**	**15-30**	**30-45**
Time of application												
Summer	36.07	32.23	27.35	859.0	760.6	469.9	188.7	178.3	161.2	14.54	13.94	11.79
Winter	36.73	32.26	27.58	860.3	764.6	667.5	190.6	177.8	162.1	15.79	14.04	11.83
Both	46.25	37.94	33.17	915.9	817.0	709.6	215.3	189.0	168.6	17.56	16.18	13.27
CD (P=0.05)	0.86	1.06	0.96	0.75	1.27	1.14	0.60	1.19	0.79	0.80	0.77	0.65
Rate of FYM (mg ha^{-1})												
0 (Absolute	26.92	24.06	20.98	754.7	669.9	496.9	170.3	170.3	149.5	11.82	10.35	10.12
15	33.76	29.75	25.45	843.2	751.7	626.1	185.7	171.5	159.9	14.63	13.52	11.38
30	39.76	34.44	32.22	879.3	776.1	671.8	189.8	179.9	163.5	15.92	15.03	12.16
45	45.54	37.91	33.41	912.7	814.4	742.7	210.7	193.1	168.5	17.34	15.62	13.36
CD (P=0.05)	0.86	1.06	0.96	0.75	1.27	1.14	0.60	1.19	0.79	0.80	0.77	0.65
N Dose (kg ha^{-1})												
0	35.16	30.62	26.27	840.5	746.3	614.6	190.0	178.4	159.9	14.77	13.62	11.56
120	37.83	32.63	28.27	854.4	759.8	654.2	192.4	179.1	160.8	15.08	13.33	11.94
CD (P=0.05)	0.65	0.92	0.77	0.93	0.81	0.77	0.76	ns	0.84	ns	ns	ns

before soil sampling was done; FYM was added for the first crop, pearl millet, and the following wheat crop used the residual nutrients. In plots where FYM was only applied in winter, soil sampling was done after taking a single crop, wheat. The micronutrient content value was significantly lower following single application of FYM compared to application of FYM during both winter and summer seasons. Application of FYM during both seasons increased total and DTPA extractable fractions of Zn, Fe, Mn, and Cu in different soil layers compared to application of FYM in one season alone or not at all.

Nitrogen dose

There was no significant difference in DTPA extractable or total content of Zn, Fe, Mn, and Cu at any of the soil depths in response to application of N fertilisers (Tables 2 and 3). However, the N fertiliser application increased the production of crops, thereby leaving more root biomass in soil for mineralisation. It is possible that the higher root mass in the soil and its subsequent decomposition might have influenced the organic carbon status of the soil along with the DTPA extractable and total availability status of Zn, Fe, Mn, and Cu to some extent, as revealed by the organic carbon status and available micronutrient status relationship curves.

Relationship between organic carbon and micronutrients

There was a general relationship between organic carbon (OC) and DTPA extractable Zn, Fe, Mn, and Cu content (Figure 1) with different R^2 values. The same trend was apparent for OC and total Zn, Fe, Mn, and Cu (Figure 2). In other words, DTPA extractable and total micronutrient content of soil increased with increasing organic carbon content of soil, which was governed by the application of FYM.

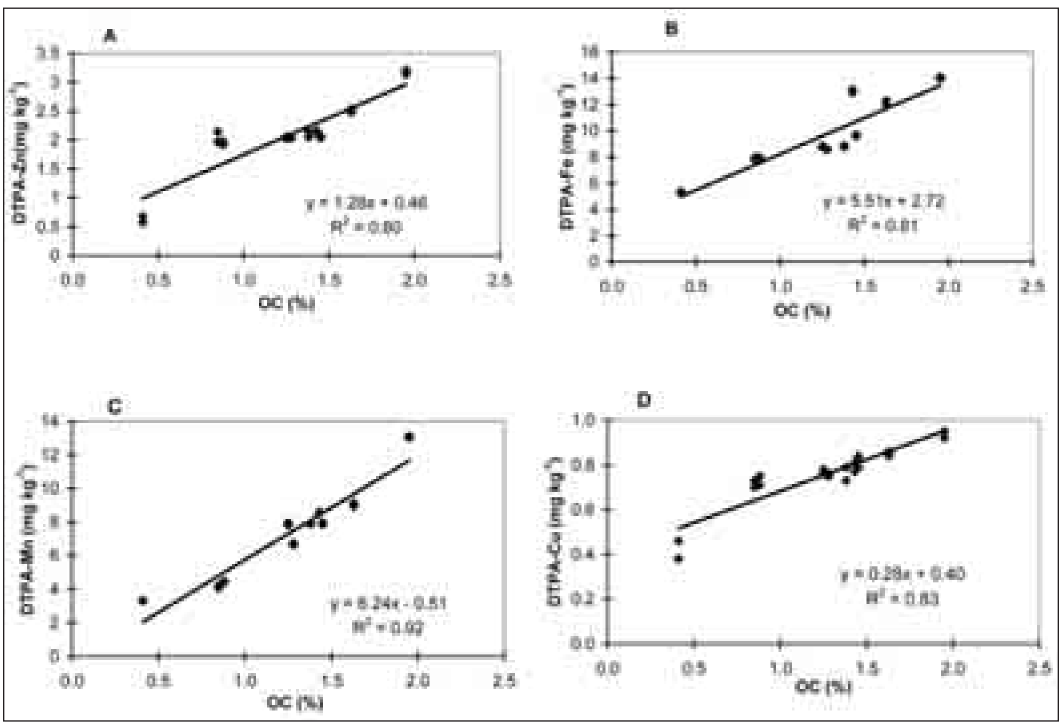

Figure 1: **Relationship between organic carbon (OC) in soils and DTPA extractable Zn, Fe, Mn, and Cu**

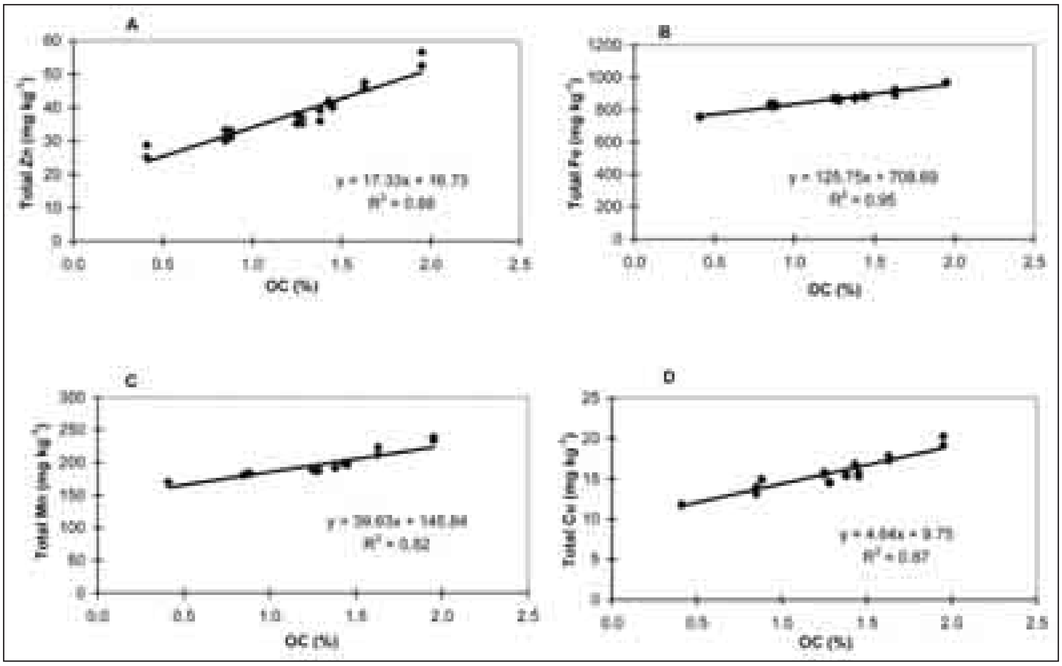

Figure 2: **Relationship between organic carbon (OC) in soils and content of total Zn, Fe, Mn, and Cu**

Conclusions

The results show that both dose and mode of application of FYM in the pearl millet-wheat cropping sequence significantly affect the DTPA extractable fraction and total availability of Zn, Fe, Mn, and Cu in soil. Application of 45 mg ha^{-1} FYM led to the highest values of micronutrients. Winter application of FYM was relatively better than summer application. Application during both seasons was much better than application only once in either of the seasons. But whether this should be recommended depends on economic considerations and availability of FYM.

Acknowledgements

I wish to thank Professor Bal Ram Singh and Dr. B.G. Shivkumar for revision of the manuscript, their comments and advice greatly enhanced this article.

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Building Contextual Knowledge: the Interface between Local and Scientific Knowledge

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Abstract

The purpose of this paper is to discuss the gap between the local knowledge of marginal farmers and scientific knowledge, based on cases from the Himalayan region. Local knowledge and local farming practices do present some solutions to micronutrient problems, but as the understanding of cause and effect is unclear, the solutions are suboptimal. Soil nutrients and human nutrition are described by people in terms such as 'power',' hot' or 'cold'; terms that do not reflect the underlying chemistry or biological processes. Equally, scientific knowledge, with its tradition of reductionist research, often has problems addressing the complexity of marginal farming systems. The knowledge gap on this side may relate to the physical environment (multiple micronutrient deficiencies), the bottlenecks of the farming systems, and the farmer/extension interface. The term ***contextual knowledge*** *seeks to combine the two sets of knowledge, local and scientific. All knowledge systems are dynamic, and the challenge is to develop strategies to improve scientific knowledge among farmers and contextual knowledge among scientists. An important step is to find a new orientation for the agricultural extension systems. Some of the new developments in Nepal may be indicators of such a change.*

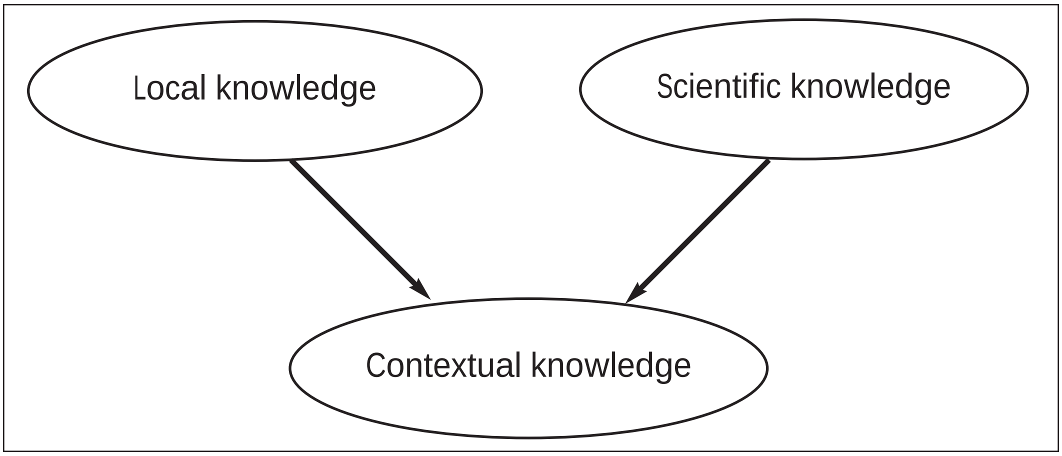
Introduction

The term 'local knowledge system(s)' (LKS) is one of several terms describing the sets of knowledge found among local people in a given region. Other terms are 'indigenous knowledge' or 'rural people's knowledge'. In my opinion the term 'local' is preferable to the term 'indigenous', as the latter may blur or be used to romanticise the concept. Although apparently easy to comprehend and define, LKS should be seen as dynamic, culturally and socially constructed, and often unevenly distributed between the 'locals' (Scoones and Thompson 1993).

Scientific knowledge system(s) (SKS) can be seen as the opposite, a positivist construction of the existing, established scientific frontier of knowledge. The traditional structure for agricultural modernisation is based on a top-down model of 'transfer-of-technology' (TOT) (Blaikie et al. 1997) which often fails because of its inability to match a complex social and natural reality – in the words of Arun Agrawal (1995) because:

> *"..the so called technical solutions are just as firmly anchored in a specific milieu as any other system of knowledge."*

When I suggest the term 'contextual knowledge', it is not with the ambition to create a new buzzword, but merely to provide a basis for discussion of knowledge systems relevant to micronutrient problems in agriculture. Contextual knowledge will, compared to a standard SKS, provide a rich comprehension of the complexities of the natural environment, the farming systems, and the social and cultural fabric in a given location – at least rich enough



to contribute effectively to sustainable, self-perpetuating changes in nutrient management at farm level. In contrast to LKS in general, contextual knowledge about nutrient management will be a farmer's conceptualisation enabling the same sustainable, self-perpetuating changes referred to above. In addition, transfer of technology and knowledge is a necessary precondition for IPNM (integrated plant nutrient management) with respect to micronutrients, and thus this paper will conclude with a discussion of how such a process can be brought about.

Strong and Weak Sides of Local Knowledge Systems

Local knowledge systems have strength in that they focus on the whole farming system and how it relates to the natural conditions as well social systems on a trial-and-error basis. According to the promoters of LKS, such as Shiva (1991), their ability to handle complexity distinguishes them favourably from SKS.

LKS often have local soil classification systems that systematise the major relevant divisions from a local perspective, with colour and texture as major indicators. On the basis of this classification, farmers have empirically-based ideas of compost requirements and similar agricultural issues. Examples can also be found of local agricultural practices that address micronutrient disorders. In Arun Valley in Eastern Nepal, some farmers drain their newly-planted paddy fields if the plants turn yellow and red. This permits temporary oxidisation and release of zinc and other micronutrients, the fields are flooded again when the plants regain their green colour. However, some farmers add urea; and this demonstrates how LKS targets symptoms rather than causes.

The weaknesses of LKS are, of course, their limited specificity – as demonstrated by DeWalt (1994); it is easy to find cases where LKS have not been able to handle ecological complexity. One of DeWalt's examples, a pest problem in Honduras referred to as 'lagosta', required advanced laboratory equipment to arrive at an explanation and this was essential for developing protection measures. Without this help, LKS left the locals with no ability to cope.

In general, micronutrient disorders fall into this category. Although visual symptoms in plants can be used diagnostically, micronutrient disorders often produce symptoms so complex or so subtle that they are difficult to deal with without chemical testing of soils and/or plant tissue. Once disorders are diagnosed, correction may require application of purchased inputs, and this can only be done if one has the knowledge about what to buy. LKS response to nutrient problems may be passive; for example growing local, non-susceptible varieties (and accepting lower yields), or it may be fatalistic (live with low yields and malnutrition without knowing what to do).

Perceptions of Nutrients and Fertilisers

In LKS, soil nutrients and fertility are normally described in general terms of ‘power’ and ‘heat’ which has clear limits when it comes to balances between different nutrients. The farmers will often not be able to distinguish between plant symptoms relating to pests or to nutrient imbalances.

Hill farmers in Nepal generally divide fertilisers into three groups.

‘Mal’ – compost/farm-yard manure (FYM) is supposed to be the real thing. Locally, there will often be a ranking of ‘mal’ according to the animal species producing it. As a rule of thumb, small animals (bats, chickens, goats) provide the best manure, large animals (horses, mules, buffaloes) produce poor manure (Tamang 1993).

‘Desi mal’, or simply ‘fertiliser’, refers to chemical fertilisers. The fertilisers available for farmers in the hills are predominantly urea, DAP (di-ammonium phosphate), and MOP (muriate of potassium); potassium is rarely used (Basnyat 1999). Use of commercial fertilisers in Nepal is the lowest in South Asia. All too often farmers use the fertilisers available with only limited ideas of the needs of the plant. Hill farmers are often reluctant to use chemical fertilisers because of the cost, and the fact that according to their experience using them leads to acidification of soils.

‘Vitamin’ is a term used to refer to anything else added to the soil or sprayed on the plants to make them appear healthy. By and large, ‘vitamins’ are applied in a haphazard manner. They include a number of single- or multi-element micronutrients, expensive and/or harmless plant extracts, as well as other growth conditioners. Multi-element micronutrient fertilisers found in Nepal unfortunately often contain nitrogen, and this can enforce greening of leaves, concealing the actual deficiencies of the plant.

One simplistic assumption about integrated plant nutrient management (IPNM) strategies and LKS is that compost/FYM will provide all the micronutrients that are needed, hence IPNM becomes a mix of chemical macronutrient fertiliser and compost/FYM. However, even if large amounts of compost/FYM are available, regional deficiencies of boron (B) or other elements may be so severe that the concentration of nutrients in compost, as well as in the soil, is too low to make up for the deficiencies, as shown in a study from the Middle Hills by Andersen and Sandvold (2000) (Figure 1).

The quality of compost/FYM is extremely variable. Lewis (1979) described how there were clear visual symptoms of Zn deficiency in the mid hills despite large applications of compost/FYM, and he suggested that Zn was bound up in organic complexes.

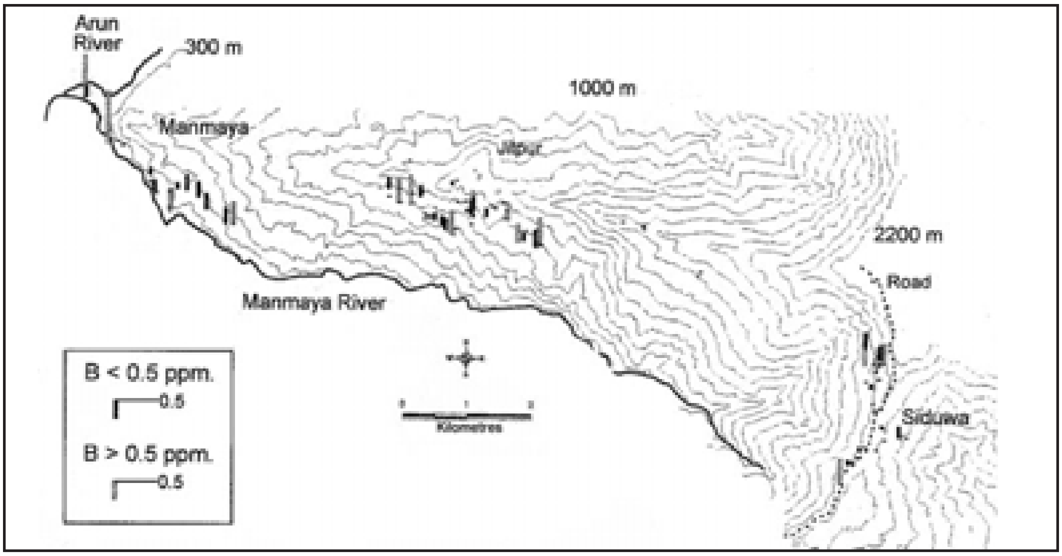


Figure 1: **Uniform pattern of boron deficiency in cultivated soils in the Arun Valley, Eastern Nepal (after Andersen & Sandvold 2000)** Note: Not even the most substantial amounts of compost/FYM applied to the soils in Siduwa village are sufficient to raise the concentration above deficiency level

Farmers may have other reasons for applying compost/FYM than providing nutrients. Using hand tools and draught animals that are often weak, it is important for farmers to keep the soil tillable, although it means maintaining the organic matter level at a higher degree than would be optimal for the availability of nutrients. Annual or biannual applications of as much as 20-30t FYM/ha have been observed particularly for potato or wheat cultivation at higher altitudes.

Scientific Knowledge

The importance of single elements for plant growth is a scientific discovery that dates back to the 1820s and 1830s, when the French scientist, Theodore de Saussure, and German scientists laid the basis for what later became known as the 'Law of the Minimum'. According to van der Ploeg et al. (1999), the original thoughts were clearly expressed by Carl von Sprengel (1828) and not, as widely believed, by Justus von Liebig. Scientific progress led to production of chemical fertilisers, which were improved through the use of rock phosphate and potassium. Gradually, scientific knowledge has progressed and now 17 elements are recognised as nutrients that are required by all higher plants (Welch 1995). Eight of these are the essential micronutrients boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn). Although a great deal of research is still needed, much is known about the requirements of plants for these elements, how they are affected by other growth parameters, and how interactions occur between various elements.

In this respect, it can be said that SKS have accumulated considerable knowledge about many issues concerning plant nutrients. Still, SKS are characterised and limited by certain important factors: firstly, the reductionist traditions in research (DeWalt 1994), and secondly the strong tradition of top-down approaches in the dissemination of research results and recommendations.

There are numerous examples of the problems of reductionism including recommendations to use chemical fertilisers in areas where they are inaccessible to farmers, to focus on labour-demanding compost-making methods in areas short of labour, and so on. Plant breeding, research on micronutrient issues is also at risk from reductionist approaches. Few, if any, breeding programmes address the multiple soil micronutrient deficiencies which most marginal farmers face in a systematic manner.

Much of the criticism of the Green Revolution (GR) highlighted what were perceived as reductionist solutions to complex problems, biased towards yields, profits, and NPK fertilisers (Shiva 1991). Of course, the researchers behind the GR are not at a stand-still. The visions from Conway's (1997) 'doubly green revolution', with their emphasis on environmental and social sustainability and new scientist-farmer partnership approaches, are probably supported by the majority of the Consultative Group on International Agricultural Research's (CGIAR's) researchers – at least in theory. Still, traditions concerning how good research is to be carried out are strong and difficult to change, as they dominate among both peer reviewers and bodies funding research.

The Traditional Top-down Extension System

The top-down structure in the traditional national agricultural extension system can be described briefly as follows: national or international research personnel carry out controlled trials which serve as a basis for development of 'recommendations'. The advice may be blanket recommendations or detailed suggestions for specific crops, soils, or regions. Next, the national authorities pass on this advice to a system of extension officers, who in turn pass it on to the farmers. Finally, the farmers adopt or reject the technology recommended.

Although various attempts have been made in reference to on-farm trials, farmers' groups, and other participation-oriented approaches, the top-down knowledge transfer structure predominates in Nepal as in many other countries. The problem is that this approach does not work, because it is based on ideal conditions that are not found in marginal farming areas.

International research does not always come up with relevant results for context-specific situations. National research bodies have neither the capacity to verify the suitability of international research results, nor to perform sufficient national research to meet the needs of local farmers. In the field of micronutrients, NARC in Nepal has only issued recommendations on the use of zinc sulphate for lowland rice and application of borax to winter wheat and cauliflower.

The resources in terms of extension officers available are normally far from satisfactory; in reality, farmers have little or no interaction with extension officers. Training of extension officers in Nepal is mostly inadequate; they have few resources and their work is subject to frequent changes in policies (Blaikie & Sadeque 2000). Evidence from the field suggests that in eastern Nepal few farmers are in regular contact with extension officers (Andersen 2000).

In theory, blanket recommendations and wide-ranging extension systems are sufficient for the intensively irrigated plains, whereas marginal, rainfed farming areas present a complexity that requires intensive agricultural extension inputs, with more officers and more site-specific recommendations than in the plains (Dobermann & White 1999; FAO/IFA 2000). In practice, the farmer/extension officer balance tends to be the opposite, leaving marginal farmers with an information gap.

Building Contextual Knowledge

In scientific knowledge systems, the development of contextual knowledge about micronutrient issues begins with the establishment of an in-depth understanding of local environments and the farming systems operating in them. One pertinent issue is the 'mapping' of soil characteristics (Andersen 2002). Mapping is a basic requirement for establishing whether or not there are spatial patterns that may impact the choice of strategies. It is often assumed that mountains and other upland areas exhibit a highly complex pattern of micronutrient disorders, meaning that blanket recommendations are difficult or impossible to issue (Dobermann and White 1999; FAO/IFA 2000). As shown in Table 1, this is not necessarily the case.

Table 1: **Micronutrient content in soil samples in three studies from the Himalayas (After Andersen 2002)**

	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

Mapping from three different areas indicates that there are some spatial patterns that could be studied for the purpose of developing general strategies for the Himalayan region. The frequencies of high and low values are basically the same in all three studies. Zinc deficiency is widespread, but there are also a small but notable number of sites with high Zn values, and about half the soils contain satisfactory amounts of this element. The spatial distribution of these deficient and high content sites is patchy and partially controlled by geology (Figure 2). Therefore, it will probably not be feasible to recommend the use of Zn fertilisers on a general basis in hill areas; recommendations for use should be based on soil testing and/or visual symptoms, and of course on a crop basis.

Application of B-added fertilisers should be considered as a general recommendation, as the pattern appears to be one of uniform deficits. B toxicity may build up in irrigated lowland areas, but is not found in any of the three studies mentioned here. B-supplemented fertilisers may be a better option than adding pure borax or boric acid, as the major technical problem appears to be to spread it uniformly in order to avoid toxicity. Unfortunately, in general there are no B-supplemented fertilisers available to Nepalese farmers.

Some general questions about diagnosing micronutrient disorders also need addressing. Chemical analyses of soil samples are in theory available at heavily subsidised rates for many farmers, including marginal hill farmers in Nepal. In practice, few individual farmers use the service, and even fewer use the existing options for testing for micronutrients. Again, this underlines that transfer of knowledge is needed to improve micronutrient balances.

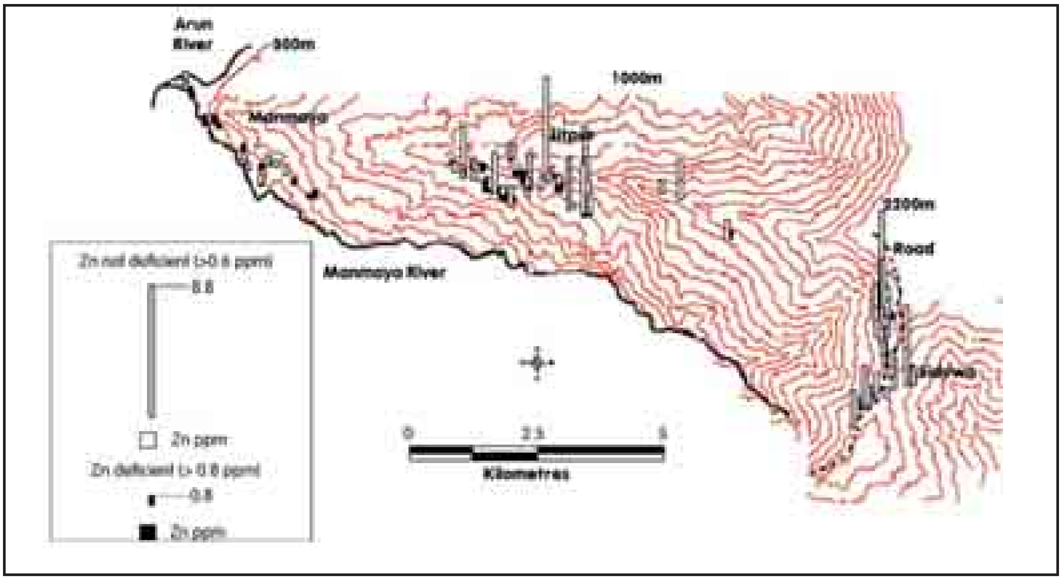


Figure 2: **Diethylene triamine pentacetic acid (DTPA) extractable zinc from soil samples (from Andersen 2002).** Note: The light bars indicate no deficiencies, black bars show deficient samples

Local knowledge systems will often use concepts that can be linked to visual symptoms of micronutrient disorders. Research on local conceptualisations of plant symptoms could be one of the first building stones for development of contextual knowledge. The advantage of visual symptoms for diagnosis is that they are cheap or free, and can also be used for a semi-literate population, using photographic information.

Public-private Partnerships: A New Model Evolving?

The criticism of traditional technology transfer does not imply that agricultural research is not important. Nor should it be implied that the state should not play a role in the dissemination of agricultural research and development (R & D). The crucial question is how to address the information gap between the present system and farmers in relation to issues related to plant nutrition and micronutrients.

Some recent developments may be a sign of new strategies developing. The Fertilizer Unit at the Ministry of Agriculture and Cooperatives issued a handbook in Nepali on fertilisers and plant nutrition in 2003; similarly the Soil Testing and Service Section (STSS) of the Department of Agriculture issued a translation of a Japanese handbook on vegetable production and plant nutrition. The latter is richly illustrated with pictures of visual symptoms of nutritional disorders, unfortunately mainly for crops that are important in Japan.

The publications have their shortcomings. They do not provide any general recommendations about what to do about micronutrient disorders once they are identified. However, they are a step forward in terms of naming and describing the problems, and furthermore, their target group includes fertiliser traders and other private actors in the agricultural sector.

In the old technology transfer regime, agricultural inputs in Nepal were supplied by the Agricultural Inputs Corporation (AIC), and private sector involvement was not organised. With liberalisation of the fertiliser market, steps have been taken to establish a new quality control system, as well as training and certification of private fertiliser traders. The new policy offers challenges, but also possibilities, because fertiliser traders and representatives of farmers' cooperatives represent some of the real interfaces between farmers and technology.

Other examples of methods of transferring knowledge should be considered: improvement of school curricula, informal education, pamphlets with pictures of visual symptoms, and suggestions about cultivation practices accompanying seeds, fertilisers, and micronutrients. The focus must be on strategies that do the following:

- identify the micronutrient issues relevant in the local context;
- suggest solutions that are feasible in the local context;
- address multiple, relevant communication interfaces with farmers; and
- stimulate the development of self-perpetuating experimentation and knowledge building among farmers.

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Commercial Fertilisers and Their Quality Control in Nepal

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Abstract

In Nepal, the fertiliser trade was completely under government control until 1997 and the Agriculture Input Corporation (AIC) had sole responsibility for purchasing and distributing quality chemical fertilisers. The total fertiliser supply was met by imports, and His Majesty's Government of Nepal (HMGN) provided price and transport subsidies to support farmers. As the demand for fertiliser grew, the need for subsidy allocations also grew and the government found it increasingly difficult to afford, resulting in shortages of fertiliser during the main cropping season. To overcome the problem, HMGN deregulated the fertiliser trade in November 1997 and phased out the price subsidies. The deregulation also removed AIC's monopoly in the fertiliser market.

After deregulation of the fertiliser trade, quality control became the major government responsibility. The government promulgated the Fertiliser (Control) Order 1997 under the Essential Commodity Act 1961 and developed the Fertiliser Guideline 1999 using the authority provided by the order. The order and guidelines provided a specific code of conduct for manufacturers, importers, and dealers to ensure the quality of fertilisers. So far, the government has approved the specifications of 27 commercially traded inorganic fertilisers, including 10 micronutrient fertilisers. It has also registered seven organic and biofertilisers. Quality control mechanisms have been developed up to district level by appointing fertiliser inspectors in each district. To ensure the supply of quality fertilisers, a National Fertiliser Policy was developed in 2002 and promulgation of a Fertiliser Act is in process.

In Nepal, the flow of multi/micronutrient fertilisers has been increasing in recent years. Around 15 per cent of farm households were applying fertilisers containing secondary and micronutrients in 2002. Several such fertilisers are available in the market without proper labelling, but with attractive packaging and advertisements. The quality control mechanism for these fertilisers is not efficient. Most of them are applied to soil and crops without testing the crop requirements. These activities may produce adverse effects on both soil fertility and crop yield. Therefore, it is necessary for the government and other agencies concerned to make farmers aware of the correct way to use multi/micronutrient fertilisers.

Background

Agriculture is the largest sector in the Nepalese economy. Fertilisers (organic and inorganic) are inevitably needed to sustain crop productivity in intensive agriculture and to meet the increasing demand for food for the growing population. Farmers in Nepal have been using organic matter such as farmyard manure, compost, and forest litter as fertiliser for their crops since time immemorial.

Chemical fertilisers were first introduced in Nepal in 1952. There was a slow growth in fertiliser use until the 1960s. With the establishment of the Agriculture Input Corporation (AIC) in 1966, a public sector enterprise under the Ministry of Agriculture (MOA), the consumption of fertiliser started rising. The government gave AIC the responsibility for procuring, storing, and distributing fertilisers in the country. Furthermore, in order to protect farmers from price uncertainties in the world market and to keep the price at an affordable level, the government established a uniform national price for fertilisers by providing price and transport subsidies to the AIC from 1972. As the demand for fertiliser grew over time, the need for subsidy allocations grew with it, and it became increasingly difficult for the government to afford the subsidies. This created shortages of fertiliser during the main cropping season.

In view of the above, His Majesty's Government of Nepal (HMGN) deregulated the fertiliser trade in November 1997 and phased out price subsidies. Recognising the need for quality control in the deregulated market, the government promulgated the Fertiliser (Control) Order 1997 under the Essential Commodity Control (Rights) Act, 1961. To facilitate implementation of the order, a Fertiliser Guideline was developed in 1999. The order and guidelines provided a specific code of conduct for manufacturers, importers, and dealers to ensure the quality of fertilisers. To enforce the order, the government appointed 75 fertiliser inspectors, one stationed at each District Agriculture Development Office (DADO). The government also upgraded the facilities of the central and regional soil testing laboratories such that they could test fertilisers.

Nevertheless, the country continued to experience uncertainties in fertiliser supplies as a results of the high fluctuation of fertiliser prices in the world market, increased cross border flow from India (fertiliser is still subsidised in India), and the lack of confidence of the private sector in the future of the fertiliser deregulation policy (Basnyat 2002). This led the government to issue a National Fertiliser Policy (NFP) in 2002. The NFP included organic, chemical, and microbial fertilisers within the definition of fertiliser.

Crop production is sometimes found to be severely affected due to deficiency of one or more secondary and micronutrient elements. Deficiency of zinc and boron is a commonly observed problem in Nepal. Various formulations of multi/micronutrient and bio-fertilisers are available in the market. Some farmers are using multi-nutrient and bio-fertilisers on a commercial scale. The majority of farmers in Nepal use both organic and inorganic fertilisers. HMGN (2003) found that 81% of farm households were applying both organic and inorganic fertilisers during 2001/02; a further 10% used only animal manure, and 8% only inorganic fertilisers. The application rate for manure was higher in the hills than in the Terai, and the inorganic fertiliser application rate was higher in the Terai than in the hills. Around 15 per cent of farm households used fertilisers containing secondary and micronutrients in 2002.

HMGN (2002) has emphasised, and the Tenth Plan (2002-07) has endorsed, the use of integrated plant nutrient management systems (IPNS) to prevent the degradation of soil fertility and minimise other likely negative impacts of chemical fertiliser use on the environment; and to promote the appropriate and balanced use of fertilisers.

Types of Commercial Fertiliser Used in Nepal

Nepalese farmers apply almost all possible types of fertilisers required for crop production.

Organic/biofertilisers

The organic fertilisers used traditionally in Nepal are compost, farmyard manure (FYM), green manure, and town waste. Usually farmers themselves prepare compost, FYM, and green manure. Based on a study conducted in four districts of Nepal (Chitwan, Tanahu, Kaski, and Parbat), Jaishy et al (1999) reported that in most cases proper composting techniques were not being used. Vermicomposting is gaining popularity in urban areas. *Rhizobium*, *Azotobacter*, blue-green algae, and *Micorrhiza* are important bio-fertilisers that are being tested by researchers and which are used by farmers to a certain extent. Among them, *Rhizobium* is the most important and even the private sector is involved in the production and marketing of inoculants. Some private fertiliser importers are importing and distributing organic and biofertilisers.

Altogether seven organic and biofertilisers have been registered by the Fertiliser Unit of the Ministry of Agriculture and Cooperatives (MOAC) after approval by NFP (see Table 1). Organic fertilisers need to be applied in large quantities to the soil, but they help to build up the soil. Biofertilisers require proper storage temperatures and there are time limits to their use. Thus it seems appropriate to produce both organic and biofertilisers at a local level rather than import them.

Table 1: **List of registered organic and biofertilisers**

Name of product	Country of origin	Organisation registered to import
Meiqi Magic Organic Fertiliser	China	Gangchen International (Pvt.) Ltd
Pensibao Fertiliser (Raja Mall)	China	Pensibao Nepal Trade rs
NAFED Biofertiliser	India	National Cooperative Federation of Nepal Ltd.
Multiplex Annapurna	India (Bangalore)	Bhadra Concern
Kwain-Thong granule bio organic fertiliser New Light bio liquid fertiliser	Thailand	New Lucky Enterprises
Pensibao Multifun ctional Nutritive Foliage Fertiliser	China	ANI CHEM NEPAL
Humus Plus 4 (Powder) Carbonite 12 (Granulated)	Australia	Manoj International Traders

Inorganic fertilisers

Among the macro elements required for the growth and development of plants, nitrogen, phosphorous, and potash are required in large amounts and should be added externally. Different types of inorganic fertilisers containing these three elements in straight, complex, and mixed forms are available in the market.

Continuous uptake of nutrients from the soil, haphazard application of inorganic fertilisers, and insufficient use of organic manure create a deficiency of micronutrients in the soil. Deficiency of secondary and micronutrients has been observed in several agronomic and horticultural crops (Joshy and Pandey 1996; Jaishy et.al 1998; Maskey et. al 2004; Tripathi and Harding 2004). The increasing consciousness of farmers and the desire to increase agricultural production has led to a rise in the use of micronutrient fertilisers in recent years. The Fertiliser Unit (MOAC 2002) reported that most of the micronutrient fertilisers available in the market contain more than one element, i.e., they are in multi-nutrient form (see Annex

1). Farmers usually do not know their characteristics and roles, but use them in the name of 'vitamins'.

Only those chemical fertilisers whose specifications have been approved by the government may be traded within the country (HMGN 1997). Initially, the Fertiliser (Control) Order (FCO) included the specifications of ten commercially traded chemical fertilisers. Realizing the need to have fertilisers containing different nutrients, 17 more fertilisers including secondary and micronutrients were later added to the list (Table 2).

Table 2: **List of fertilisers whose specifications have been approved by HMG/N**

	Name	Type	Form/ Description
1	Diammonium Phosphate (18:46:0)	Complex	Granulated
2	Muriate of Potash (0:0:60)	Straight	Crystalline
3	Muriate of Potash (0:0:60)	Straight	Granular
4	Ammonium Sulphate (21:0:0)	Straight	Crystalline
5	Urea (46:0:0)	Straight	Granulated
6	Ammonium Phosphate Sulphate (20:20:0)	Complex	Granulated
7	Ammonium Phosphate Sulphate Nitrate (20:20:0)	Complex	Granulated
8	Nitro Phosphate (20:20:0)	Complex	Granulated
9	Single Superphosphate (0:16:0)	Straight	Powdered
10	Single Superphosphate (0:16:0)	Straight	Granulated
11	Triple Superphosphate (0:46:0)	Straight	Solid
12	Zinc Sulphate Heptahydrate (21% Zn) $ZnSo_4.7H_2O$	Straight	Crystalline
13	Zinc Sulphate Monohydrate (33% Zn) $ZnSO_4.H_2O$	Straight	Powdered
14	Manganese Sulphate (30.5% Mn)	Straight	Solid
15	Borax (Sodium Tetra -borate) (10.5% B) $Na_2B_4O_7.10H_2O$ (10.5% B)	Straight	Powdered
16	Solubor $Na_2B_4O_7.5H2O+Na_2B_{10}O_{16}.10H_2O$ (19% B)	Straight	Solid
17	Copper Sulphate $CuSo_4.5H_2O$ (24% Cu)	Straight	Solid
18	Ferrous Sulphate $FeSo_4.7H_2O$ (19% Fe)	Straight	Solid
19	Ammonium Molybdate (52% Mo) $(NH_4)_6Mo_7O_{24}4H_2O$	Straight	Solid
20	Chelated Zinc as Zn -EDTA (12% Zn)	Straight	Crystalline/powder
21	Chelated Iron as Fe-EDTA (12% Fe)	Straight	Crystalline
22	Calcium Ammonium Nitrate (25:0:0)	Straight	Solid
23	Calcium Ammonium Nitrate (26:0:0)	Straight	Solid
24	Potassium Sulphate (0:0:50)	Straight	Solid
25	NPK(10:26:26)	Complete	Granulated
26	NPK(12:32:16)	Complete	Granulated
27	NPK(20:20:10)	Complete	Granulated

EDTA = ethylenediaminetetracetic acid

Quality Control Mechanisms

It is difficult to bring mixed fertilisers containing micronutrients and hormones (commonly called vitamins) under the quality control mechanism. Quality control of organic fertilisers is also more difficult than that of inorganic fertilisers. Organic fertilisers are prepared from a variety of sources and they are complex. Although the NFP has included organic and microbial fertilisers under the definition of fertiliser, they have yet to be brought under the quality control mechanism.

Regulations

As of 2004, the regulations related to fertiliser quality control are as follow.

- Essential Commodity Control (Rights) Act 1961
- Fertiliser (Control) Order 1997
- Fertiliser Guidelines 1999

The promulgation of a Fertiliser Act is in progress.

Stakeholders involved in the supply of quality fertiliser

The following stakeholders are involved in the supply of fertilisers and their quality control.

- MOAC /DOA/ DADOs
- Fertiliser inspectors
- Local administration
- Authorised laboratories/authorised analysts and other laboratories approved by the Nepal Bureau of Standards
- Importers/manufacturers
- Independent surveyors
- Dealers/retailers
- Farmers

The different responsibilities of and legal requirements for these are summarised in the following.

Role of the Ministry, Department and DADOs

The ministry and the department are responsible for developing regulations and facilitating implementation of the regulations for supply of quality fertilisers to the market. DADOs are responsible for monitoring fertiliser supplies in the districts. They also carry out various training, interaction and other programmes for farmers and fertiliser dealers/retailers in their districts to create awareness about balanced fertilisation and the use of quality fertiliser.

The role of fertiliser inspectors

The ministry has extended the quality control mechanism up to district level by appointing a fertiliser inspector in each district. The fertiliser inspector is an officer level staff member of the DADO. In order to facilitate supply of quality fertilisers to farmers, fertiliser inspectors are assigned the following roles, responsibilities, and authority.

- Monitoring the supply, distribution, and stock of fertilisers in their districts
- Requiring manufacturers, importers, or dealers to submit records on production, import, distribution and stock of fertilisers

- Taking samples of fertilisers or raw materials used in manufacturing fertilisers from dealers/retailers, godowns, or manufacturers at any convenient time
- Investigating whether any person or agency is doing anything against the law or the Act
- Filing cases if any person or agency has manufactured or imported or sold fertilisers against the FCO, or if the sample taken and analysed is of low quality

Local administration

Fertiliser is included in the category of essential commodities. The Chief District Officer (CDO) has the right to look after cases that come under the scope of the Essential Commodity Control (Rights) Act (HMGN 1967). Fertiliser inspectors should take the help of the local administration in performing their duties and filing cases against wrongdoers.

Fertiliser testing and analysing services

There are seven authorised laboratories and one accredited laboratory for testing and analysing all types of fertilisers as per the FCO 1997. These laboratories test reference samples as well as complaint samples. If fertilisers are found to be sub-standard, legal action can be taken on the basis of the analysis reports of these laboratories.

Authorised laboratories

- Soil Testing and Services Section, Hariharbhawan
- Regional Soil Testing Laboratory, Jhumka, Sunsari
- Regional Soil Testing Laboratory, Trishuli, Nuwakot
- Regional Soil Testing Laboratory, Khairanitar, Tanahu
- Regional Soil Testing Laboratory, Khajura, Banke
- Regional Soil Testing Laboratory, Dhangadhi, Kailali
- Nepal Bureau of Standards and Metrology

Laboratories accredited by the Nepal Bureau of Standards and Metrology

- Nepal Environment and Scientific Services

Fertiliser testing kit boxes for testing adulteration of fertilisers

Quick test kit boxes have been developed by the Soil Testing and Services Section of the DOA and distributed by the MOAC in the 24 Terai and valley districts, as these are prone to sales of substandard fertilisers. With the help of these kit boxes, adulteration in different types of fertilisers can be tested instantly. The ministry has also provided training to the DADO staff and fertiliser dealers in all the 24 districts on the use of the kit boxes. This is designed to enhance district capabilities for protecting farmers from the purchase of fake fertilisers.

Fertiliser importers

- Only those fertilisers can be imported which have approved specifications as per the FCO 1997, Section 5.
- The following certificates are mandatory for importers when importing fertilisers from abroad:
  - Manufacturer's certificate to ensure the country of origin and nutrient contents in the fertiliser including the chemical composition;
  - Loading port certificate from an independent surveyor (international) to guarantee the quality, quantity, packaging, and labelling

– Unloading point certificate to guarantee the quality, quantity, packaging, and labelling

The manufacturer's certificate and the loading port certificate from the country of export should be presented at the point of entry in Nepal (customs' office). The unloading point can be the customs entry point or importer's godown (HMGN 1997). There are accredited independent surveyors available to issue the unloading point certificate.

Loading port certificates should match the unloading point certificate (within the tolerance limit). Packaging and labelling of imported fertiliser should be as per the FCO 1997, Section 20. Every importer should submit a monthly report to the Fertiliser Unit of MOAC on import, distribution, and stock of fertilisers (HMGN 1999).

Manufacturers

- Fertiliser manufacturing companies should register their fertilisers at the Fertiliser Unit, MOAC, before manufacturing. For this, fertiliser companies should submit applications to the Fertiliser Unit as per the FCO, Section 13.
- Periodic reports should be submitted to the Fertiliser Unit on production, sale, stock, and price of fertilisers.
- The registration certificate of registered fertilisers should be renewed with the Fertiliser Unit every three years.

At present, three mixing and blending companies have registered different grades of fertilisers and are manufacturing fertiliser grades of 20:20:0 and 20:20:10.

Independent surveyors

Importers and manufacturers should obtain certificates from independent surveyors that verify the quality, quantity, labelling, and packaging of fertilisers. The requirements should be met for quality, quantity, labelling, and packaging as per the FCO. For this purpose, the MOAC has accredited the following surveyors

- Investigators, Legal Advisors and Surveyors, New Road Gate
- Nepal Environmental and Scientific Service (P.) Ltd., Thapathali
- Sata Engineering Associates, Dugambahil, Kathmandu
- International Claim Bureau, Thapathali, Kathmandu

Dealers/retailers

- Any firm or person wishing to sell fertiliser needs to secure a certificate of registration from the appropriate DADO as per the provisions of the FCO. The registration certificate is valid for two years from the date of registration or renewal.
- As per the provisions of the Fertiliser Guidelines 1999, Section 5, every dealer should submit a monthly report to the DADO or the Service Centre/Sub-Service Centre on fertiliser transactions.

Conclusions

The commercial fertilisers used in Nepal are mainly inorganic fertilisers containing nitrogen, phosphorous, and potash. Farmers, fertiliser dealers, extension workers, laboratory technicians, and other stakeholders are familiar with the nitrogenous, phosphatic, and potassic fertilisers, and complex fertilisers containing these three nutrient elements. The rules and regulations for controlling the quality of these fertilisers are well specified and the laboratory facilities for testing and analysing them are also well developed. Considering the importance of IPNS for sustainable soil-fertility management in intensive agriculture, the NFP has broadened the definition of fertilisers to include organic, inorganic, and microbial fertilisers. However organic and bio-fertilisers have yet to be brought under the legal framework.

The use of inorganic fertilisers containing micronutrients has been practised in a haphazard way by some farmers, without knowing their characteristics and roles. Since micronutrients are required in small quantities for plant growth, soil nutrient testing facilities also need to be extended so that they can assess soil nutrient levels and requirements. Users, extension personnel, traders, and other stakeholders are not so familiar with these fertilisers. Therefore, the quality control mechanism for these fertilisers needs to be developed in order to protect farmers from their misuse and to promote sustainable agricultural development.

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Annex 1: **Characteristics of the 23 micronutrients available in Birgunj as per the study conducted by the Fertiliser Unit in 2002**

Name of product	Content	Available quantity (pack)	Price* (US $)	Recommended dose	Target crop	Manufacturer	Remarks
Multiplex (liquid) for Foliar Spray	Fe 0.5% Mn 0.2% Zn 5% Cu 0.5% Mo 0.02% B 0.5%	100 ml bottle 250 ml bottle 500 ml 1 litre 5 litre 20 litre	0.52 0.98	50 ml in 20 litres of water	Field, horticultural and plantation crops	Karnataka Agro Chemicals Bangalore	
Multiplex Zinc EDTA (Solid)	Zn EDTA 12%	50 gm bottle	0.70	250 gm Zn EDTA in 500 litres of water sufficient for one ha of land	Field, horticultural and plantation crops	Karnataka Agro Chemicals Bangalore	
Multiplex Micronu trient Fertiliser for Foliar Spray BORON	B 10.5%	500 gm packet	1.40	500 gm in 200 litres water	Field, horticultural and plantation crops	Karnataka Agro Chemicals Bangalore	
Multiplex, Zinc High (Soil Application)	Fe 1% Mn 0.2% Zn 8% Cu 1% Mo 0.03% B 1%	1 kg 10 kg 50 kg	0.56 (Nepal) 0.88 (India)	15 kg/ha	Field, horticultural and plantation crops	Karnataka Agro Chemicals Bangalore	
Agromin Foliar Multi Micronutrient Fertiliser	Fe 0.5% Mn 0.2% Zn 3% Cu 0.5% Mo 0.02% B 0.5%	100 ml 250 ml 500 ml 1 litre 5 litres 20 litres	0.85 3.37 -	0.5-1% for wheat, maize, pulse, oilseed, vegetables; 1-2% for sugarcane	Cereals, vegetables and cash crops	Aries Agrovet Industries Ltd, Aries House Plot No. 24 Deonar, Gorandi Mumbai 400043	

EDTA = Ethylenediaminetetracetic acid, N = nitrogen, Ca = calcium, Mg = magnesium, S = sulphur, Zn = zinc, Mn = manganese, Fe = iron, Cu = copper, B = boron, Mo = molybdenum, Cl = chlorine. *Original prices in NRs and IRs converted at a rate of US$1= NRs 71, or IRs 44

Annex 1: cont.

Name of product	Content	Available quantity (pack)	Price* (US $)	Recommended dose	Target crop	Manufacturer	Remarks
Agromin Soil Application (Chelated)	Fe 1% Mn 0.2% Zn 4% Cu 1% Mo 0.03% B 1%	1 kg 2.5 kg 5 kg (1 kg technical) (4 kg carrier) 10 kg	0.74 - 3.16 - - 5.90	20-30 kg/ha			
Chelamin (Zn) Foliar Spray	Zn EDTA 12% N 3.5%	50 gm 100 gm 500 gm	0.93	250 gm in 250 litres of water for one hectare area with standing crop	Cereals, vegetables and cash crops	Cereals, vegetables and cash crops	
Chelamin soil application chelated	Zn 12%	500 gm technical + 10 kg carrier	8.42	500 gm technical and 10 kg carrier for 1 ha of land			
Microplex (Foliar Spray) (Liquid)	Zn 5% Fe 0.2% Mn 0.2% Cu 0.5% Mo 0.02% B 0.5%	1 litre	2.92	500 ml in 100 litres of water	All crops	Microplex (India) A -1, A-2, MIDC Wardha (M.S.)	
Microplex (Foliar Spray) Liquid	Fe 3% Mn 0.5% Zn 8% Cu 0.2% Mo 0.01%	100 ml	0.52	500 ml in 100 litres of water	All crops	Microplex (India) A -1, A-2, MIDC Wardha (M.S.)	
Zinoplex - F (Foliar Spray)	Chelated Zn 12%	200 gm	0.70	500 ml in 100 litres of water	All crops	Microplex (India) A -1, A-2, MIDC Wardha (M.S.)	
Hi Power Liquid Micronutrient fertiliser	Zn 5% Fe 2% Mn 2% Cu 0.5% Mo 0.05% B 0.5% (PH 3.5)	100ml 250 ml	0.70 1.47	350-500 ml in 150-200 litres of water	All crops	Ever Green Chemical India, Usha Kiran Building, Azaolpur Commencial Complex, Delhi - 33	

Annex 1: cont.

Name of product	Content	Available quantity (pack)	Price* (US $)	Recommended dose	Target crop	Manufacturer	Remarks
Evergreen vegetable special	Zn 5% Fe 2% Mn 2% Cu 0.5% Mo 0.05% B 0.5% (PH 3.5)	0.5 kg	1.19	3 g/litre of water	Leafy vegetable beans cucurbits, onions, garlics	Ever Green Chemical India, Usha Kiran Building, Azaolpur Commencial Complex, Delhi - 33	
High Zinc (soil application)	Zn 6% Fe 3% Zn 1% Cu 0.05%	10 kg bag		3 g/litre of wate r	Cereal crops	Ever Green Chemical India, Usha Kiran Building, Azaolpur Commencial Complex, Delhi - 33	
Micro power f oliar spray	Increase efficiency of nutrients	100 ml	0.72	1250 ml in 500 litres of water for 1 ha	Cereal crops	Jitesh Chemicals Co., Mumbai	
Micro power foliar spray	Fe 0.5% Zn 5% Mn 0.2% Cu 0.5% B 0.5% Mo 0.02%	100 ml	0.42	100 ml in 150-200 litres of water	Cereal crops	Jitesh Chemicals Co., Mumbai	
Durga shakti zinc High soil application	Fe 1% Mn 0.2% Cu 1% Zn 8% Mo 0.03% B 1%	1 kg 5kg	0.90 4.27	15 kg/ha	Cereal crops	Durga Chemical and Fertilisers Lakhisarai, India - 811311	
Tracel - 2 micronutrient spray chelated	Zn 5% B 0.5% Cu 0.5% Mo 0.02% Mn 0.2% Fe 0.5%	500 gm		5 gm/litre, 750 litres of spray for 1 ha land	Cereal, oil seed, pulses, vegetable and fruits	Rallis India Agro Chemical India	Contains balanced micronutrient , potash 7% and Mg 1.2%
Multi neutrion chelated zinc	Zn EDTA12% N 3.5%	250 gm	1.57	500 g of multi neutrion per hectare	Wheat, potato, sugarcane, cotton and other crops	J.B. Chemicals Dhrashan Ganj Lucknow	
Agron Plus High Zinc Soil application	Not mentioned	1 kg	0.56	2.5 kg/ha	Paddy, wheat, sugarcane	S.D. Biotech Ltd. Industrial Area, Alipur, Delhi	

Managing Soil Fertility Problems of Marginal Agricultural Lands through Integrated Plant Nutrient Management Systems: Experiences from the Hills of Nepal

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Abstract

Hill farmers generally have to subsist on marginal land, partly because fertile topsoil tends to be washed away from sloping land, which then becomes marginal. The causes of decline in soil fertility in the Nepalese hills are diverse. One way of approaching it is by employing an integrated plant nutrient system (IPNS), a holistic approach which integrates all components of soil, plant, and nutrient management to achieve higher crop yields and better soil health. The farmers' field school (FFS) approach was adopted to disseminate the concept of plant nutrition management. Soil analysis was carried out to understand the status of plant nutrients in the soils, and a nutrient balance sheet was prepared by means of discussions with farmers. A total of 54 FFS were implemented throughout the mid-hills. Farmers learned about acidic soil management through organic matter management, more than 60% of the farmers adopted improved organic matter (OM) management practices, and realised the value of splitting doses of nitrogen fertilisers. Farmers' groups were empowered through regular meetings and close observation of plant growth stages and soil agro-ecosystems. Farmers became capable of handling soil analysis, particularly for nitrate, nitrogen, pH, and soil microbes using tools. An improvement in pH indicated a significant positive impact of IPNS in ameliorating the poor soil fertility status. Improved soil fertility resulted in an increase in crop yields by 26%. Soil analysis reports also showed an increase in soil fertility status, in particular increases in OM, nitrogen (N), phosphorous (P), and potassium (K) when compared to the base year even within a one to three-year time span. Micronutrients, particularly boron (B) and molybdenum (Mo) were found to be crucial for cauliflower yields, and adding 20 kg/ha borax increased yield by 45%. Application of urine to cauliflower crops also corrected B deficiency symptoms; however research is needed to find out the effect of liquid manure on micronutrient levels. IPNS was found to be an appropriate technology to mitigate soil fertility problems in marginal agricultural land and FFS was proved to be a good tool for disseminating the technology to the grass roots level in farming communities.

Introduction

The Sustainable Soil Management Programme (SSM-P), introduced at the beginning of 1999, is a technical cooperation programme between His Majesty's Government of Nepal (HMGN) and the Government of Switzerland. The overall goal of SSM-P is to reduce the decline in soil productivity. Its objective is to promote improved, sustainable soil management practices through government organisations (GOs) and non-government organisations (NGOs) and partners: viz., male and female farmers. The major guiding principles of the programme are participation and empowerment of the key actors, explicit gender orientation, institutional linkages between research and development organisations, combinations of 'pull' (technology) and 'push' (market forces) in line with the Agricultural Perspective Plan's (APP) priorities, a look at 'win-win' situations (short-term economic gains coupled with long-term ecological sustainability), and a judicious mix of indigenous and new technologies.

The objective of this brief paper is to highlight the approaches, major activities, and experiences gained during the implementation of the programme on integrated plant nutrient systems (IPNS) using farmer field schools (FFS). Based on the experience of the programme, suggestions are also given for research and extension for improvement of the soil fertility situation in hill farming systems.

Status of Soil Fertility in the Hills of Nepal

It is a well established that soil fertility in Nepal is declining (Sthapit et.al. 1988; Subedi et al. 1989; Tamang 1992; Joshi, et. al. 1995). Various workers have identified more and less common causes of declining soil fertility. Their findings show that soil erosion, nutrient mining with increased cropping intensity and use of high-yielding varieties (HYVs), reduced quantity of farm-yard manure (FYM), and imbalanced used of chemical fertilisers are the major factors leading to overall soil fertility decline. Table 1 summarises the current soil fertility status in Nepal.

Table1: **Summary of the current soil fertility status in Nepal (%)**

Soil fertility parameters	Samples analysed	Low	Medium	High
Total nitrogen	9872	48	41	11
Available phosphorous	8942	35	24	41
Available potassium	9522	27	33	40
Organic matter	7520	62	33	5

Source: Jaishy 2000

The issue of soil fertility is complex involving different technical and socioeconomic factors and can only be addressed by developing a holistic soil management approach. SSM-P is trying to address this issue by promoting different sustainable soil management (SSM) practices through training and demonstration with farmers.

Concepts and Need for IPNS in Nepal

In recent years, increased use of high-yielding crop varieties in intensive cropping systems have led to an increased demand for nutrients. The locally available sources of nutrients, mainly farm-yard manure (FYM), compost, and biologically fixed nitrogen are not sufficient to meet the needs. Depletion of organic matter content has been at the centre of the overall soil fertility decline and has led to an increasing reduction in nutrient balance in the soil. Farmers in accessible areas have started to use chemical fertilisers as a means of coping with the reduced nutrient availability. However, imbalanced use, and inappropriate timing and methods, of fertiliser application have resulted in adverse effects on soil productivity, on sustainability, and on environmental quality. A more efficient, economical, and integrated nutrient management system is needed.

'Integrated plant nutrient system' (IPNS) describes the concept of integrating all available means of soil, nutrient, and crop management in order to achieve optimum land productivity and sustainability. It includes the complementary and efficient use of external inputs where locally available sources of plant nutrients are not sufficient to achieve an optimum yield. It emphasises the principle that fertiliser and manure should be applied on the basis of soil fertility status, crop demand, and available resources. IPNS is, therefore, an approach that seeks to both increase agricultural production and safeguard the environment for the future. Not only does IPNS rely on balanced nutrient application, it also emphasises their conservation and improved efficiency.

The appropriate design for IPNS depends on local conditions and farmers' knowledge. This concept is now widely seen as an opportunity and challenge for promoting better soil management at the farm level. Since the concept had not been widely tested in field conditions in Nepal, SSM-P with the Directorate of Soil Management of the Department of Agriculture (DoSM/DOA) took the initiative of developing and testing the approach together with farmers in the middle hills of Nepal; and this brought together local and new knowledge and contributed to the design of productive and sustainable land management systems. So far, the following progress has been made.

- A workshop on IPNS was organised jointly by the Soil Testing and Service Section (STSS); Soil Science Division (NARC); Fertiliser Unit, Ministry of Agriculture and Cooperatives (MoAC); and SSM-P in February 2000 which synthesised and documented the available information on different components of IPNS in Nepal.
- A farmer field school (FFS) on IPNS was tested in the field with a maize/finger millet system in the mid-hills with a collaborating institution (CI) of SSM-P in Sindupalanchowk district. The programme was successful and farmers learned about integrated nutrient management of maize and finger millet crops. This has enabled farmers to produce maize with a two-thirds' reduction in fertiliser use, indicating improved efficiency of fertiliser use. More FFS were planned by different CIs in the season after 2000.
- A national level Working Group was established of representatives from the Nepal Agricultural Research Council (NARC); the STSS of the Department of Agriculture and Co-operatives; Fertiliser Unit of the MoAC; RARS Lumle; District Agricultural Development Office (DADO) Kavre; Institute for Sustainable Agriculture Nepal (INSAN); and the Programme Management Unit (PMU) of SSM-P. The meeting discussed and agreed upon a model of IPNS to support a common concept for the extension of IPNS in Nepal. Three main elements of IPNS were defined: the domains, the topics, and the approach. Revision of the national working group took place in 2003 when the Institute of Agriculture and Animal Science (IAAS) was included, hence linking this concept to an academic institution as well.

Domains for IPNS

IPNS is location and cropping-system specific. Thus, recommendations for IPNS need to be targeted to macro-domains with similar locational conditions and cropping systems. Within these macro-level domains, there remains a wide variability in micro-level conditions between locations and in crop management between farmers.

It was agreed, that the macro-level domains need to be targeted through the development of specific IPNS for each of these domains. The micro-level differences need to be covered through the formation of community clusters and the organisation of farmer-field schools (FFS) in which location-specific management can be discussed with farmers.

The Field Implementation Approach of IPNS

The most difficult aspect of handling FFS for IPNS is the design of the best location-specific nutrient management. The following key steps need to be considered while designing and implementing location-specific nutrient management for a given domain or system.

System selection: A system and domain for field implementation of IPNS is selected in a broader sense; for example, a maize/millet system.

Site or location selection: For a given system, one or more representative sites are selected for field implementation. As far as possible, representative, homogenous, and one cluster of farmers should be selected.

Assess soil status: Information on soil parameters, such as soil organic matter content, pH, nutrient availability, texture, extent of nutrient leaching, and erosion of the selected site should to be gathered through site visits and laboratory analysis.

Fixing of yield target: Expected yield levels should be targeted based on the availability of farm resources.

Calculation of nutrient balance: A nutrient balance can be calculated indicating how much and which nutrients are to be added based on the two estimates above. Emphasis should be given to organic matter balance.

Listing available nutrient sources: All available internal (farm level) and external (purchased) nutrient sources should be listed.

Integration : All available nutrient sources should be integrated.

Determine the amount, time, and methods of application suitable for a given crop, cropping system, and land type.

Different land, crop, and nutrient management options to increase the efficiency of farm resources are suggested in the following.

- *Increase organic matter incorporation* – Organic matter (OM) is the storehouse of plant nutrients or, in other words, the life of the soil. Its balance should always be considered in IPNS. The measures for increased OM can be improving the quality of FYM, increasing fodder production, stall feeding of animals, use of green manure/biomass, and efficient recycling of organic residues.
- *Improve the quality of FYM* – The quality of manure that Nepalese farmers use is very poor. There is ample room to increase the nutrient content, primarily nitrogen, through quality fodder production, proper collection or conservation of urine, and proper decomposition and application methods.
- *Reduce soil erosion* – Erosion of surface soil, particularly during the pre-monsoon rains, causes significant loss of nutrients from the soil. Reducing this erosion through different means, such as reducing bare land, mulching, cover crops, proper terracing, and so on, helps substantially.
- *Legume integration* – Integrating legumes into farming systems contributes significantly to nutrient supply through symbiotically fixed nitrogen.
- *Growing more crops that need manure in the rotation* – If crops like vegetables and potatoes are grown at least once a year, it helps to build up the organic matter balance and is believed to improve the physical and chemical properties of the soil.

- *Selection of less nutrient demanding crops* – There are certain crops/varieties that demand relatively lower amounts of nutrients. Selection of such crops helps nutrient management.
- *Balanced soil reaction* – Alkalinity or acidity of soil reduce the availability of many plant nutrients. Timely correction of soil pH through the application of organic manure and amendment helps nutrient availability.
- *Avoid excessive use of chemical fertilisers* – There are many instances in which farmers apply excessive or imbalanced amounts of chemical fertilisers. Improper timing and excess application of chemical fertilisers also cause wastage of resources as well as creating soil problems. So, only needs-based application is strictly recommended in an IPNS.
- *Minimise pesticide use* – Many pesticides persist in the soil for a long time and are harmful to soil lifeforms, e.g., earthworms and other beneficial organisms. Use of pesticides should be restricted for better soil productivity.

Results from an IPNS Farmers' Field School

Farmers expect higher productivity from IPNS. In areas with market access, they are interested in higher crop yields with optimum use of local or external inputs. Farmers in remote areas are interested in increasing their crop yields from locally available inputs and in minimising the need for external inputs. A total of 51 IPNS-FFS were carried out in different cropping systems in the working areas of SSM-P (Table 2).

Table 2: **IPNS FFS implemented in 2003/04**

District	Systems	Total integrated plant nutrient system farmers' field schools (IPNS-FFS)
Dolakha	maize - cauliflower; maize - wheat	2
Sindhupalchok	maize - millet; maize - cauliflower	6
Kavre	maize - wheat; maize - cauliflower	3
Syangja	maize - cauliflower	5
Parbat	maize - millet; maize - cauliflower	11
Baglung	maize - cauliflower; maize - millet	11
Surkhet	maize - wheat; maize - cauliflower	5
Baitadi	maize - wheat	5
Tanahun	maize - wheat	1
Palpa	maize - wheat	1
Ilam	maize - wheat	1

Source: SSMP 2003

A large amount of information on soil conditions, crop yields, inputs used, and other crop or field observations were generated through the FFS in 2002. Some groups and facilitators carefully recorded all the observations, while others provided rough estimates. The information is still being summarised. Table 3 shows an example of nutrient management treatment under IPNS and the farmer plots in different FFS. Other observations like varietal comparisons, weed management, and intercropping tests are not included.

Nutrient management in 2003 focused on nitrogen management. Analysis of soil nitrogen indicated that at most sites there was no need for basal application of N-fertilisers in addition to manure application, especially in the rainy season. There is a substantial amount of free N in the soil at the beginning of the season which rapidly declines once the monsoon rains set in. Field observations by farmers also confirmed the leaching of N into deeper soil layers (Figure1).

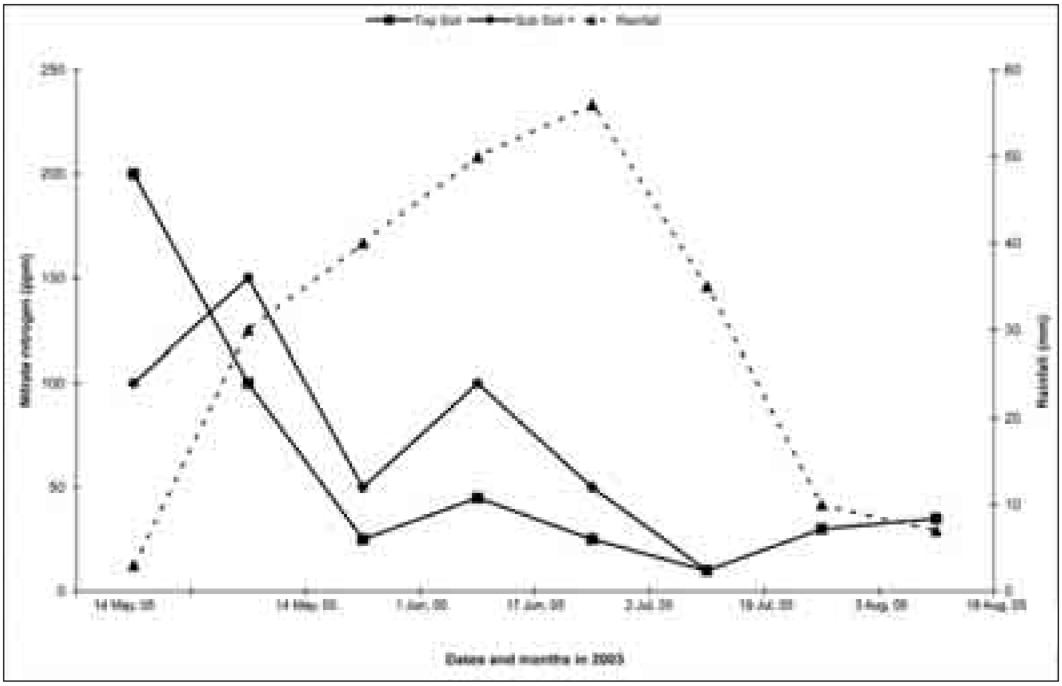

Figure 1: **Nitrate nitrogen levels in the soil as measured during a FFS**

Results are summarised in Tables 3, 4, and 5 for selected IPNS-FFS in areas identified as micronutrient deficit in boron (B), zinc (Zn), and molybdenum (Mo). The results show the positive impact of application of micronutrients. Cauliflowers were found to be very critical in many areas for B and Mo, whereas maize was found to be Zn deficit. Wheat was also found to be very sensitive to B application.

The results showed that efficient nutrient management has a significant impact on crop yield as well as on soil health. Soil pH, OM, nitrogen (N), phosphorous (P), and potassium (K) contents were often changed positively (SSMP 2003).

Micronutrients play a crucial role in crop productivity. Table 5 shows the results from different sub plots of IPNS-FFS in micronutrient trials. These results give a clear message that without considering micronutrients, optimum crop yield is impossible. Application of micronutrients increased crop yields from 15 to 45%, and overall by 20%, in IPNS sub trials (micronutrient treatments) in which all management practices were kept the same except for micronutrient application.

Micronutrient treatments were carried out in different places across the sites selected using farmers' observations and reports on likely deficiency symptoms of those micronutrients.

Table 3: **Results related to nutrient management of selected IPNS -FFS on maize -cauliflower based cropping systems**

Input/output		IPNS plots		Farmers' plots	
		Maize	Cauliflower	Maize	Cauliflower
Site 1	Urea (kg/ha)	58	100	80	155
	DAP (kg/ha)	39	100	30	112
	FYM (kg/ha)	19,650	23,580	19,650	23,580
	Urine (L/plant)		0.20		
	Yield (kg/ha)	**3.34**	**33.00**	**2.61**	**27.74**
Site 2	Urea (kg/ha)		100	80	155
	DAP (kg/ha)	30	100	30	112
	FYM (kg/ha)	19,650	23,580	19,650	23,580
	Urine (L/plant)	0.05	Borax 10 kg/ha		
	Yield (t/ha)	**2.96**	**30.20**	**2.61**	**26.74**

Source: DCRDC 2003

Key: DAP= Diammonium phosphate, FYM = farmyard manure

Table 4: **Results related to nutrient management of selected IPNS -FFS on maize -wheat based cropping systems**

Input/output		IPNS plots		Farmers' plots	
		Maize	Wheat	Maize	Wheat
Site 1	Urea (kg/ha)	58	100	80	155
	DAP (kg/ha)	39	100	30	112
	FYM (kg/ha)	19,650	20,580	19,650	20,580
	Yield (kg/ha)	**3.44**	**3.10**	**2.51**	**2.21**
Site 2	Urea (kg/ha)	30	30	80	50
	DAP (kg/ha)	30	10	40	50
	FYM (kg/ha)	19,650	21,580	19,650	21,580
			Borax 20 kg/ha		
	Yield (t/ha)	**2.56**	**3.20**	**2.41**	**2.14**

Source: BJJS 2004

Key: DAP= Diammonium p hosphate, FYM = farmyard manure

Table 5: **Micronutrient treatments in sub plots of IPNS -FFS in different crops at different sites**

Organisation and districts	Crops	Treatments (micronutrients)	Yield (t/ha)	
			IPNS plots	Farmers' plots
CDECF, Sindhupalchok (n=4)	Maize	Zinc sulphate (10 kg/ha)	4.31	3.63
DCRDC, Baglung (n=3)	Cauli	Borax (20 kg/ha)	35.41	27.31
DCRDC, Baglung (n=3)	Cauli	Mo (333 ppm)	33.21	30.25
DADO, Baglung (n=1)	Cauli	Borax (20 kg/ha)	29.31	27.33
BJJS, Baitadi (n=3)	Wheat	Borax (20 kg/ha)	2.95	2.32
CDRC, Syangja (n=2)	Cauli	Borax (20 kg/ha)	29.85	17.33

CDECF = Community Development and Environmental Conservation Forum; DCRDC = Dhaulagiri Community Resource Development Center; District Agriculture Development Office; BJJS = Basuling Janajagriti Samaj; CDRC = Community Development Resources Centre; n = number of replications; cauli = cauliflower

Research needs for IPNS

Observations from FFS on IPNS indicate that the development of models and recommendations for IPNS for specific sites can be improved. The predominant soil, topography, climate, land use, and socioeconomic conditions determine, to a certain extent, the problems of the individual farm system. More discussion and concrete information about these aspects can enrich the FFS. They need to be included in the curriculum for FFS.

Data on the relationships between nutrient status, soil management, and crop yield are limited. At the same time, the calculation of nutrient balances relies on such relationships. Thus, longer-term data on IPNS from a wide range of sites need to be developed. The implementation of IPNS over several years on a number of selected sites may contribute such data. The further development of IPNS will be a continuous process of identifying innovations, experimentation with farmers, and feedback to research. Table 6 lists some major research issues identified so far from FFS on IPNS.

General learning about IPNS and FFS

- *Location-specific IPNS* – IPNS addresses location-specific soil problems and thereby helps to sustain soil fertility.
- *Cropping system focus* – IPNS addresses the problems facing the entire cropping system for the whole year, and thus helps sustain soil fertility and crop productivity.

Table 6: **Topics for future research to address problems encountered in extension of IPNS**

Topic	Opportunities for research / research need
Simple assessment methods for nutrients	• Simple tools are available for assessment of pH, N, and soil microbial activity; however, no simple tools are available for the assessment of the status of OM, P, K or other micronutrients. • Can simple tools be developed for these?
Micronutrient management	• Field observations in FFS for IPNS indicate micronutrient deficiencies in many localities; this confirms surveys done by research • Micronutrient fertilisers are often not available, too expensive, or difficult to use for farmers; exploration of local resources for micronutrients (e.g., plant species, ashes, urine, local sediments , ….) may provide alternatives.
Local liquid fertilisers	• Farmers have confirmed the utility of urine and urine teas as valuable liquid fertilisers and organic pesticides; preliminary data show a 2 to 3-fold increase of P and K in urine teas if fermented with some plant leaves. • Research on urine tea preparation and on the factors that determine tea quality is needed; farmers will use local resources, therefore we need to know which plants can greatly increase the value of urine teas.
Soil acidity and acidification management	• Some areas have inherently low soil pH; in other areas the use of fertilisers contributes to soil acidification because the buffer capacity of the soils is low; application of large amounts of lime is not feasible in many areas. • Research on acidity-tolerant crop varieties, on the buffering capacity of local resources, and on the careful mobilisation of P or the careful use of P-fertilisers in these soils is needed.

Source: SSMP 2003

- *Learning by doing and seeing* helps to address the problems immediately – by testing and adding and growing and seeing improvement in the field; thereby it helps to form a basis for sustainable agriculture.
- *Frequent interactions* between technicians and farmers create a bond and confidence.
- *Multiplier effect* – Transferred technologies are disseminated quickly from farmer to farmer giving multiplier effects through community efforts.
- *Empowers farmers* – Builds capacity and enhances community efforts. It guides and supports the decision-making skills at micro-level and enhances the analytical and decision-making process of the farmer.
- *Information feed-back* – IPNS FFS can provide information about dominant soils, topography, and land-use patterns in each district. This can be used for the IPNS base maps, soil fertility maps, and GIS which are being developed by STSS and NARC.
- *Local nutrient balance calculations* – Local staff and farmers are able to use simple methods to calculate nutrient balance sheets for different crops for certain levels of production.

Specific technical learning related to nutrient management

- *Timing of nitrogen (N) application* – It was a key learning experience for farmers that N levels may be high in the soil. The timing of N-application depends on the N-level in the soil.
- *Improved FYM* – Farmers conducted trials on improved FYM against normal FYM and found that the yield response from improved FYM was better.
- *Urine use* – It was confirmed that urine can replace urea. Testing of urine in cauliflower showed reduced B deficiency. Farmers agreed that this needs to be verified.
- *FYM top dressing* – Improved FYM (well decomposed) can be top-dressed. The idea was tested by one group in a field with a poorly performing crop. They found that the crop recovered quickly.
- *DAP top dressing* – Farmers tested diammonium phosphate (DAP) as a top-dressing on maize at 40 days after sowing and found a good response in soils with P-deficiency. DAP is usually recommended for application only before planting.
- *Micronutrients may be crucial* – Some experienced farmers observed boron (B) deficiency in cauliflower before the extension staff and applied B to their plots. They got a better crop, and this created awareness among all participants.
- *IPNS is a systems' approach* – Performance of different varieties, new crops in the cropping pattern, mulching, and other factors need to be included. One farmers' group learned that off-season cauliflower can be planted in millet-based systems.
- *Nutrient balance* – Nutrient use by farmers is often unbalanced. In particular, farmers can reduce application rates and production costs by using organic fertiliser on cash crops.
- *Urine application on vegetables* – Application of urine on cauliflowers, cabbage, and radishes has led to recovery from B deficiency in some areas. However, further systematic research is essential to verify this outcome.

Key methodological learning

- *FFS as a regular process* – Regular meetings are needed; farmers recommended holding meetings about twice a month.
- *Farmer-led experimentation (FLE) as a part of FFS* – Learning can be improved if farmers conduct experiments and discuss the outputs with the group.
- *Farmers manage an IPNS plot on their own farms* – Some organisations promoted this and found it very stimulating for group members.
- *Training of facilitators* – A week-long training course for the local facilitators is not sufficient. Intensive follow-up, monthly experience exchange meetings, and strong technical backstopping are essential.
- *Curriculum for FFS* – The curriculum for IPNS should be more practical and location-specific.

Conclusions

The integrated plant nutrient system is an appropriate technology for addressing declining soil fertility; and farmers' field schools are an equally appropriate tool for taking this technology to the grass roots. The trials started with various cropping system models, but the IPNS models are still not sufficient for needs. For technology diffusion in an effective and practical way, it is important to develop human resources. The decline in soil fertility presents a challenge, and improvement in quality of FYM/compost is seen to be an important aspect in improving soil productivity. The timing and method of fertiliser application are crucial for efficient and effective use of fertiliser inputs.

Micronutrient deficiency is being reported by farming communities, particularly in cole crops, wheat, and rice. Therefore, ecologically-based, detailed research on micronutrient sources and recommendations from such research are highly relevant and essential in order to increase the productivity of soils and crops.

Building capacity at the institutional level is essential in order to implement FFS efficiently. Quality training for local facilitators with sufficient time for conceptualising the basics of the technical aspects of IPNS and FFS process are essential, as is reaching many farmers and people involved in this sector. Information sheets and simple guidelines need to be developed and distributed, and should be location-specific.

Acknowledgements

The collaborating institutions of SSM-P who are involved in the promotion of IPNS-FFS and the farming communities are gratefully acknowledged for their participation in the whole process from planning to evaluation.

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Effect of Micronutrient Loading, Soil Application, and Foliar Sprays of Organic Extracts on Grain Legumes and Vegetable Crops under Marginal Farmers' Conditions in Nepal

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Abstract

Various methods of micronutrient supplementation such as nutrient loading through priming water, soil application of micronutrient fertilisers, and foliar spray of cattle urine or stinging nettle (Urtica dioica L) extracts were evaluated on chickpeas, field peas, mung beans, cucumber, broad-leaf mustard, and radishes under farmers' management conditions in the Terai and hills of Nepal. Soil analysis showed that the soils were low to medium in boron and zinc with moderately acidic reactions. In chickpeas, soil application of borax at 20 kg ha^{-1} and zinc sulphate at 14 kg ha^{-1} gave significantly higher yields over the control treatment. Similarly, loading 0.05% sodium molybdate through priming solution and soil application of molybdenum at 0.5 kg ha^{-1} (sodium molybdate at 1.22 kg ha^{-1}) resulted in an increase in nodulation and yield in both chickpeas and mungbeans. Four to five foliar sprays of cattle urine diluted to 20% with water increased field pea and chickpea yields by 27 and 11%, respectively. In a different set of on-farm trials, six to 10 foliar sprays with a 20% solution of stinging nettle extract at 15-day intervals increased seed yield of broadleaf mustard, radishes, and peas by 31, 18, and 14% respectively over the control treatments. In a similar study on cucumber, over 50% increase in fruit yield was observed after spraying of nettle extract. There is further scope for research for developing efficient methods of applying micronutrients and exploring the use of plant extracts for invigorating crop growth and increasing yield under marginal conditions.

Introduction

The sustainability of Nepalese agriculture is in jeopardy. Soil fertility is declining as a result of degradation of the natural resource base, depletion of soil organic matter, high rates of soil erosion, increased cropping intensity, and inadequate replenishment of soil nutrients (Carson 1992; Joshi and Pandey 1996; Sherchan and Gurung 1996; Tripathi et al. 1999; Vaidya et al. 1995). Application of farm-yard manure (FYM) is the traditional way of supplying plant nutrients and thereby sustaining crop productivity. However, the farmer's capacity to apply sufficient manure is curtailed due to declining numbers of livestock, which in turn is the result of deforestation and cultivation of marginal land previously used for grazing (Carson 1992; Schreier et al. 1995). In the western hills of Nepal, Tripathi (1999) found most of the soil samples were acidic (pH 3.7-6.5), and 33% of samples were low in organic carbon (OC), 6% in total nitrogen (N), 8% in available phosphorous (P), 35% in exchangeable potassium (K), 87% in boron (B), and about 20% in zinc (Zn), manganese (Mn), and copper (Cu).

Integration of diverse strategies is essential for the sustainable replenishment of soil nutrients and thus for sustaining crop productivity. These include improvement in farm-yard manure preparation and handling, green manuring, legume intensification in the cropping systems, crop rotation, stall feeding of livestock through the expansion of fodder planting, and supplementation of additional nutrient requirements through chemical fertilisers (Carson 1992; Joshi and Ghimire 1996; PAC and ICIMOD 1994). Foliar application of plant nutrients has proved to be an effective approach for correcting nutrient deficiencies and increasing the efficiency of supplemental use of nutrients (Tagliavini et al. 2002; Dixon 2003). However, the use of chemical fertilisers is limited due to inaccessibility in the remote hilly areas and the fact that many farmers across all ecological regions of the country are too poor to afford them. Thus a search for appropriate technological options for crop nutrition suitable for small and marginal farmers is essential.

Recently, supplementary approaches to crop nutrition, such as nutrient loading through seed priming and foliar feeding with organic sprays, have received growing interest because of their suitability for small and marginal farmers. There are a few empirical studies that furnish ample evidence of the effectiveness of plant extracts as plant growth promoters (Fuglie 2000; Malaguti et al. 2002).

In this paper, we present the results of on-farm studies of the effects of nutrient loading through seed priming, foliar sprays of cattle urine and nettle extract, and integrated use of organic and inorganic nutrient sources in marginal rice fallows in the Terai and maize-based cropping systems in the hills of Nepal since 2001. The study of nettle extract spray on vegetables has been completed and the studies of nutrient loading and integrated plant nutrient management studies are still in progress. This paper presents excerpts of the findings of studies completed so far.

Materials and Methods

Studies were carried out on-farm on rainfed rice fallows, i.e., land that remains fallow after the rice harvest in October-November until the next planting of rice in June-July, in Kapilbastu, Saptari, and Jhapa districts in the Terai. Studies were also carried out on land in maize-based systems in the Myagdi and Dadeldhura districts in the hills of Nepal. The organisation FORWARD conducted these studies in collaboration with the district agricultural development offices (DADO) of the respective districts. With the facilitation of FORWARD staff, farmers were actively involved in the trial implementation and evaluation at standing crop and post-harvest stages. Joint monitoring of standing crops was carried out by a multidisciplinary group of scientists that encouraged on-site dialogue between farmers and scientists. The data obtained from the trials were compiled and analysed using Excel, Minitab, and MSTAT C packages.

Molybdenum loading through seed priming of chickpeas

The chickpea trials were carried out on farmers' fields in rainfed rice fallows in the winter of 2003/04 with five replicates per district. The trials were planted between early November and early December 2003. In Kapilbastu, there were five treatments: (i) planting of normal seeds (farmers' practice), (ii) seed priming with plain water; (iii) seed priming with plain water plus *Rhizobium* inoculation; (iv) seed priming with 0.5% solution of sodium molybdate

(Mo loading) plus *Rhizobium* inoculation; and (v) seed priming combined with *Rhizobium* inoculation but with sodium molybdate added to the soil at 500g molybdenum (1220g sodium molybdate) per hectare. The same treatments were used in Saptari and Siraha, except that the trial with soil application of sodium molybdate was omitted and thus there were only four treatments. The trials were replicated five times across the farms. The treatments were applied on the chickpea variety KAK 2 with a seed rate of 80 kg ha^{-1} and plot size of $75m^2$ per treatment.

Prescribed crop protection measures included seed treatment with Thiram at 2g kg^{-1} of seed, pre-flowering preventive sprays with Bavistin against botrytis grey mould (BGM) disease, and other protection measures as needed. Other management and input levels were left to the farmers for their own practice.

Molybdenum loading through seed priming of mung beans

The trials were carried out on farmers' fields in rainfed rice fallows. There were two treatments: (i) seed priming with plain water and (ii) seed priming with a 0.5% solution of sodium molybdate. Treatments were laid out in paired plots of 100 m^2 with eight replicates per district. The treatments were applied on mung bean variety NM 94 with a seed rate of 30 kg ha^{-1}.

The crop was planted in rows at spaces of 40x10 cm. Planting took place from the third week of March to the first week of May 2004. Plant protection measures were followed as required. Since the mung bean does not have synchronous maturity, pod picking of up to three times was suggested. Other aspects of management and input levels were as per farmers' practice. Relevant agronomic parameters, biotic and abiotic stress, and root nodulation count of 10 sample plants at the flowering stage, were recorded regularly by field staff.

Cattle urine spray on chickpeas and field peas

The trials were carried out on farmers' fields in rainfed rice fallows. Trials were conducted separately on chickpeas and field peas and involved paired comparison of urine-spray versus no-spray plots replicated three times in each district. Crops were planted from early November to early December 2003 immediately after the rice harvest. Cow or buffalo urine diluted four times with water was sprayed at 15 day-intervals from one month after the crop emerged. Thus, the crop received two to three sprays with urine for peas and three to five sprays for chickpeas. The spray volume was approximately 450 l ha^{-1}. The variety used was KPG 59 for chickpeas and E-6 for field pea trials with a seed rate of 60 kg ha^{-1} in both cases. Management common to both treatments included seed treatment with Bavistin at 2g kg^{-1} of seed. Other management and levels of input were as per farmers' practice. Observations were recorded on yield parameters and pest incidence.

Integrated plant nutrient management of chickpeas

The trials were carried out on farmers' fields in rainfed rice fallows and included the following six treatments:

1. farmyard manure (FYM) at 5t ha^{-1}
2. FYM at 5t ha^{-1} + cattle urine spray (4 times dilution with water) at 450 l ha^{-1}
3. FYM at 5t ha^{-1} + cattle urine spray + boron (borax 20 kg ha^{-1})
4. FYM at 5t ha^{-1} + cattle urine spray + zinc (zinc sulphate 14 kg ha^{-1})

5. FYM at 5t ha^{-1} + cattle urine spray + boron + zinc
6. control (without any fertilisers).

There were two replicates at each farm. Each experimental unit had an area of 50 m^2. Chickpea variety KPG 59 was used with a seed rate of 60 kg ha^{-1}. The trial planting lasted from early to late November in the 2002/03 and 2003/04 winter seasons. Prescribed management included seed treatment with Bavistin at 2g kg^{-1} of seed, pre-flowering preventive spray with Bavistin against BGM disease, and other protection measures as required. Other management factors were as per farmers' practices.

Farmyard manure was applied to all treatments except the control at 5t ha^{-1} during land preparation; soil application of borax at 20 kg ha^{-1} and zinc sulphate at 15 kg ha^{-1} was applied prior to seed sowing; spraying of cattle or buffalo urine at 20% concentration (1 part urine to 4 parts water) was carried out at 15-day intervals until harvest with approximately 450 l ha^{-1}. The observations were mainly focussed on yield-related parameters.

Nettle extract spray

On-farm trials were carried out on radishes, broadleaf mustard, peas, and cucumber in farmers' fields in maize-based cropping systems in the western and far-western hills of Nepal in 2001/02. The treatments included spraying of nettle extracts at various concentrations and fermentation levels as given below.

1. 10% solution of fresh nettle extract in water
2. 20% solution of fresh nettle extract in water
3. 10% solution of fifteen-day fermented nettle extract in water
4. 20% solution of fifteen-day fermented nettle extract in water
5. 10% solution of fresh nettle extract in cattle urine
6. 20% solution of fresh nettle extract in cattle urine
7. Cattle urine at 20% concentration
8. Water as a control

The treatments with cattle urine were only applied to cucumber. Nettle extracts were obtained by three different methods: (i) by grinding fresh nettle leaves and stems in water, (ii) by fermenting chopped nettle leaves and stems in water, and (iii) by grinding fresh nettle leaves and stems in cattle urine. For fresh extraction of nettle sap, the required amount of nettle leaves and stems (by weight) was ground with a mortar and pestle with an equal amount of water and the content then strained to remove floating particles. For the fermented extraction, the required amount of chopped, fresh nettle shoots with leaves was steeped in an equal amount of water in a plastic bucket and covered for 15 days. After steeping, nettle extract was obtained by squeezing and straining the content first through a mosquito net and then through a double layer of muslin cloth. Both fresh and fermented extracts thus obtained were considered to be 100% in strength (stock solution) and sprayed immediately after dilution with water at 10 and 20% strengths at 500 l ha^{-1}. About 1 l stock solution was obtained from 1 kg fresh weight of nettle shoots.

Radishes, broadleaf mustard, and peas were sown from early October to early November 2001 and cucumber was planted in the second week of March 2002 at the recommended spacing. Six sprays for peas and cucumber and eight to ten sprays for seed crops of broadleaf mustard and radishes were applied at fortnightly intervals starting three weeks after crop emergence. Considering a farm as a replication, the trials were replicated four to five times per location.

Observations on both vegetative and reproductive parameters and crop response to biotic and abiotic stresses were recorded regularly. Since the major objective of the study was to observe the effect of nettle extract on suppression of crop diseases, special attention was paid to scoring *Alternaria* blight of broadleaf mustard and radish, and powdery mildew of peas and cucumber. Disease scoring was started when the diseases were noticed and continued at 15-day intervals until maturity for broadleaf mustard, radishes, and peas, and at weekly intervals until fruit harvest in the case of cucumber. The percentage leaf infection from the dates of observations were used to calculate the area under disease progress cure (AUDPC). The AUDPC was calculated using the following formula (Shaner and Finney 1977) in Microsoft Excel 2000.

$$AUDPC = \sum_{i=1}^{n} (Y_{i+1} + Y_i)\, 0.5\, (T_{i+1} - T_i)$$

Where,
Y_i = per cent infection at i^{th} date
T_i = date on which the disease was scored

Those treatments showing lower AUDPC values are considered superior.

Results and Discussion

Effect of molybdenum loading on chickpeas

The results of the five replicates in Kapilbastu district (Table 1) and two replicates in Saptari district (Table 1), gave a very clear indication that seed priming with 0.5% solution of sodium molybdate, and soil application at 1220g ha^{-1} enhances root nodulation in chickpeas. In Kapilbastu, soil application of sodium molybdate was significantly better in terms of both grain yield and root nodulation. However, the results did not show any clear effect on grain yield and related parameters for rhizobial inoculation or seed priming with sodium molybdate solution.

In Saptari, data were only available from two trials. However, subjective interpretation of the data shows that chickpeas responded well to seed priming, rhizobial inoculation, and sodium molybdate loading. The treatment with a combination of rhizobial inoculation and sodium molybdate loading produced the highest yield and highest scale of nodulation. The increments in yield over the control treatment were of the order of 33, 36, and 113% in seed priming, rhizobial inoculation, and combination of rhizobial inoculation and molybdenum loading treatments, respectively.

Nutrient loading through seeds could be a viable technological option for poor farmers in Nepal. However, this needs further verification with more replicates before recommendations can be made.

Table 1: **Comparative performance of seed priming with plain water and molybdenum loading of chickpeas in Kapilbastu district during the cropping season 2003/04** †

Treatments	Final plant stand	Pods per plant	Seeds per pod	Grain filling %	Plant height	Grain yield (t ha^{-1})	Nodulation score (1-5) ‡
Kapilbastu							
Farmers' practice	13.5	34.2	1.05	61.7	42.75	0.25ab**	1.25
Seed priming in water	11.0	24.8	1.0	78.7	42.5	0.20b	1.40
Rhizobial inoculation	16.5	31.25	1.05	59.57	38.75	0.21ab	1.60
Rhizobium + Mo loading	14.0	28.95	1.17	67.57	46.00	0.15b	1.90
Mo soil application	15.0	45.75	1.30	58.3	49.75	0.34a	2.40
F test (0.05)	NS	NS	NS	NS	NS	*	*
CV%	19.82	49.71	14.04	23.8	13.09	35.47	21.72
SE	1.38	8.20	0.07	6.95	2.87	40.64	0.185
Saptari							
Farmers' practice	9	25.8	1.3	54.0	2.05	0.22	-
Seed priming in water	11	29.65	1.2	56.5	2.35	0.29	31
Rhizobial inoculation	12	29.3	1.1	55.5	2.85	0.30	36
Rhizobium + Mo loading	13	31.6	1.3	56.0	3.00	0.47	113

† Average of four replications ; ‡ Nodulation score on 1-5 scale; ** Means in the column followed by the same letter do not differ significantly by LSD at p=0.05

Effect of molybdenum loading on mung beans

The results of seventeen replicates across three districts indicated that molybdenum loading could be a very promising option for farmers for enhancing nitrogen fixation through root nodulation and thereby increasing the yield of mung beans in the spring season. Both grain yield and root nodulation were significantly higher in the molybdenum-loaded treatment over the normally primed seeds (Table 2). Other growth and yield parameters did not differ significantly between treatments. Molybdenum loading through seeds can be a promising component of integrated plant nutrient management for mung beans and resulted in a 20% yield increase. It is a simple and low-cost technique and hence especially useful for poor farmers in Nepal.

Table 2: **Comparative performance of seed priming with plain water and molybdenum loading of chickpeas in Kapilbastu, Saptari and Jhapa districts in the spring season 2004**†

Parameters	Mean of treatments		Significance (P-value)
	Seed primed in plain water	Seed primed in sodium molybdate solution	
Days to 50% flowering	37.2	37.2	NS
Days to 50% pod set	48.9	48.9	NS
Plant population per sq. m.	14.2	15.8	NS
Number of pods per plant	22.1	22.3	NS
Number of unfilled pods per plant	2.1	2.0	NS
Number of grains per pods	11.7	11.7	NS
Plant height (cm)	43.0	44.6	NS
Days to first picking of pods	61.6	62.1	NS
Number of nodules per plant	28.2	37.0	** (<0.01)
Grain yield (t ha^{-1})	0.45	0.54	** (<0.01)

† Results of seventeen replicates across three districts

Urine spray on chickpeas and field peas

Both chickpeas and field peas responded well to urine spray. In chickpeas, the urine sprayed plot produced a significantly higher yield ($p = 0.025$) than the control plot. Mean grain yield was 0.65t ha^{-1} in the urine sprayed plot and 0.59t ha^{-1} in the control plot, an approximately 11% increase in yield due to urine spray. The yield pattern of the treatments over all farms (replicates) is shown in Figure 1.

The treatments also differed significantly in terms of number of grains per pod ($p = 0.03$) and plant height ($p = 0.02$) with the mean values of 1.69 grains and 48.3 cm in urine sprayed plots and 1.62 grains and 46.9 cm in the control plot. There was no significant difference between the treatments for the percentage of unfilled and borer-damaged pods. This implies that the increase in yield due to urine spray could be because of nutritional supplementation rather than as a result of its pesticidal effects.

Similarly in field peas, paired t-tests showed a highly significant difference ($P = 0.001$) in yield between urine-sprayed and unsprayed treatments. The urine sprayed plots produced an approximately 28% higher mean yield (0.24t ha^{-1}) than the control plot (0.18 ha^{-1}). The yield pattern of the treatments over farms (replicates) is shown in Figure 2.

The results corroborate earlier findings that four sprays with sheep urine on Chinese cabbage increased yield by 82% over the control and by 24% over urea top-dress in the western hills of Nepal (Joshi 1992; Ghimire 1992).

Although urine spray is effective in both field peas and chickpeas, it has some limitations for its applicability. Firstly, it is difficult to obtain enough urine to treat large areas. Secondly, farmers must adopt stall-feeding and make some investment for improvement of the animal stall to collect the urine, and this may deter poor farmers. Nevertheless, some ingenious farmers have already adopted the practice of using urine sprays on vegetable crops.

Integrated plant nutrient management of chickpeas

Only the results of the 2002/03 season are analysed and presented in this paper, as the trials in 2003/04 succumbed to BGM and pod-borer. Analysis of variance of grain yield showed a significant difference ($p = 0.03$) due to treatment. In Jhapa and Kapilbastu there was a clear response of the crop to nutrient supplementation of the soil. However, the response was not as evident in Saptari. It was realised during joint monitoring that there were some limitations to the selection of a suitable site for the trial in Saptari. However, on average, all fertilised treatments had higher yields than the unfertilised check treatment.

The percentage of unfilled pods was significantly lower ($p = 0.018$) in boron-supplemented treatments, with 9-11% damage compared to 23.5% damage in the control treatment. In the rest of the treatments, the percentage of abnormal pods decreased with increased supplementation of nutrients by 21, 17 and 14% in FYM, urine spray, and zinc supplied treatments respectively.

Mean yields of different nutrient supplementation treatments are shown in Figure 3. Treatments with boron application and combined application of boron and zinc produced the highest mean yields of 1.3t ha^{-1} and 1.2t ha^{-1} respectively. The control treatment was the lowest yielder (0.6t ha^{-1}).

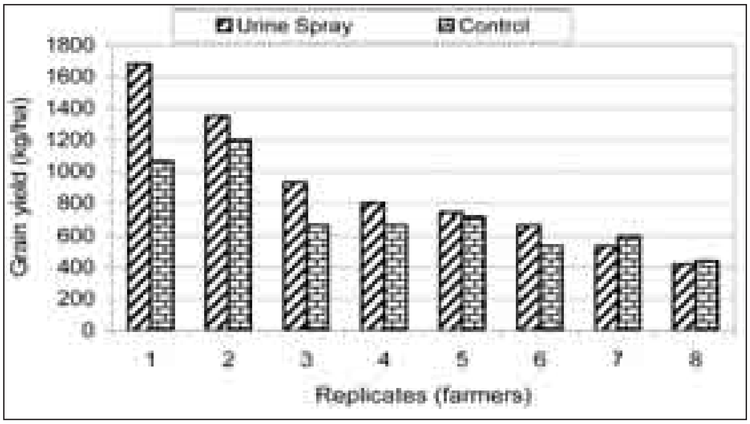

Figure 1: **Effect of cattle urine spray on grain yield of chickpeas in rice fallows in Kapilbastu, Saptari, and Jhapa districts, 2002/03 winter season**

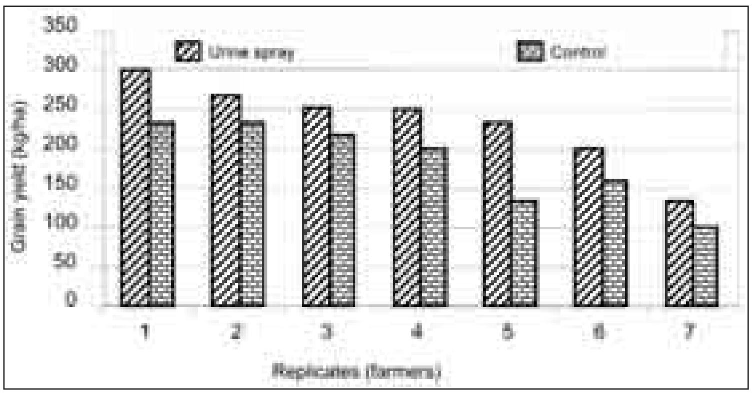

Figure 2: **Effect of cattle urine spray on grain yield of field peas in rice fallows in Kapilbastu, Saptari, and Jhapa districts, 2002/03 winter season**

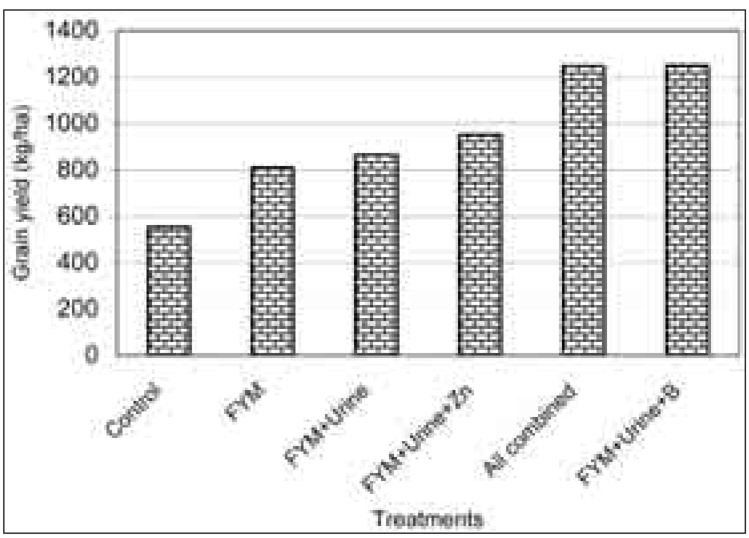

Figure 3: **Grain yield means of various nutrient management treatments in chickpeas**

It is clear that supplementation with boron contributed substantially to increasing the yield of chickpeas, while there was a moderate response to the application of farmyard manure and zinc. The trial will be repeated with more replicates for further verification of these findings.

Nettle extract spray in broad-leaf mustard, radishes, peas, and cucumber

Nettle sprayed plots, especially at higher concentration (20%), had a lower incidence of foliar diseases and higher yield for all test crops. There was a marked effect of nettle extract on the suppression of *Alternaria* blight (*Alternaria* spp.) on broadleaf mustard and radishes, and of powdery mildew (*Erysiphe polygoni*) on peas and cucumber. The control plot had a significantly higher AUDPC value (Table 3) and an increase in concentration of the spray had more effect on disease suppression, as reflected by the lower AUDPC value. This may be because of the fact that the stinging nettle contains a number of active phytochemicals with fungicidal properties (USDA-ARS-NGRL 2002).

Table 3: **Effect of nettle extract on foliar disease development of broadleaf mustard (BLM), radishes, peas, and cucumber in the Western and Far -western hills of Nepal, 2001/02**

Treatments	Area under disease progress cure (AUDPC)			
	BLM†	Radish†	Peas†	Cucumber#
Fresh nettle extract in water (20%)	86.79	55.70	106.29	60.48
Fresh nettle extract in water (10%)	105.74	59.00	125.81	124.04
Fermented nettle extract in water (20%)	99.25	54.40	112.18	41.37
Fermented nettle extract in water (10%)	111.83	59.20	132.97	99.73
Fresh nettle extract in urine (20%) **	-	-	-	29.86
Fresh nettle extract in urine (10%) **	-	-	-	64.99
Urine spray (20%) **	-	-	-	36.52
Control (water spray)	125.33	63.00	195.91	156.89
P-value	0.00	0.00	0.03	0.01
CV%	10.25	7.45	46.92	38.58

† means of nine replications across two sites ; # means of two replications; ** treatment applied only to cucumber

Table 4 shows the average yields of the test crops in the trial. There was a significant difference between the treatments in seed yield of broadleaf mustard ($p = 0.02$). Although the treatments stood at par for seed yield of peas and radishes and fruit yield of cucumber, in all cases there were higher yields in nettle-treated plots over the control. Moreover, there was a general tendency towards higher yields with higher concentrations of the nettle extract spray. The results show that a 20% solution of fermented nettle spray gave the consistently highest seed yields with increases in broadleaf mustard of 31.4%, radishes 18.5%, peas 14.6%, and cucumber 102% over control treatments.

The nettle extract spray could have multiple effects on crops including disease suppression, nutrient supplementation, and hormonal activities. It is reported that nettle leaves are rich in calcium (Ca) (5,940-33,0000 ppm), magnesium (Mg) (860-8,600 ppm), nitrogen (N)

Table 4: **Effect of nettle extract on seed yields of broad leaf mustard (BLM), radishes, and peas and fruit yield of cucumber in the western and far-western hills of Nepal, 2001/02**

Treatments	Seed yield (t/ha) †			Fruit yield (t/ha) #
	BLM	Radish	Peas	Cucumber
Fresh nettle extract in water (20%)	4.79	1.09	5.20	23.65
Fresh nettle extract in water (10%)	4.51	1.39	4.94	23.75
Fermented nettle extract in water (20%)	5.25	1.07	5.74	27.50
Fermented nettle extract in water (10%)	4.33	1.05	5.41	21.53
Fresh nettle extract in urine (20%) **	-	-	-	22.64
Fresh nettle extract in urine (10%) **	-	-	-	22.29
Urine spray (20%) **	-	-	-	15.80
Control (water spray)	3.99	0.92	5.01	13.61
P-value	0.02	0.49	0.19	0.35
CV%	11.45	12.22	15.72	29.56

† Means of nine replications on two sites ; # Means of two replications ; ** Treatment applied only on cucumber

(10,000-55,0000 ppm), sulphur (S) (1,200-6,665 ppm), silicon (Si) (1,170-6,500 ppm), chlorine (Cl) (2,700 ppm), iron (Fe) (44-418 ppm), potassium (K) (6,700-37,220 ppm), and dozens of active chemical compounds (USDA-ARS-NGRL 2002). Therefore, the sprays made from nettle leaves are rich foliar fertilisers that invigorate plant growth and improve their disease resistance (GCA 2002; Peterson and Jensen 1985, 1986; Diver 2004). A study on the use of moringa leaf juice on various crops in Nicaragua showed similar growth-promoting effects, and it was found that one of the active substances contained in moringa leaves was zeatin, a plant hormone from the cytokine group, which was responsible for crop growth invigoration (Fuglie 2000). Malaguti et al. (2002) observed beneficial effects of leaf sprays based on seaweed extract on the quality and colour (red) intensity of apples. Whether nettle also contains such hormonal substances is an interesting issue for further research.

Conclusion

In the context of small and resource-poor farmers in Nepal, recommendation of technologies based on high-cost external inputs have little practicality because farmers are unable to afford them. Farmers are aware of the problems of soil degradation, but are not technically or financially equipped to respond appropriately. The responses of crops to supplementation of plant nutrients are evident from the on-farm trials. A search for other supplementary nutrient management options suitable for small farmers is underway and some promising results are already in hand. Among the low-cost and/or local resource-based options for supplementing nutrients, use of cattle/buffalo urine and nettle leaf extracts for foliar feeding of crops have shown great promise. Preliminary results of molybdenum loading through the seeds of leguminous crops, such as chickpeas and mung beans are also encouraging. With further verification and fine-tuning of the state-of-the-art practices, micronutrient loading through seeds and foliar sprays with urine and locally available plant extracts could be promoted as supplementary nutrient management options to increase crop yields and food security for marginal farmers.

Acknowledgements

This document is an output from a project (Plant Sciences Research Programme Project R8221) funded by the Department for International Development (DFID), UK, and administered separately by the Centre for Arid Zone Studies (CAZS), University of Wales, UK; and another DFID-funded project administered by the Seed Sector Support Project (SSSP), Nepal. The views expressed are not necessarily those of DFID. The authors would like to thank all the farmers who participated in various districts of Nepal for their contributions to this research. The FORWARD management and field staff who helped in this research are thankfully acknowledged.

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Soil Fertility Problems and Strategies to Reduce Them in the Himalayan Region of India

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Introduction

The hill soils of the Indian Himalayan region vary widely in their kind and properties and are spread across the states of Jammu & Kashmir, Himachal Pradesh, Punjab, Uttar Pradesh, Bihar and the north-east hill region. The fertility of these soils suffers from various micronutrient deficiencies. Strategies are being developed to correct micronutrient deficiencies through fertilisation and other amendments, and are helping to achieve optimum crop productivity to a considerable extent in some areas. In this paper, the soil fertility problems resulting from micronutrient deficiencies or excess, and methods for their alleviation, are discussed by state.

Jammu and Kashmir (J&K)

Fertility Status

Ladakh, Jammu & Kashmir – Analysis of DTPA extractable micronutrients in soils (Entisols) in the cold-arid zone of Ladakh showed levels of Zn, Fe, Mn, and Cu ranging from 0.02 to 3.86, 1.56 to 14.6, 2.12 to 5.9, and 0.20 to3.7 mg kg^{-1} soil, respectively, with 30% of soils deficient in Zn and nearly 26% deficient in Fe (Jalali et al. 2000). Sub-tropical, intermediate, temperate, and cold-arid soils showed Zn deficiency in 22, 24, 18, and 30% of samples, respectively. In the Jammu region 31, 26, 23, 19, 13, and 10% of samples in Jammu, Rajouri, Doda, Kathua, Udhampur, and Poonch districts, respectively, showed Zn deficiency. The available Zn content in these soils ranged from 0.1 to 6.1 mg kg^{-1}. Further investigations revealed that about 51% of soils in the mid-hills were also deficient in Fe as well as 24% in Zn (Jalali and Sharma 2002; Jalali and Pareek 2003). In the soils of Kashmir, available Zn was higher in the high altitude (kandi) soils (0.37-0.60 mg kg^{-1}) than in the valley basin (0.15-1.0 mg kg^{-1}) and karewas (Hapludalfs) soils (0.27-0.80 mg kg^{-1}). The Zn status in almost all the soils was in the deficient range and that of Cu, Fe, and Mn in the adequate range (Jalali et al. 1989). Thus Zn deficiency is one of the major constraints in these soils. The content of available micronutrients decreased with pH and increased with soil organic matter (SOM) content. The magnitude of Zn deficiency decreased with increase in SOM content and increased with increase in soil $CaCO_3$ and pH (Jalali and Sharma 2002; Jalali et al. 1989).

Correction of deficiency

Field crops – The productivity of rice, wheat, maize, rapeseed, and mustard improved markedly with Zn application to the soils of the intermediate and sub-tropical zones in the Jammu region. Application of 4.4 kg ha^{-1} Zn as a top dressing gave maximum maize and rice grain yield responses of 48.5 and 17.9% respectively; the basal Zn application lead to wheat and rapeseed yield increases of 11.8 and 7.6%. The residual effects in the paddy-wheat cropping system lasted for two years (Jalali et al. 1999; Sharma et al. 2003; Jalali and Pareek 2003).

Fruit crops – The soils of citrus, mango, and guava orchards contained low available (DTPA) Zn (0.26-2.48 mg kg^{-1}). Some 53% of soil samples were deficient in Zn, whereas all the soils contained adequate levels of available Cu (0.22-2.54 mg kg^{-1}), Fe (4.5-63.5 mg kg^{-1}), and Mn (1.92-36.2 mg kg^{-1}). Leaf analysis also showed Zn deficiency in 40% of mandarin samples, 56% of mangoes, and 30% of guavas, but not in 'ber' samples. No deficiencies of Fe, Mn, or Cu were observed in the leaves. Deficiency of N, P, K, and S was also severe in orchard soils, up to 75, 45, 22, and 44% of samples, respectively; these appear to have masked the beneficial effects of Zn application to obtain optimum productivity. A strategy of correction of macronutrient deficiencies needs to be adopted while alleviating micronutrient deficiencies (Sharma et al. 2001; Jalali and Pareek 2003).

Himachal Pradesh (HP)

Fertility Status

Valley areas under wheat and rice cultivation – In the wheat growing areas of Suwan and Nurpur, Chhota Bhangal, Bath and Kulu, Jahu, Janjethi, Shimla, and Ponta, 28% of soil samples and 12% of wheat plant samples were deficient in Zn. In the Palam Valley, 66% of soils and 31% of wheat samples suffered from Zn deficiency; in the remaining area, 20-25% of the soils were deficient in Zn. In the rice-growing soils of Nurpur, Kangra, Bath and Kulu valley, the available micronutrient content in soils ranged from 1.6 to 50.0 mg kg^{-1} for Fe, 1.5 to 48.0 mg kg^{-1} for Mn, 0.1 to 7.8 mg kg^{-1} for Cu, and 0.3 to 1.5 mg kg^{-1} for Zn. Seventeen per cent of soil samples were deficient in Fe in the Kangra Valley; 1.3 and 20.0% were deficient in Cu in the Kangra and Bath valleys; and 20.0, 14.2, and 11.8% were deficient in Zn in the Bath, Kulu, and Kangra valleys respectively (Verma and Tripathi 1982, Tripathi et al. 1994).

Vegetable growing soils – In the major off-season vegetable growing area in the Spiti valley and Kinaur district, 16-42% of soil samples were deficient in available Fe, 18-34% in Mn, and 11-65% in Zn (Parmar et al. 1999). The availability of Fe and Mn decreased significantly with increase in soil pH and $CaCO_3$ content and that of Zn with increase in pH. The availability of all three micronutrients increased with increase in SOM content.

Orchard soil – The soils in the apple orchards of the Shimla Hills had 35 and 70% Zn deficiency, 30 and 94% B deficiency, and 50 and 35% Mo deficiency in surface and sub-surface soils respectively. Thus the nutrient status of sub-soil needs to be taken into account when ascertaining the fertility status of orchard soils (Bhandhari and Randhawa 1985). In another study, Sharma and Bhandhari (1995) observed that only available B was low in 57% of soil samples from a group of Delicious apple orchards. Leaf analysis indicated that 11, 5, and 40% of orchards were low in Zn, Cu, and B respectively. The high deficiency of B is attributed to an acidic soil reaction coupled with the high humidity of the region.

Typical pedons (profiles) – In ten typical pedons, available Zn content varied from 0.1 to 2.8 and 0.4 to 4.8 mg kg^{-1}, available Cu from 6.2 to 40.5 mg kg^{-1}, and available Fe from 3.8 to 52.5 mg kg^{-1} respectively. Most of the pedons were deficient in Zn only. The availability of micronutrients generally increased with increase in soil organic matter and decreased with increase in soil depth (Tripathi et al. 1994).

Correction of deficiency

Potato – Nearly 76% of the brown hill soils of the potato-growing areas were deficient in Zn and 31% in Cu. In these soils, the response of potato to addition of Zn, Cu, Fe, Mn, B, and Mo ranged between 1.0 and 7.6, 2.2 and 6.1, 1.1 and 4.0, 1.5 and 3.9, 3.2 and 4.4, and 1.0 and 3.5 t ha^{-1}, respectively. Zn efficient potato varieties have also been identified (Grewal and Trehan, 1990).

Wheat – In Palampur soils, wheat showed a significant response to Cu application of 107 kg ha^{-1}, and paddy to Zn and Fe of 456 to 764 kg ha^{-1}. In Kangra, Palampur, and Kulu districts, a significant response (242-276 kg ha^{-1}) of maize to Zn application was observed (Kanwar and Randhawa 1974).

Punjab (Sub-mountain Areas)

Litchi orchard soils – A study on the nutritional status of litchi orchards in the sub-mountain districts of Hoshiarpur, Gurdaspur, and Ropar showed 97, 14, 3, and 3% of orchards to have a low or medium fertility status for Mn, Zn, Cu, and B, respectively. None were deficient in Fe. Thus the major deficiencies were in Mn and Zn and application of these might improve the yield of litchi fruit (Hundal and Arora 1993).

Uttar Pradesh (UP)

Foothill Terai soils – Zinc deficiency is a serious soil fertility constraint in the foothill Terai soils of Uttar Pradesh; field-scale deficiency of Zn in rice was recorded for the first time in these soils. A long-term fertiliser experiment (LTFE) with an intensive rice-wheat-cowpea cropping system on these soils (Mollisols) depleted the available Zn from adequate (2.77 mg kg^{-1}) to deficient level (<1.0 mg kg^{-1}) after 12 years. Application of 11 kg Zn ha^{-1} restored the soil Zn fertility status and improved the productivity of the system by 0.48t ha^{-1}. Application of 15t FYM ha^{-1} annually also maintained the Zn level in the adequate range and improved the productivity by 0.44t ha^{-1} (Nand Ram 1998). Thus the strategy to reduce the Zn deficiency problem on such Mollisols is to apply either Zn fertiliser or FYM to achieve a sustainable high productivity of the system. In a similar LTFE in Himachal Pradesh on Typic Hapludoll under a maize-wheat system, there was no Zn or other micronutrient deficiency even after 25 years. Thus the emergence of micronutrient soil fertility problems depends on the soil type and the cropping system. Clear Zn deficiency symptoms have been observed in maize, pulses, and citrus fruits in these areas. The deficiency problem arises after one year of growth in citrus orchards when the root system reaches down deep below the plough layer to a layer low in available Zn. The available Zn content and distribution in six soil series of Nainital Terai soils representing poor, imperfect, and moderately well drained soils was deficient, ranging from 0.08 to 0.60 mg kg^{-1} soil. Available Zn decreased with soil depth and was mainly regulated by the SOM content (Vittal and Gangwar 1974; Bhardhawaj and Prasad 1981).

Hill districts of Almora, Pithoragarh and Chamoli – The micronutrients Zn, Cu, Fe, Mn, Mo, and B were deficient in 74, 20, 17.3, 20, 18.6 and 24% of soil samples, respectively, from the three hill districts of Almora, Pithoragarh, and Chamoli (Rawat and Mathpal 1981). The availability of these micronutrients decreased significantly with increase in soil pH and $CaCO_3$, and increased with increase in organic C content.

Valley soils of the Garhwal Division – The soils of the Bageshwar and Garur valleys of the Kumaon Division and Ranichauri area of Garhwal Division of UP contained 2.6 to 30.8 mg kg^{-1} of available Fe (NH_4OAc extractable) and were thus considered well supplied with Fe, taking 2.0 mg Fe kg^{-1} as the critical limit (Kumar et al. 1981). Normally, however, 4.5 mg Fe kg^{-1} is taken as the critical limit, and according to this all the soils of Garur fall into the deficient category.

Correction of deficiency

Rice and Potato – A significant response of rice grain was observed to 5 kg Zn ha^{-1} in a rice-wheat system on Zn deficient deep alluvial soil in Doon Valley of UP, and of wheat grain to a residual level of 10 kg Zn ha^{-1}. Considering the net return and Zn use efficiency, 7 kg Zn ha^{-1} is recommended for rice-wheat rotation to achieve optimum yield and return (Bhardhawaj and Prasad 1981). In acid soil at Ranichauri, Tehri Garwal, potato responded to the application of B (Dwivedi and Dwivedi 1992).

Bihar

Chhotanagpur plateau soils – These soils are highly acidic and deficient in Mo. Soil applications of 1.0 to 1.5 kg Mo ha^{-1} to cauliflower significantly increased the curd yield by 14-18%, although whiptail malady – the Mo deficiency disorder – caused crop losses of only 1-2% during the winter (rabi) season. In another field experiment with cauliflowers on a red sandy loam soil (Ultic Haplustalf, pH 5.2, available Mo deficient), both 0.1% foliar and 1.0 kg Mo ha^{-1} soil application significantly increased the curd diameter and weight (Kotur 1995).

North-Eastern Hill Region

This area includes the states of Meghalaya, Tripura, Assam, Manipur, and Sikkim.

Meghalaya

Soils

East-Khasi hill soils – Boron deficiency is a commonly observed micronutrient disorder in the Alfisols or acid soils in humid regions. With acute B stress in these soils, application of B decided the success or failure of crops (Dwivedi et al. 1990b). Available B was determined using six extractants. Of these, only four: mannitol-$CaCl_2$, hot-water soluble (HWS), HWS-boiling, reflex, and DTPA-NH_4HCO_3 were found promising with respective critical limits of 1.0, 0.7, 0.7, and 0.6 mg kg^{-1}. Soils testing below these critical limits responded significantly to B fertilisation (Dwivedi et al.1993).

Rice soils – About 35% of rice growing acid soils were deficient in B and 17% in Zn. However, the content of available Mn, Fe, Cu, Co, and Mo was in the adequate range (Nongkynrih et al. 1996).

Soils under different land-use systems – The total and available micronutrient status of soils of the Ri-bhoi district of Meghalaya under various land-use systems – 'bun' cultivation, terrace, natural forest, and valley land – was assessed. Burning under bun cultivation led to a decrease in available Fe, Zn, and Cu, and increased Mn content four-fold (Venkatesh et al. 2003). Total micronutrients also increased on burning. However, the level of available and total micronutrients after three years of bun cultivation was almost the same as the initial status. The highest contents of available Fe, Zn, and Cu and lowest of Mn were observed in valley land soils.

Transformation of Zn – Transformation of applied Zn into different forms was investigated in six wetland acid rice soils (pH 5.0-5.7, organic C 0.9-5.1%). Close to 4.2, 23.1, 19.6, 18.8, and 19.6% of Zn was transformed into water soluble and exchangeable, organically complexed, manganese oxide, amorphous sesquioxide, and crystalline sesquioxide bound forms respectively. Submergence caused a gradual decrease in all the forms of Zn. Thus the bulk of the applied Zn transformed into strongly-bound forms and only a small portion remained available to plants. Plants drew Zn largely from the Mn oxide fraction. The transformation of applied Cu in these soils was similar (Singh et al. 1999; 1999a).

Correction of deficiency

Boron in pea-wheat cropping system – The direct and residual effect of liming (1.5, 3.0, and 6.0t ha^{-1}) and of B (1.5, 3.0, and 6.0 kg ha^{-1}) on the yield of pea and corn grown in a sequence were studied in a field experiment on a sandy loam acid Alfisol at Barapani, Meghalaya. Concentration of B in plant parts increased appreciably with increasing rates of B application but decreased with increasing rates of lime. Application of B significantly increased the hot-water soluble B from 0.24 to 0.89 mg kg^{-1} soil, but increasing rates of lime application significantly decreased B from 0.66 to 0.41 mg kg^{-1} (Dwivedi et al. 1990b; 1992; 1993). Direct application of 1.5 kg B ha^{-1} significantly increased the pod and stover yield of peas (Dwivedi et al. 1992). A sharp decline in yield occurred at higher rates of applied B, suggesting it has a toxic effect for peas. Liming accentuated B deficiency in the absence of applied B because of fixation of soluble B on Al and Fe oxides as a result of increase in pH, but lime cured the toxic effect arising from high rate of B application. Application of 1.5 kg B ha^{-1} and 3.0t lime ha^{-1} gave optimum pea productivity, but the residual effect of 1.5 kg B ha^{-1} was insufficient to meet the need of the succeeding corn crop. The residual levels of 3.0 - 4.5 kg B ha^{-1} and 1.5t ha^{-1} of lime met the B requirements of corn to produce significantly higher yields and are recommended. Concentration of B in plant parts increased appreciably with increasing rates of B application but decreased with increasing rates of lime. .

Boron in summer and winter season crops – Direct and residual effects of 0, 0.5, 1.0, and 1.5 kg B ha^{-1} in four summer (rainy) season (kharif) and winter (rabi) crops were studied on B deficient sandy-loam acid Alfisols (pH 5.05, organic C 1.65%, hot-water soluble B 0.18 mg kg^{-1}) at Barapani (Dwivedi et al.1990b). The cropping sequences were rice-lentil; finger-millet-pea; composite maize-mustard; and soybean-linseed. Boron concentration in the shoots, grains, and straw increased progressively with rates of B application. As a result, grain yields increased significantly for all crops up to 1.0 kg B ha^{-1}, beyond which the yield of maize and finger-millet decreased sharply. This shows that the gap between the toxicity and adequacy limits of B are quite narrow for these crops. The magnitude of response to B was maximum in finger-millet (1.5t ha^{-1}), followed by rice (1.93t ha^{-1}), maize (1.98t ha^{-1}), and soybean (0.43t ha^{-1}). The succeeding winter crops in the rotation also responded significantly to residual levels of 1.0 kg B ha^{-1}, except for linseed which responded down to a 1.5 kg B ha^{-1} level. The crops differed in response; the maximum was in linseed followed by mustard, peas, and lentils. Both Ca and Mg affected the B availability or its use by crops, as revealed by a significant antagonistic relationship between the grain yield and the Ca/B (r= –0.53*) and Mg/B (r= –0.65**) ratios in crops.

Zinc and Copper in Rice – Rice responded to Zn and Cu significantly; application of 5 mg Zn kg^{-1} and 1.25 mg Cu kg^{-1} soil gave the optimum yield. The dry-matter rice yield, and Zn and Cu concentration in the plants were significantly correlated with initial DTPA extractable Zn and Cu. Soil testing below the critical level of 1.2 mg Zn kg^{-1} and 0.7 mg Cu kg^{-1}, and plants testing below 35.9 mg Zn kg^{-1} and 7.0 mg Cu kg^{-1} needs application of Zn and/or Cu to obtain optimum rice yield (Dwivedi et al. 1990a; Singh et al. 1999, 199b; Singh and Nongkynrih, 2000).

Tripura

The fertility status with respect to available Zn, Cu, Fe, and Mn was higher in lowland than in upland soils, whereas B and Mo contents were higher in upland than in lowland soils. However, all the micronutrient cations were in the adequate range. Nearly 29% soils were deficient in B and 50% in Mo. As soil pH increased, available Zn, Cu, and B content decreased significantly in upland soils. The available Cu and Fe content increased with increase in organic C, while that of Zn and Mo decreased (Datta and Gupta, 1984; Datta and Munna Ram, 1993).

Assam

Fertility status

Alluvial, bheel, forest and tea soils – Micronutrient status was evaluated in seven soil profiles from old alluvium in Nowgong, new alluvium in Tejpur, forest soil in Gauhati, hill soils in Diphu and Naysbunglow, tea garden soil in Jorhat, and bheel soil in Cachar. Available B content in these profiles varied from 0.02 to 1.43 mg kg^{-1} and all the surface soils contained sufficient B. The available Mo varied from 0.015 to 0.053 mg kg^{-1} soil and was in the range of deficiency to marginal fertility. Available Cu ranged between 0.87 and 2.50 mg kg^{-1}. Cu content was the lowest and organic C the highest in bheel soils. The forest, hill, and bheel soils were rated low in available Cu, the result of the high intensity of weathering and leaching in these acid soils (Chakraborty et al. 1979, 1980, 1981). Available Cu increased significantly with increase in pH (r= 0.524*). Available Zn ranged from 4.8 to 16.9 mg kg^{-1} soil and its fertility status was high. Deficiency of B ranged between 5 and 65% and was higher under fruit and field-crop ecosystems (42-65%) than under pasture- (32-45%) and forest ecosystems. Available B was less in high than in low rainfall areas of lateritic soils (Borkakati and Takkar 2000).

Correction of deficiency and toxicity

Boron and Mo – Toria (rapeseed *Brasssica campestris*) did not respond to the application of B and Mo at the Regional Agricultural Research Station, Shillongani, and Nagaon, Assam. But their application significantly increased the oil content (Patgiri 1995).

Manipur

Fertility Status – The fertility status of Zn, Cu, Fe, and Mn in seven profiles from Manipur indicated inadequate or marginally adequate levels of available Zn only (Sen et al. 1997).

Sikkim

The available micronutrient status in 44 soil samples (pH 4.2-5.9, organic matter 2.0-8.4%) from the eastern, western, and southern districts revealed adequate Zn, Fe, and Mn levels; their content ranged from 0.47 to 3.0, 5 to 210, and 0.05 to 6.2 mg/kg, respectively. The available Cu content ranged between 0.05 and 0.5 mg/kg; about 33% of the soils were Cu deficient (Khera and Pradhan, 1980). Total and available Cu and Mn and available B content decreased, and that of available Zn and Fe in soil increased markedly with increase in altitude. About 85 and 94% of soils were deficient in B and Mo respectively. These soils were sufficient in Zn, Cu, Fe, and Mn (Yashoda, and Avasthe 1995).

Orchard soils – The micronutrient cation status of soils and trees (leaf samples from non-bearing twigs) from 32 mandarin orchards in the acidic hilly terrain of the high-rainfall area of Sikkim was assessed (Patiram et al. 2000). Although the soils contained sufficient available Zn (2.9-11.8 mg kg^{-1}), Cu (0.4-5.1 mg kg^{-1}), Fe (6.8-110.6 mg kg^{-1}),and Mn (252-1822 mg kg^{-1}) in surface soil, the leaves in 33% of the orchards were low in Zn and Mn, but sufficient in Cu and high to excess (80%) in Fe. Leaf analysis appears to be a useful tool for determining the nutritional status of mandarin trees or the fertility status of soils, and for this there is a need to establish their critical levels.

Iron Toxicity

Occurrence of wetland rice bronzing disease – Acid Alfisols are widely distributed in the states of HP, UP, J&K, and Meghalaya, and in the east Khasi hills and the narrow valleys of Tripura. These soils generally exhibit widespread occurrence of bronzing disease in rice grown under wetland conditions. The visual symptoms of the disease are brown spots spread over almost the entire leaf surface, which later curls and dries. Under greenhouse conditions, the disease has been shown to result from excessive concentration of Fe in diseased plants, 805 mg kg^{-1} compared to 480 mg kg^{-1} in the normal plants (Verma and Tripathi 1984). Submergence is mainly responsible for this disorder. Incorporation of 3t lime ha^{-1} delayed the bronzing symptoms and sustained the yield in HP. In Tripura and the east Khasi hill soils of the Meghalayas, rice bronzing disease is much more prevalent in soils with shallow water tables (<40 cm), high in organic C (>2.99%), and low in pH (<5.5) (Singh et al. 1992). Severe Fe toxicity symptoms in plants were closely associated with a 3.1 fold level of Fe in diseased compared to normal plants and high active Fe (>1.2%) and organic C (2.99%) content, continuous submergence, and impeded soil drainage conditions (Singh et al. 1992). Iron toxicity was responsible for the low yields of rice in these soils (Prasad and Ram 1985). In Assam, application of As-benomyl, a systemic fungicide, alone and with FYM, significantly retarded the decrease in redox potential which appreciably decreased available Fe and Mn and their total uptake in rice. As a result Fe toxicity decreased and grain and straw yield of rice markedly increased (Bhattacharya et al. 1996).

Summary and Conclusions

This paper highlights micronutrient soil fertility problems and strategies to reduce these in the Himalayan region of India. Zn deficiency is one of the major constraints to high productivity of field and fruit crops in the soils of Jammu and Kashmir. Copper, Fe, Mn, B and Mo deficiency has not been reported. The productivity of rice, wheat, maize, and rapeseed improved markedly with Zn application. In the soils of HP, fertility problems have been observed with respect to all the micronutrients, but the problem of Zn and Cu was more predominant in wheat, rice, maize, and potato growing soils and of B in some apple orchards. Application of these micronutrients markedly improved the productivity of crops. Zn efficient potato varieties have also been identified. In UP, Zn deficiency has been a serious soil fertility constraint in the foothill (Mollisol) Terai soils. Soil-cropping systems determined the emergence of specific micronutrient fertility problems. Intensive cultivation using the rice-wheat-cowpea system on Terai soils depleted the available Zn from adequate to deficient level after 12 years. Application of Zn or FYM restored the depleted Zn status of soil and markedly improved the productivity of the system. But in a similar experiment on Typic Hapludoll under the maize-wheat system in HP, neither Zn nor any other micronutrient deficiency appeared even after 25 years of cultivation. In Bihar, deficiency of Zn, Cu, and Fe has been shown in hill and forest soils. In the North-Eastern Hill Region, micronutrient fertility problems, largely of B and Zn, have been observed in the acid soils of Assam, Meghalaya, Tripura, and Sikkim. Significant responses have been observed of rice and wheat to B and Zn and of mustard to B application alone and together with lime amendment. Coarse-textured soils, soils low in organic C, and soils located in high rainfall areas contain less available B than fine-textured soils, or soils high in organic C. In Assam, deficiency of B ranged between 5 and 65% and was higher under fruit and field-crop ecosystems (42–65%) than under pasture (32-45%) and forest ecosystems. Available B was less in high than in low rainfall areas of lateritic soils. Deficiency of the macronutrients N, P, K, and S also occur in orchards and need to be managed together with micronutrients to fully realise the benefits of micronutrient input. The micronutrient status of sub-soil or a profile, and leaf analysis, need to be taken into account while ascertaining the fertility status of orchard soils. Residual effects of Zn, B, and lime or FYM amendments have been observed and need to be taken into account in the fertiliser schedule for specific soil-cropping systems. The soil properties pH, organic C, texture, and $CaCO_3$ appreciably regulated the available status of micronutrients in all the soils. Iron toxicity, a bronzing disease in wetland rice, is a serious soil fertility problem in Meghalaya, HP, and Tripura. It originates from high active Fe, high organic C, and shallow water table and impeded drainage conditions.

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Alleviating Micronutrient Deficiencies in Alkaline Soils of the North West Frontier Province of Pakistan: On-farm Seed Priming with Zinc in Wheat and Chickpea

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Abstract

In the North West Frontier Province of Pakistan, most soils are either coarse or fine textured, moderately to strongly calcareous, alkaline, and deficient in zinc. A series of on-station and on-farm trials were implemented between 2002 and 2004 to assess the response of wheat and chickpeas to the addition of zinc.

For wheat, two trials showed that soil applications of about 13 kg ha^{-1} $ZnSO_4$ increased grain yield on average by 338 kg ha^{-1} (15%). Other experiments had shown that priming seeds with water (soaking them for eight hours before sowing) resulted in significant benefits to yields in many crops, including wheat and chickpeas. Preliminary experiments with wheat established that seeds could be primed safely with dilute solutions of zinc sulphate ($ZnSO_4$) and that 0.4% zinc (Zn) was safe and effective. Eight additional trials produced a mean increase of 615 kg ha^{-1} by using seeds primed with 0.4% Zn in comparison with non-primed seeds. Data from two trials that included seeds primed with water alone established that about half of the increase was due to zinc while half was due to the effect of priming with water. The benefit:cost ratio for soil application was only 8:1, whereas for priming seeds with 0.4% zinc it was about 360:1 (about 160 for the response to zinc alone).

The safe, optimum concentration for priming chickpea seeds was much less: 0.05% Zn. In nine trials, this treatment increased the grain yields of chickpeas from 1050 kg ha^{-1} to 1552 kg ha^{-1} in comparison with non-primed seed. Yield increases in individual trials ranged from 10-122%, with a mean of 48%. Data from two trials that included seed primed with water alone established that about half of this increase was due to zinc while half was due to the effect of priming with water. The benefit:cost ratio for priming chickpeas with 0.05% Zn was 1500:1 (about 750:1 for the response to the zinc).

Introduction

The North West Frontier Province (NWFP) of Pakistan contains seven agro-ecological zones across a total geographical area of 10.1 million hectares. The physiography varies from wide alluvial plains to hills and mountains interspersed by narrow valleys. Only two million hectares of the province is cultivated due to the relief and adverse climate. Forty per cent of cultivated land is irrigated by canals; the remaining area depends on rainfall. The province produces around a million tonnes of wheat (mostly irrigated), some six per cent of Pakistan's wheat production, and about 17,000 tonnes of chickpeas (mostly rainfed), about three per cent of the country's production (GoP 2004).

The climate of the cropped area varies from warm humid to hot dry subtropical continental from northern to southern districts, with rainfall from above 650 mm to less than 200 mm per annum. Soils vary, but in general are moderately calcareous and alkaline in nature (see below for details of sites). Zinc (Zn) deficiency in Pakistan was first recognised by Yoshida and Tanaka (1969) when Hadda disease in rice was diagnosed as Zn deficiency. Later, research established the incidence of widespread Zn deficiency in all rice growing tracts of the country (Chaudhry and Sharif 1975; Kausar et al. 1976). Now Zn fertilisation is widely recommended for rice. Zn deficiency has also been reported in wheat (Khattak and Parveen 1986a), maize (Rashid et al. 1979), and other crops (Tahir 1981; Khattak and Parveen 1986a; Rashid and Qayyum 1991).

An FAO study (Sillanpa 1982) on the micronutrient status of soils in Pakistan showed that about 62% of soils in Punjab, 100% in Sindh, and 7% in NWFP were deficient in Zn. Kausar et al. (1976) also indicated that 86% of all samples from the four provinces were Zn deficient. Khattak and Parveen (1986b) reported that, out of 320 soil samples collected from NWFP, 23% were deficient in Zn. This study included samples of forest soils, but district-wise data revealed that nearly 50% of samples were Zn deficient in Karak district and 100% in the loess soils of the Peshawar Valley. Based on extensive research carried out on micronutrients in soils and crops, it has been estimated that about 70% of the presently cultivated area of the country can be considered Zn deficient. Zinc deficiency is the third most serious crop nutrition problem in the country after nitrogen (N) and phosphorous (P) deficiency (Rashid 1996).

Nevertheless, the use of zinc sulphate as a soil additive is not a common practice among farmers in NWFP. In this paper, we test two hypotheses. First, the hypothesis that wheat and chickpeas respond to additional Zn in NWFP conditions was tested. Second, the feasibility of an alternative to soil amelioration was determined.

This alternative approach involves soaking seeds in dilute solutions of zinc sulphate before sowing. It is now well established that 'on-farm' seed priming with water alone is effective in bringing about a substantial increase in yields of chickpea (Harris et al. 1999; Musa et al. 2001) and wheat (Harris et al. 2001) in South Asia. There are several advantages to using seed priming to deliver micronutrients to seeds: the effects of uneven application of zinc to the soil are avoided as each seed is exposed to the nutrient; uptake is guaranteed; and the amounts required are likely to be in orders of magnitude less than for soil application. Conversely, risk of toxicity may be increased by priming.

We report below the results from a series of in vitro, on-station, and on-farm trials in which the yield response to addition of zinc was determined for chickpeas and for wheat, and seed priming with zinc sulphate was compared with soil amelioration using the same material. The results were used to prepare a preliminary benefit:cost analysis.

Materials and Methods

Experimental sites

NWFP Agricultural University is located in Peshawar city, the capital of North West Frontier Province. Peshawar has a warm to hot semi-arid sub-tropical continental climate with a mean annual rainfall of about 360 mm. 'Mini-plot' and 'research station' trials were carried out at the NWFP Agricultural University research station. The soil is a silty clay loam derived from piedmont alluvium, deep and well-developed; and it belongs to the Great Group Haplustalfs, is well drained and moderately calcareous (12% lime), with a pH of 8.3. The soil is deficient in nitrogen and phosphorous but has adequate potassium (K). Organic matter is less than 1%. Canal irrigation is available.

Karak District is approximately 200 km south of Peshawar. Mean annual rainfall is less than 350 mm with a semi-arid, hot subtropical continental climate. Loamy sands and sandy loams have been formed from weathering of surrounding sandstone rocks, deposited by rain torrents, and mostly belong to Great Groups – Torrifluvents and Torripsamments. Underground water is deep and saline. There are few sources of irrigation and agriculture is mostly dependent on rainfall. Soils are non-saline and moderately calcareous (8.5% lime) with an alkaline reaction (pH 8.1). Organic matter is less than 0.5% and crops are predominantly rainfed with some supplementary irrigation from tubewells.

Risalpur, in Nowshera District, also has a semi-arid, hot subtropical continental climate with a mean annual rainfall of less than 550 mm. Soils are either loamy sand formed from Kabul River alluvium, which are used to grow chickpeas under rainfed conditions, or silt loam (water redeposited loess), which are used to grow wheat with canal irrigation. Sandy soils are moderately calcareous (10% lime) with a pH of 8.2 and silt loam soils are strongly calcareous (14% lime) with a pH of 8.3.

Experimental design and cultural details

Experimental trials, five on wheat and eight on chickpeas, were carried out in miniplots at the agricultural research station and on farmers' fields, during two rabi (post-rainy) seasons (2002/03 and 2003/04), to study the effect of Zn seed priming on these crops. Two additional trials were also carried out on the response of wheat to soil applied Zn fertiliser (Table 1). Twenty-two participatory farmer trials (FAMPAR) were completed in four villages during 2003/04 to validate the Zn seed priming effect. Particulars of the trials are given in Tables 1 and 2 for wheat and Table 3 for chickpeas.

All trials apart from FAMPAR trials of wheat (trials 6, 7, and 8 in Table 2) were laid out as random block designs with 3 or 4 replications. The appropriate amount of seed per treatment was sealed in perforated plastic bags and the bags were soaked for 6 hours for chickpeas and 10 hours for wheat. The seeds were soaked either in fresh water (where water priming was included – trials marked § in Tables 2 and 3) or in an aqueous solution of zinc sulphate fertiliser of the required grade (Zn 22.5%, S 12% and pH 3.0) manufactured by the National Fertiliser Corporation of Pakistan: 18.18g per litre for wheat and 2.22g per litre for chickpeas. After soaking, bags were removed, drained off, and seed surfaces dried in the shade to ensure clump-free sowing.

The land to be used was well prepared after irrigation or rainfall; 60 kg P_2O_5 ha^{-1} and 24 kg N ha^{-1} as diammonium phosphate (DAP) were applied before sowing for both crops. No additional nitrogen (N) was added for chickpeas, whereas for wheat, N fertiliser was supplemented as urea in 2 or 3 split doses to a total of 80 kg ha^{-1}. Both crops were sown in rows 30 cm apart at seed rates of 80 kg ha^{-1} for chickpeas (variety Beetle-98 in all trials) and 100 kg ha^{-1} for wheat (variety Gazanavi-98 in trials 1, 2 and 4 in Table 2 or variety Tatara

Table 1:	Grain yields of wheat with and without incorporation of 13 kg ha^{-1} zinc sulphate in the soil				
No.	**Site (DOS)**	**Trial type (replications)**	**Yield (no Zn)**	**Yield (+Zn)**	**Increase (%)**
1	Peshawar (15-11-03)	RBD (4)	2143	2459	15 (ns)
2	Peshawar (15-11-03)	RBD (4)	2235	2594	16 (***)
	MEAN		**2189**	**2526**	**15**

Table 2:	Grain yields of wheat with and without seed priming for 10 hours in a 0.4% aqueous solution of zinc sulphate (trials marked § also included a treatment in which seed was primed with water alone [data in text])				
No.	**Site (date of sowing)**	**Trial type (replications)**	**Yield (not primed)**	**Yield (primed + Zn)**	**Increase (%)**
1	Peshawar (17-12-03)	Tubs (6)	4250	5067	19 (ns)
2	Peshawar (3-12-03)	Mini-plots (4)	3367	4300	28 (ns)
3	Peshawar (20-11-03)	RBD (4)	3100	3528	14 (ns)
4	Peshawar (3-12-03)	RBD (4)	2234	2676	20 (*)
5	Peshawar§ (2-12-03)	RBD (4)	2215	2722	23 (*)
6	Risalpur (2-12-03)	FAMPAR (10)	2136	2454	15 (ns)
7	Risalpur§ (16/17-11-03)	FAMPAR (4)	3335	4250	27 (*)
8	Karak (20/30-10-03)	FAMPAR (8)	2976	3525	18 (*)
	MEAN		**2952**	**3565**	**21**

Table 3:	Grain yields of chickpea with and without seed priming for 6 hours in a 0.05% aqueous solution of zinc sulphate (trials marked § also included a treatment in which seed was primed with water alone [data in text])				
No.	**Site (DOS)**	**Trial type (replications)**	**Yield (not primed)**	**Yield (primed + Zn)**	**Increase (%)**
1	Peshawar (29-11-02)	Mini-plots (3)	816	1814	122 (ns)
2	Peshawar (3-12-03)	Mini-plots (3)	1341	1790	34 (ns)
3	Peshawar§ (11-12-02)	RBD (3)	1219	1344	10 (ns)
4	Peshawar§ (3-12-03)	RBD (3)	819	1307	60 (ns)
5	Karak (21-10-03)	RBD (4)	738	1434	94 (*)
6	Karak (16-10-03)	RBD (4)	1614	1880	16 (ns)
7	Risalpur (26-10-03)	RBD (4)	806	1150	43 (ns)
8	Risalpur (27-10-03)	RBD (4)	794	1413	78 (**)
9	Risalpur (28-10-03)	RBD (4)	1302	1839	41 (*)
	MEAN		**1050**	**1552**	**48**

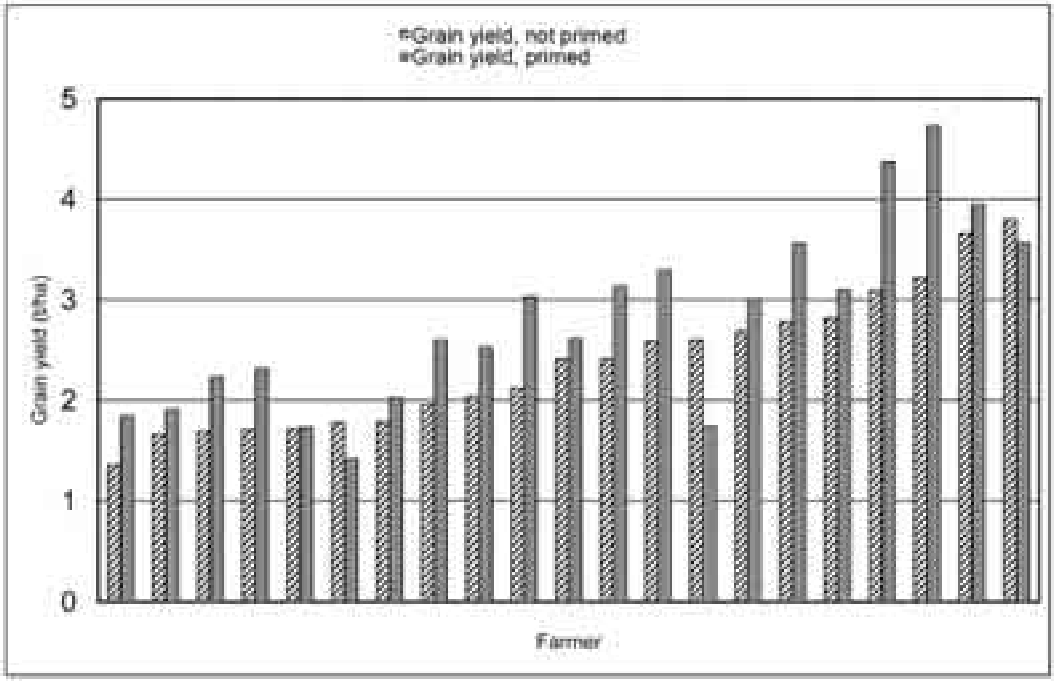

Figure 1: **Grain yields of wheat in 22 participatory trials with farmers (trials 6, 7 and 8 in Table 2)** Notes: striped bars = non-primed seed; hatched bars = seeds primed with 0.4% zinc sulphate for 10 hours before sowing; data are ordered according to yield of the non-primed treatment; standard error of difference between the two treatment means (significant at P = 0.001) was 0.11.

in trials 1 and 2 in Table 1 and trials 3, 5, 6, 7 and 8 in Table 2). Pests and diseases were controlled for chickpeas. All crops were irrigated apart from the rainfed trials of chickpeas at Risalpur (trials 7, 8 and 9 in Table 3). Yields were assessed by harvesting the whole plot (trials 1 and 2 in Table 1, trial 3 in Table 2 and trials 1, 2, 3, 5 and 6 in Table 3), whole rows (trials 1 and 2 in Table 2) or four randomly-selected quadrats of $1m^2$ (trials 4, 5, 6, 7 and 8 in Table 2 and trials 4, 7, 8 and 9 in Table 3).

FAMPAR trials on wheat were carried out in one village of Karak and two in Risalpur (Nowshera) Districts, with each farmer as a replicate. Twenty kg of seed of cv. (variety) Tatara were given to each farmer and half the seed was soaked in 0.4% zinc solution (200g $ZnSO_4$ fertiliser grade in 11 litres fresh water, measured using a plastic bottle of known volume) either by project staff or farmers themselves. Soaked seeds were air dried before sowing. The recommended fertiliser, cultural, and irrigation practices were followed as described above. Yields were assessed as the mean of four $1m^2$ quadrats placed randomly in each plot. All data were subjected to analysis of variance.

Results

Wheat

In the two trials at Peshawar in which zinc sulphate was incorporated into the soil at a rate of about 13 kg ha^{-1}, wheat grain yields increased by 15 % on average, although the increase was not statistically significant in one of the trials (Table 1).

In the eight trials in which zinc was supplied by priming seeds for 10 hours in a 0.4% solution of zinc sulphate before sowing, yield increases ranged from 14 to 28%, with a mean increase of 21%; half of the results were statistically significant and half were not (Table 2). The three FAMPAR trials (6, 7 and 8 in Table 2) showed an overall highly significant 17% mean increase in yield with nineteen of the 22 farmers trials that contributed showing increases in yield (Figure 1).

Chickpeas

In nine trials of chickpeas in which seeds were primed for 6 hours in 0.05% zinc sulphate solution before sowing, yields increased by 10 to 122%, mean 48%, although differences were statistically significant in only three of the trials (Table 3). The mean yield increase in the statistically significant trials (5, 8 and 9 in Table 3) was 71%.

Effect of water or zinc alone

The effect of priming with water can be separated from that due to added zinc by considering additional data from the trials for seed primed with water alone (marked § in Tables 2 and 3). For wheat, priming without zinc produced an 11% increase in grain yield over controls (Table 4); the remaining 10% (of the overall 21%) can be attributed to the zinc. This increase is similar to the 12% increase in wheat grain yield when zinc sulphate was applied to the soil (Table 1). Two chickpea cases were considered (Table 4), one using the mean of both the trials marked § in Table 3, the other omitting the case in which priming with water alone showed no effect. The increase in yield resulting from the effect of zinc was calculated to be either 24 or 30%.

Using representative prices for grain and the cost of zinc sulphate at the appropriate dosage, it is possible to compare the benefit:cost ratios of the two methods of zinc application (Table 5). The ratio is very high for application by priming in wheat (165:1) and chickpea (752:1) because so little zinc sulphate needs to be used. The ratio following application to the soil for wheat (calculated using the yield data from the two trials in Table 2), is much smaller (8:1) because farmers have to use much more zinc sulphate. In addition, it does not include

Table 4: **Estimated yield increase (kg ha^{-1}) due to seed priming and due to the effect of zinc applied through seed priming (percentage increases over controls are shown in brackets)**

Variable	Crop yield (kg ha^{-1})		
	Wheat	Chickpea[B]	Chickpea[C]
Mean yield without priming or zinc	2952	1050	1050
Increase after priming with zinc and water[A]	613 (21%)	502 (48%)	502 (48%)
Increase[§] after priming with water alone	331 (11%)	251 (24%)	191 (18%)
Increase due to zinc[A]	282 (10%)	251 (24%)	311 (30%)

Notes: [§] Using data from two trials in which priming with H_2O alone was included as a treatment
[A] 0.4% Zn for wheat; 0.05% Zn for chickpeas
[B] Using mean data from two trials in which priming with H_2O alone was included as a treatment
[C] Using data from one trial in which priming with H_2O alone was included as a treatment

Table 5: Partial budget and benefit:cost analysis (excluding labour) of providing zinc sulphate to wheat and chickpeas by priming seeds and by direct application to the soil		
Item	**Wheat**	**Chickpea**
Price of grain	Rs10 kg^{-1}	Rs 18 kg^{-1}
Extra grain yield du e to zinc (priming)	282 kg ha^{-1}	[B]251 kg ha^{-1}
Cost of zinc sulphate (priming)	Rs 17 ha^{-1}	Rs 6 ha^{-1}
Extra net income (priming)	Rs 2803 ha^{-1}	Rs 4512 ha^{-1}
Benefit:cost ratio (priming)	165:1	752:1
[a]Benefit:cost ratio (soil application)	8:1	no data

Notes: [a]3380 kg ha^{-1} divided by Rs 442 cost of zinc sulphate at rate of 13 kg ha^{-1}; [b]Using mean data from two trials (case B in Table 4)

the cost of the extra labour required to spread the compound evenly across the field. If the effect of zinc and of priming with water are combined (Tables 2 and 3) the benefit:cost ratios rise to 362:1 for wheat and 1506:1 for chickpeas.

Discussion and Conclusions

There was a positive response to the addition of zinc in all the trials reported in Tables 1, 2, and 3. Although not all the differences were statistically significant, there were no cases in which the addition of zinc reduced yields. Thus the data from these 19 trials suggest consistently that both wheat and chickpea respond positively to zinc addition under the conditions pertaining in NWFP. The size of the response of wheat to the element is similar whether it is applied through seed priming or by incorporation into the soil. However priming, which needs only small amounts of zinc sulphate, shows far higher profitability; the approach becomes even more attractive to resource-poor farmers when the beneficial effect of priming itself is taken into account. The further grain increase, and the fact that priming with water is essentially cost free, almost doubled the benefit:cost ratio.

No data were obtained on the response of chickpeas to soil to which zinc has been applied, but it is likely that the response would also be positive because priming chickpeas directly with zinc had a marked effect. In the case of chickpeas it was also possible to discriminate between the effects of the zinc and that of priming itself, although there is some uncertainty because of the variability of the two trials used to estimate the size of the two effects. The chickpeas seemed to respond more strongly than wheat to both the zinc and the priming, a difference that has been observed before. Harris et al. (2001) reported an average increase of about 15% due to seed priming with water for wheat in South Asia (range 5-36%, reflecting the wide degree of variation in the level of management between the test sites), whereas Musa et al. (2001) measured a mean increase in chickpea yields of around 35% over two years in Bangladesh. Rashid et al. (2002) observed positive responses to seed priming for both crops in Pakistan.

Adequate Zn nutrition of plants depends on several factors besides the ability of the soil to supply this nutrient. Interactions occur between Zn and other plant nutrients and may take place in the soil or at the soil-root interface affecting Zn absorption by the plant. Antagonistic effects of some cations, especially copper (Cu) and Zn, on the uptake of each other have been demonstrated in crops such as wheat, maize, and rice (Chaudhry and Loneragan 1970; Kausar et al. 1976; Rashid et al. 1979; Tahir 1981). It seems likely that priming seeds with zinc solutions could minimise these external interactions, although antagonistic effects may also occur within the plant itself, affecting translocation, re-distribution, and assimilation of nutrients. In addition to phosphorous (P) and N interactions with Zn, other nutrients such as Zn, Cu, iron (Fe) and manganese (Mn) inhibit each other's uptake, possibly because of competition for the same carrier sites (Chaudhry and Loneragan 1970; Rashid et al. 1979). Further research is required to test whether zinc applied through seed priming has any negative effects on the uptake and use of other nutrients.

We conclude that, in NWFP, wheat and chickpeas respond positively to supplementary zinc supplied as zinc sulphate. In wheat, the degree of the response to the element itself is similar whether it is applied to the soil or by priming with an aqueous solution. However, in both wheat and chickpeas, significant additional yield benefits result from the priming process itself. This, together with the much smaller amounts of zinc sulphate required for application through priming, makes priming a very much more attractive option than soil application for resource-poor farmers growing crops on zinc-deficient soils. The positive results of the 22 participatory trials with farmers suggest that zinc priming is a practical option for farmers in NWFP.

Acknowledgements

We thank Mr. Mohammad Naveed for his technical assistance and all the farmers who participated in the field trials. This paper is one of the outputs from a project (Plant Sciences Research Programme R7438) funded by the United Kingdom's Department for International Development (DFID) and administered by the Centre for Arid Zone Studies (CAZS), University of Wales, for the benefit of developing countries. The views expressed are not necessarily those of DFID.

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Commercial Horticulture Farming and its Effect on Soil Fertility: A Case Study from Peri-urban Agriculture in the Kathmandu Valley

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Abstract

The tremendous growth in commercial horticulture in peri-urban areas in the third world raises the question: does it deplete the soil or provide the incentive to balance soil fertility. This study from the Kathmandu Valley shows that when farmers switch to commercial horticulture, they improve their soil fertilisation practices through the use of chemical fertilisers, purchased chicken manure, compost, and compound micronutrient fertilisers which are available in the market. However, one important constraint is the lack of technical knowledge; both fertilisers and pesticides are applied haphazardly. Boron deficiency and soil acidification are particular problems in the area.

Introduction

Peri-urban agriculture provides a critical source of livelihood and food for many urban dwellers, particularly low income households in developing countries (ECOSOC 2000). In the peri-urban agricultural system in Kathmandu Valley, a wide spectrum of production systems can be found, ranging from household subsistence to large-scale commercial production. Growing of plants and trees in urban and peri-urban areas has occurred since the dawn of urbanisation in Nepal, but modernisation and commercialisation have increased urban demand for horticultural products. Traditional rotations of cereals with vegetables are being replaced by still more intensive horticulture. It is a very dynamic production sector; with rapid and frequent changes in crops and heavy use of agricultural inputs.

Knowledge and Technology Transfer

After the 1970s, the view of technology transfer has focussed consciously on agriculture as an active partnership between rural people and agricultural extensionists (Scoones and Thompson 1993). In this respect, outsiders play an important role in the transfer and exchange of knowledge and ideas between farmers and others. Technology transfer and progress can help to produce more, safer, and higher quality food and agricultural products, at low cost as well as with lower depletion of the natural resource base. There is a risk, however, that scientific technology or knowledge transfers – developed as they may have been in 'laboratories' or at least isolated from existing local knowledge – will fail to capture the unique relationship that farmers have with their own environmental and agricultural practices and the knowledge, and its framework, which is handed down through generations. In theoretical contexts of agriculture, Pretty and Chambers (1993) criticise science not as a body of knowledge, principles and methods, but on the basis of the beliefs, behaviour, and attitudes that accompany it. Similarly, in 1992 Marglin (quoted in Hogg 2000) went further suggesting that modern science, because it portrays itself as the totality of knowledge, cannot peacefully coexist with the tacit knowledge of farmers. Common to these perspectives is an appreciation, however varied, of the interplay between power and knowledge. There is a dialectical interplay between the two. For Howes and Chambers (quoted in Hogg 2000) the need of 'scientists' to lean on scientific knowledge to legitimise their superior status is at the root of a bias against polyculture systems.

However, knowledge is not evenly distributed throughout society. Different individuals are recognised as 'specialists' in particular fields and are key to the transmission of knowledge within a community or family. Knowledge transmission is not based on simple communication channels or linkages, but involves human agency and occurs within socially and politically constituted networks of different actors, organisations, and institutions (Scoones and Thompson 1993).

In contemporary agricultural development theory, farmers are no longer seen as ignorant and naive: they are experimenters, who dynamically interact with their environment and who do not passively adopt the extension's fixed packages of technology, but rather adapt them to their own circumstances. They maintain the diversity, create new farming systems, apply technologies appropriately to different environments, and design new machinery and new methods of pest control or fertiliser application (Rhoades 1989; Maurya 1989). However, there is still a long way to go in order to join scientific traditions with farmers' needs.

Blaikie and Sadeque (2000) criticise the agricultural research traditions in Nepal for being narrowly focused on biological, physical, and mechanical aspects, and neglecting for the most part the social, economic, and cultural context in which the technology is applied. Research is produced within the realms of NARC (Nepal Agricultural Research Council). In theory, NARC produces knowledge and the extension offices transfer the knowledge to the local farmers' level.

The extension system at local level consists of a network of junior technicians and junior technical assistants (JTs/JTAs). Different models for extension have passed through the system, but the low qualifications of the JT/JTAs and a lack of clear and coherent policies have restricted the achievements of agricultural extension goals (Ibid.).

The study area was very close to the city centre and had good access to extension officers, in spite of that it is still in a shadow in terms of agricultural extension. None of the farmers had regular contact with the extension offices, and no farmers had used the state-subsidised facilities for soil testing.

The farmers are constantly looking for affordable new technology and knowledge which is suitable for them. When they do have problems with production, they visit either agro vets or discuss their problems with other farmers. During the study period, we made contact with several farmers who were using chemical fertilisers and 'vitamins' on their land. They transfer their knowledge to each other verbally when they face problems and in this way receive new information regarding agricultural systems.

Generally, the knowledge and technology transfer is based on a market-oriented mechanism. Markets themselves do not develop new techniques or technologies, although they can help to transfer knowledge and technology among the farmers and from institutions to the farmers. Markets merely provide more or less good signposts or paths for new technological change in agriculture. In practice, many of the commercial farming inputs arrive at the local market with scanty or no declarations of content, not to mention user instructions.

Farmers tend to avoid risk and high investment, and mechanisation is absent. Technical modernisation is based on improved varieties of seeds, chemical fertilisers, pesticides, and micronutrients, in addition to some irrigation improvement.

Peri-urban farmers use different local techniques for sustainable agriculture which are mainly based on the characteristics of crops. The traditional practices that contributed to sustainability are the use of organic or farmyard manure (FYM), the use of riverbed sand, and cultivation of drought resistant crops. The local knowledge of farmers, their perceptions, attitudes, ideas, and behaviour in relation to methods of operation and ongoing changes is of great concern in the context of the peri-urban agricultural system.

Study Site

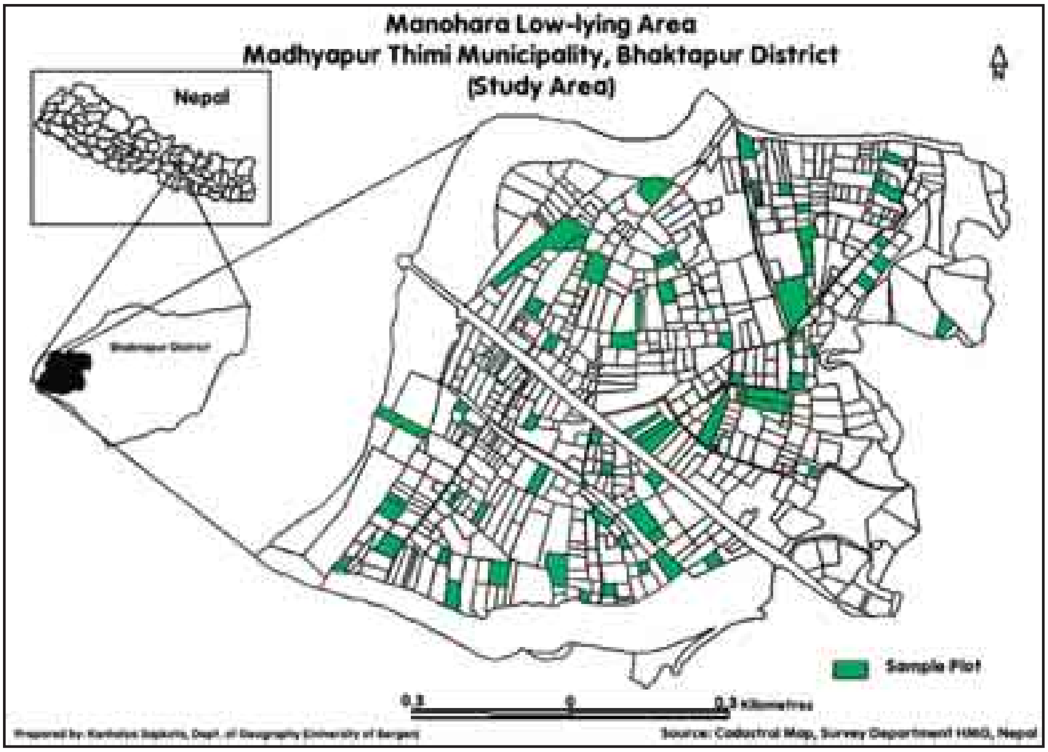
Manohara, a low-lying (phant) area of Bhaktapur district lying in the central part of the Kathmandu Valley, was selected for a variety of reasons. Firstly, it is typical of an area where agriculture has been practised intensively; in terms of production, this location is good and suitable for all seasonal crops. Secondly, the traditional irrigation system is still preserved, although not sufficient for rice production outside the monsoon season, and intensive horticultural practice is the main characteristic of the area. The area is near to major market centres, and it is a major producer of perishable vegetables for urban dwellers. Local farmers can easily transport farm inputs, i.e., agricultural tools, fertilisers, and pesticides. Good transportation facilities permit transport of perishable vegetable products to the urban centre and other areas by lorry, bus, motorcycle, or bicycle. The area is located at an elevation of about 1300m and falls within the warm temperate belt. During the winter season, night frost may occur, but the climate permits year-round cropping.

Horticulture is mainly a single-house enterprise, and it involves the whole process from the beginning to farm selection to harvesting. In this whole process, farmers use their own knowledge in the best way, intending to get a good harvest by selection of different crops for different plots. The rotation is important. There has been a great degree of specialisation in horticulture in the study area.

Basically, the climate is dominated by the south-eastern monsoon rains. These rains bring about 80% of the annual precipitation from June-September. The rainfall is heaviest from the second half of June to the first half of September, with considerable annual variation in the total number of rainy days.

The soil in general is medium to light textured with a strongly acidic reaction. The area is situated in an alluvial plain which has some undulating surfaces.

Intensive farms in peri-urban areas use a lot of inputs on a small area of land; however, good quality soil suitable for agriculture is relatively scarce. Thus, local indigenous farmers designed their crops to produce a maximum yield from rather small fields. Traditionally,



farmers use intercropping, with plantation of several kinds of vegetables mixed together in the same field (Table 1). Green vegetables and spices are the main crops planted by local farmers who rely on multiple cropping. There are several reasons why local farmers choose to undertake multiple cropping including yield, resources (soil nutrients, water, and sunlight), use efficiency, pest and disease reduction, weed suppression, and spreading labour costs.

On typical farmland, different vegetables are planted together, for example chamsur (cress), palungo (spinach), dhaniya (coriander), sounp (fennel), or methi (fenugreek) are planted together with khursani (chilli). Different types of vegetables grow row by row or in alternate strips, each consisting of several rows of the same crops, or they may be grown in more complicated spatial patterns, or, indeed, at random. Hedgerow planting of onions and garlic is used for biological pest control.

Almost all types of vegetables are cultivated intensively in this area. However, only a very few vegetables are specialised in which cannot grow in the off-season. Some farmers also grow paddy in the monsoon season in bagar khet (sandy/gravelly lowland) and sim khet (wet lowland). However, they are moving from a traditional paddy-based farming system to modern intensive horticulture. One step in this respect is the application of large amounts of river sand in order to make paddy soils looser and better drained.

Compost use and production

Most of the farmers studied practised intensive agriculture that had allowed them to produce food and vegetables and manage plant diseases for some decades with few outside inputs.

Table 1: **Types of crops grown**

Main crop	Crops planted together with the main crop	Months for sowing and harvesting
khursani (chilli)	chamsur (cress), palungo (spinach), dhaniya (coriander), sounp (fennel) or methi (fenugreek)	Falgun/Chaitra (March) – Ashadh/Srawan (July)
lasun (garlic)	dhaniya (coriander), jiri ko sag (lettuce), celery	Mangsir (November/December) – Chaitra (March/April)
couli/ bandagovi (cauliflower/cabbage)	tori (indian rape), dhaniya (coriander), pyaj (onion)	Bhadra/Asoj (August/September) – Magh/Falgun (February/March)
pyaj (onion)	jiri ko sag (lettuce), mula (radish), couli (cauliflower)	Mangsir/Poush (December) – Chaitra/Baishakh (April)
gajar (carrot)	chamsur (cress), palungo (spinach), dhaniya (coriander)	Bhadra/Asoj (August/September) – Mangsir (November/December)
bhanta (brinjal/ aubergine)		Bhadra (August/September) – Mangsir/Push (December)
salegam (turnip)	chamsur (cress), palungo (spinach), dhaniya (coriander), sounp (fennel) or methi (fenugreek)	Asoj/Kartik (October) – Mangsir/Push (December)
mula (radish)	tori (indian rape), dhaniya (coriander)	Bhadra/Asoj (August) – Kartik/Mangsir (November)
dhan (paddy)		Jestha/Ashadh (June/July) – Kartik/Mangsir (November/December)
Some Off-season Vegetables		
couli (cauliflower)	dhaniya (coriander)	Ashadh/Srawan (July) – Asoj/Kartik (October)
rayo (broad leaf mustard)	lasun (garlic), mula (radish)	Srawan (July/August) – Bhadra (August/September)
chamsur (cress)	palungo (spinach)	Bhadra (July/August) - Srawan (July/August)
salegam (turnip)	chamsur (cress), palungo (spinach), dhaniya (coriander)	Mangsir/Push (December) – Asadh (May/June)
mula (radish)	tori (indian rape), dhaniya (coriander)	Mangsir (October/November) – Falgun (February)
pyaj (onion)	rayo (broad leaf mustard)	Chaitra/Baishakh (April) – Ashadh/Srawan (July)
gajar (carrot)	lasun (garlic)	Mangsir (October/November) – Falgun (February)
Source: Field Survey, 2002		

Many of their successful practices have been forgotten or abandoned, especially in the case of peri-urban farmers but also rural farmers, but some are still using traditional farming systems and management in this area. A traditional farming system is based usually on practices that have been passed down for many generations. In the region as a whole, most of the farmers are still using the traditional ways of farming, and the horticulture described here is a small, although growing activity.

Use of compost in peri-urban agriculture is a rather old concept, so the use of compost and manure were integral parts of this study. Organic waste can be re-used to make compost. Composting is an activity that helps to turn waste into a good soil conditioner which can be used for agricultural practices (Hart and Pluimers 2000). In this area, most of the farmers applied farmyard manure or compost manure combined with inorganic fertiliser for the improvement of and for sustaining soil quality.

Ten to 15 years ago, most of the local farmers applied night soil to maintain soil fertility. They believed that night soil is the main source of nutrients for vegetables. Now this practice has almost disappeared because of the availability of different industrial nutrients (i.e., chemical fertilisers and micronutrients). Another traditional practice is to dig up a fertile, clayey sediment layer, popularly known as *kalimati* (black soil), and use it to improve soil quality.

In general, direct application of manure is not recommended, because it can lead to problems of excess nitrates in the plant, and excessive raw manure can burn plants and lead to toxic levels of nitrates in leafy green. Some farmers in the past faced this problem when they used manure directly, but now they are more conscious and do not apply raw manure directly to plants.

According to the farmers, when they used only farm-yard manure (FYM), organic manure, and home-made pesticides and insecticides, the quality of land was very good and the soil was in good and fertile condition. After the haphazard use of chemical fertilisers, they complain that the quality of land has deteriorated and they face problems of damaged plants. They still prefer to apply organic manure to fields because of the high cost and the low quality of chemical fertilisers and other nutrients.

There are various options in the use of compost and urban waste, apart from for agriculture in peri-urban areas. Linking compost with urban agriculture seems to have the most potential because of low transportation costs and direct benefits to low-income earners. This reduces nutrient cycles, transport costs, the use of chemical fertilisers and available space, and labour intensive productivity. For agriculture, farmers mainly use compost, farm-yard manure directly derived from poultry and other livestock, and organic waste. They use compost to maintain and/or increase soil fertility for greater crop production. Due to the lack of scientific knowledge, most hill farmers do not have any real perception of the quality of compost. But in peri-urban areas, farmers might have different attitudes, knowledge, ideas, and practical experience of the quality of compost and other manures as well as their use to improve soil fertility.

Two basic types of soil fertility maintenance generally applied in this area are manuring and management. Crop residues are burned, and the ash added to the farmland; chicken and livestock manure are spread on fields; and leaf litter and night soil (in some cases) are also spread on agricultural land. These activities are practised widely on both khet (irrigated lowland) and bari (rain fed upland) land. On the basis of local knowledge, local farmers also use farmyard manure (FYM) for almost all vegetable plants. FYM is a mixture of straw, cow dung, urine, and other plant materials. According to the farmers, raw cow dung is not good for vegetable farming. They prefer FYM which regulates the supply of nitrogen and also changes the colour of the soil, an essential factor for absorbing sunlight.

Compost can serve as a soil amendment to improve the soil moisture and nutrient holding capacity, increase soil organic matter, and ultimately improve plant growth and yields. Composting can be used as an alternative form of weed control and to increase soil fertility in vegetable crop production systems. During the field study, we collected four different types of compost manure for laboratory analysis at NARC. All the compost manure we collected for laboratory analysis contained good amounts of primary nutrients (Table 2). Poultry manure, which is bought by farmers from outside, contains high levels of nitrogen (N), phosphorous (P), and potassium (K). Similarly, FYM has very good levels of phosphorous.

Table 2: **Analysis of Sample Manure**

Manure	Nitrogen %	Phosphorous %	Potassium %
Poultry + Mixed	0.58	1.74	3.78
Compost + FYM	0.73	1.90	4.76
Poultry	1.06	1.50	5.46
Compost + Mixed	0.88	1.31	3.78

Source: Field survey 2002

Use of fertilisers in horticulture

Although the main emphasis of this paper is on the use of nutrients/micronutrients in horticulture and the effects on soil fertility, some additional analyses of soils were carried out in order to obtain further information on factors affecting the behaviour of nutrients/micronutrients in soils. In general, most plants and vegetables grow by absorbing nutrients from the soil. Their ability to do this depends on the nature of the soil. Soils in the Manohara low-lying area generally had good qualities in terms of texture and nutrient content, which makes some soils more productive than others.

According to Chaudhary and Manandhar (1996), Nepal's per hectare nutrient consumption is not only the lowest in Asia but also highly unbalanced in terms of N, P, and K application. In the study area, N and P dominated the supply. Cropping patterns do not incorporate legumes and other crops having nitrogen-fixing ability, but are mostly focused on market-oriented crops which remove significant amounts of nutrients from the soil. Farmers have adopted improved varieties of seeds. Due to this fact, they began to give less attention and importance to the traditional nutrients (organic manures from various sources like FYM, green manure, crop residues) that improve chemical and physical properties of the soil. Farmers argued that even though the supply of chemical fertilisers is increasing, they are unable to maintain soil fertility and yields are declining.

For a long time in this area, cultivation of the same surface soil has led to it being slowly drained of nutrients. Most of the crops are grown on the same farmland and in the same few inches of soil; and this has been tilled, year in – year out, for decades. Farmers are facing the problem of soils drained of essential nutrients due to unnecessary and haphazard use of chemical fertilisers and pesticides. They say that when they sprayed pesticides on the soil, some vegetables and crops which they have cultivated all their lives reacted negatively. Some vegetables dried out and even died after the use of pesticides. This might be due to the loss of soil fauna that originally released locked-up minerals and helped to keep the soil fertile, but it may also be attributed to the toxic effects of the uncontrolled amounts of pesticides sprayed on crops – even a few days before harvest. The use of pesticides in Nepal is characterised by very weak regulations, little if any control, and lack of knowledge and awareness among farmers (Dahal 1994).

The use of chemical fertiliser has been increasing in the study area since its introduction in the 1960s. The study did not allow for a detailed quantitative analysis of the use of fertilisers, but, as indicated by the soil values below, the amount is high.

Despite the acidity of the soil, farmers have ceased using agricultural lime. A general explanation given in Nepal is that the bulkiness and cost involved in liming is rarely justified by the production benefits. Therefore, the farmers normally rely on the buffering effect of compost only.

Quality of chemical fertilisers

Chemical fertilisers attract farmers and they appreciate them for quick action, ease of handling, easy access and availability, and comparatively low cost per unit of plant nutrients. Moreover, in the beginning, they were relatively cheap and often produced dramatic increases in yields. Chemical fertilisers normally improve soil fertility and increase agricultural crop yields. Modern agriculture is dependent on chemical fertilisers that are manufactured or mined and chemically processed.

The increases in yields have been facilitated primarily by the introduction of improved varieties of seeds and the use of chemical fertilisers and pesticides. The consumption of fertilisers in Nepal has also escalated after market liberalisation. According to Basnyat (1999), consumption escalated from 37,522t in 1997/98 to 219,038t in 1998/99. Now, chemical fertilisers have become the major input for agriculture. Farmers use both the chemical fertiliser and compost manure on agricultural land. Some farmers claim that the chemical fertilisers that are available in the local market are not as good as previously (before market liberalisation). Basnyat (1999) collected 24 fertiliser samples for laboratory analysis (analyses in six different laboratories); his analyses indicated that urea of Indian origin had a low nitrogen content, almost all of the diammonium phosphates (DAPs) of Indian origin were either spurious or substandard, and that muriate of potash (MOP) of Indian origin had slightly low potassium content.

In contrast to the results of Basnyat, the samples that we collected contained satisfactory levels of nutrients (Table 3). However, some farmers still do not like chemical fertilisers for different reasons. They find that chemical fertilisers make the soil hard and difficult to plough. They accelerate decomposition of organic matter, leading to degradation of soil structure and increased vulnerability to drought because of the reduced water-holding capacity of the soil (Carson 1992). Acidifying fertilisers (DAP) decrease the soil pH, lower the availability of some plant nutrients, and increase vulnerability to some diseases. Likewise, they also argued, yields of some crops were now declining and, the most important point,

Table 3: **Analysis of fertilisers**							
Fertiliser	**Origin**	**Total N (%)**	**Total P_2O_5 (%)**	**Total K K_2O_0 (%)**	**Formal content**		
					N	**P**	**K**
Urea	India	45.9	-	-	46	0	0
DAP	India	16.90	46.04	-	18	46	0
Urea	Indonesia	46.01	-	-	46	0	0
Complex	India	11.62	20.11	-	20	20	0
Potash	India	-	-	57.67	0	0	60
Urea	Korea	46.0	-	-	46	0	0
Urea	UAE	46.0	-	-	46	0	0
Source: Field Survey, 2002							

farmers were increasingly at the mercy of fertiliser traders who were unable to deliver supplies to farmers in a timely or cost-effective manner. It does not mean that local farmers always avoid using chemical fertilisers. Some of them have very good things to say regarding the use of chemical fertiliser on their farmland. For example, some farmers said that chemical fertilisers make it possible to cultivate throughout the year, that crop and vegetable yields increased greatly, and that cash earned by selling more vegetables helped to improve their household economy.

Similarly, farmers from the study area have been using different types of micronutrients ('vitamins') for different vegetables. All the farmers were using some sort of micronutrients; for example, they use Vegimex, a compound micronutrient product containing nine different elements. In 2003, the local agro-vets, sold about six litres of Vegimex, indicating that each farmer used about 50 ml on average of Vegimex micronutrients and suggesting that the amount of micronutrients used is small and only determined by leaf colour. Farmers also use other micronutrient products for different vegetables, but the information available does not permit firm conclusions. Most farmers do not have any specific micronutrients for particular vegetables, because of their lack of knowledge about the availability of micronutrients. The knowledge gap includes traders, and it is having a negative impact on their sales because appropriate inputs would be more cost effective and increase farmers' willingness to use them. There are no government institutions facilitating the use of micronutrients in the area.

Methodology

Primary data were collected during the fieldwork which started in May 2002 and ended in September 2002. A survey of the area was undertaken using a checklist-questionnaire; the purpose was to gain information about the best general locations for the preferred cultivation sites identified by field work from surveys of seventy-five households.

The source of primary data was based on structured and semi-structured (content focused) interviews with sample households, preliminary or exploratory field observations, subjective assessment, and contacting of key informants and resource persons. In addition several discussions were held with local key informants, and relevant information collected through semi-structured interviewing techniques. This helped the study team establish a good relationship with the informants and other local people, and made it easy for us to obtain the relevant information.

To gain a better appreciation of the epistemologies and practice of peri-urban farming, we held detailed interviews (question focused) with selected local farmers. In addition to the farmer interviewees, numerous interviews were also held with local persons who seemed to have good knowledge about agricultural practices; for example, members of the elected administrative body and shopkeepers selling different chemical fertilisers and micronutrients ('vitamins'). Initially we asked them abstract questions and more general questions at the end. This is known as a pyramid-interviewing strategy (Hay 2000). This strategy helped build up rapport by starting with easy to answer questions about an informant's duties or responsibilities, or their involvement in an issue (Ibid).

To achieve the goal of this study, we collected different information for quantitative analysis. The nutrient contents of soil and compost are quite variable. They are affected greatly by the raw materials from which they are derived. For the analysis of nutrients in the soil and manure, soil samples from different plots of land and manure samples were taken to test for different minerals and properties (i.e., N, P, and K). We collected samples from those households where we had held interviews. This helped us analyse the level of nutrients in the fields, which is directly related to crop production and the socioeconomic status of particular landowners or tenants. In the meantime, the knowledge, attitudes, and behaviour of local farmers regarding nutrients were also explored in an effort to understand local knowledge about the use of manure and chemical fertilisers in agriculture.

For the selection of soil samples, the following procedures were followed.

- First, a cadastral map was obtained from the Department of Survey and the categories of land parcels in the study area were stratified.
- Sample plots were selected from each category.
- A quadrat was designated as a ten-metre square sampling site
- A geo-positioning system (GPS) meter was used to confirm the coordinates of the sample plot.
- On the quadrat, surface soil samples were collected from ten different areas, including from the four corners and from the centre.
- With the help of a soil auger, we dug a hole 12 cm deep.
- The soil samples were mixed thoroughly to obtain a composite soil sample.
- Samples of about 150-200g were collected in plastic bags, and each sample bag was tagged with a number.

Compost samples were collected from households for analysis of N, P, and K.

Seventy-five representative soil samples were collected for analysis at the SSD (Soil Science Division), NARC. The following methods were applied.

- pH analysis: using a pH meter (1:1 soil water ratio)
- Nitrogen analysis (N%): total nitrogen analysis by the Kjeldahl method
- Available phosphorous (P_2O_5): the Olsen method using Olsen extraction
- Available potassium (K_2O): 1N ammonium acetate at pH 7 was used in the lab test
- Organic matter: Walkey-Black titration method

- Available boron (ppm): hot water extraction (modified Berger and Trugo method)
- Available zinc (ppm): The method of extraction was AAAC-EDTA (acid ammonium acetate-ethylenediaminetetracetic acid) method, determination with an atomic absorption spectrophotometer (AAS)

Status of Soil

The most common views expressed were that, although the soils are of high quality, they are fragile and in need of careful management. Soil fertility and nutrient management influence agricultural productivity. Maintaining soil fertility is an important step in creating sustainable agriculture. In this area, farmers are practising different methods of soil fertility management, i.e., applying both organic and inorganic fertilisers. The benefits of chemical fertilisers are that they are low cost and ease to apply. But farmers claim that when chemical fertilisers and other pesticides were introduced, production increased and then problems occurred in terms of the loss of soil quality. According to them soil turned drier and harder and certain vegetables which they had cultivated traditionally did not grow properly. It seems that soil fertility is gradually declining due to inadequate and imbalanced nutrient application and improper farming practices.

Table 4 shows the status of soil nutrients in the study area. The overall findings indicate that the levels of nutrients are not much of a problem, except for boron. Most soil pH values fall within 3.5 to 5.4 (extremely acidic to moderately acidic), indicating pH problems to be more serious than reported from other middle hill areas, for instance the Jhiku Khola area (where the pH value was 4.94 in red soil and 4.78 in non-red soils). Reaction (pH) is probably the single most important parameter in predicting the fertility of soil. Correct management of soil pH is important for providing optimal growing conditions for specific crops; reducing potential for deficiency of certain nutrients; and efficient use of fertilisers. It has a significant influence on other soil chemical properties as well as on biological organisms. The effect of soil pH is high on the solubility of minerals or nutrients. Most minerals and nutrients are more soluble or available in acid soils. The availability of nitrogen is somewhat restricted at low pH values, whereas that of phosphorous is best at intermediate pH levels.

Table 4: **Soil property analysis**

Soil property	Mean (n = 75)	Rating	Standard deviation	Minimum	Maximum
pH	4.59	strongly acidic	0.35	3.5	5.4
Organic matter (%)	2.36	low	0.82	0.13	4.56
Total N (%)	0.16	medium	0.16	0.038	1.138
Available P*	1038.69	very high	381.55	90	2179
Exchangeable K	318.24	high	138.66	96	749
Boron	0.0051	very low	0.0053	0.0	0.02
Zinc (AAAC-EDTA)	3.8462	medium	2.0752	0.480	9.226

Source: Field Survey, 2002 * Possible laboratory error

About 12% of the samples were very low to low in total N, but the average was in the medium category. A large variation in available P levels is evident: the levels were high to very high. Although the farmers applied purchased chicken manure as well as DAP fertiliser, the P figures are suspiciously high, and it is probable that a laboratory error has occurred. About 55% of exchangeable K values were in the range of high to very high.

Boron is highly deficient, which agrees well with findings from elsewhere in the region (Andersen 2000 and this volume). Zn, normally a widespread deficiency problem in the hills, does not seem to be a problem, probably due to the use of chicken manure and compost/FYM.

Relationship of organic matter (OM) to other nutrients

Organic matter influences the physical and chemical properties of soils far beyond the proportion of the small quantities present (Brady 2002). The main source of organic matter is plant tissues. In general, the tops and roots of trees, shrubs, grasses, and other native plants supply large quantities of organic residue.

Soil organic matter contains about 50% carbon, 40% oxygen, 5% hydrogen, 4% nitrogen, and 1% sulphur (Brady 2002). Most of the other nutrients are also associated in some way with organic matter, which affects the availability of nutrients for plant growth. Addition of organic matter to the soil increases its ability to hold nutrients. The relationship between organic matter and other nutrients is highly significant in this area (Table 5). Soil organic matter correlates extremely well with a number of important soil physical, chemical, and microbiological properties. As soil nutrients such as available nitrogen, phosphorous, and sulphur increase, other nutrients like potassium , boron, and zinc also increase. However, one thing this study suggests about boron is that FYM alone is not enough to redress the deficiency.

Table 5: **Correlation between organic matter and different soil nutrients**

Properties	r – value
OM – pH	- 0.03132
OM – N	0.122909
OM – P	0.224612
OM – K	0.228343
OM – Zn	0.481858
OM – B	-0.07806

Source: Field Survey, 2002 (Note: soil analysis at the Soil Science Division, NARC, Nepal)

Some of the farmers use cover crops of different vegetables and grasses that can gradually add organic matter to the soil and help retain nutrients from one season to the next. Cover crops contribute to soil organic matter and fertility; for example, legumes decay quickly because their residues have a high nitrogen content thus they are more valuable as sources of nitrogen than as sources of organic matter. Farmers used different cover crops on their farmland for this.

The relationship of organic matter with nitrogen is correlated in this area, because organic matter is also one of the major components in fixation of nitrogen in the soils. It means that when organic matter increases in the soil, the level of nitrogen also increases. None of the relationships of organic matter with other nutrients except boron was statistically significant.

Conclusions

When farmers move from traditional cereal and vegetable production to commercial horticulture, they improve their soil management by using a combination of compost/FYM, purchased chicken manure, chemical fertilisers, and micronutrient fertilisers. However, their access to scientific knowledge is restricted by the limitations of their own knowledge, in addition to limitations in the national extension system and in the market. There is an information gap, and this means that farmers have problems maintaining soil quality. As a result, soil nutrient values in the area studied were reasonably good for most nutrients, but fertiliser-induced acidity and boron deficiency remained problems. Still, the soil management was better than that of non-commercial agriculture, and intensification and commercialisation may be among the keys to more balanced soil nutrition.

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Session 4

Soil and Plant Interactions

Effect of Micronutrients on Production of Maize (*Zea Mays L.*) in the Acid Soils of Chitwan Valley

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Abstract

Field experiments were held during the summer and winter seasons of 2003 and 2004 respectively in the acid soils of the National Maize Research Programme's (NMRP) farm. The objectives of the study were to identify which micronutrients were deficient in the soils and the effect on grain production, and to recommend micronutrients that would improve the quality and quantity of the produce. No significant yield advantage was found between the recommended amounts of major plant nutrients nitrogen (N), phosphorous (P_2O_5) and potash (K_2O) at a rate of 120:60:40 kg per hectare and the various combinations of micronutrients: sulphur (S), boron (B), zinc (Zn), molybdenum (Mo), iron (Fe), and copper (Cu). The same was found for stover yield and thousand grain weight of maize. The productivity of maize was found to be somewhat higher in winter than in summer with the same treatment and variety of maize. Response to micronutrients was not consistent in the two seasons. In the summer season all micronutrients demonstrated a response except for sulphur. The crop yield decreased in the absence of B, but there was no significant difference from the treatment without micronutrients. In the winter season, there was an indication of deficiency of S only and there was no response to other micronutrients. Nitrogen (N) and potassium (K) uptakes by maize grains were higher with the application of major and micronutrients but there was no significant difference except with the control plot. The treatment without sulphur also gave a significantly lower uptake of N and K, but phosphorous (P) uptake was not significant compared to the control plot. Nitrogen was recorded as deficient in leaf samples in the summer season, whereas P and K were adequate. During the winter season N, P, and K were adequate in the leaf samples. Diethylene triamine penta acetic acid (DTPA) extractable Zn was found to be below the critical level while Fe and manganese (Mn) were adequate. Zinc content in maize leaf was deficient, whereas Cu and Mn were in the normal range and Fe was in excess. A significant relationship was found between Zn and Mn content in the leaf and soil test, but not for Fe.

Introduction

The importance of essential micronutrients in Nepal was realised about two decades ago when wheat sterility problems were encountered in the eastern part of the country. At that time the micronutrient identified was boron. In areas where intensive agriculture is practised application of zinc has become a regular feature. In addition, the problem of micronutrients has been observed especially in the context of horticultural crops such as fresh vegetables and citrus fruits. Boron and magnesium are the most constraining nutrients for cauliflower from a quality perspective (Baral et al. 1986; Khatri-Chhetri and Karki 1979). Khatri-Chhetri and Schulte (1984) found B and Zn were the most limiting nutrients for the soils of the Chitwan Valley. Further, Khatri-Chhetri and Schulte (1985) reported that maize responded to the application of N and P, secondary nutrients, and micronutrients. There has been a tendency to ignore the quality aspect. But gradually it has been realised that agricultural produce must contain adequate levels of essential macro and micronutrients because of their important role in human nutrition (Darrell 1991).

The soil of the Rampur agricultural farm has the typical composition of soils in the Chitwan Valley, which are also found in the upper piedmont of the Terai region; these have been recognised as young alluvium soils. The soils are strongly acidic and very light textured. The clay content is less than 12%. The effective soil depth is very shallow. The cation exchange capacity (CEC) of soils is in the range of 1 to 2 m.e./100g of soil. Since the establishment of the farm, mono-cropping (maize only) has been practiced. In 1981, sulphur was identified as an essential micronutrient for the farm (Dr SP Pandey personal communication 2003). A few years ago, efforts were introduced to improve the soil quality by growing green manure crops and applying compost. In addition, borax and zinc sulphate are applied regularly. Following this, there was an improvement in crop productivity. However, application of micronutrients is very expensive, and indiscriminate application could cause toxicity in the soil in the long run. Usually, farmers do not grow green manure crops on upland to enrich the soil. Decline in productivity is widespread among similar types of soils in the valley and elsewhere where maize and vegetables are grown in a rotation. In this context, an experiment was designed to identify the limiting micronutrients and their effect on maize production and to recommend the micronutrients that could improve the productivity and quality of maize.

Materials and Methods

Field experiments were carried out during the summer and winter seasons of 2003 and 2004 in a randomised complete block design (RCBD) with four replications. The experimental plot size was 4.5 X 5.0m. The net harvest area for yield estimation was 15m^2. The row to row and plant to plant spacings were 75 and 25 cm respectively. The maize variety used in the experiment in both seasons was Rampur Composite. The seed rate was 20 kg/ha. For the summer season, maize was sown on 28 May 2003 and the crop harvested on 4 September 2003; for the winter season, maize was sown on 25 September 2003 and harvested on 26 February 2004.

Ten treatments of various combinations of chemical fertilisers containing zinc, iron, boron, molybdenum, sulphur, copper, and manganese were given as summarised below.

T1 = Control without organic manure or chemical fertiliser
T2 = 120:60:40 kg N:P_2O_5:K_2O/ha
T3 = T2+ B (5 kg/ha), Zn (5 kg/ha), Mo (0.5 kg/ha), S (20 kg/ha), Mn (12 kg/ha), Cu (5 kg/ha), and Fe (12 kg/ha)
T4 = Similar to T3 except B not applied
T5 = Similar to T3 except Zn not applied
T6 = Similar to T3 except S not applied
T7 = Similar to T3 except Mn not applied
T8 = Similar to T3 except Fe not applied
T9 = Similar to T3 except Cu not applied
T10 = Similar to T3 except Mo not applied

The sources of fertilisers were urea, di-ammonium phosphate (DAP), muriate of potash (MOP), ammonium molybdenum, zinc sulphate, borax, copper sulphate, cupric oxide, iron sulphate and iron oxide, manganese oxide, iron oxide, and zinc chloride. All the required micronutrients, phosphorous, and potash were applied according to the treatments as a basal application. However, nitrogen (N) was split into two applications with half applied as basal and the remaining half side dressed when the maize crop was at knee height.

Plant samples were taken at random from six plants from an experimental plot when the crop was at maximum vegetative stage. After crop harvest, grains were analysed for N, P, and K contents. Soil samples were taken before planting and after crop harvest and analysed for DTPA extractable Zn, Mn, Cu, and Fe. Standard methods were followed to analyse soil and plant samples at the Soil Science Division (SSD), Khumaltar.

Results and Discussion

Thousand-grain weight, grain, and stover yields

There was no significant effect of treatment on thousand-grain weight in either season, the only difference was that the seeds were heavier during the winter than in the summer season (Table 1). There was no significant effect of the treatments on the grain and stover yield in the summer season but there was a highly significant effect in the winter; the yield difference was significant only between the control plot and the rest of the treatments (Table 1), but not among treatments. Boron deficiency had been suspected since Khatri-Chhetri and Karki (1979) reported a high response of cauliflower to borax application at a rate of 10 kg/ha. However, no response to B application was recorded in the maize in either season. Khatri-Chhetri and Schulte (1985) found an increase in the yield of maize due to application of Cu, S, and Mg in a multi-locational trial. In this experiment, omission of S, B, or Cu did not affect the yield. The relationship between thousand-grain weight and grain yield in the summer season was not significant; but during the winter a significant result was obtained with R^2 = 0.591. In both seasons a significant relationship was demonstrated between the stover and grain yields of maize (Figure 1).

Higher productivity from the September planting

The productivity of maize from the September planting was five to six times higher than for the summer maize (or April/May) planting with the same variety of maize (Rampur composite). The reason could be greater efficiency of nutrient uptake by crops in that season and the longer growing period. Schmidt et al. (1978) reported similar results; but they found no difference in productivity among local varieties between summer and winter seasons. They further reported that during the summer infestation with insects and diseases was greater than in winter.

N, P, and K content in maize leaves

There was a substantial difference in N and P content in the ear leaves of maize between the seasons. The N and P contents in the leaf samples were greater during the winter season. Little difference was found in K content between seasons (Table 2). The concentrations of P and K in the plant tissue were higher than the critical value in both seasons, showing that P and K are not a problem in the Rampur farm soil. The critical values of N, P, and K are 2.75, 0.24 and 1.74% respectively, as cited by Khatri-Chhetri and Schulte (1984), thus the concentration of N was below the critical value in the summer season, but above the critical value in the winter season. The productivity of maize irrespective of the treatment corresponded to the concentration (Figure 2). The results show that efficiency of applied nutrients is high during the winter and low in the summer. The main reason could be the loss

Table 1: Thousand-grain weight (THW), grain weight (GRW) at 12 % moisture and stover yield (STV) of maize (sun dried)						
Treatment	Summer season 2003			Winter season 2003/04		
	THW (g)	GRW (kg/ha)	STV (t/ha)	THW (g)	GRW (kg/ha)	STV (t/ha)
T1 control	313.1	794	4.74	424.5	3875	5.99
T2 NPK only	325.2	1616	6.69	465.8	6615	9.35
T3 NPK+all MTs	333.5	1422	6.63	451.1	6845	10.06
T4 (T3-B)	312.9	1264	5.78	480.9	7576	9.98
T5 (T3-Zn)	253.4	1404	6.32	485.8	6898	10.91
T6 (T3-S)	327.2	1841	7.06	476.2	6212	9.36
T7 (T3-Mn)	324.3	1451	6.24	481.2	6992	10.09
T8 (T3-Fe)	335.9	1446	5.98	454.0	7007	9.75
T9 (T3-Cu)	322.8	1308	5.47	478.8	7118	10.73
T10 (T3-Mo)	314.3	1571	5.90	487.2	6966	10.22
F test	NS	NS	*	NS	**	**
SED	34.1	344.7	0.67	23.46	482.3	0.92
LSD	–	707.4	1.37	48.14	989.7	1.88
CV %	5.3	34.5	15.5	7.1	10.3	13.4

THW = thousand grain weight; GRW = grain weight; STV = stover yield; F test or F -ratio = ratio of variance; SED = standard error deviation; LSD = least square deviation; CV = coefficient of variation ; NS = not significant

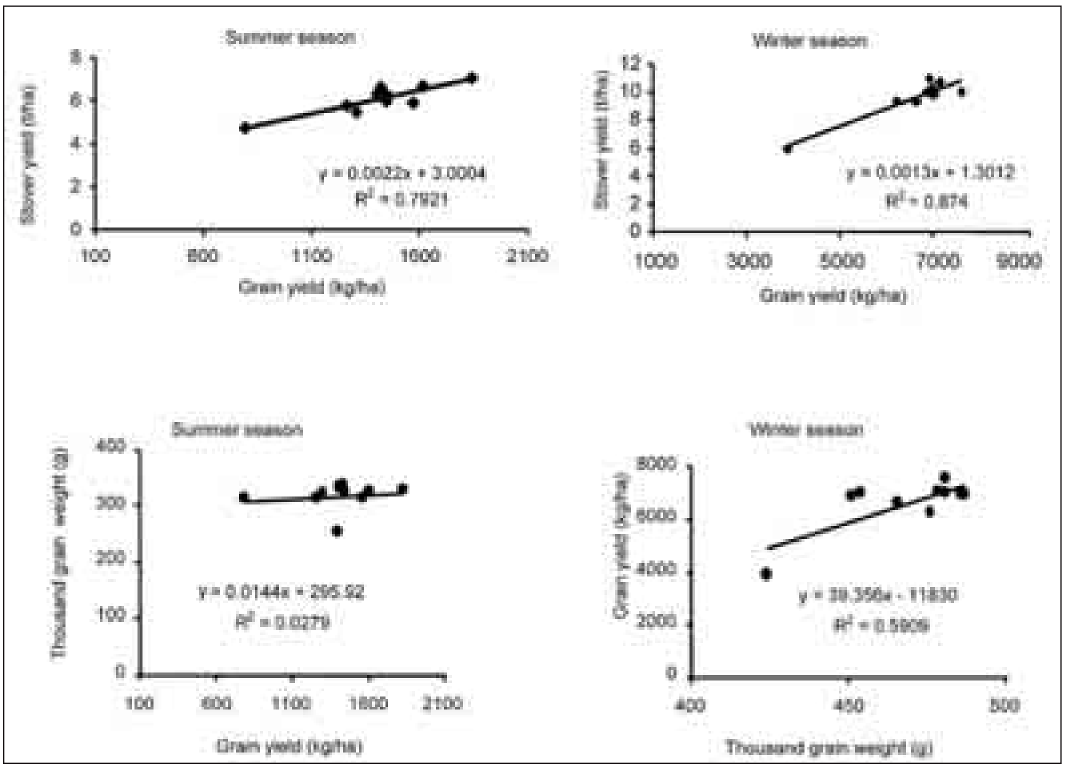

Figure 1: **Relationship between thousand-grain weight, stover yield, and grain yield of maize in the summer and winter seasons**

Table 2: **N, P, and K content in maize leaves at the tasselling stage**						
Treatment	**Summer season (2003) (leaves)**			**Winter season (2003/04) (leaves)**		
	N%	**P%**	**K%**	**N%**	**P%**	**K%**
T1 control	1.42	0.473	2.406	2.33	0.92	2.55
T2 NPK only	1.87	0.434	2.727	3.07	0.90	2.93
T3 NPK+all micro	1.29	0.367	2.748	3.17	0.97	2.82
T4 (T3-B)	1.59	0.543	2.538	3.23	0.91	3.13
T5 (T3-Zn)	1.90	0.406	2.550	3.14	0.79	2.77
T6 (T3-S)	1.79	0.440	2.760	3.14	1.09	2.93
T7 (T3-Mn)	1.93	0.337	2.573	2.70	1.05	3.02
T8 (T3-Fe)	1.80	0.404	2.631	3.22	1.06	3.11
T9 (T3-Cu)	1.73	0.472	2.573	3.06	0.85	3.13
T10 (T3-Mo)	1.69	0.169	2.583	3.15	0.76	3.24
F test	*	NS	NS	NS	NS	NS
SED	0.195	0.1158	0.212	0.3026	0.1481	0.1967
LSD	0.3997	0.2373	0.4346	0.620	0.3036	0.4032
CV%	16.3	40.5	11.5	14.1	22.5	9.4

F test or F-ratio = ratio of variance; S ED = standard error deviation; LSD = least square deviation; CV = coefficient of variation ; NS = not significant

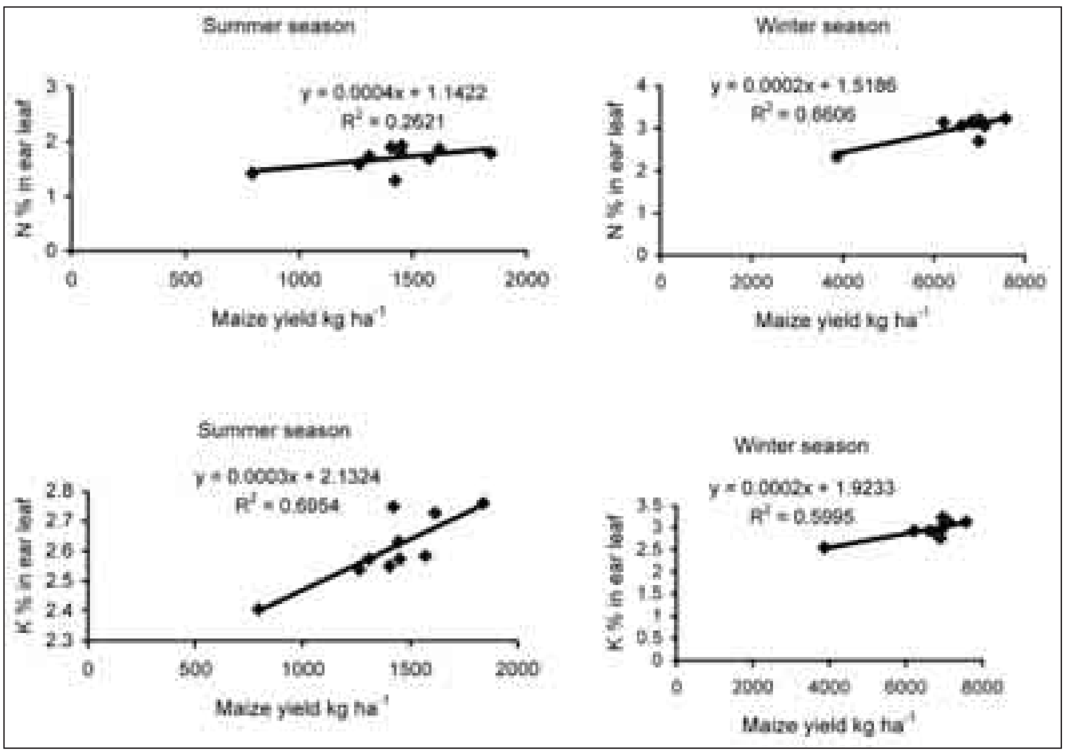

Figure 2: **Relationship between maize yield and nutrient (N&P) content in the ear leaf**

of N in the form of nitrate through leaching in summer, since the Rampur soils are light textured and quite porous.

A significant relationship was observed between the maize yield and N content of the ear leaves in winter, but in the summer, the relationship was not significant. The relationship between the K content and the maize yield in both seasons was significant, whereas no relationship was observed between the P content in the ear leaf and the maize yield in either season (Figure 2). This shows that N and K contributed strongly to the maize yield.

Uptake of N, P, and K by grains

P uptake by grain was not affected by the application of micronutrients in the winter season. However, the mean uptake decreased to 10.81 kg/ha in the absence of Mn, which was the lowest value in any plot. The lowest values for N uptake by grain (65.3 kg/ha) was found in the control plot. N uptake was not affected by application of specific micronutrients (Table 3). However, there was an indication that N uptake might be affected if S is not applied. A similar trend was observed for K. The lowest uptake of K was in the control plot (16.74 kg/ha), and there was no significant difference between the rest of the treatments, except for the treatment in which S was not applied. After the control plot, the treatment without S showed the second lowest K uptake (23.3 kg/ha).

DTPA Extractable micronutrients

The levels of DTPA extractable micronutrients in soil after the winter harvest are shown in Table 4 together with some other soil fertility attributes. DTPA extractable Zn was below the critical limit, whereas Fe and Mn were adequate and above the critical values cited by Pandey and Bhandari (1984). Das (2000) also cited that the critical level of Zn in soils for maize crops is in the range of 0.38 to 1.0 mg/kg. Since there is an antagonistic effect between P and Zn, the availability of Zn is restricted despite the soil being acidic. The maize did not

Table 3: **N, P, and K content in grain and uptake in 2003/04 winter season**

Treatment	N,P, and K content in grains			N, P, and K uptake (kg/ha)		
	N%	P%	K%	N	P	K
T1 control	1.64	0.399	0.420	65.3	15.31	16.74
T2 NPK	1.52	0.265	0.456	101.2	18.36	30.13
T3 NPK+all micro	1.45	0.417	0.410	99.35	28.6	28.15
T4 (T3-B)	1.56	0.338	0.410	118.34	25.79	31.17
T5 (T3-Zn)	1.60	0.392	0.410	109.94	27.36	28.48
T6 (T3-S)	1.56	0.367	0.375	97.01	22.53	23.30
T7 (T3-Mn)	1.69	0.152	0.423	118.54	10.81	29.62
T8 (T3-Fe)	1.62	0.398	0.423	113.42	27.86	29.74
T9 (T3-Cu)	1.47	0.260	0.443	105.28	17.68	31.53
T10(T3-Mo)	1.56	0.325	0.410	108.86	22.29	28.73
F test	NS	NS	NS	**	NS	**
SED	0.1156	0.1723	0.0321	12.03	10.86	3.345
LSD				24.66	22.26	6.86
CV%	10.4	73	10.9	16.4	71	17.0

F test or F-ratio = ratio of variance; S ED = standard error deviation; LSD = least square deviation;
CV = coefficient of variation ; NS = not significant

Table 4: Soil pH, SOM, P, and DTPA extractable micronutrients after the crop harvest in the 2003/4 winter season						
Treatment	**DTPA extractable (ppm)**			**Some soil fertility attributes**		
	Zinc (Zn)	**Iron (Fe)**	**Manganese (Mn)**	**pH**	**SOM %**	**Avl. P kg/ha**
T1 control	0.154	111.6	29.52	4.8	1.89	156.1
T2 NPK only	0.332	109.0	30.40	4.87	1.90	124.8
T3 NPK+all micro	1.090	108.1	31.20	4.52	2.01	165.2
T4 (T3-B)	0.506	106.8	31.42	4.72	1.98	86.1
T5 (T3-Zn)	0.564	112.7	31.04	4.82	2.27	165.7
T6 ((T3-S)	0.534	113.3	30.98	4.52	2.19	134.8
T7 (T3-Mn)	0.518	112.9	31.10	4.62	2.03	222.6
T8 (T3-Fe)	0.748	112.1	31.88	4.60	1.96	104.8
T9 (T3-Cu)	0.732	112.6	32.76	4.70	2.25	124.3
T10 (T3-Mo)	0.544	111.8	32.80	4.75	2.44	94.3
F test	**	NS	**	NS		
SED	0.1732	4.402	0.520	0.112		
LSD	0.3552	9.030	1.168	0.2306		
CV%	42.9	5.6	2.4	3.4		

F test or F-ratio = ratio of variance; SED = standard error deviation; LSD = least square deviation; CV = coefficient of variation ; NS = not significant; SOM = soil organic matter

respond to Zn despite low availability in the soil. This shows that the critical value for maize is not well correlated in the Rampur farm soils and environment. The analysis of the remaining nutrients is in progress, as a result, conclusive recommendations cannot be given in this paper. Since the soils are acidic, availability of molybdenum (Mo) was one factor considered, but no significant response was observed. High P availability has a synergetic effect on Mo, and this could be a reason for the lack of response to Mo application (Das 2000). DTPA Zn and maize yield were correlated exponentially and found to be significant (Figure 3). Similarly, a significant relationship was observed between DTPA Mn and crop yield. However, the relationship was not significant in the case of Fe.

Leaf content of micronutrients (Zn, Cu, Mn, and Fe)

Zinc content in the leaf samples of maize at the tasselling stage was in the deficient range (Table 5). However, zinc content in the leaves receiving those treatments in which zinc was supplied was in the normal range apart from the treatment without sulphur whose results indicated Zn as deficient. The difference in Zn content among the treatments was not significant (Table 5). Manganese was in the range from normal to excess. The control plot showed a significant difference from other treatments in Mn content. However, leaves from the plot to which Mn was not supplied, but to which other micronutrients were supplied were found to have significantly greater Mn content (Table 5). Copper was in the normal range (Table 5) and significantly lower than the rest of the treatments, except for T1, T2, and T6. But again the treatment without Cu but with other micronutrients was found to be greater in Cu content. Iron was excessive in all the treatments (Table 5).

There was a significant relationship between micronutrient content in the ear leaves of maize at the tasselling stage, and DTPA extractable Zn and Mn (Figure 4). There was no relationship, however, between the Fe in soils and plant samples. Because of the significant correlation, DTPA could be applied to improve the micronutrients in soils.

No significant relationship was found between the maize grain yield and content in grain of Zn, Fe, and Mn (Figure 5).

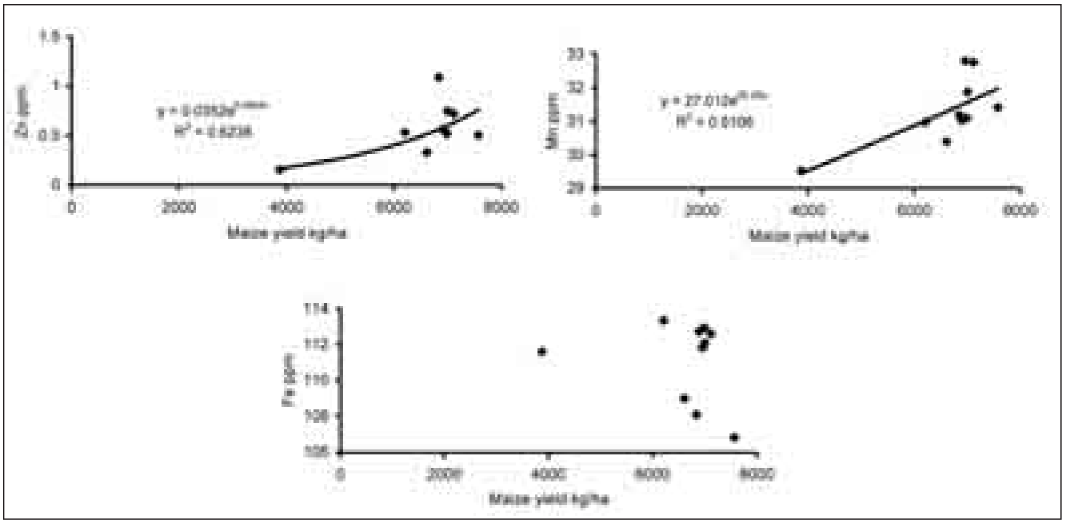

Figure 3: **Relationship between DTPA extractable Zn, Mn, and Fe and maize yield in the winter of 2004**

Table 5: Zn, Mn, Cu, and Fe content in the ear leaves and maize grains (ppm)

Treatments	Micronutrients in the ear leaves at tasselling stage (ppm)				Micronutrients in maize grains after harvest (ppm)			
	Zn	Mn	Cu	Fe	Zn	Mn	Cu	Fe
T1 control	14.2	151	7.9	9387	15.2	532	10.7	26768
T2 NPK only	10.9	205	8.3	10121	14.4	535	11.2	26951
T3 NPK+all micro	30.7	271	9.8	10495	20.0	538	10.5	27126
T4 (T3-B)	27.4	263	11.0	10831	18.6	542	11.1	27490
T5 (T3-Zn)	13.4	277	10.1	11166	18.8	547	11.4	27523
T6 ((T3-S)	16.6	265	9.3	11177	18.9	548	11.6	27704
T7 (T3-Mn)	20.5	263	10.1	11812	21.3	552	11.5	27908
T8 (T3-Fe)	23.4	280	9.3	12021	22.4	556	11.7	27913
T9 (T3-Cu)	27.2	324	11.5	12371	16.0	563	11.4	28018
T10 (T3-Mo)	30.3	331	10.8	12547	22.1	561	12.5	28233
F test	NS	**	*	**	NS	**	NS	**
SED	8.26	33.8	1.03	421.2	3.35	4.461	0.69	109.1
LSD	16.92	69.22	2.12	862.5	6.8	9.14	1.41	219.2
CV%	52	12	14.8	5.3	24	1.2	8.5	0.5

F test or F-ratio = ratio of variance; SED = standard error deviation; LSD = least square deviation;
CV = coefficient of variation; NS = not significant

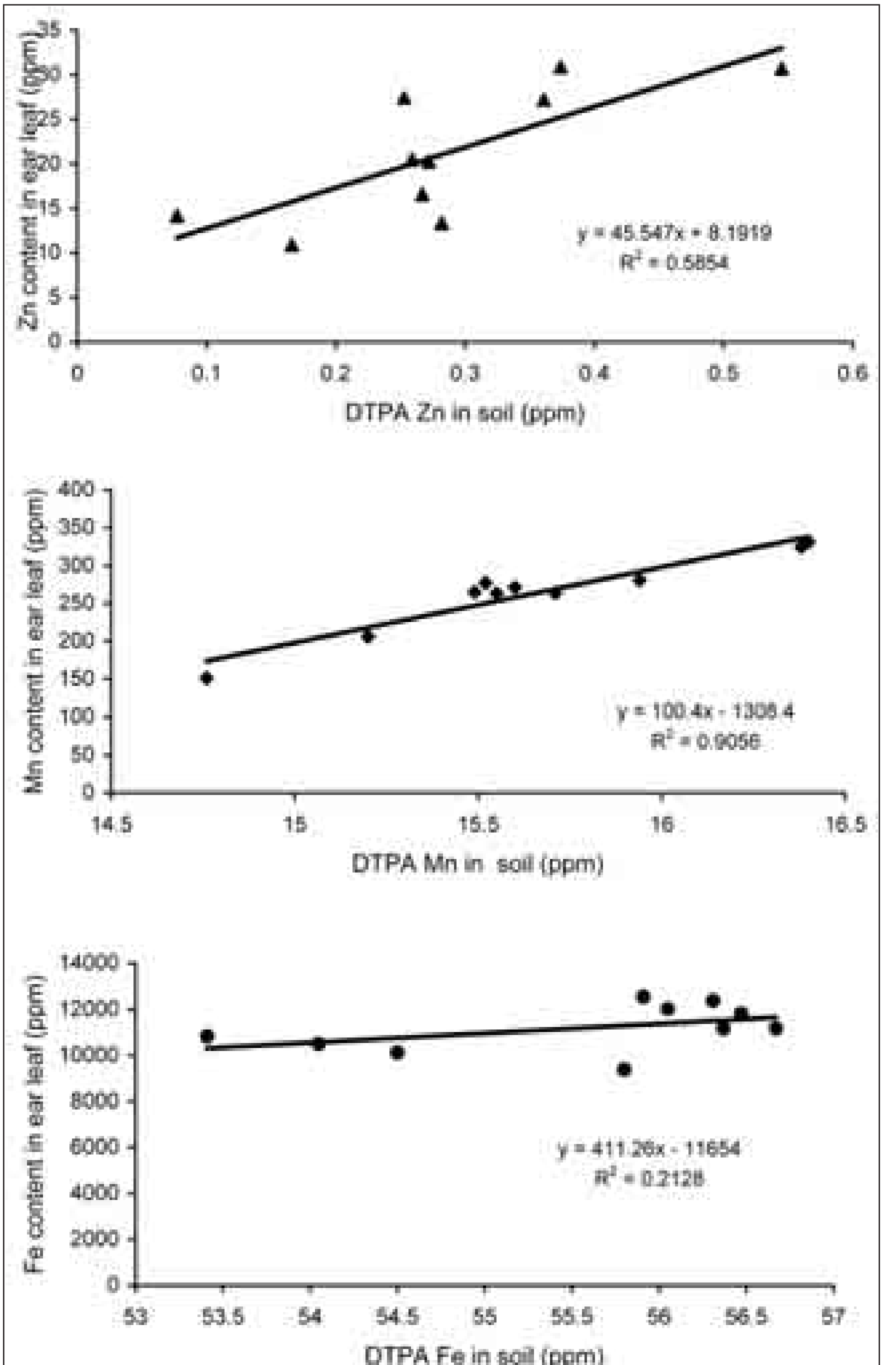

Figure 4: **Relationship between DTPA extractable Zn, Mn, and Fe in soils and content in ear leaves of maize**

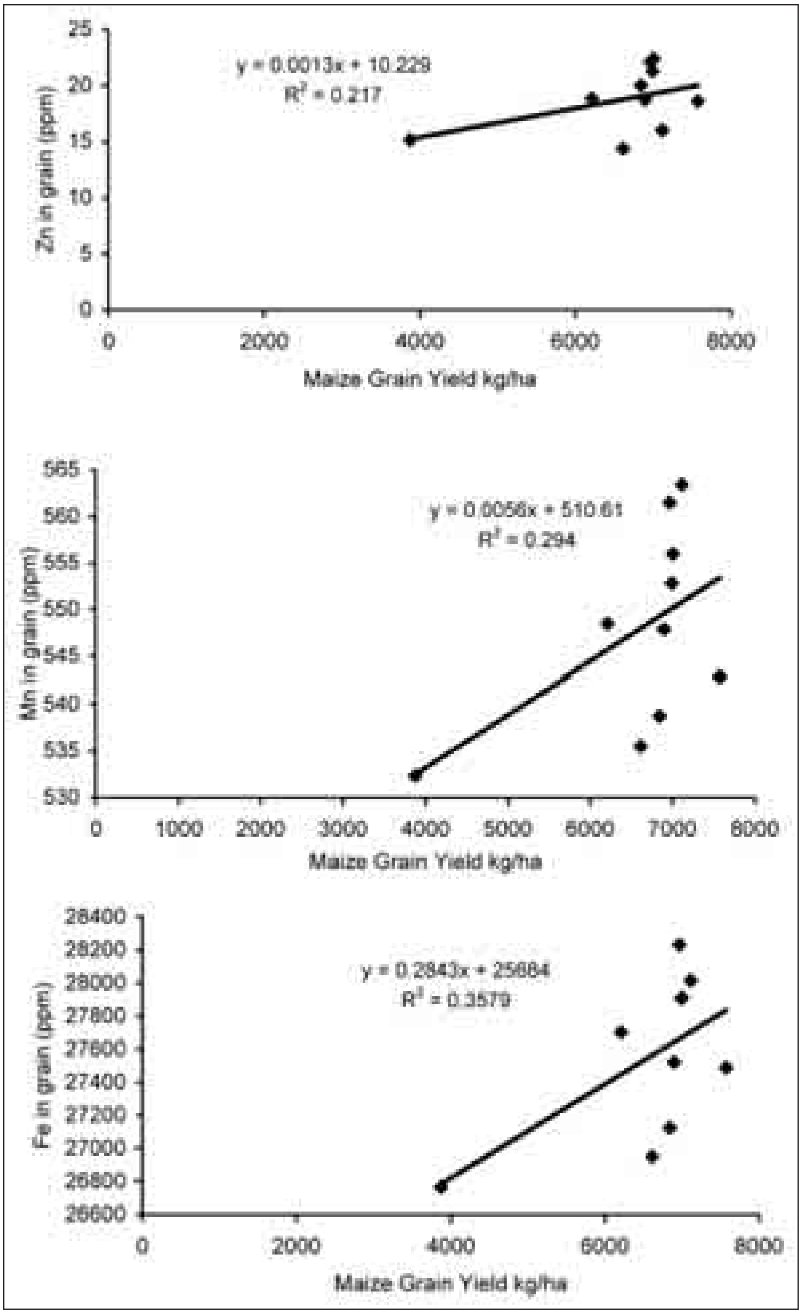

Figure 5: **Relationship between the maize grain yield and micronutrient content in grains**

Conclusions

Maize demonstrated no statistically significant response to micronutrients applied to soils in either the summer or winter seasons. The productivity of maize was more responsive to the planting season. The same level of nutrients from various fertilisers was applied to soils in both seasons, but crop production was higher in September planted maize. Although there was an indication of response to micronutrients, the results were inconsistent. No significant relationship was found between N and K content in leaf samples and grain yield. No relationship was found for P content; uptake of P by maize grains was not affected by the treatments. N and K uptakes were lowest in the control plot. K uptake was second lowest when S was not supplied. Similarly, there was an indication of a lower N uptake by grains. DTPA Zn and Mn in soil samples had a significant relationship with maize yield. No relationship was found with Fe. Similarly, there was no relationship between DTPA Fe and Fe content in the leaves. However, a significant relationship was seen between nutrient content in leaves and the DTPA soil tests for Zn and Mn.

Not all micronutrient tests could be carried out due to the lack of facilities in Nepal. In future more attention should be given to laboratory tests and field experiments, and these should be looked at from both the productivity and nutritional point of view.

Acknowledgements

The authors would like to thank the Laboratory In-Charge, Dr. K.B Karki, and Mr. R.C Munankarmi for their kind support in plant and soil analysis. Mr. B. Chaudhary and Mr. R. Upreti are also acknowledged for assistance in laboratory work. The NMRP field staff, Mr. D.D. Neupane, Mr. Himlal Bohara, and Mr. Ram K. Chaudhari, are also thanked for their sincere support in trial management and data observations.

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Enhancing Effect of Micronutrients on the Grain Production of Toria (*Brassica Campestris Duth. Var. Toria*) in Chitwan Valley

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Abstract

Experiments were conducted during 2001 and 2002 in farmers' fields as well as on the farmland of the National Maize Research Programme (NMRP) to evaluate the effects of different micronutrients, namely, boron (B), zinc (Zn), sulphur (S), and agricultural lime (calcium [Ca], and magnesium [Mg]) on the grain production of toria (Brassica campestris Duth. Var Toria). Plant growth (plant height, branch numbers, and pod numbers per plant) was significantly affected by the use of different micronutrients on toria crops when planted in the farmers' fields, but the increase was not significant at the research farmland of NMRP, Rampur. Application of B, Zn, and S produced the highest grain yield (1115 kg/ha) of toria under farmers' field conditions. Sulphur and boron together produced only 1077 kg/ha. The productivity of toria was very low on the research farmland of NMRP. Similar amounts of Zn, B, and S micronutrients produced only 568 kg grains/ha. Approximately 55% increment in yield over the control plot in farmers' field conditions and 52% on research farmland were observed when the crop was supplied with S, Zn, and B. The results suggest that the soil type, production environment, and management practices were quite different between the farmer's field and the research farmland. Nevertheless, they showed that the application of micronutrients (S, B, and Zn) is essential for achieving higher yields.

Introduction

Micronutrients are elements with specific and essential physiological functions in plant metabolism (Epstein 1965). Compared to macronutrients, micronutrients are required for growth in lower amounts and serve mainly as activators of enzyme reactions. The most characteristic visible symptoms of zinc (Zn) deficiency in dicotyledons are short internodes (rosetting) and a decrease in leaf expansion (little leaf). Stunted growth is often combined with chlorosis of the youngest leaves. In monocotyledons, chlorotic bands occur along the midribs of leaves combined with red, spot-like discoloration. Zinc deficiency symptoms on older-leaves are mainly the result of phosphorous-toxicity (Marschner and Cakmak 1986). Plant species differ considerably in their boron (B) requirements. The concentration range between B-deficiency and B-toxicity is quite narrow, so special care is required when B-fertiliser or composts rich in boron are applied (Romheld and Marschner 1991). Boron deficiency symptoms appear at the terminal buds and in the youngest leaves as retarded growth or necrosis. The diameters of stem and petioles are increased. The latter may lead to symptoms such as stem crack. Boron deficiency induces an increase in the drop of buds, flowers, and developing fruits. In addition to the reduction or even failure of seed and fruit set, the quality of fruit is often affected by malformation (Romheld and Marschner 1991). The total concentration of boron in most soils varies from 2-200 mg per kg, and less than 5% of the total soil boron is generally available to plants (Das 2002). Sulphur (S) deficiency is rarely a primary constraint in acid tropical soils but can readily become a problem once they are brought into intensive cropping systems. Sulphur deficiency is now recognised to be widespread in intensive cropping systems (Probert and Samosir 1983). Many tropical soils have much lower total and available sulphur contents than temperate soils (Neptune et al. 1975). Burning the vegetation during land clearance depletes soil S-reserves by releasing large amounts into the atmosphere. According to Kamprath and Till (1983) 5-7 ppm of S are needed in the soil solution of highly-weathered soils to enable most crops to make good growth. Crops differ widely, however, in their S requirements. Oilseeds (toria), grain legumes, and cotton have high S requirements. Micronutrients such as sulphur (S) and boron (B) have been found deficient in the maize- growing soils of Chitwan Valley. Thus, these elements should be applied to increase yields (Pandey and Srivastava 1987). Pandey and Srivastava (1987) conducted experiments on micronutrients at Rampur for five years and reported that S and B were the nutrient elements limiting yields under Rampur's soil conditions. Sulphur is a major nutrient that is rarely in the spotlight. Plants that have insufficient S show characteristic symptoms that may resemble those of N-starvation. Khhatri-Chhetri (1982) studied the role and occurrence of major and micronutrients in the soils of Chitwan Valley. He recognised the deficiencies of primary, secondary, and micronutrients in these soils. Srivastava and Neupane (1997) carried out long-term fertility trials on maize-toria rotations.

Srivastava and Neupane (1997) reported that the fourth toria crop yield had seriously declined with all treatment applications compared to that of the second crop of toria in a five-year study cycle. The fourth crop of toria produced the highest grain yield of 364.3 kg/ha in the plots that received 100:40:30 kg NPK/ha plus 20 kg sulphur, one kg of boron and one ton of dolomitic lime applied to the 3^{rd} crop of maize. The residual effects of micronutrients to toria production were observed to be positive in this experiment. Toria (*Brassica campestris*) and rapeseed yield the most important edible oils. The oil content of the seeds ranges from 30 to 48%. Toria is an annual plant and is more or less surface fed, enabling its successful cultivation under drier conditions. The crop is grown in both tropical and sub-tropical countries. India occupies the first position in the world with regard to both acreage and production of toria and rapeseed. Toria thrives best in light to heavy loam soils. Forty kg nitrogen (N) is optimum for all rapeseed and toria crops in rainfed areas. Besides nitrogen, toria requires sulphur and other micronutrients, especially boron, for increased grain yield production in Chitwan soils as they are not present in sufficient quantity for good crop growth. Singh (1983) recommended sulphur application along with NPK fertilisers at 60-90 kg N, 60 kg P_2O_5, and 40 kg K_2O/ha to toria crops. Tuladhar et al. (2004) reported that Chitwan soils (196 composite samples) were deficient in B and zinc (Zn) but sufficient in copper (Cu), iron (Fe), and manganese (Mn). More than 50% of samples collected were found to be high in Cu and Fe, whereas 100% of soils were found to be low in B and Zn. The overall objective of the study described here was to increase toria grain yield using micronutrients in Chitwan soils.

Materials and Methods

Field experiments on the use of micronutrients with toria (*Brassica campestris* Duth. Var. Toria) were carried out in a farmer's field at Sukra Nagar, Chitwan, in 2001 and on-station (OS) on the farmland of the National Maize Research Programme (NMRP) in 2002 to evaluate the effects of different micronutrients on plant growth and grain production. A local variety of toria was used in the experiments. A randomised complete block design (RCBD) with three replications was used at both sites. A total of eight treatments, see below, were used in the experiment. The farmer's practice treatment was excluded from the experiment carried out on NMRP farmland. Fertilisers were applied on all the plots at the rate of 60:40:20 kg $N:P_2O_5:K_2O$ per ha except on the farmer's practice plots. In one treatment, NPK was supplied by single super phosphate (SSP), ammonium sulphate (AS), and muriate of potash (MOP), in all others from urea, diammonium phosphate (DAP), and muriate of potash (MOP). In one treatment no micronutrients were added, in another agricultural lime was added instead of micronutrients in the form of fertiliser. Micronutrients were added to the selected plots at the rate of 20 kg sulphur (elemental S), 10 kg borax, and 5 kg of Zn/ha from zinc chloride ($ZnCl_2$), with one treatment including all three micronutrients and the other treatments two each of the three. The toria seeds were broadcast on 20 sq.m plots (4 x 5m). The crop was sown in the month of Kartik (November) and harvested in Magh (February). The plant growth characteristics and grain yield were recorded and analysed statistically using the least square deviation (LSD) method (Gomez and Gomez 1984). The treatments are listed below.

T1 = farmer's practice (0.5 kg/plot of oil-cakes; treatment not used in on-station research).
T2 = per ha: no micronutrient application, + 60:40:20 kg $N:P_2O_5:K_2O$ from urea, diammonium phosphate (DAP), and muriate of potash (MOP)
T3 = per ha: 10 kg borax + 5 kg Zn + 20 kg elemental sulphur + 60:40:20 kg $N:P_2O_5:K_2O$ from urea, DAP, and MOP
T4 = per ha: 10 kg borax + 5 kg Zn + 60:40:20 kg $N:P_2O_5:K_2O$ from urea, DAP, and MOP
T5 = per ha: 5 kg Zn + 20 kg elemental sulphur + 60:40:20 kg $N:P_2O_5:K_2O$ from urea, DAP, and MOP
T6 = per ha: 10 kg borax + 20 kg elemental sulphur + 60:40:20 kg $N:P_2O_5:K_2O$ from urea, DAP and MOP
T7 = per ha: 60:40:20 kg $N:P_2O_5:K_2O$ from ammonium sulphate (AS), single super phosphate (SSP), and muriate of potash (MOP)
T8 = per ha: 2t of agricultural lime plus 60:40:20 kg $N:P_2O_5:K_2O$ from urea, DAP and MOP

Results and Discussion

Response of micronutrients on plant growth of toria

Plant height, production of branch numbers, and pods per plant of toria (*Brassica campestris* Duth. Var. Toria) were significantly affected by the application of micronutrients under farmer's field conditions at Sukra Nagar, Chitwan (FF) (Table 1). The effects on plant height, branch numbers, and pod production observed on-station (OS) were not significant. The tallest plant height of 76.3 cm was observed when the crop was treated with S, B, and Zn with NPK (T3) whereas the lowest plant height of 56 cm was observed at the 'farmer's practice' plots which were only treated with oil-cakes (T1) in farmer's fields (FF). The highest number of branches (7.2 branches per plant) was produced by the crop treated only with S and B with NPK and the lowest number of branches (3.2 branches per plant) was also produced in 'farmer's practice' plots (T1). No significant effects on branch production were observed when the crop was planted on the farmland of NMRP (OS) at the same levels of fertilisation and micronutrient application (Table 1). In the farmer's field trials, the highest pod numbers (104.3 pods per plant) were produced when the crop was supplied with NPK from ammonium sulphate, single super phosphate, and muriate of potash (T7) followed by the crop treated with S and B plus NPK supplied from urea, DAP, and MOP (T6, Table 1). Production of the highest number of grains per pod (16.6) was obtained when the crop was treated with B and Zn plus NPK in the farmer's field (T4); but the effects of micronutrients were not significant (Table 1). On station, the highest number of grains per pod (10.4) was produced when the crop was supplied with S, B, and Zn plus NPK (T3) and the lowest (6.6) when the crop was fertilised only with NPK from urea, DAP, and MOP (T2). Application of NPK from AS, SSP, and MOP (T7) led to better grain production (7.7 grains per pod) than application of NPK from urea, DAP, and MOP (6.6 grains per pod) (T2, Table 1).

Table 1: **Plant growth of toria as affected by micronutrient applications in farmer's field (FF) conditions and in the NMRP on -station- farmland (OS)**

Treatment	Plant height (cm)		Branch numbers (no.)		Pods per plant (no.)		Grains per pod (no.)	
	FF	OS	FF	OS	FF	OS	FF	OS
T1	56.0	ND	3.2	ND	36.3	ND	14.2	ND
T2	65.3	51.6	5.2	2.6	60.3	75.3	15.0	6.6
T3	76.3	62.0	6.8	2.6	94.3	104.6	14.5	10.4
T4	73.3	56.3	6.1	2.4	92.3	78.6	16.6	8.3
T5	67.0	58.3	6.2	2.6	87.3	99.0	16.0	8.9
T6	68.3	55.0	7.2	2.9	100.0	92.3	11.7	8.4
T7	71.3	59.3	6.2	2.5	104.3	86.0	14.1	7.7
T8	66.0	57.3	5.3	2.6	76.3	78.3	14.0	7.1
CV (%)	4.36	18.26	15.57	9.10	9.69	15.94	4.90	14.90
F-test	***	NS	***	NS	***	NS	NS	*
LSD (0.05)	5.31	18.55	1.59	0.42	13.80	24.89	3.73	2.18

FF = farmer's field; OS = on -station; ND = not done; NS = not significant; LSD = least square deviation

Effects of micronutrients on toria yield

Table 2 shows the response of straw and grain yield to the different treatments. The impact of micronutrients on grain yield was highly significant. The highest grain yield of 1115 kg/ha was recorded when the crop was treated with S, B, and Zn plus NPK (T3) followed by treatment with S and B plus NPK (1076.6 kg/ha, T6), both under farmer's field conditions (FF). The lowest yield under FF conditions (605 kg /ha) was from the 'farmer's practice' plot (T1). The crop produced higher yields (985.3 kg/ha) when fertilised with NPK from AS, SSP, and MOP (985.3 kg/ha, T7) than with NPK from urea, DAP, and MOP (715.6 kg/ha, T2). The response of grain yield on-station was not significant, but as in the FF experiments, the highest grain yield (568 kg/ha) was also recorded following treatment with S, B, and Zn plus NPK (T3) and the lowest (372 kg/ha) following treatment with only NPK from urea, DAP, and MOP (T2). The latter was also lower than the yield obtained following application of NPK from AS, SSP and MOP (553 kg/ha, T7).

The effect of micronutrients on straw yield production (Table 2) was significant under farmer's field conditions with the highest straw yield (3440 kg/ha) observed when the crop was treated with S, B, and Zn (T3). The effects on-station were not significant but the highest straw yield (1013.3 kg/ha) was obtained after treatment with NPK alone from AS, SSP, and MOP (T7) and the lowest with NPK alone from urea, DAP, and MOP (T2).

Table 2: **Response of micronutrients on the straw and grain yield of toria**							
	Grain yield production (kg/ha)		**Straw yield production (kg/ha)**		**Yield increment (%)**		
	FF	**OS**	**FF**	**OS**	**Over T1 in FF**	**Over T2 in FF**	**Over T2 in OS**
T1	605.0	ND	2048	ND	00.00	0.00	0.00
T2	715.6	372.0	2560	556.6	18.18	0.00	0.00
T3	1115.0	568.0	3440	813.3	84.29	55.81	52.68
T4	990.0	500.0	3170	790.0	63.63	38.34	34.40
T5	961.7	524.0	3220	653.3	58.95	34.39	40.86
T6	1076.6	508.0	3300	931.6	77.95	50.44	36.55
T7	985.3	553.0	3200	1013.3	62.85	37.68	48.65
T8	756.6	443.0	3160	663.3	25.05	5.72	19.08
CV (%)	6.30		8.90	26.41	41.4		
F-test	***		***	NS	NS		
LSD (0.05)	99.49		463.0	318.4	319.46		
FF = farmer's field; OS = on -station; ND = not done; NS = not significant; LSD = least square deviation							

Conclusions

1. Plant height, branch numbers, and pod production per plant were significantly affected by the application of micronutrients under farmer's field conditions, but not on the farmland of NMRP. The highest pod number (104.3 pods /plant) was produced when the crop was supplied with NPK from ammonium sulphate (AS), single super phosphate (SSP), and muriate of potash (MOP) followed by the crop treated with sulphur and boron plus NPK supplied from urea, DAP, and MOP.

2. The impact of micronutrients on grain production was observed to be significant when the crop was planted in the farmer's field, but not on the farmland of the NMRP. The highest grain yield in the farmer's field (1115 kg /ha) was obtained when the crop was treated with B, Zn, and S plus NPK fertilisers; the yield was more than 80% higher than with the usual farmer's practice. The highest grain yield on-station (568 kg/ha) was also recorded when the crop was treated with B, Zn, and S plus NPK fertilisers, and the lowest (372 kg/ha) when the crop was supplied only with NPK fertilisers from urea, DAP, and muriate of potash.

3. The highest straw yield (3440 kg/ha) was observed under farmer's field conditions, after treatment with S, B, and Zn plus NPK.

Acknowledgements

Sincere thanks go to Mr. S. P. Srivastava, Senior Soil Scientist, NMRP, for his hard work in conducting this experiment. Thanks are due to Mr. Krishna Adhikary, Former Maize Coordinator, NMRP, for his kind help in providing official support and logistics to carry out this experiment.

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Increasing Wheat and Rice Productivity in the Sub-Tropics Using Micronutrient Enriched Seed

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Abstract

Many soils in the high rainfall sub-tropics are deficient in micronutrients, especially zinc (Zn), boron (B), and molybdenum (Mo). In vivo micronutrient enrichment of seed via foliar applications of micronutrients on the mother plants was evaluated as a strategy to address soil micronutrient deficiencies because farmers have limited access to soil testing for micronutrients. Seed enrichment was expected to alleviate soil deficiencies and to provide resistance against seedling root diseases. Fertiliser salts of Zn, Mo, nickel (Ni), copper (Cu), manganese (Mn), and boron (B) were sprayed at recommended concentrations five or ten times during the growth stages of wheat and rice, respectively. Both wheat and rice seed were enriched with all micronutrients, except B. Wheat seedling emergence and vigour were enhanced with seed enriched with micronutrients compared to unenriched seed. We believe this is due to increased resistance to soil borne pathogens. Wheat and rice seeds enriched with micronutrients that were sown in farmers' fields had increased yields relative to unenriched control seeds. Wheat yields increased an average of 25% in twelve of forty-seven on-farm trials in northwest Bangladesh. Rice yields increased an average of 22% in twelve of seventeen on-farm trials in the same area. Results indicate that seed enriched with micronutrients could improve yields of both wheat and rice in areas with micronutrient deficient soils without soil testing.

Introduction

Micronutrients stored in seeds and grain are essential for initial crop growth during germination and early seedling establishment. Inadequate reserves of seed micronutrient stores result in poor seed viability and diminished seedling vigour, especially when the seeds are sown in soils poor in micronutrients or when certain biotic (e.g., soil-borne pathogens) or abiotic (e.g., drought) stresses occur (Welch 1986; 1999). The rice-wheat cropping pattern of Bangladesh is primarily found on lighter-textured soils with wheat grown immediately following the monsoon rice crop. Yields of rice and wheat in Bangladesh are low, averaging 3.5t ha^{-1} and 2.1t ha^{-1}, respectively (FAOSTAT 2004). These low yields indicate that there are many constraints to crop productivity, including soil micronutrient deficiencies (Figure 1), poor crop establishment, and poor root health (Duxbury et al. 2004). High cropping intensity combined with little retention of crop residues and limited return of animal manure to soils exacerbates soil micronutrient deficiencies. Unfortunately, soil testing facilities for micronutrients are not widely available in the region. Furthermore, few farmers in Bangladesh use micronutrient inputs, even in areas with known soil micronutrient deficiency problems.

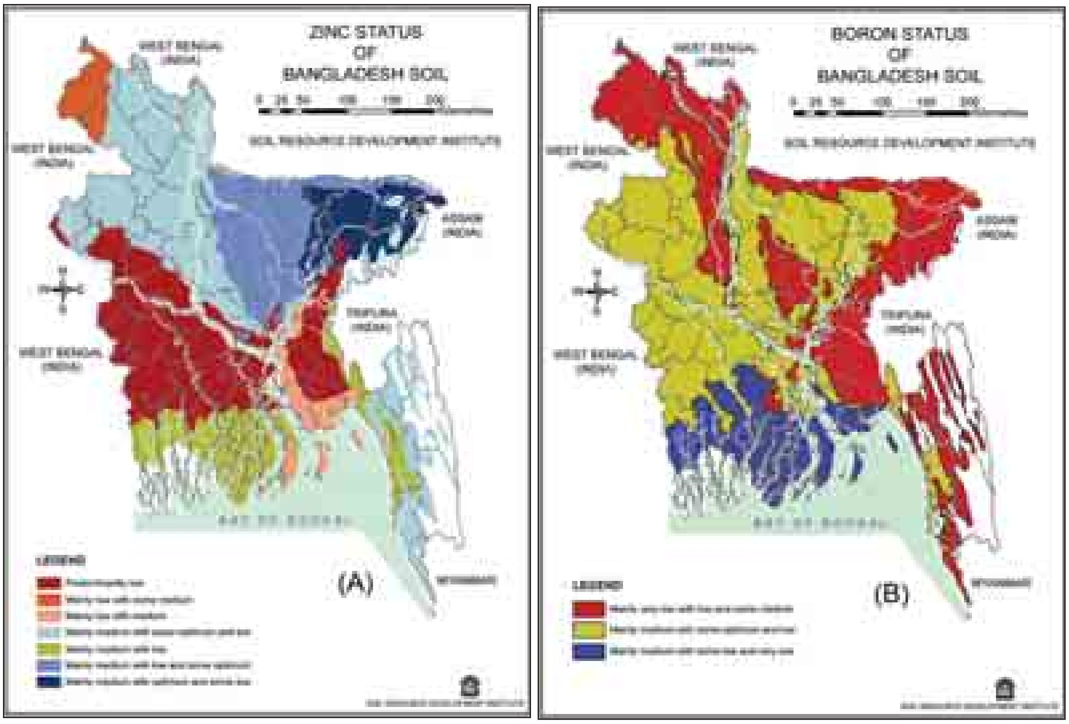

Figure 1: **Soil zinc (A) and boron (B) status in Bangladesh.** Source: Soil Resource Development Institute, Bangladesh Agricultural Research Council. Note: Areas shaded red, yellow, and pink indicate regions with low zinc/boron status.

Low stand density of wheat is often found despite relatively high farmer seeding rates (up to 200 kg ha^{-1}) (Meisner et al. 2003), which suggests that seed quality may also contribute to low yields. Most farmers' produce their own seed as the government supplier, Bangladesh Agricultural Development Corporation (BADC), can only provide 12–15% of the total seed requirement and private suppliers provide insufficient quantities.

Widespread soil micronutrient deficiencies and poor seed quality prompted us to test the hypothesis that seed enriched with micronutrients in vivo will provide yield benefits compared to unenriched seed in micronutrient deficient soils. Furthermore enriched seed would improve seed quality and seedling vigour by increasing seedling tolerance/resistance to soil-borne pathogens. As a result, enriching seed with micronutrients may be a strategy for overcoming micronutrient deficiencies and soil health problems at the farm level.

Materials and Methods

Seeds were enriched with micronutrients by foliar application during growth of the mother plants at the Wheat Research Centre, Nashipur, Bangladesh. Seed enrichment was undertaken for the wheat variety Kanchan, the major wheat variety grown in Bangladesh; the newly-released wheat varieties Sourav, Gourab, and Shatabdi; and the rice varieties, BR11, BR32, and BR33. The total amount of micronutrients applied per crop was 4 kg ha^{-1} for Zn and Mn; 1 kg ha^{-1} for Cu; and 0.5 kg ha^{-1} for B, Mo, and Ni. Nutrients were sprayed in five equal splits for wheat, beginning two weeks after sowing and continuing up to anthesis, and in 10 equal splits for rice. The nutrient sources used were zinc, copper, manganese, and nickel sulphates, boric acid, and sodium molybdate. Plants not receiving foliar sprays were grown at the same time to generate seed for use in unenriched control treatments. Various micronutrient combinations were used, including the complete suite and the complete suite minus individual nutrients. A Zn-only foliar spray treatment was also included. Not all treatments were included each time that enriched seeds were generated or with each variety.

Wheat and rice grains produced through foliar sprays were harvested and stored separately from unenriched grain. Grain samples were digested in nitric acid and analysed for micronutrient content by inductively-coupled plasma (ICP) atomic emission spectroscopy.

Trials were undertaken at the research station and on farmers' fields in northwest Bangladesh to compare the performance of enriched seeds, unenriched control seeds, and farmers' seeds for the various wheat and rice varieties. The trials carried out in each of three 'upazillas' (a rural administrative subdivision of a district) (Dinajpur Sadar, Kaharol, Kaunia) varied in design and replication. In the 1996/97 wheat season, seeds from various micronutrient treatments were used in an unreplicated design. Subsequently, only seeds from the complete micronutrient treatment were used with two replications in 1997/98 and three replications thereafter. A replicated plot trial with the rice variety BR32 was carried out at nine farms in Dinajpur Sadar, Kaharol, and Kaunia upazillas plus one additional farm at Chuadanga during the 2000 monsoon rice season. Plot size for farmer trials was three by four metres and seed was planted in rows by hand (20 cm apart, 15 rows/plot) to avoid problems with seed being planted at different depths. All soils were sandy in texture.

In addition to the field trials, a pot study was undertaken with Kanchan in 1998/99 to improve understanding of the impacts of micronutrient enrichment on seedling emergence, survival, and vigour. Pots were set up in groups of three using micronutrient enriched, control unenriched, and farmers' seeds in soil from a particular farm. Seeds were planted in pots which were buried in the ground at the Wheat Research Centre (WRC), Nashipur. A total of nine soils (three each from farms in Dinajpur Sadar, Kaharol, and Kaunia) were used with two replicates of each seed source. The soil was watered as necessary to ensure good growth. Seedling emergence, plant biomass, and root health evaluations were determined at 40 days after seeding. Root health evaluations used a rating scale of 1 (healthy roots, no visible disease symptoms) to 9 (greater than 75% of root tissue is diseased, reduced in size, and with advanced signs of decay) (CIAT 1987).

Results and Discussion

Seed Enrichment with Micronutrients

Significant increases in Zn, Mn, Cu, Mo, and Ni content were found for each of the four wheat varieties tested relative to unenriched controls (Figure 2: Ni not shown). Volatility of B during acid digestion precluded accurate results for B enrichment by wet digestion, but no enrichment was evident. Averaged across the four varieties, micronutrient concentrations of wheat seeds were enriched 10 to 20 fold for Mo and Ni; 1.6 to 2.0 fold for Zn; and 1.1 to 1.5 fold for Mn and Cu (Figure 3).

Foliar applications of micronutrients to rice variety BR11 increased micronutrient content of the seed slightly. Greater differences were observed for rice variety BR32 relative to unsprayed controls, with seed concentration enriched 6 fold for Mo; 1.5 fold for Mn; 2.6 fold for Zn, and 3 fold for Cu (Figure 4).

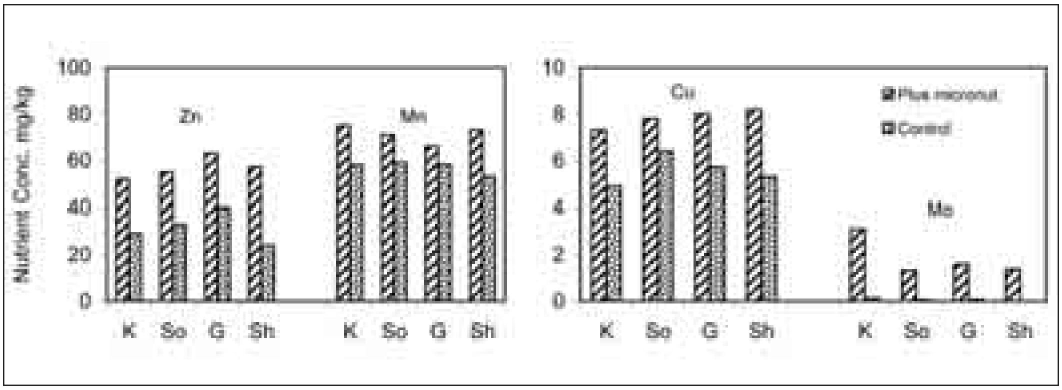

Figure 2: **Effect of foliar application of micronutrients on Zn, Mn, Cu, and Mo contents of whole grain of Kanchan (K), Sourav (So), Gourab (G), and Shatabdi (Sh) wheat varieties**

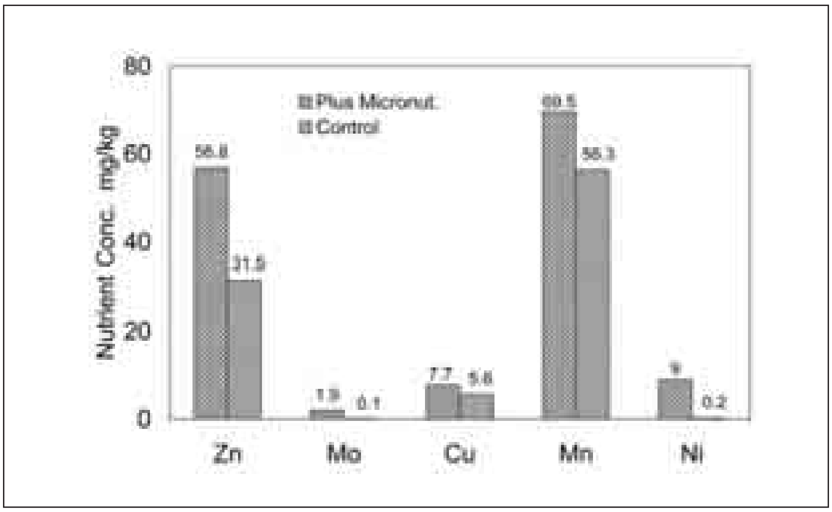

Figure 3: **Effect of foliar application of micronutrients on Zn, Mn, Cu, Mo, and Ni contents of wheat grain (average of 4 varieties)**

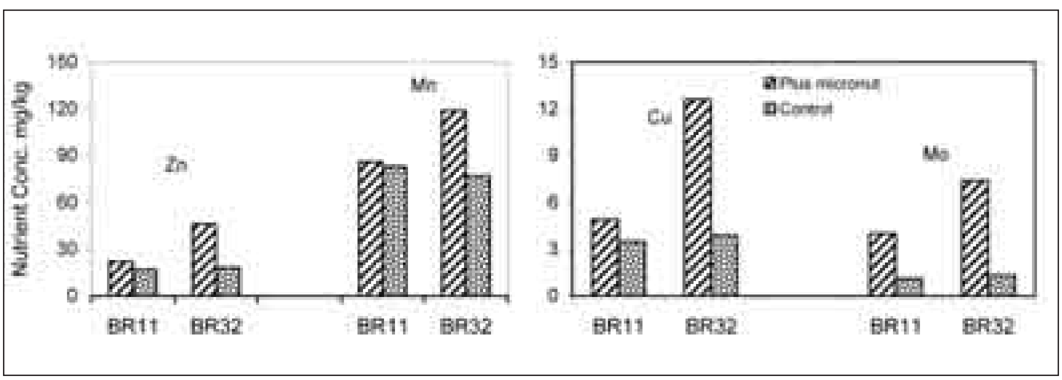

Figure 4: **Effect of foliar application of micronutrients on Zn, Mn, Cu, and Mo contents of whole grain of BR11 and BR32 rice varieties**

Effect of micronutrient-enriched seeds on wheat yields

At the research station, wheat yields were significantly increased ($p<0.05$) with micronutrient enriched seeds compared to the control unenriched seed in trials over three consecutive years for four different varieties of wheat (Table 1). The average increase ranged from 7 to 18 %, with Gourab being the least responsive and Kanchan the most responsive. Average yields were similar for all varieties, both with (3.8-4.1 t/ha) and without (3.4-3.6 t/ha) seed enrichment with micronutrients.

Treatments in which wheat seed was enriched with Zn only gave the same yield as complete seed enrichment (Zn, Mo, Cu, Mn, and Ni), indicating that the observed yield responses were primarily due to higher levels of Zn in enriched seed (data not shown). However, yield response of the variety Shatabdi was shown to be due to seed enrichment with both zinc and molybdenum at a second site at the research station (Table 2).

Table 1: Effect of micronutrient enrichment of seeds on wheat yields at the Wheat Research Centre, Nashipur

Variety and seed type	Grain yield t/ha				Increase over control %
	2000	2001	2002	Mean	
Kanchan					
Enriched	3.60[1]	4.59	3.98	4.06	18
Control	2.82	4.09	3.41	3.44	
Sourav					
Enriched	4.02	3.91ns	4.07	4.00	15
Control	3.16	3.81ns	3.49	3.49	
Gourab					
Enriched	3.20	4.21ns	4.02	3.81	7
Control	2.88	4.18ns	3.64	3.56	
Shatabdi					
Enriched	2.89	4.65	4.29	3.94	12
Control	2.34	4.28	3.91	3.51	

[1]Yield with micronutrie nt (MN) enriched see d was significantly greater ($p< 0.05$) than that with unenriched control seed except where indicated by ns (non significant)

Table 2: Effect of selective micronutrient enrichment of seeds on yield of Shatabdi wheat at the Wheat Research Centre, Nashipur

Treatment	Grain yield (t/ha)	
	2001	2003
Enriched Seed		
Complete[1]	4.20 ab[2]	4.20 a
Zn only	4.07 b	3.93 b
Zn + Mo only	4.32 a	4.22 a
Unenriched Seed	3.76 c	3.58 c

[1] Includes Zn, Mo, Cu, Mn, and Ni

[2] Letters indicate significant differences within columns at $p< 0.05$

Between 1996 and 2000, 47 trials were carried out on farmers' fields to compare wheat yields from seeds generated at the research station (micronutrient enriched and unenriched) with yields from farmers' seed. Figure 5 shows the results from a subset of the farmer trials. Yield was higher with enriched seed in 12 out of 47 trials, reflecting both spatial and temporal variability. The mean increase in wheat yield in the trials in which the micronutrient enriched seed out-performed unenriched seed was 25% (0.69 t/ha).

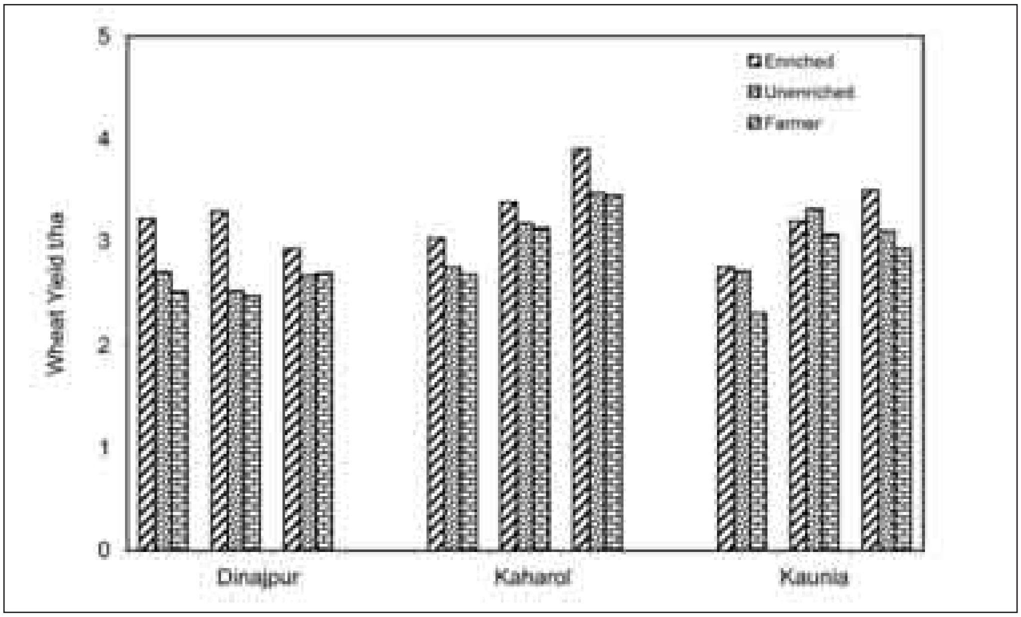

Figure 5: **Effect of micronutrient-enriched seed on wheat yields at selected farmers' fields in northwest Bangladesh**

Impact of soil B deficiency and wheat variety on yield

As Figure 1B indicates, soil boron levels in Bangladesh are low, and this can lead to sterility and significant yield losses of wheat. Although we did not find B enrichment in wheat seeds that had received foliar B applications, yield responses to enriched seed were positive compared to unenriched controls at sites were B deficiency was observed (Figure 6). We postulate that the yield response to enriched seed at these sites was due to Zn and/or Mo. On-farm trials with the varieties Kanchan and Shatabdi included addition of 1 kg B ha^{-1} to soils as borax. Compared to non-enriched control seed, yields were increased by 21-31% with micronutrient-enriched seed plus boron fertilisation; by 11–13% with enriched seed alone; and by 11-23% with control seed plus boron fertilisation (Figure 6). Shatabdi was more responsive to B addition than Kanchan, indicating that it is more susceptible to B deficiency. Mean yield with farmers' seed, which was Kanchan, was 12% less than that with control seed, indicating that farmers' seed was of lower quality compared to the seed produced at the research station.

Impact of micronutrient enriched seed on rice yield

Replicated plots with micronutrient enriched rice seeds of varieties BR11 and BR32 were planted at the Wheat Research Centre (WRC) to evaluate the impact of micronutrient seed enrichment on rice productivity. Enriched seeds were compared with unenriched control seeds. A third treatment tested the effect of additional micronutrient spraying on previously enriched seeds. Seed enrichment significantly ($p<0.05$) increased the yield of BR32 by 1.1 t/ha, an increase of 37% over the control (Figure 7). Extra spraying with micronutrients had no additional benefit, thereby demonstrating that the seed enrichment was sufficient to overcome soil micronutrient deficiencies. No micronutrient treatment effects were observed with BR11. Yields of BR11 were roughly a third of those obtained with BR32, because of selective attack on this variety by gall midge.

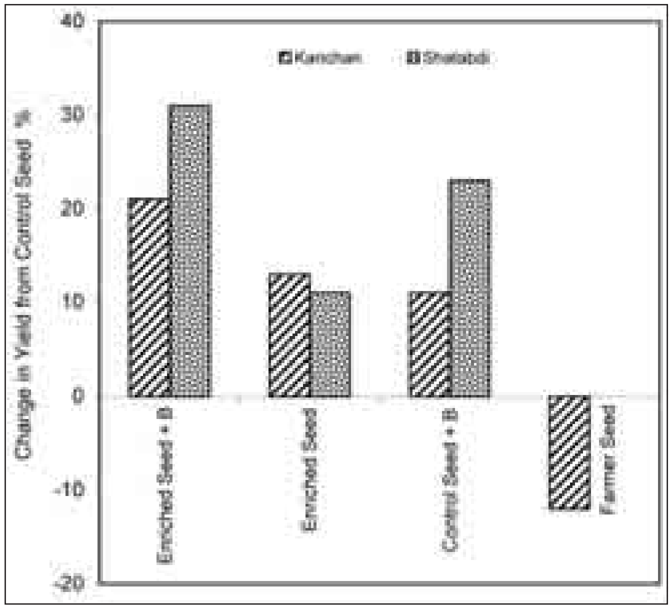

Figure 6: **Effect of seed enrichment and B application to soil on wheat yield (average of 9 farms).** Note: Mean control seed yields were 3.0 t/ha for both varieties

Likewise, on farmers' fields, BR32 micronutrient-enriched seed produced higher yields in six out of nine trials (Figure 8). The average yield increase was 25%, with a range in response of 15 to 41%. Rice plants from micronutrient-enriched seed were also observed to be more resistant to lodging.

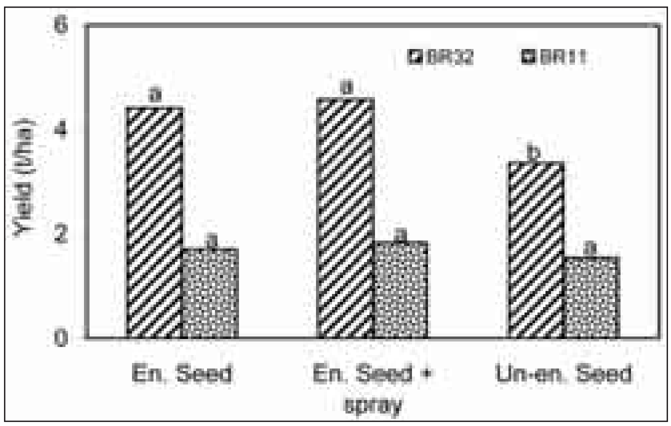

Figure 7: **Impact of micronutrient enriched (En) seed and enriched seed plus additional micronutrient sprays on rice yield relative to unenriched (Un-en) (control) seed for varieties BR11 and BR32.** Note: letters indicate significant differences at $p<0.05$ within a variety.

Further investigations at the WRC with differentially enriched rice seed suggest that both Zn and Mo were responsible for the observed yield responses (Table 3). Rice seed enriched with Zn only produced yields that indicated a partial response. Likewise, when all micronutrients except Mo were included, yields were lower than with the complete micronutrient treatment although still significantly higher than unenriched controls, suggesting that Mo deficiencies were also addressed by seed enrichment. Similar responses to differentially enriched rice seed were seen on farmers' plots (data not shown).

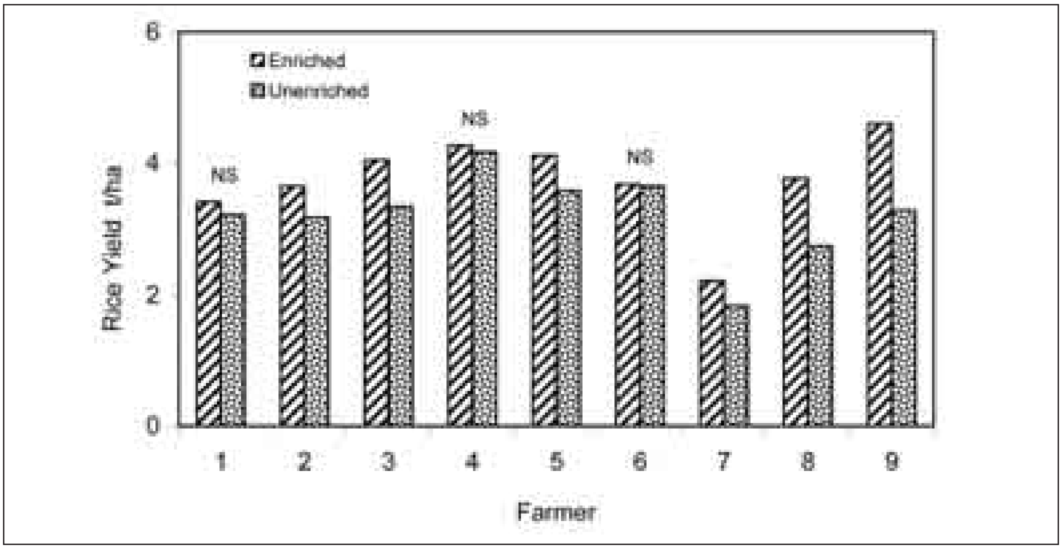

Figure 8: **Impact of micronutrient-enriched rice (BR32) seed in farmers' fields.** Note: Differences between treatments significant at $p<0.05$ unless indicated (NS)

Table 3: **Effect of differential micronutrient seed enrichment on yield of BR32 rice at the Wheat Research Centre, Nashipur**

Treatment	**Rice yield t/ha**
Complete (Zn, Mn, Cu, Mo, B)	4.6 a
Zn only	4.0 b
Complete minus Mo	4.1 b
Control	3.6 c
Note: Letters indicate significant differences at $p < 0.1$	

Why are yields higher with micronutrient-enriched seed?

Rice and wheat yield responses to micronutrient-enriched seed were likely to be the result of improved germination, seedling emergence, vigour, and root health due to increased resistance to root infections from soil-borne pathogens. Healthier root systems would also increase the capacity of the plant to acquire nutrients and water from the soil. Work by Thongbai et al. (1993), Grewal and Graham (1996), and McCay-Buis et al. (1995) has shown that seed with high levels of both Zn and Mn provides resistance to take-all, root rot, and crown rot diseases in small grains. Likewise Rengel and Graham (1995 a, b) found that high zinc seed promoted crop growth and increased yield when planted in soils deficient in this nutrient. Previous work by Chatterjee and Nautiyal (2001) confirms the importance of molybdenum in improving the germination and seedling vigour of wheat.

Micronutrient-enriched seed performed better than non-enriched control seed in the wheat seedling emergence and seedling performance soil-pot study using nine farmers' soils (Figure 9). In many cases, control seed performed better than farmers' seed, which supports previous observations that poor quality farmers' seed limits crop performance. Overall,

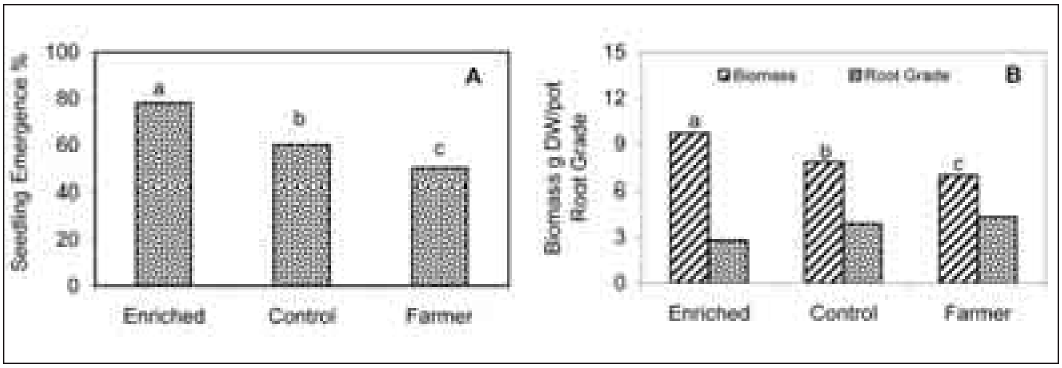

Figure 9: **Impact of micronutrient seed enrichment on seedling emergence (A), and biomass and root health (B) for Kanchan wheat.** Note: Data are means from 9 farmers' soils; letters indicate significant differences at $p<0.05$

seedling emergence increased from 50% with farmers' seed, to 61% with control seed, and to 78% with micronutrient enriched seed (Figure 9A). Similarly, the biomass of 40-day old plants from micronutrient-enriched seed was 24 and 40 % higher than that from control and farmers' seed, respectively (Figure 9B). Root health of plants grown from micronutrient-enriched seed was rated as good (score of 2.8 on the 1-9 scale) compared to that from non-enriched seed which was rated as slightly worse than moderate (score of 4.3) (Figure 9B). The root health data indicate that seedlings grown from micronutrient-enriched seed had a greater ability to resist or tolerate root infections from soil-borne pathogens.

Seed enrichment with micronutrients also had an effect on resistance to soil-borne pathogens later on during crop growth. Bipolaris leaf blight (BpLB) was evaluated after flowering in a replicated trial at WRC with micronutrient-enriched and unenriched seed treatments of four wheat varieties. Less BpLB was found on wheat plants grown from enriched seed for all wheat varieties (Figure 10).

Can micronutrient-enriched seed be a strategy to overcome micronutrient deficiencies at the farm level?

While micronutrient enrichment of both wheat and rice grain can be achieved at the experimental level by foliar application of micronutrients, this method is too laborious and not practical for farmers. Efforts were undertaken to produce micronutrient-enriched wheat and rice seed on farmers' plots using soil fertilisation instead of foliar sprays. In trials on six farms, soil fertilisation was almost as effective as foliar sprays at increasing the concentration of micronutrients (Zn and Mo) in wheat grain (Figure 11). On average, the concentration of Zn in the wheat grain increased by a factor of 1.7 and of Mo by a factor of 13.

Unfortunately, soil fertilisation with micronutrients did not increase concentration of Zn or Cu in rice grain, although it did achieve a two-fold increase of Mo (Figure12). This result is consistent with Sarah Johnson's findings that Zn availability decreases quickly when soils are flooded (see these proceedings). Other strategies under consideration to enrich rice grain with Zn under farmers' conditions are applications of Zn to floodwater (post anthesis) or applying Zn to aerobic rice seedbeds to overcome Zn deficiency during crop growth.

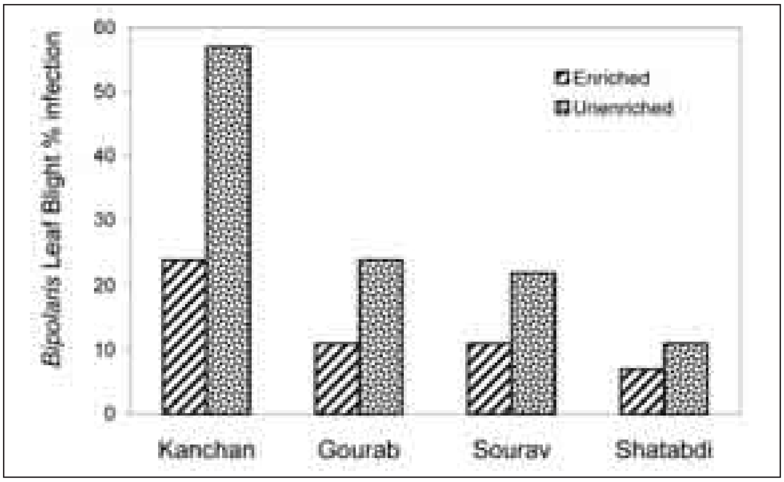

Figure 10: **Effect of micronutrient seed enrichment on infection by *Bipolaris* leaf blight in four wheat varieties**

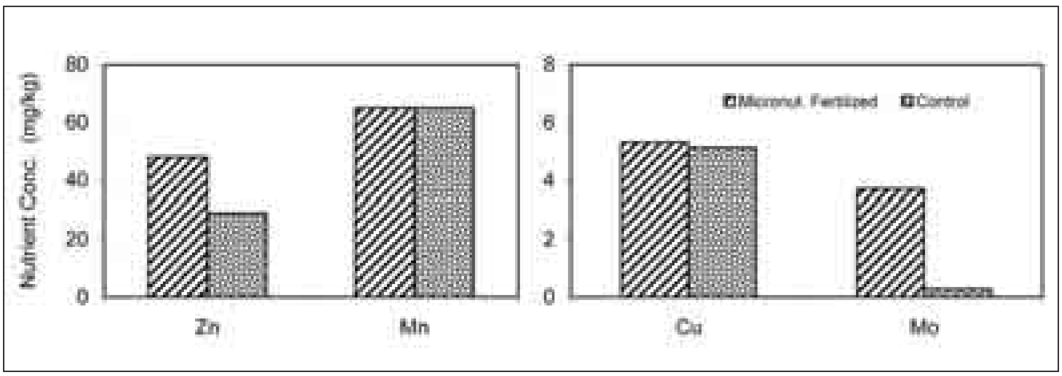

Figure 11: **Effect of soil fertilisation with micronutrients on wheat micronutrient content from farms in Bangladesh; data are means from 6 farms**

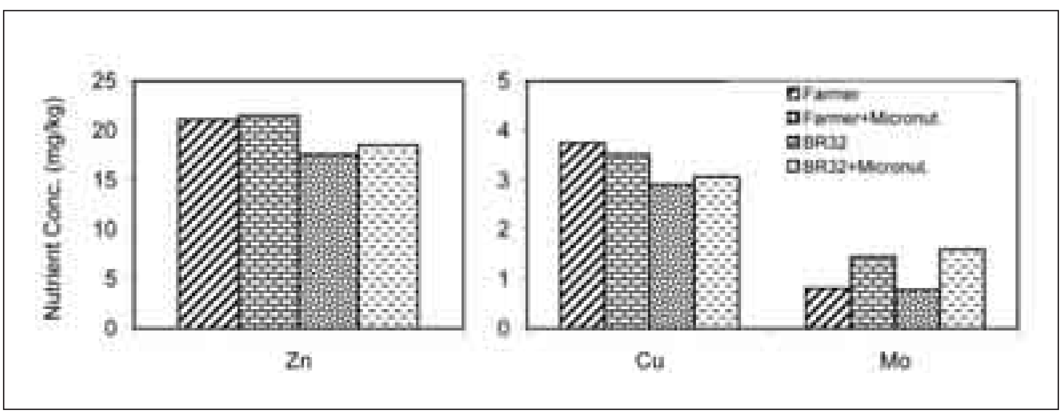

Figure 12: **Effect of soil fertilisation with Zn, Cu, and Mo on rice grain micronutrient content.** Note: Data are means from 13 farms using the farmers' rice varieties and BR32

Conclusions

Soil micronutrient deficiencies are prevalent in Bangladesh and contribute to poor seed viability as well as diminished seedling vigour under biotic stress (soil-borne pathogens). Poor seedling performance ultimately leads to low crop yields. Micronutrient seed enrichment provides an avenue to alleviate soil micronutrient deficiencies and to provide resistance against seedling root diseases.

Seed enrichment with Zn, Cu, Mn, and Mo was achieved in several wheat and rice varieties by foliar application of micronutrients. Micronutrient-enriched wheat seed out-performed unenriched seed on 26% of tested farms, with a mean increase in wheat yield of 0.69t ha^{-1}. Likewise rice yields were increased 15-41% in farmer trials with micronutrient-enriched seed relative to unenriched seed.

Data for wheat seedling emergence, biomass, and root grade supported our hypothesis that micronutrient seed enrichment improves seedling vigour and root health by increasing resistance to soil-borne pathogens. Treatments with micronutrient-enriched seed also showed significantly less *Bipolaris* leaf blight infection when compared to unenriched control seed.

Foliar spraying is not practical for Bangladeshi farmers as a means of generating their own micronutrient-enriched seed. Farmers can easily generate micronutrient-enriched wheat seed by soil fertilisation but more research is needed to develop simple methods to enrich rice seed.

Acknowledgements

The authors would like to acknowledge funding from the US AID Soil Management Collaborative Research Support Program to Cornell University (711203-LAG-G-0097-0002-00). Furthermore, we would like to dedicate this paper to the memory of A.A. Siddique who was integrally involved in evaluating the impact of micronutrient-enriched seed on root health.

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Effect of Phosphorous and Zinc Fertilisation on the Productivity of Transplanted Aromatic Rice

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Abstract

The incidence of micronutrient deficiencies in crops and cropping systems has increased markedly in recent years in India. The important reasons are: increase in area under intensive cropping systems, decreased proportion of farm-yard manure (FYM)/organic manures compared to chemical fertilisers, increased use of straight fertilisers, losses of micronutrients through leaching/soil erosion, excess liming of acid soils, and cultivation of high-yielding varieties of different crops. The use and efficiency of macronutrients depend on the availability of micronutrients in the soil. The interaction of phosphorous (P), a macronutrient, and zinc (Zn), a micronutrient, is very important for rice cultivation. Therefore, a field experiment was carried out to study the effect of phosphorous and zinc fertilisation on growth, yield attributes, yield, and phosphorous uptake of aromatic rice. Application of 40 kg P_2O_5/ha (phosphorous pentoxide) in combination with 5 kg Zn/ha was found suitable for achieving greater productivity of aromatic rice. P uptake by aromatic rice increased significantly with each successive increase in P up to the highest level (i.e., 60 kg P_2O_5/ha). However, zinc application did not affect the P uptake significantly.

Introduction

Scores of assessments have been made of the occurrence of micronutrient deficiencies in Indian soils and crops (Katyal and Agarwala 1982; Katyal 1985; Takkar et al. 1997; Rattan et al. 1999). All estimates point to the possibility of wide-scale occurrence of Zn deficiency in Indian soils: the extent is almost 50%. Sustaining the supply of deficient micronutrients along with macronutrients in appropriate amounts and right proportions is a key to maximising productivity gains in rice. This is especially true for a country like India, where the chances of raising four to five million tons of additional food to feed 15 to 17 million more people every year through area expansion are very poor. The influence of micronutrients on the optimum use of macronutrients is rooted in the fact that if supply of the former falls short of what is needed for optimum crop growth and yield, response to the latter will be impaired in economic and environmental terms. Many studies have proven this relationship (Takkar et al. 1997; Rattan et al. 1997).

The macronutrients include nitrogen (N), phosphorous (P), and potassium (K), and the optimum use of these has been evaluated with or without the involvement of micronutrients, typically zinc (Zn), in rice-based cropping systems. Apart from the direct role of micronutrients in overcoming inherent deficiency and enhancing response to NPK treatment, they also assert an interactive effect on the uptake and use of macronutrients. P and Zn interaction is a typical example. Many controlled greenhouse studies have shown that Zn deficiency interferes with P metabolism (Safaya 1976; Loneragan et al. 1982; Nayak and Gupta 1995). As a consequence of this association, plants tend to accumulate more P, develop symptoms resembling Zn deficiency, and yield less. An optimum level of Zn application overcomes this antagonism and assures restoration of normal yields (Sakal et al. 1996). In some studies, the P and Zn interactive effect was found to be statistically non-significant (Sharma and Bapat 2000). In studies, where P and Zn were optimally balanced, this interactive effect disappeared and maximum yield and response to P application was obtained (Takkar et al. 1976). In instances in which P/Zn ratios turned out to be wider, either due to heavy dressings with P fertilisers or because of sub-optimal supply of Zn, deficiency of Zn became more severe leading to a measurable fall in Zn uptake and yield. Most of these studies on P and Zn nutrition are related to coarse/non-scented rice. Therefore, a field experiment was planned to study the effect of phosphorous and zinc fertilisation on growth, yield attributes, and yields of aromatic rice. Another aim was to estimate the uptake of P by aromatic rice as influenced by P and Zn fertilisation.

Materials and Methods

A field experiment was carried out during the rainy (kharif) season of 2002 at the experimental farm of the Indian Agricultural Research Institute, New Delhi, India, to study the effect of phosphorous and zinc fertilisation on the productivity and phosphorous uptake of aromatic rice under transplanted puddled conditions. The soil at the experimental site was sandy clay loam (sand 51.8%, silt 22.1%, clay 26.1%) with a pH value of 8.15, organic carbon 0.52%, available nitrogen 195 kg/ha, available P 16.2 kg/ha , available K 285.6 kg/ha, and diethylenetriaminepentaacetic acid (DTPA) extractable Zn 0.75 ppm in furrow slice soil. The treatments, consisting of 16 possible combinations of four phosphorous levels (0, 20, 40, and 60 kg P_2O_5/ha) in main plots and four zinc levels (0, 2.5, 5.0, 7.5 kg Zn/ha) in sub-plots, were allocated in a split plot design with three replications. Twenty-five day old seedlings of ‘Pusa Basmati 1’, a high yielding aromatic rice variety, were transplanted on 8 July 2002, at 20 x 10 cm spacing, keeping two seedlings per hill. The total amount of phosphorous and zinc, as per the treatment, was applied before transplanting in the form of single super phosphate and zinc sulphate, respectively. Nitrogen was applied through urea in three equal splits, 1/3 each at transplanting, active tillering, and panicle initiation stages, respectively. A five to six cm depth of water was maintained throughout the rice cultivation season rice; irrigation was stopped two weeks before the rice harvest. The crop was harvested on 15 October 2002. At harvesting, 10 hills from each plot were picked at random for measurement of panicles/hill, panicle length, panicle weight, spikelets/panicle, filled grains/panicle, and 1000-grain weight. A net plot area (4.8 x 1.6m) of eight rows from each plot was harvested and their respective weights recorded for total biomass and grain yield estimation. The harvest index (%) was obtained by dividing the grain yield with the biological yield (grain + straw) multiplied by 100. The recorded data and observations were tested for statistical significance using the analysis of variance technique (Gomez and Gomez 1984).

Results and Discussion

Growth and yield attributes

The increasing rates of phosphorous application encouraged the growth and yield attributes of aromatic rice (Tables 1 and 2). The highest P levels (40 and 60 kg P_2O_5/ha) resulted in the maximum recorded plant heights, both levels produced significantly taller plants compared to other P levels and the control. The significant effect of phosphorous application on yield attributes, viz. grain weight/panicle and 1000-grain weight, was only recorded up to

40 kg of P_2O_5/ha. However, effective tillers/hill, total grains/panicle, and filled grains/panicle continued to increase significantly up to the highest level of P, i.e., 60 kg P_2O_5/ha. The fertility percentage of rice grains also increased significantly as a result of phosphorous application compared with no P application. However, there was no significant effect on grain fertility beyond 20 kg of P_2O_5/ha. In general, application of phosphorous encourages the production of dry matter in rice, which eventually results in improved growth and yield attributes. Zinc application also increased the plant height and yield attributes, viz., effective tillers/hill, panicle length, panicle weight, total grains/panicle, filled grains/panicle, and 1000-grain weight, over control. No interaction effect between

Table 1: **Effect of phosphorous and zinc fertilisation on growth and yield attributes of aromatic rice ('Pusa Basmati 1')**

Treatment	Plant height (cm)	Effective tillers/hill (no.)	Panicle length (cm)	Grain weight (g/panicle)
Phosphorous levels (kg P_2O_5/ha)				
0	93.5	8.2	25.5	2.23
20	97.5	9.3	26.9	2.35
40	103.5	10.5	27.9	2.50
60	104.0	10.9	28.2	2.57
CD (P = 0.05)	2.21	0.11	1.78	0.08
Zinc levels (kg Zn/ha)				
0	96.0	8.5	25.7	2.07
2.5	98.2	9.4	26.7	2.42
5.0	101.0	10.2	27.7	2.55
7.5	103.2	10.6	28.3	2.60
CD (P = 0.05)	2.99	1.6	1.68	0.29

Table 2: **Effect of phosphorous and zinc fertilisation on yield attributes of aromatic rice ('Pusa Basmati 1')**

Treatment	Total (grains/panicle)	Filled (grains/panicle)	Fertility (%)	1000-grain weight (g)
Phosphorous levels (kg P_2O_5/ha)				
0	103.2	87.2	84.4	20.23
20	108.7	96.2	85.5	21.28
40	114.2	98.7	86.4	22.32
60	117.5	101.5	86.2	22.47
CD (P = 0.05)	0.41	1.37	1.00	0.28
Zinc levels (kg Zn/ha)				
0	106.5	90.7	85.0	19.87
2.5	108.7	93.7	86.1	21.53
5.0	113.0	97.0	85.7	22.25
7.5	115.5	99.2	85.8	22.68
CD (P = 0.05)	4.12	3.84	0.88	1.84

phosphorous and zinc applications was observed in this study. In general, the lower rates (2.5 kg/ha) of Zn application could not bring a significant increase in yield attributes, viz., effective tillers/hill, panicle length, total grains/panicle, filled grains/panicle, and grain weight/panicle over control. However, all the above parameters became significant ($P<0.5$) over control when the level of Zn was raised to 5 kg/ha. Further increase to 7.5 kg/ha did not exert any significant impact on any of the yield attributes studied. Overall, medium levels of zinc (5.0 kg/ha) had a favourable effect on most of the yield attributes. Rice has responded significantly to zinc application in many other studies elsewhere in India.

Yield and phosphorous uptake

Grain, straw, and biological yields and harvest index of aromatic rice were influenced significantly by the application of both phosphorous and zinc (Table 3). Straw and biological yield of rice increased progressively and significantly with an increase in each successive level of phosphorous, i.e., up to 60 kg P_2O_5/ha. Phosphorous is known to increase the uptake of other nutrients, especially N, that may have caused an increase in dry matter production and hence eventually biological and straw yields of rice. Phosphorous application affected the grain yield of rice significantly during the present investigation, but it only increased significantly up to 40 kg of P_2O_5/ha, with no further significant increase at 60 kg of P_2O_5/ha. The increase in yield with application of 40 kg of P_2O_5/ha over lower P doses was caused mainly through a significant improvement in grain weight/panicle and 1000-grain weight. Also the significant increase in P accumulation in plants added to the improved grain yield under P application. The increase in grain yield of rice in India has been reported by Rao and Shukla (1999), Raju et al. (1992), and Kumar et al. (2002). The harvest index (%) of rice decreased slightly but significantly ($P<0.5$) at each successive increase in P level. The increasing levels of grain yield might have resulted in a decrease in harvest index at increased P levels.

The lower rates (2.5 kg/ha) of Zn application did not bring a significant increase in grain and biological yields over control. However, both the above parameters became significant ($P<0.5$) over control when the level of Zn was raised to 5 kg/ha. Further increase in the level

Table 3: **Effect of phosphorous and zinc fertilisation on grain, straw, and biological yields, and harvest index of aromatic rice ('Pusa Basmati 1')**

Treatment	Grain yield (mg/ha)	Straw yield (mg/ha)	Biological yield (mg/ha)	Harvest index (%)
Phosphorous levels (kg P_2O_5 /ha)				
0	4.29	7.89	12.17	35.2
20	4.56	8.61	13.17	34.6
40	4.71	9.46	14.17	33.2
60	4.74	9.74	14.47	32.8
CD (P = 0.05)	0.09	0.08	0.09	0.53
Zinc levels (kg Zn/ha)				
0	4.29	8.06	12.35	34.8
2.5	4.52	8.70	13.22	34.2
5.0	4.70	9.21	13.91	33.8
7.5	4.79	9.72	14.51	33.0
CD (P = 0.05)	0.38	0.62	0.98	0.81

of zinc to 7.5 kg/ha did not exert any significant impact on either grain or biological yield. The favourable effect of a medium level of zinc (5.0 kg/ha) on most of the yield attributes over the control resulted in significant improvement in grain yield at this level. Rice responded significantly to zinc application in many other studies elsewhere in India as reported by Kumar et al. (2002). The highest grain and biological yields were recorded with 7.5 kg Zn/ha, but these were at par with 5.0 kg Zn/ha application.

Phosphorous application significantly influenced the P concentration and uptake in grain and straw, and total P uptake in the present study (Table 4). P concentration in grain increased progressively and significantly with each successive increase in its level, i.e., up to 60 kg P_2O_5/ha. However, there was no significant change in P concentration of straw beyond 40 kg of P_2O_5/ha. P uptake in grain, straw, and total (grain + straw) increased significantly ($P<0.5$) with each successive increase in P level, i.e., up to 60 kg of P_2O_5/ha. It is known that only a very small fraction of applied P is bioavailable for uptake by plants, the increasing P levels increased the bioavailabe P proportionately in the soil, which caused the increased P concentration and uptake in rice parts. The increase in P uptake caused by increasing its levels has been reported in other studies in India (Kumar et al. 2002; Rao and Shukla 1999). Contrary to P application, zinc application did not affect either P concentration or uptake in grain and straw.

The interaction effect of phosphorous and zinc on growth, yield attributes, grain yield, and P uptake of rice was found to be not significant in the present investigation. The optimum proportion of both these nutrients is required to realise higher plant growth and yield. Excess application of P fertiliser can induce zinc deficiency and increase plant requirements for Zn (Robson and Pitman 1983). But in the present study the moderate levels of P did not induce zinc deficiency in the crop and subsequently the interaction effect of zinc and phosphorous was not significant.

Table 4: Effect of phosphorous and zinc fertilisation on grain P concentration, straw P concentration, grain P uptake, straw P uptake, and total P uptake of aromatic rice ('Pusa Basmati 1')

Treatment	Grain P concentration (%)	Straw P concentration (%)	Grain P uptake (kg/ha)	Straw P uptake (kg/ha)	Total P uptake (kg/ha)
Phosphorous levels (kg P_2O_5 /ha)					
0	0.14	0.08	6.05	6.29	12.36
20	0.16	0.10	7.33	8.64	15.97
40	0.18	0.12	8.52	11.40	19.91
60	0.19	0.12	9.03	12.23	21.26
CD (P = 0.05)	0.005	0.013	0.16	0.12	0.17
Zinc levels (kg Zn/ha)					
0	0.17	0.11	7.25	8.84	16.09
2.5	0.17	0.11	7.64	9.51	17.15
5.0	0.17	0.10	7.95	9.86	17.81
7.5	0.16	0.10	8.09	10.35	18.46
CD (P = 0.05)	NS	NS	NS	NS	NS

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Molybdenum Response of Chickpea in the High Barind Tract (HBT) of Bangladesh and in Eastern India

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Abstract

Chickpea (Cicer arietinum L.) grown on residual soil moisture after the rice harvest is a promising crop for the High Barind Tract (HBT) of Bangladesh, an uplifted, slightly undulating area in northwestern Bangladesh where the soils have an acid surface horizon (pH 4.5-5.5 at 0–10 cm) but are neutral to alkaline with depth (pH >6 below 20 cm). Major constraints to chickpea cultivation are initial and terminal drought stress, pod borer (Helicoverpa armigera), and nutrient deficiency. Application of phosphorous (P) fertiliser can increase chickpea yields, but even when this is done symptoms of reddening, yellowing, and necrosis of older leaves are widespread across the HBT. Nodulation is generally sparse but responses to Rhizobium inoculation have been inconsistent. To determine which elements could be limiting to chickpea, a small-plot field experiment was conducted in the southern HBT in the 2001/02 season. A subtractive design was used in which the absence of either sulphur (S), boron (B), zinc (Zn), or molybdenum (Mo) was compared to a complete nutrient control. Only Mo was found to be limiting, giving a grain yield response of 73%.

In 2002/03, multilocational trials in farmers' fields were conducted to test the effect of soil application with 500g Mo ha^{-1} and Rhizobium inoculation. Despite frequent rain during the reproductive phase, causing unprecedented infestation by Botrytis grey mould and exacerbating damage by pod borer, grain yield responses to Mo application alone were 173% in the northern HBT, 61% in the central-north HBT, and 58% in the southern HBT. There was a further slight, non-significant response to Rhizobium inoculation.

There are no compound fertilisers containing Mo available in Bangladesh, and it is impractical to broadcast the small amount of Mo required evenly (<500g Mo ha^{-1}). Previous studies indicated that sufficient Mo and Rhizobium could be added via seed priming – soaking the seed in water overnight prior to sowing. In the 2003/04 season, the effect of adding Mo alone or Mo with Rhizobium via seed priming was compared with surface application of Mo in multilocational trials in farmers' fields. Adding Mo alone to the priming water did not significantly improve yield over the control, but there were significant responses to adding both Mo and Rhizobium in priming, of the same order as the response obtained when Mo was applied directly to the soil.

The response of chickpea to Mo, applied either through priming or broadcast on the soil surface, and with inoculation of Rhizobium through priming, was evaluated in on-farm trials conducted on rice-fallow lands with acid soils in eastern India in 2003/04. In 29 trials with chickpea cv. ICCV 2, the mean yield increase *over a control without Mo (mean yield 869 kg ha^{-1}) was 21.6% when Mo was applied through seed priming water and 20.3% when Mo was applied to the soil. In 19 trials with chickpea cv. KAK 2, the mean yield increase over a control without Mo (mean yield 784 kg ha^{-1}) was 16.8% when Mo was applied through seed priming water and 24.6% when Mo was applied to the soil.*

The results suggest that the severe nitrogen (N) deficiency of chickpea crops commonly observed in the HBT and in eastern India is caused by inadequate levels of Mo and Rhizobium in the soil. This problem can be alleviated effectively by a simple low-cost technology within the scope of resource-poor farmers by adding these entities in the seed priming process. To confirm this technology and its acceptability to farmers, it is intended to carry out a large number of farmer-implemented, operational-scale evaluations in the 2004/05 season.

Introduction

Chickpea (*Cicer arietinum* L.) is an important grain legume in the Middle East and South Asia. It normally grows on receding soil moisture on the alkaline soils of these regions; the crop has evolved on and is adapted to such soils (Saxena and Singh 1987). In Bangladesh, it is increasingly being grown on residual soil moisture after rainy season rice in the High Barind Tract (HBT) in the northwest of the country (Musa et al. 2002). The soils in this region are formed on alkaline alluvium, but the surface soils have acidified in the humid, tropical climate (pH 5.0-6.0 at 0-20 cm but pH 6.0-7.5 below 20 cm) (Brammer 1996). Chickpea yields are usually <1t ha^{-1} even though the yield potential for the region, obtained in some plots under favourable circumstances, is >2t ha^{-1}. The major constraints to chickpea cultivation in the region are drought stress and pod borer (*Helicoverpa armigera*), but in many locations vegetative growth is stunted with yellowing and reddening of older branches and their eventual necrosis. These symptoms resemble nitrogen (N) and/or phosphorous (P) deficiency (Smith et al. 1983). Experiments using inoculation of *Rhizobium* have been carried out at various times, but responses have been negligible and inconsistent (e.g., Kumar Rao et al. 2001). Although growth and yield responses to P application can be found (e.g., Ali 2000), addition of P fertiliser does not necessarily alleviate the symptoms.

It is possible to alleviate drought effects on chickpea through seed priming (Musa et al. 2001) and use of varieties with a duration providing a better match to the period of soil moisture availability. It is also possible to minimise pod borer damage through an integrated pest management (IPM) approach (Johansen and Musa 2004; Musa and Johansen 2003b). However, to increase yields and stability of yield, it is necessary to diagnose and address the suspected nutrient limitations. Besides P deficiency, sulphur (S) deficiency is increasingly recognised as a limitation to the yields of many crops in Bangladesh, especially those of oilseeds and pulses (Brammer 1996). Boron (B) deficiency is reported to be widespread in many crops, including chickpea crops, in northern Bangladesh where surface soils are acid (Ahmed and Hossain 1997). Boron deficiency also severely limits chickpea yields in the acid soils of the Terai in Nepal (located just to the north of Bangladesh); and chickpea also responds to Mo on these soils (Srivastava et al. 1997). In the predominantly alkaline soils of Bangladesh (unlike in the HBT with its acid surface soil), zinc (Zn) deficiency is common (Brammer 1996), and this may be a problem for roots feeding on deeper soil horizons in the HBT.

There are large areas of rice-fallow land in adjacent parts of India and Nepal with acid soils but otherwise apparently suitable for chickpea cultivation, but they are rarely used for chickpea or other legume cultivation (Subbarao et al. 2001). Diagnosis of the nutrient constraints to chickpea cultivation in the HBT of Bangladesh may also have relevance to these areas. A programme was introduced to first diagnose the nutrient limitations, and second develop methods for alleviating any deficiencies detected that are relevant for the resource-poor farmers of the region who grow chickpeas.

Materials and Methods

Diagnostic trial, 2001-02

An experiment was conducted using a subtractive experimental design with the following treatments.

1. Control: no seed treatment or addition of minor elements
2. Seed-treated control: seed priming (soaking of seeds in water for eight hours overnight prior to sowing), inoculation with *Rhizobium*
3. Full nutrient control (all): Treatment 2 with the following elements added (kg ha^{-1}): 1.0 B + 0.5 Mo + 5 Zn + 20 S – reagent grade salts were used.
4. Treatment 2 with Mo + Zn + S; i.e., all minus B
5. Treatment 2 with B + Zn + S; i.e., all minus Mo
6. Treatment 2 with B + Mo + S; i.e., all minus Zn
7. Treatment 2 with B + Mo + Zn; i.e., all minus S

An experiment was carried out in a farmer's field at Chabbishnagar Village, Godagari Upazilla, Rajshahi District, HBT (southern part), Bangladesh. Soil samples were taken at depths of 0–10, 0–15, and 15-30 cm, with one composite sample per replication. They were analysed by the Soil Resources Development Institute (SRDI), Shyampur, for pH, organic carbon, total N, and available P. A complete randomised block design was used with four replications. The plot size was 1.8 x 2.0m, with six rows of chickpea variety BARI chola 5 sown 30 cm apart and 2m long. The land was ploughed and levelled on 16 November 2001 and fertilisers added and seeds sown on 17 November 2001. Furrows were opened to about 6-8 cm depth and fertiliser added evenly throughout the furrows of a plot, according to treatment. Test fertilisers were mixed with river sand to aid even distribution. Phosphorous was also added to each plot in the furrows at 20 kg P ha^{-1}, as triple superphosphate (TSP). Furrows were then partially filled with soil, to a depth of 4-5 cm, in order to prevent direct contact of the seeds with fertiliser and hence possible nutrient toxicity, and seeds placed at 5 cm intervals within a row. The furrows were immediately covered and spray irrigation applied to the soil surface through a hose. This was considered necessary to ensure even germination. Previous attempts to carry out the experiment in the preceding two seasons had had to be abandoned due to uneven emergence caused by rapid drying of the soil surface once furrows were opened. Careful planting in rows in small plots was considered necessary in order to reduce variability to the extent that treatment differences could be detected.

The crop was grown rainfed, with only 16 mm of rainfall falling on the crop during January/February 2002. Plots were thinned to give a within-row spacing equivalent to 10 cm at 20-30 days after sowing. No weeding was necessary. Sprays of *Helicoverpa* nuclear polyhedrosis virus (HNPV) were given to the crop on 5 and 23 January 2002 to control pod borer (*Helicoverpa armigera*) (Musa and Johansen 2003b). This proved effective as there was negligible pod damage. Vegetative growth was ranked in each plot on 2 February 2002. The plot with the least growth was designated '1' and that with most '5'. A plot intermediate between these was designated '3'; a plot intermediate between '1' and '3' was designated '2'; and one between '3' and '5' was designated '4'. All other plots were ranked in relation to these reference plots. Due to the small plot size, plant samples were not cut to calibrate rank with dry mass; thus only rankings were analysed. Plots were harvested at maturity on 22 March 2002. The central two rows of each plot were harvested to avoid border effects, grain was separated from above-ground residues, and all samples were sun-dried. Four adjacent plots along one edge of the experiment nearest a footpath had been damaged by passing humans and grazing animals. These included two full nutrient control plots (Treatment 3) and one each of 'minus B' (Treatment 4) and 'minus Zn' (Treatment 6). It was therefore considered appropriate, and necessary, to exclude these plots from the statistical analysis of the experiment. A missing plot technique was applied prior to analysis of variance, according to Steel and Torrie (1980).

Multilocational Mo experiments

In order to determine how widespread Mo deficiency is across the HBT, and whether or not a *Rhizobium* response can be found in the presence of Mo, on-farm trials were carried out in the northern (Porsha), central (Gomostapur), and central-southern (Amnura) regions of HBT in 2002/03. Treatments were applied as follows.

1. Control: recommended agronomic practices for chickpea (Musa and Johansen 2003a), including seed priming, 20 kg P ha^{-1} as TSP, hand broadcasting, cross-ways ploughing, rainfed, IPM for pod borer and so on
2. As for control but Mo added as sodium molybdate, mixed with river sand, at a rate of 500g Mo ha^{-1}
3. As for control but with Mo added and *Rhizobium* inoculation with inoculum from the Bangladesh Institute of Nuclear Agriculture (BINA), including lime pelleting after coating seed with sticker and inoculum

The experiment was laid out in a randomised block design in farmers' fields with five dispersed replications each at three locations with acid surface soils: a) Naogaon District, Porsha Upazilla – farm of Shamsul Huq, Gupinathpur village (Nithpur); b) Chapai Nawabganj District, Gomostapur Upazilla – farm of Md. Ashraf Ali, Borodadpur village ; and c) Chapai Nawabganj District, Nawabganj Sadar Upazilla, Amnura – farm of A. Mannan, Sukhandighi village. The unit plot size was 10 x 10m. The three treatment plots of a replication were placed near each other in the same field. The chickpea variety BARI chola 5 was sown as follows: Porsha – 25 November 2002; Gomostapur – 26 November; Amnura – 27 November.

Soil samples were taken at depths of 0-10, 10-20, and 20-30 cm at each location, one set from the approximate location of each replication (i.e., 5 replications of samples per site). They were analysed by SRDI, Shyampur, for pH, organic carbon, total N, and available P. Sub-samples of the 0-10 and 10-20 cm samples were sent to ICRISAT for estimation of the most probable number (MPN) of chickpea rhizobia (Toomsan et al. 1983) and analysis of soil Mo after extraction with ammonium bicarbonate-diethylenetriamine-pentaacetic acid (AB-DTPA) and measurement using an inductively-coupled plasma (ICP) emission spectrometer according to the method of Sims (1996). Plant symptoms and incidence of pests and diseases were noted during crop growth. Nodulation was scored, according to the visual ranking scale of Rupela (1990), on 8 February at Amnura and 9 February at Porsha and Gomostapur. Five plants per plot were dug up and ranked. Plots were harvested as follows: Porsha – 5 April 2003; Gomostapur – 3 April; Amnura – 6 April. At harvest, 5 x 1m^2 quadrats were cut from each plot and plant number and grain and residue yields estimated after air drying. Some seed samples from treatments with and without Mo (Treatment 2) were ground and sent to Cornell University, USA, for Mo analysis by inductively coupled atomic emission spectroscopy (Gupta 1998).

Mo x priming experiments

To determine if Mo could be applied in the seed priming process, and whether a response to *Rhizobium* could be obtained in the presence of Mo, on-farm trials with the following treatments were established at three locations in the HBT in the 2003/04 season.

1. Control: recommended agronomic practices for the HBT (Musa and Johansen 2003a), i.e., seed priming, 20 kg P ha^{-1} as TSP, hand broadcasting, cross-ways ploughing, rainfed, IPM for pod borer, and so on
2. As for control but Mo added as sodium molybdate at the rate of 500g Mo ha^{-1}, mixed with river sand and spread on the soil surface prior to ploughing
3. As for control but Mo added to the priming water at the rate of 0.5g sodium molybdate l^{-1} priming solution, ensuring that all seeds were covered with the priming solution but that most of the priming water was absorbed by the seeds after 8 hours
4. As for control but with both Mo and *Rhizobium* (BINA inoculum) added in the priming solution (*Rhizobium* inoculum at 4g l^{-1} priming solution) (Kumar Rao et al. in prep)

The experiment was laid out in a randomised block design in farmers' fields with five dispersed replications each at three locations with acid surface soils: a) Naogaon District, Porsha Upazilla, Shaharandpur Village; b) Chapai Nawabganj District, Gomostapur Upazilla, Borodadpur Village ;and c) Rajshahi District, Tanor Upazila, Mundamallah Village . Unit plot size was 7.07 x 7.07m (50m^2). The four treatment plots of a replication were placed next to each other in the same field. The chickpea variety BARI chola 5 was sown as follows: Porsha – 30 November 2002; Gomostapur – 29 November; Tanor – 1 December. The crops were grown rainfed following the practices recommended by Musa and Johansen (2003a).

Soil sampling and analysis, nodulation estimation (5 February 2004 at all locations), harvesting (Porsha and Gomostapur – 29 March 2004; Tanor – 28 March 2004) were carried out as described for the previous season. However, two replications were discarded from the Porsha site, due to irrigation spillage from adjacent fields, and one from Gomostapur due to poor establishment.

Mo x priming experiments Eastern India, 2003/04

Seventy-two on-farm trials with the following three treatments were conducted in selected rice-fallows of Orissa, Chattisgarh, Jharkhand, eastern part of Madhya Pradesh, and West Bengal states of India during the 2003/04 post-rainy season with the objective of knowing the response of chickpea crops to Mo applied through seed priming in comparison to Mo applied to soil. The three treatments were as follows.

1. Primed chickpea seed + *Rhizobium* but without Mo (control) (4g of peat-based *Rhizobium* culture were mixed with one litre of water used to prime one kg chickpea seed – seed priming comprised of soaking the seed in water for four to six hours, followed by air drying to facilitate seed handling for sowing)
2. Primed chickpea seed + *Rhizobium* + Mo (Mo was added as sodium molybdate at a rate of 0.5g l^{-1} of priming water per kg of chickpea seed)
3. Primed chickpea seed + *Rhizobium* but with Mo added to soil at a rate of 500g Mo ha^{-1} as sodium molybdate – 12.2g of sodium molybdate was mixed with river sand or fine soil and applied evenly to a 10 x 10m plot and mixed with soil before sowing.

The three treatments were placed close to one another in a given farmer's field. A composite soil sample was taken from a depth of 0–15 cm from the control treatment for chemical analysis. A basal dressing of 150 kg single superphosphate ha^{-1} (= 24 kg P_2O_5 ha^{-1}) was given uniformly by broadcasting it to all the treatments. Two chickpea varieties, namely, ICCV 2 and KAK 2, both cream-coloured Kabuli varieties, were used for these trials: however, only one variety was used in a given farmer's field. The seed was sown following rainy season rice in November/December 2003, either by dropping it in a furrow behind the plough then covering it during the next pass of the plough or broadcasting followed by cross-ways ploughing and laddering. The crop was grown rainfed and farmer managed. The crop was sampled for nodulation near flowering time. For this, three to five plants in each treatment were uprooted carefully and assigned a nodulation ranking according to Rupela (1990). At crop maturity in March 2004, three to four quadrats of 1 m^2 per treatment were harvested and sun dried. Observations on the plant stand, grain yield and stover yield were recorded. The yield data were analysed using REML (restricted or residual maximum likelihood) with a linear fixed model – GENSTAT version 7.1.0.198); overall treatment means of each genotype are presented with a standard error of deviation. Chickpea grain samples were ground, digested with a tri-acid mixture sulphuric, nitric, and hyperchloric acid (H_2SO_4 + HNO_3 + $HClO_4$) and the digest analysed for Mo by inductively-coupled plasma (ICP) emission spectrometer (Benton Jones and Case 1990).

Results

Diagnostic trial, 2001/02

The soil at the Chabbishnagar location was typical of that across the HBT (Brammer 1996) with acid soil at the surface, pH increasing with depth, and low organic carbon and total N levels decreasing with depth (Table 1).

From the end of January 2002, there was a lighter green colour and, in early February, less estimated vegetative growth in plots to which Mo was not added (viz. Treatments 1, 2, and 5) (Table 2). The oldest branches of plants in plots with Mo had much less red and yellow colouration than those in plots without Mo. At harvest, grain yield was significantly less in plots without Mo (Table 2). Compared to the 'minus Mo' treatment, yield was 73% higher in the full nutrient control due to addition of Mo alone. There was a similar effect on yield of total aerial biomass (grain yield + residue yield), although there was a late recovery of growth in the non-nutrient controls (Treatments 1 and 2) (Table 2). Omission of B, Zn, or S did not cause any reduction in growth or grain yield (Table 2).

Table 1: Soil analyses mean ± standard deviation at locations of on-farm experiments in the High Barind Tract, 2001/02 to 2003/04 seasons (n = 4 in 2001-02 and n = 5 subsequently)					
Location in HBT	**Soil depth (cm)**	**pH (1:2 soil: water)**	**Organic C (%)**	**Total N (%)**	**Available P (Olsen's $\mu g\ g^{-1}$)**
2001/02 season					
Chabbishnagar - south	0-10	4.9 ± 0.05	1.6 ± 0.03	0.07 ± 0.005	5.3 ± 1.35
	0-15	5.4 ± 0.05	1.2 ± 0.10	0.07 ± 0.005	4.7 ± 0.71
	15-30	6.2 ± 0.21	0.7 ± 0.08	0.04 ± 0.010	2.6 ± 0.54
2002/03 season					
Porsha – north	0-10	5.3 ± 0.51	2.7 ± 0.17	0.12 ± 0.035	3.3 ± 0.88
	10-20	5.9 ± 0.42	1.7 ± 0.28	0.09 ± 0.031	1.7 ± 0.53
	20-30	6.3 ± 0.34	0.9 ± 0.07	0.08 ± 0.004	1.0 ± 0.33
Gomostapur – central-north	0-10	5.8 ± 0.38	2.3 ± 0.33	0.12 ± 0.007	1.1 ± 0.61
	10-20	6.5 ± 0.51	1.6 ± 0.18	0.07 ± 0.028	1.4 ± 0.38
	20-30	7.5 ± 0.30	1.0 ± 0.09	0.07 ± 0.011	1.3 ± 0.42
Amnura – central-south	0-10	5.9 ± 0.41	2.1 ± 0.21	0.09 ± 0.026	2.0 ± 1.57
	10-20	6.7 ± 0.36	1.4 ± 0.07	0.07 ± 0.019	2.4 ± 1.45
	20-30	7.3 ± 0.23	0.8 ± 0.07	0.05 ± 0.011	1.5 ± 0.81
2003/04 season					
Shaharandpur – north	0-10	4.6 ± 0.07	1.6 ± 0.07	0.09 ± 0.004	1.9 ± 0.21
	10-20	5.2 ± 0.26	1.0 ± 0.08	0.06 ± 0.000	1.5 ± 0.14
	20-30	6.3 ± 0.23	0.6 ± 0.16	0.04 ± 0.009	1.2 ± 0.18
Gomostapur – central-north	0-10	5.3 ± 0.21	1.3 ± 0.13	0.08 ± 0.008	2.2 ± 0.98
	10-20	6.1 ± 0.26	0.9 ± 0.14	0.05 ± 0.001	1.5 ± 0.49
	20-30	6.8 ± 0.26	0.5 ± 0.07	0.03 ± 0.005	1.3 ± 0.28
Mundamullah – south	0-10	4.8 ± 0.40	1.4 ± 0.20	0.12 ± 0.015	3.1 ± 0.98
	10-20	5.4 ± 0.76	0.8 ± 0.21	0.07 ± 0.015	2.5 ±0.64
	20-30	6.2 ± 0.49	0.5 ± 0.08	0.05 ± 0.008	2.8 ± 1.10

Multilocation Mo experiments, HBT 2002/03

Soil surface pH was lowest at Porsha, but at all locations pH increased with depth (Table 1). Organic carbon, total N, and available P declined with soil depth and were generally at low levels (Table 1). The concentration of Mo in the soil was below the detectable limit of 0.02 ppm at all locations. There were most native rhizobia, of the type that could nodulate chickpea, at Amnura, and least at Porsha (Table 3). By early February 2003, treatment differences were apparent at all locations, with more yellowing/reddening and less growth vigour in the control treatment. At Porsha and Gomostapur, treatments with Mo were a bright, dark green, consistent with nitrogen adequacy. At Porsha only, there appeared to be a further response to addition of *Rhizobium*. Nodulation was poor in the control treatment at all locations and consistent with the N deficiency symptoms apparent (Table 3). Addition of Mo alone caused a significant increase in nodulation over the control. Addition of *Rhizobium* caused a further nodulation response only at Porsha, consistent with the lowest *Rhizobium* population found here (Table 3). It therefore seems that rhizobia able to nodulate and form N-fixing nodules in chickpea were present at all sites, but that addition of Mo was required for proper functioning of nodules.

Table 2: Effect of different nutrient treatments on eye-estimated vegetative growth at 77 days after sowing, and grain and residue yield at harvest (125 days after sowing), Chabbishnagar, High Barind Tract, Bangladesh, 2001/02 post-rainy season			
Treatment	**Growth ranking [1]**	**Grain yield ($g\ m^{-2}$)**	**Aerial biomass ($g\ m^{-2}$)**
1. Zero control	2.1	117	288
2. Seed treated control	2.0	105	249
3. Full nutrient control	3.4	163	334
4. All –B	3.5	164	328
5. All –Mo	2.1	94	211
6. All –Zn	3.8	140	329
7. All –S	4.0	152	327
Standard error of difference between means	*±0.63*	*±16.6*	*±26.8*
Significance of difference	*P<0.05*	*P<0.005*	*P<0.001*

[1] Eye estimated growth ranking where 1 is least growth and 5 is most growth.

Table 3: Estimation of chickpea rhizobial population and mean nodulation ratings [1] in on-farm molybdenum response trials conducted during the 2002/03 rabi season, HBT, Bangladesh (MPN g^{-1} dry wt. soil; mean and range)			
Source of sample	**Location**		
	Porsha	**Gomostapur**	**Amnura**
Rhizobial population (MPN g^{-1} dry wt soil [2])			
0-10 cm soil	4×10^1 ($0 - 1.5 \times 10^2$)	4.99×10^6 ($0 - 2.45 \times 10^7$)	4.99×10^3 ($1.5 \times 10^2 - 2.47 \times 10^5$)
10-20 cm soil	5×10^1 ($0 - 1.5 \times 10^2$)	1.2×10^4 ($1.5 \times 10^2 - 4.36 \times 10^4$)	4.94×10^5 ($1.5 \times 10^2 - 2.45 \times 10^6$)
Nodulation score			
Control	1.0	1.4	1.1
+ Mo	2.3	2.9	2.0
+ Mo + *Rhizobium*	3.5	3.0	2.3
SE (±) [3]	*0.33*	*0.34*	*0.37*
Significance	*P<0.005*	*P<0.005*	*P<0.05*

[1] According to the 1-5 scale of Rupela (1990) where 1 = minimal nodulation and 5 = abundant nodulation;
[2] MPN = most probable number; [3] Standard error of difference between two sample means.

Unusually excessive rain in March and April 2003 resulted in an unprecedented severe infestation of *Botrytis* grey mould (BGM) and promoted pod borer damage, thereby generally lowering yields. This effect of excess moisture was most severe at Gomostapur. Nevertheless, responses of grain yield and total aerial biomass to Mo were apparent at all locations, although the variability at Amnura prevented the response reaching significance there (Table 4). The overall Mo response across sites was significant (Table 4). Only at Gomostapur was there an additional response to application of *Rhizobium*.

Addition of Mo to the soil markedly increased seed concentration of Mo at Porsha from 1.35 mg g^{-1} in the control to 3.57 mg g^{-1} with Mo. Respective values for Amnura were 0.64 and

Table 4: Effect of application of Mo and *Rhizobium* on grain and total aerial biomass yield of chickpea in the HBT in the 2002/03 season				
Treatment	Location			
	Porsha	Gomostapur	Amnura	All locations
Grain yield (t ha^{-1})				
Control	0.37	0.33	0.70	0.47
+ Mo	1.01	0.54	1.10	0.88
+ Mo + *Rhizobium*	1.12	0.70	1.13	0.98
SE (±)[1]	*0.156*	*0.033*	*0.197*	*0.152*
Significance	*P<0.005*	*P<0.005*	*n.s.*	*P<0.001*
Aerial biomass yield (t ha^{-1})				
Control	1.02	1.03	1.68	1.25
+ Mo	2.28	1.35	2.63	2.09
+ Mo + *Rhizobium*	2.61	1.70	2.49	2.27
SE (±)[1]	*0.314*	*0.093*	*0.473*	*0.336*
Significance	*P<0.005*	*P<0.005*	*n.s.*	*P<0.001*

[1] Standard error of difference between two sample means

0.86 mg g^{-1} and for Gomostapur 0.67 and 0.53 mg g^{-1}. The pod damage due to rainfall and BGM infestation at the reproductive stage may have contributed to such variability and lack of response at Amnura and Gomostapur. A separate study on the effects of Mo fertilisation on accumulation of Mo in vegetative tissue and seed was carried out at Amnura in this season, and the results are being reported separately.

Mo x priming experiments HBT, 2003/04

Trends of decreasing acidity, organic carbon, total N, and available P with soil depth were apparent at each trial location, as in previous seasons (Table 1). Soil Mo concentrations were below the detectable limit of 0.02 ppm. Rhizobial numbers in 2003/04 soil samples are currently under assessment. Nodulation was poor at all locations in control treatments and only significantly improved in the presence of Mo and *Rhizobium* at Gomostapur and Mundamullah (Table 5). In contrast to the previous season, there was no rain during the chickpea growing period in 2003/04 and crops suffered terminal drought stress, with consequent yield reduction. Only at Gomostapur was grain and aerial biomass yield significantly improved by addition of Mo to the soil (Table 6). Addition of Mo and *Rhizobium* in the priming water had a similar effect, but addition of Mo alone to the priming water did not significantly increase yield above the control. These trends were similar at the other locations but statistical significance was not reached (Table 6), although the overall response across sites was significant.

Mo x priming experiments Eastern India, 2003/04

A total of 245 soil samples at depths of 0-15 cm, representing farmers' fields having rice-fallows in Chattisgarh, Madhya Pradesh; Orissa, West Bengal; and Jharkhand were collected and analysed for pH and Mo at the ICRISAT Centre, Patancheru, Andhra Pradesh, India. So far about 90 of these samples have been analysed for B, S, available P (Olsen's P), Zn, and organic carbon. The results indicate that the soils are mostly acidic with mean pH ranging

Table 5: **Mean nodulation ratings[1] in on-farm Mo response trials conducted during the 2003/04 rabi season, HBT, Bangladesh.**

Source of sample	Location		
	Shaharandpur	Gomostapur	Mundamullah
Control	1.2	1.1	1.7
Soil applied Mo	1.3	1.6	1.7
Mo with priming	1.1	1.9	2.1
Mo + *Rhizobium* with priming	1.7	2.3	2.8
SE (±)[2]	*0.29*	*0.40*	*0.33*
Significance	*n.s.*	*P<0.10*	*P<0.05*

[1] According to the 1-5 scale of Rupela (1990) where 1 = minimal nodulation and 5 = abundant nodulation
[2] Standard error of difference between two sample means.

Table 6: **Effect of adding Mo and *Rhizobium* in the priming solution on grain and total aerial biomass yield of chickpea at three locations in the HBT in the 2003/04 season**

Treatment	Location			
	Shahrandpur	Gomostapur	Mundamullah	All locations
Grain yield (t ha^{-1})				
Control	0.62	0.32	0.67	0.54
Soil applied Mo	0.89	0.68	0.96	0.84
Mo with priming	0.66	0.48	0.93	0.69
Mo + *Rhizobium* with priming	0.93	0.61	0.92	0.82
SE (±)[1]	*0.180*	*0.090*	*0.218*	*0.126*
Significance	*n.s.*	*P<0.01*	*n.s.*	*P<0.01*
Aerial biomass yield (t ha^{-1})				
Control	1.42	0.74	1.30	1.15
Soil applied Mo	2.07	1.37	1.91	1.78
Mo with priming	1.57	1.01	1.76	1.45
Mo + *Rhizobium* with priming	2.06	1.25	1.74	1.68
SE (±)[1]	*0.388*	*0.172*	*0.366*	*0.210*
Significance	*n.s.*	*P<0.05*	*n.s.*	*P<0.001*

[1] Standard error of difference between two sample means

5.4-7.5. The Mo content of the rice-fallows was either nil or less than 0.04 ppm (Table 7). Most of the soils were deficient in B, S, and available P (Olsen's P, data not presented). The soil analysis for native populations of chickpea *Rhizobium* is in process.

A total of 72 on-farm trials spread over the five states of India mentioned above were sown. In many of these trials the chickpea plants were light green in the control plots, i.e., without Mo, but greener in the plots that received Mo either through seed priming or soil application. Sixty-nine out of 72 trials were sampled at flowering time and scored for nodulation ranking

Table 7: **Mean of soil pH and Mo levels at 0 -15 cm in rice fallows in eastern India, some fields of which were used for Mo response trials with chickpea during the 2003/04 season**

State	District	No. of farmers fields	pH	Mo (ppm)
Madhya Pradesh	Satna	60	6.78	0.021
Madhya Pradesh	Dindori	41	6.66	0.008
Madhya Pradesh	Mandla	34	6.68	0.038
Jharkhand	Latehar	8	6.46	0.036
West Bengal	Purulia	39	6.12	0.029
West Bengal	Malda	2	5.79	0.033
West Bengal	Darjeling	1	4.32	0.052
Chattisgarh	Bastar	11	6.02	0.024
Orissa	Sundergarh	6	5.69	0.001
Orissa	Kandamal	5	5.93	0.002
Orissa	Mayurbhanj	23	6.54	0.002

on a scale of 1 to 5 (Rupela 1990). The nodulation was lowest in the 'control' plot. Mo application through seed priming resulted in a 58% increase in chickpea nodulation compared to the control, while soil application of Mo resulted in a 31% increase in nodulation over the control (Table 8). These results suggest that Mo application was essential for proper nodule development and functioning.

At maturity, yield data were collected from only 48 trials (29 trials having cv. ICCV 2 and 19 trials having cv. KAK 2) as the remaining trials were damaged either by theft by human beings and damage by animals or by drought stress. Molybdenum application through seed priming increased grain yield of ICCV 2 by 21.6% (1057 kg ha^{-1} vs 869 kg ha^{-1}), while soil application of Mo resulted in 20.3% increase (1045 kg ha^{-1} vs 869 kg ha^{-1}) (Table 9). Molybdenum application either through seed priming or soil application increased stover yield by 15%. In the case of cv. KAK 2, a bold seeded Kabuli chickpea variety, Mo application through seed priming increased grain yield by 16.8% (916 kg ha^{-1} vs 784 kg ha^{-1}), while soil application of Mo increased the yield by 24.6% (977 kg ha^{-1} vs 784 kg ha^{-1}). Stover yield of KAK 2 was also increased by Mo application – 20.2% through seed priming and 28.5% through soil application (Table 9).

Discussion

In the diagnostic trial, alleviation of the yellow and red coloration in the oldest branches in treatments with Mo added is consistent with the role of Mo in nitrogen fixation (Srivastava 1997). At this location, the pH of the soil was strongly acidic near the surface and increased with depth (Table 1), which would indicate unavailability of Mo to plants in the surface soil at least (Lindsay 1972). There was no response to addition of either B, Zn, or S and thus Mo deficiency appears to be the major nutrient limitation to growth and yield of chickpea crops at this location.

The soil at this location is typical of that across the HBT, at least in terms of pH changes with soil depth (Brammer 1996). It could thus be expected that there would be a Mo limitation across the entire region and, therefore, multilocational trials to measure Mo response across the HBT were initiated in the 2002/03 season. It was realised that Mo

Table 8: Mean nodulation ratings[1] of chickpea grown in rice fallows in on-farm Mo response trials conducted during the 2003/04 season, eastern India						
State	**Village**	**T 1[2]**	**T 2**	**T 3**	**SE (±)[3]**	**Significance[4]**
West Bengal	Gobradhi	0.3	1.3	0.4	0.16	P<0.05
West Bengal	Jahajpur	1.5	2.6	2.4	0.28	P<0.05
West Bengal	M. Sahar	0.8	1.2	1.2	0.14	ns
West Bengal	Parkidi	0.9	1.6	0.9	0.18	P<0.05
Jharkhand	Sirish	2.3	2.6	2.3	0.23	ns
Madhya Pradesh	Bhodhgundi	1.5	1.9	1.6	0.17	ns
Madhya Pradesh	Divlaha	0	0.7	1.3	0.24	P<0.05
Madhya Pradesh	Kanpur	0.7	1.3	1.3	0.19	ns
Madhya Pradesh	Mudukhua	2.3	2.3	1.7	0.77	ns
Madhya Pradesh	Patni	1	2.7	1.7	0.19	P<0.01
Madhya Pradesh	Padariya	1.6	1.8	2.4	0.20	P<0.05
Madhya Pradesh	Rohania	1.7	2	2	1.26	ns
Madhya Pradesh	Singarpur	1.1	1.5	1.3	0.13	ns
Madhya Pradesh	Umariya	0	0.7	1.3	0.24	P<0.05
Chattishagarh	Chivurgaon	0	2	1	0.33	P<0.05
Chattishagarh	Kirigoli	0	1.1	0.7	0.11	P<0.01
Chattishagarh	Kondagav	0	1.2	0.7	0.22	P<0.01
Orissa	Asana	1.2	1.3	1.3	0.09	ns
Orissa	Kanchikana	0.6	2.8	1.2	0.31	P<0.01
Orissa	Thakurpalli	1.6	1.4	1.4	0.51	ns
	Mean	0.9	1.7	1.4		

[1] According to the 1-5 scale of Rupela (1990) where 1= minimal nodulation and 5= abundant nodulation.
[2] T1 = Control (seed primed with *Rhizobium*); T2 = Seed primed with *Rhizobium* + Mo;
T3 = Seed primed with *Rhizobium* but Mo applied to soil; [3] Standard error of difference between means
[4] P = probability; ns = not significantly different

Table 9: Effect of Mo application through seed priming and soil application on grain and stover yields of chickpea cvs. ICCV 2 and KAK 2 in farmers' fields of eastern India following rice, post-rainy season 2003/04				
Treatment	**Chickpea cultivar**			
	ICCV 2[1]		**KAK 2[2]**	
	Grain yield (t ha^{-1})	**Stover yield (t ha^{-1})**	**Grain yield (t ha^{-1})**	**Stover yield (t ha^{-1})**
Control (no Mo)	0.87	1.71	0.78	1.57
Mo applied by seed priming	1.06	1.97	0.92	1.89
Mo applied to soil	1.05	1.96	0.98	2.02
SE (±)[3]	*0.036*	*0.069*	*0.050*	*0.129*
Significance	*P<0.01*	*P<0.01*	*P<0.01*	*P<0.01*

[1] Mean of 29 on-farm trials spread over Orissa, West Bengal, Jharkhand, Madhya Pradesh and Chattisgarh states of India; [2] Mean of 19 on-farm trials spread over Madhya Pradesh, Orissa and Chattisgarh; [3] Standard error of difference between two sample means

deficiency may have been limiting any response to *Rhizobium* inoculation, and so a treatment with *Rhizobium* inoculation was included. The 2002/03 results confirm that Mo deficiency is widespread across the HBT, and that it occurs when pH of the surface soil is in the range pH 5-6, even though sub-surface soil pH tends towards neutral. Although addition of *Rhizobium* in the presence of Mo further improved nodulation, it only significantly improved crop growth and grain yield at one location, Gomostapur. Addition of Mo alone significantly improved nodulation (Table 3), and this indicates that its presence is necessary for nodule development.

In the on-farm experiments initially conducted, Mo had been applied through a carrier, inert river sand, due to the small amounts of Mo required to improve functioning of the nitrogen-fixing symbiosis. This is impractical for resource-poor farmers to implement over large areas. In other countries where Mo deficiency is common, macronutrient fertilisers are fortified by adding appropriate amounts of Mo (e.g., molybdenised superphosphate in Australia). No such compound fertilisers are available in Bangladesh. Another common method of applying Mo is through a seed dressing, such as inoculation of *Rhizobium* on to seed (Murphy and Walsh 1972), but the experience of resource-poor farmers in South Asia adopting seed-dressing techniques has usually not been successful (e.g., failure to adopt *Rhizobium* inoculation technologies even when good responses can be demonstrated – Rupela et al. 1994). Other methods of applying Mo include soil or foliar fertilisation of the seed crop to load the seed with sufficient Mo for the next generation; again, not practical for resource-poor rural communities.

Recent studies in Nepal have shown that sufficient Mo can be loaded into chickpea seed through soaking seed prior to sowing in a solution with Mo (Johnson 2004). A concentration of 0.5g sodium molybdate l^{-1} of water was found optimum, adding sufficient Mo to the seed to elicit a Mo response but not enough to induce Mo toxicity. During 1998/99 to 2001/02, a successful programme of seed priming of chickpeas was carried out in the HBT (Musa et al. 2001). This involved soaking the seed overnight for eight hours prior to sowing in order to increase seedling vigour in rapidly drying seedbeds. Mean yield increases due to priming were in the range of 20-50% over the four-year period (Musa et al. 2001) and farmers readily adopted this simple but effective technology (Saha 2002). It was therefore considered worthwhile to try combining Mo application with the seed-priming process. Further, Kumar Rao et al. (2001) had shown that when *Rhizobium* was added in the priming solution its effectiveness was the same as that of seed inoculation by traditional methods. Thus there was the possibility of combining Mo and *Rhizobium* application with the priming process already adopted which was tested in the HBT in the 2003/04 season.

In the HBT, adding Mo to the priming solution was not as effective as soil application of Mo, but adding both Mo and *Rhizobium* in priming was as effective (Table 6). The best nodulation was also obtained in the primed treatment with both Mo and *Rhizobium* (Table 5). It therefore appears necessary to add both Mo and *Rhizobium* inoculum to overcome the problem of inadequate N fixation in the HBT which is caused by both Mo deficiency and low numbers of native rhizobia that are infective and effective for chickpea crops.

In general, the analysed rice-fallow soils of eastern India were of low fertility with pH in the acidic to neutral range (about 5 to 7). Our recent studies indicate that most of the rice-fallow soils were either devoid of chickpea rhizobia or if present they were in low numbers. Further, the soils were deficient not only in Mo but also in other nutrient elements such as available P, B, and S. Molybdenum application resulted in a significant increase in chickpea nodulation, growth, and final yields, and it created a positive impact on farmers. Therefore it is imperative to recommend *Rhizobium* inoculation and application of Mo for effective symbiosis and nitrogen fixation of chickpeas particularly in rice-fallows of eastern India. We also need to know the extent of limitation of chickpea growth and yield as a result of other nutrient deficiencies such as B, S, and others. If they play a critical role in legume growth, then we need to consider ways of supplementing these specific nutrients as well.

Addition of requisite amounts of Mo and *Rhizobium* to the priming solution shows promise as a technique that is feasible for use by resource-poor farmers to overcome Mo, and ultimately N, deficiencies in chickpeas. Widespread farmer-managed evaluation of the technique is now required in potential chickpea-growing areas with acid soil in South Asia. This would require production of packets of the requisite quantities of Mo salt and *Rhizobium* inoculum to be added to a specified volume of water as the seed-priming solution. After training in quality control, preparation of such packets could be developed as a village-level enterprise, contributing to local income generation. Packets and the recipe to follow could then be distributed to farmers. Such a programme is intended for Bangladesh, eastern India, and Nepal in the 2004/05 chickpea season.

Despite the promise of pursuing on-farm evaluation of the technique, some further back-up research is needed. For soil application of Mo, a rate of 500g Mo ha^{-1} was used, although optimum rates could be much less (e.g., 50-200g Mo ha^{-1}; Murphy and Walsh 1972). To add Mo through seed priming, only around 10g Mo ha^{-1} is required. However, further work is needed to establish optimum concentrations in the priming solutions to meet the Mo requirements of the plant but to avoid Mo toxicity to the germinating seed. There may be varietal differences in this regard. Also, this technique of applying Mo, and *Rhizobium* if required, in the priming solution needs to be evaluated for other crop species that are grown on acid soils. Efforts are also required to establish protocols for quality control of Mo and *Rhizobium* supply and use, so that farmers will have confidence in the technology.

Further work is also required to establish the extrapolation zone of the technology, the regions prone to Mo deficiency in South Asia. Primarily, this is defined by soil acidity (Cox and Kamprath 1972; Johansen et al. 1997) and thus comprehensive geographic information system (GIS) maps indicating the soil reaction characteristics of the region are needed. Measures of soil Mo have not previously proved very useful for prediction of Mo response, due to the dependence of Mo availability to plants on soil pH. Critical values of Mo in chickpea tissue have yet to be established, as reports of Mo responses in chickpeas are rare as they are normally cultivated on neutral to alkaline soils. Actual growth response to Mo obtained in the field also needs to be plotted on GIS to obtain a comprehensive picture of Mo deficiency across the region; and thus scope will be provided for its correction through priming technology.

Acknowledgements

We thank the technical support staff of BARI-OFRD-Barind (2001/02) and PROVA for their inputs into these experiments. We are grateful to the participating farmers for use of their land for experimentation and their continued interest in developing improved methods of cultivation for chickpeas. We thank our collaborating partners, namely, the Catholic Relief Services (CRS)-India Program and Gramin Vikas Trust (GVT) – Eastern India Rainfed Farming Project, for their inputs into these experiments. This paper is an output from projects (Plant Sciences' Research Programme R7540, R8269 and R8221) funded by the UK Department for International Development (DFID) and administered by the Centre for Arid Zone Studies (CAZS), University of Wales, for the benefit of developing countries. The views expressed are not necessarily those of DFID.

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Wheat Sterility Induced by Boron Deficiency in Nepal

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Abstract

This paper describes the nature and extent of wheat sterility in Nepal, its relation to boron deficiency in soil, and research carried out to circumvent the problem. Sterility (grain set failure) problems in wheat in Nepal have been reported since the introduction of semi-dwarf wheat varieties during the mid 1960s. The problem is widespread in the eastern, central plains, and mid hill areas of Nepal. The extent of the problem is severe, ranging from 0 to 100% grain set failure depending upon genotypes. Boron deficiency has been considered a major factor among the various factors causing wheat sterility. Boron deficiency problems have also been reported in some other crops such as vegetables and legumes.

Application of boron to the soil at sowing has a significant positive effect on the number of grains per spike, reduction of sterility, and increased wheat grain yields. Screening of a large number of genotypes in a boron deficient soil showed great genetic variation in sterility ranging from 0 to 100%, suggesting the possibility of selection for low soil boron efficient genotypes.

Introduction

Bread wheat (*Triticum aestivum* L.) is the third largest cereal crop in Nepal after rice and maize and plays an important role in the country's food security. Nepal produces 1.387 million tonnes of wheat annually from 0.665 million hectares. The present national average wheat yield is 2087 kilograms per hectare. Although wheat is grown throughout the country, 93% of its total acreage lies in the mid hills and plains. More than 85% of the wheat area of the country is farmed in a rice-wheat system. The remaining 15% includes maize-wheat, maize+millet-wheat, and other combinations. The total and partial factor productivity of the rice-wheat cropping system has declined in recent years (Hobbs and Morris 1996). Soil micronutrient deficiencies are widespread in the 12 million hectares in South Asia where the rice-wheat system is followed (Nayar et al. 2001) and have contributed to declining productivity in this system. Of these zinc (Zn), boron (B), iron (Fe), molybdenum (Mo), and manganese (Mn) are the major micronutrients found to be insufficient in the soil.

Wheat sterility was first observed in Brazil in 1962 (da Silva and da Andrade 1980). Widespread sterility was observed in Nepal in 1964 when improved, high-yielding Mexican wheat was introduced and in introduced Indian cultivars in the following year (Mishra et al. 1992). Factors suggested to be responsible for sterility include boron deficiency (Rerkasem and Loneragan 1994), low radiation (cloudy dull weather, morning fogs, mists) (Willey and Holliday 1971, Saifuzzaman 1995), low temperature during reproductive development (Sthapit et al. 1989; Subedi 1992), waterlogging at flowering, low soil nitrogen and dry wind (Mishra et al. 1992), high temperatures (Saini and Aspinall 1982), high humidity (Dawson and Wardlaw 1989), low humidity (Galrao and Sousa 1988), drought or water shortage (Saini and Aspinall 1981), and high pH (Bell and Dell 1995). Of all these factors, boron deficiency and cold temperatures are the only causes that have been conclusively proven: sterility was effectively reduced by boron application in one study (Sthapit 1988). A soil boron concentration of <1 ppm is considered deficient (Landon 1992). In some cases, however, notably at higher altitudes, low temperature stress was suspected as a contributing factor because boron application did not cure sterility (Sthapit 1988).

Soil boron deficiency not only results in sterile young terminal florets but also in sterile older florets situated at the base of a spikelet. Boron is essential for cell wall development of the generative organs and wheat pollen is very sensitive to adequate boron supply for germination and growth (Matoh et al. 1992; Rerkasem and Loneragan 1994). Boron deficiency results in the failure of pollen tube growth due to a reduction in development of the pollen tube cell wall leading to failure in fertilisation, or sterility (Blevins and Lukaszewski 1998; Rerkasem and Jamjod 1997). Therefore, a crop of a wheat variety susceptible to sterility may have luxurious vegetative growth, but boron deficiency at the critical stage of anthesis would result in sterile spikes with low yield.

Climatic conditions (such as cloudy days and low or high temperature), very high soil pH, waterlogging, and so on influence the degree of crop response to boron application in wheat (Bell and Dell 1995; Saifuzzaman 1995; Mishra et al. 1992). Boron is readily leached. It is estimated that there is a 30% reduction in soil boron concentration after 25 mm of rainfall. The occurrence of such a fall during the reproductive stages is also likely to cause boron deficiency (Ralph 1992).

During the late 1960s and early 1970s, wheat sterility in Nepal was confined to the eastern Terai (Sarlahi to Jhapa) and Chitwan Valley (Figure1), but it is now increasing and extending to other areas where it was not a problem before. It is seen in the low hills, high hill rainfed lands, and Terai areas of the central and western development region. The problem is slowly extending towards the western and mid-western Terai. The extent of the problem ranges from 0 to 100% sterility, depending upon the wheat variety.

Sterility caused by cold temperature can be managed to some extent in the high hills by adjusting planting dates. Application of boron at a rate of 2 kg/ha has been observed to be very effective in mitigating the sterility to a great extent, but some varieties have been reported to be non-responsive. The best solution would appear to be to breed varieties tolerant to low soil boron content. Genetic variability for tolerance to low soil boron exists, and varieties can be selected for this trait (Bhatta 2000; Rerkasem and Jamjod 1997; Sthapit 1988; Joshi and Sthapit 1995). This paper summarises the results of variety screening with and without boron in boron deficient soils.

Methods of sterility estimation

There are six methods of sterility estimation described by Sthapit and Subedi (1990): 1) the visual method; 2) Lumle Agricultural Centre (LAC) method; 3) modified Chinese method; 4) International Maize and Wheat Improvement Centre (CIMMYT) method; 5) Thai method; and 6) Chinese method. The most commonly used methods in Nepal are the visual, LAC, and Thai methods. In the visual method, spike sterility in per cent is estimated by visual observation after the anthesis and later stages. However, this method needs some experience in identifying sterile spikes.

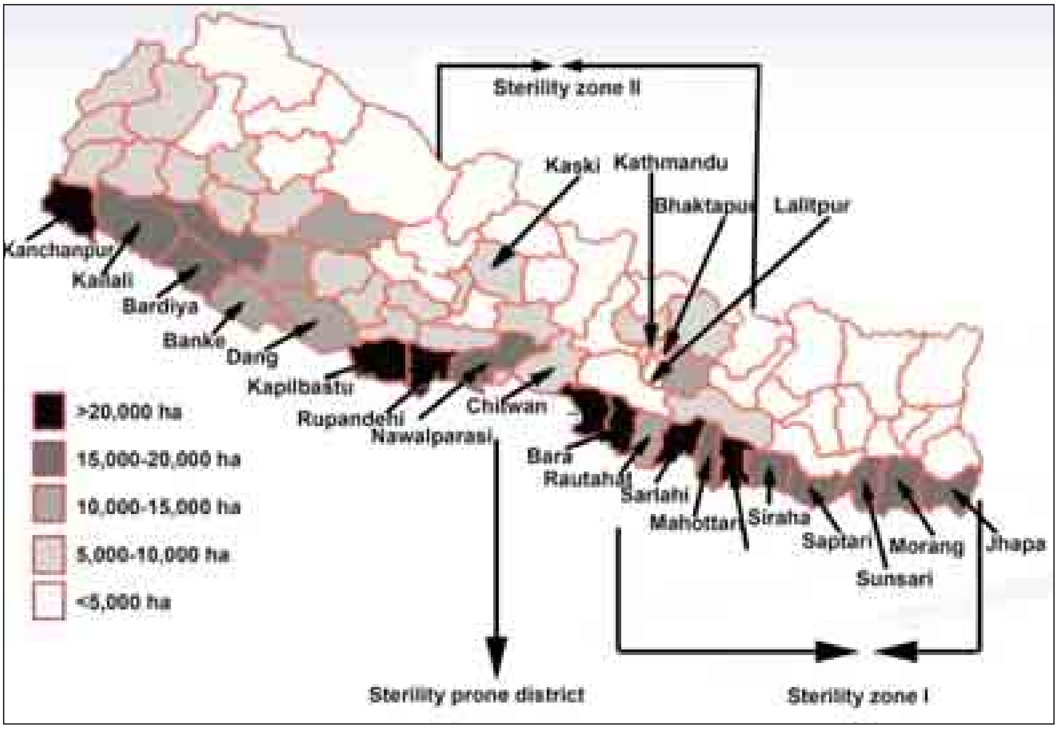

Figure 1: **Wheat growing areas and sterility prone zones in Nepal**

In the LAC method:

$$\text{sterility}\,\% = \frac{a-b}{a.100}$$

where, a = the number of florets per spike, b = number of grains set per spike.

In the Thai method:

$$\text{sterility}\,\% = \frac{c-d}{c.100}$$

where, c = number of F1+F2 florets per ten central spikelets, d = number of grains per ten F1 + F2 florets of ten spikelets.

All six methods for estimating sterility were studied by Sthapit and Subedi (1990) and a similarity was found among all methods. They concluded that for variety screening, the visual method of estimating sterility is useful, easy, rapid, and labour saving.

Materials and Methods

Many investigators of wheat sterility in Nepal have carried out studies during the last two decades. Past studies on wheat sterility mainly concentrated on finding the causes of sterility, surveying wheat sterility, methods of estimating sterility, and the effect of boron and other nutrients on sterility. So far there have been no reports of variety screening for genotypes with low soil boron tolerance, despite the availability of sufficient genetic variability among wheat germplasm.

In earlier investigations, data was gathered on boron sensitive genotypes and other factors affecting sterility. During the 1999 wheat season, 31 wheat genotypes with wide genetic bases were planted in four rows of plots two metres long, with and without boron, on the Sipaghat rice-wheat site in Kabre district. Sipaghat is situated at a fairly low altitude (650-750 masl). Boron at a rate of 2 kg/ha was used as a basal application. Visual observation of sterility was made at Zadok's growth stage 71 by carefully looking at and grasping the spike.

Another experiment with two dates for planting and three wheat varieties was carried out at Tarahara Agricultural Station during the 1987/88 wheat season to study the effect of boron, date of planting, and variety on spike sterility. Boron was applied to the soil in amounts of 1.65 kg/ ha before sowing. Other nutrients (nitrogen, phosphorous, and potassium [NPK]) were applied as per recommendations. Wheat was planted on December 8th and 22nd to investigate the effects of planting time on sterility. Estimation of sterility was arrived at using the LAC method described in this paper. Three popular wheat varieties, Nepal 297, UP 262, and BL 1022 were selected for the study.

The National Wheat Research Programme (NWRP) has emphasised the need to identify genotypes tolerant to low soil boron content. For this purpose, the Jute Research Programme (JRP) situated at Itahari in Sunsari district has been selected as a screening location. The soils at the JRP site are light textured and deficient in soil boron (<0.2 ppm), and susceptible wheat genotypes exhibit 100 per cent sterility. The NWRP is screening a large number of genotypes for the purpose of identifying sterility tolerant varieties. Two hundred genotypes were planted during the wheat seasons of 2002/03 and 317 genotypes during 2003/04. They had different genetic bases and were planted in two rows of plots two metres long. Other inputs and management conditions were provided as per recommendations. Sterility percentage of genotypes was recorded on the basis of visual observation during the post anthesis stage.

During the 2003/04 wheat season, participatory varietal selection consisting of seven genotypes took place in six farmers' fields differing in boron content in Kaski district. Soil analysis was carried out for available NPK, organic matter, boron, and pH. The percentage sterility for a susceptible genotype, BL 1813, was assessed using the LAC method.

Results and Discussion

Varietal differences and response of applied boron

The thirty-one wheat genotypes evaluated at the Sipaghat rice-wheat site during the 1999 wheat season, with and without boron, showed great genotypic variation in terms of sterility (Table 1). There was a clear-cut difference among genotypes in spike sterility. Sterility among genotypes in plots without added boron (boron minus) varied from 1 to 100 %. There was a drastic reduction in sterility in plots to which boron was added (boron plus), indicating that boron deficiency is a major cause of sterility in the area. Sterility among genotypes in boron plus plots varied from 0 to a maximum of 5 %, whereas in boron minus plots some varieties exhibited up to 100% sterility. Two of the control varieties, Achyut and Annapurna[-1], had a high degree of sterility (70 to 80%) in boron minus plots.

Table 1: Response of 31 wheat genotypes to applied boron (2 kg/ha) in a sterility screening nursery, Sipaghat, Kabre district, 1999			
SN.	**Genotype**	**Sterility % (+ Boron)** [1]	**Sterility % (- Boron)** [1]
1	BL 1473	1	4
2	WK 823	1	5
3	NL 769	2	5
4	NL 810	1	70
5	WK 831	2	99
6	NL 818	1	99
7	NL 783	2	60
8	NL 816	1	95
9	NL 820	4	90
10	BL 1692	1	5
11	BL 1720	5	100
12	BL 1724	0	5
13	BL 1810	1	95
14	NL 750	0	15
15	NL 753	2	90
16	NL 781	2	70
17	NL 792	2	60
18	NL 867	1	2
19	NL 868	5	95
20	NL 870	2	70
21	NL 872	0	1
22	NL 876	1	15
23	NL 901	0	3
24	NL 902	0	1
25	NL 903	0	1
26	RR 21 (control)	0	2
27	UP 262 (control)	1	3
28	Bhrikuti (control)	3	15
29	Rohini (control)	0	2
30	Achyut (control)	2	80
31	Annapurna^{-1} (control)	0	70

Source: Bhatta 1999 (u npublished data) ; [1] Sterility scores were based on visual observation

Response to planting dates and applied boron

In the 1987/88 study, a wide variation was found in spike sterility (0 to 82%) among the different treatments: planting date, variety, and boron application (Table 2). Application of boron at 1.65 kg/ha significantly reduced spike sterility, regardless of planting date but there were varietal differences (Table 2).

Table 2: Percentage spike sterility of wheat cultivars (UP 262, Nepal 297, and BL 1022) as influenced by dates of boron application at Tarahara agricultural station, 1987				
Variety	Planting date			
	Minus boron		Plus boron @ 1.65 kg/ha	
	8 Dec	22 Dec	8 Dec	22 Dec
UP 262	27.0	3.0	0.3	0.0
Nepal 297	41.7	8.3	10.0	1.0
BL 1022	15.0	81.7	0.0	1.7
Source: Sthapit 1988				

Genotypic variability to low soil boron content

A large number of wheat genotypes were evaluated at the Jute Research Programme, Itahari, Sunsari district, under low soil boron content (<0.2 ppm) in the wheat seasons of 2003 and 2004. Two hundred genotypes with differing genetic base were included in the test during 2003 and 317 during 2004. Spike sterility among genotypes ranged from 0 to 100% in both years (Figures 2 and 3). Several genotypes had 0 to 5% spike sterility, demonstrating tolerance to low soil boron content. During the 2004 season, 43 genotypes of the 317 genotypes screened exhibited 0% spike sterility, and 76 showed very low (1-5%) sterility. In contrast, 58 showed 100% spike sterility. This study showed that boron efficient genotypes could be identified and selected in terms of good agronomic types simultaneously.

Participatory varietal selection

In participatory variety selection (PVS) trials carried out on six farmers' fields, the degree of spike sterility of wheat variety BL 1813 was found to vary with soil pH and boron content of the soil (Table 3). The lowest sterility (11.6%) was observed in Madhav Baral's field, which had slightly acidic soils and a boron content of 0.39 ppm. The table indicates some relationship between soil pH, boron content, and spike sterility. Spike sterility was highest in Gita Adhikari's field (85%) despite it having the highest soil boron (0.83 ppm) presumably as a result of the high soil pH; a similarly high sterility was observed in Mukti Tiwari's field despite the comparatively low pH, presumably as a result of the very low soil boron (0.08 ppm), whereas low sterility was observed in Madhav Baral's field with slightly acidic soil and high organic matter, although boron was only medium. In general, it seemed that high soil pH restricts the availability of boron and plays a role in sterility.

The wheat genotypes listed in Table 4 were identified and selected from a hot spot in the eastern Terai. These genotypes not only have low spike sterility but are also good agronomic types. These types show that it is possible to select genotypes that are both good agronomic types and sterility tolerant through plant breeding and screening them in hot spots.

Conclusions and Recommendations

a) Wheat sterility has become a potential threat to wheat production in many parts of the country, including the mid-hills and the Terai.
b) Boron deficiency, cold temperature, and waterlogging at anthesis are considered to be the major factors causing spike sterility in wheat in Nepal.
c) Boron deficiency induced sterility is serious in the low hills and the Terai where the rice-wheat system is common.

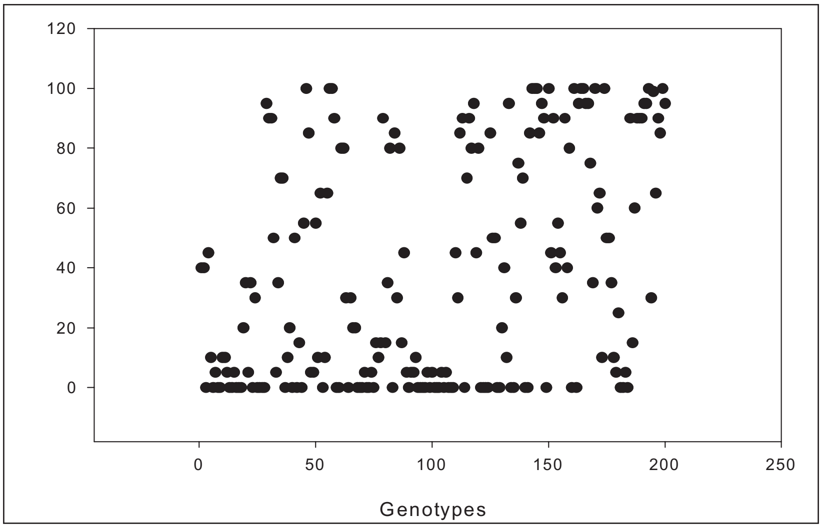

Figure 2: **Genotypic variation in wheat sterility, Jute Research Programme, 2003**

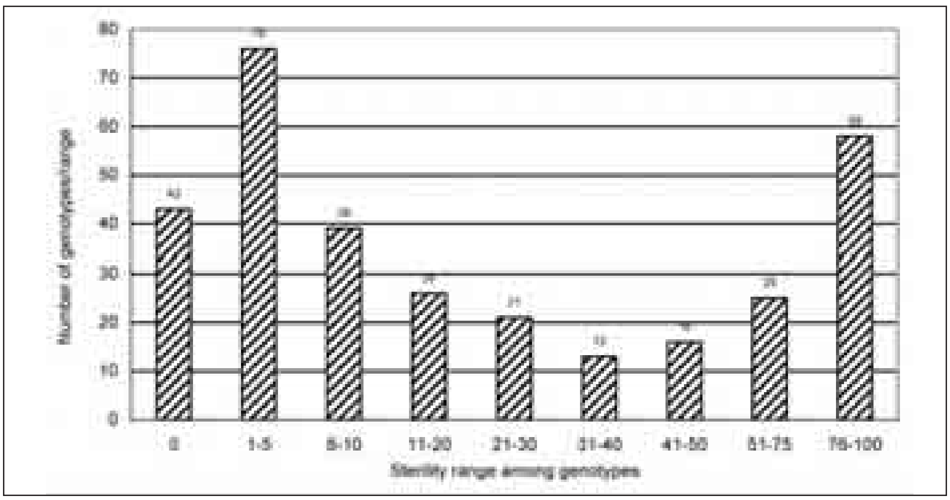

Figure 3: **Differential response of genotypes to wheat sterility, Jute Research Programme, 2004**

Table 3: Percentage sterility of variety BL 1813 planted in different farmers' fields, and soil characteristics in six mother trials in Kaski (2003/04)

			Soil characteristics					
Farmers conducting mother trial	**Sterility (%)**	**Soil type**	**pH**	**% OM**	**%N**	**P_2O_5 (mg/kg)**	**K_2O (mg/kg)**	**Boron (ppm)**
Sita Bhandari	63	S. Loam	7.87	1.03	0.07	9.6	16.4	0.21
Madhav Baral	11.6	S. Loam	5.96	3.05	0.16	7.85	21.2	0.39
China Lamichhane	66.7	S. Loam	7.83	1.08	0.07	5.55	21.6	0.15
Mukti Tiwari	81.1	S. Loam	6.4	1.28	0.08	5.6	28.1	0.08
Chandrakanta Pageni	77.4	S. Loam	8.04	2.64	0.14	7.9	51.6	0.09
Gita Adhikari	85	S. Loam	8.05	2.77	0.15	2.1	36	0.83
OM = organic matter								

Table 4: **Wheat varieties/lines that are good agronomic types and have tolerance to sterility under low soil boron conditions in the eastern Terai**

Varieties/lines	Sterility %
BL 2195	5
BL 2196	1
BL 2151	Trace
BL 2173	Trace
BL 2175	1
BL 2153	Trace
BL 2169	Trace
BL 2163	Trace
BL 2158	Trace
BL 2202	Trace
BL 1473*	Trace
Nepal 297*	Trace

Source: Bhatta 2000 (unpublished data)

* Nepal 297 and BL 1473 are the two popular varieties tolerant to sterility in Nepal.

d) The adverse effects of spike sterility in wheat caused by soil boron deficiency could be corrected by applying 2 kg/ha of boron to the soil at planting time.
e) There is wide genetic variability in tolerance to sterility caused by boron deficiency.

The following recommendations are made.

a) Wheat varieties efficient in soils with low boron content that are also good agronomic types need to be developed and identified through plant breeding and screening in hot spot locations.
b) The findings of conventional plant breeding techniques should be linked to biotechnological tools to identify potential donors of sterility tolerant traits through molecular markers.
c) Boron deficient areas in the country need to be identified and GIS (geographical information systems) maps of them prepared.

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Annexes

Annex 1: Summary of Group Discussions

Tasks

- Summarise major findings and make recommendations
- Identify important issues
- Develop outline for future study (Brief PCN)

Group A: Human nutrition
Group B: Soil/plant interaction
Group C: Soil nutrient management/Soil mapping

Group A: Human nutrition

Major findings, recommendations, and issues

- Many findings were described in the workshop. The major finding is that agriculture and nutrition are closely linked. Throughout the workshop, new knowledge was gained from and by the participants.
- Education and awareness: the role of micronutrients in human health is vital and rural poor communities need to receive this knowledge.
- Nutrient providers are none other than the 'farmers', so we should educate and mobilise them.
- There is a lot of discrete knowledge; everything needs to be put in a concise way to lead to an outcome, maybe in the form of a programme or policy.
- Knowledge has not yet been made available or acceptable to the farmers.

Future plans/studies

- Constitute a working group that involves agriculture, nutrition, and health department people.
- The working group should come up with a plan that identifies/addresses the problems pertaining to the area.
- The working group should consider policy makers, education, and training, and this should be followed up by a case study.
- Finally the organisations interested should develop strategies and objectives to achieve nutritional security and form a work plan.

Group B: Soil/plant interaction

Findings

- Zn, B, Mo, and Fe deficiency is widespread in most of the soils of India, Nepal, Bangladesh, and Pakistan. B and Mo deficiency are particularly common in acidic soils, and Zn deficiency in most rice soils.
- Grain legumes respond to Zn, B, Fe, and Mo in most of the deficient soils in India, and toria responds to B, Zn, and Mo in sandy loam acidic soils of Nepal.
- In India, aromatic rice responds to Zn.
- B-efficient cultivars have been identified for cultivation in the B-deficient soils of Nepal.
- Priming of chickpea seeds with *Rhizobium* and Mo in west Bangladesh and eastern

India, and priming of wheat and chickpea seed with Zn in Pakistan, proved effective in correcting the deficiency of Mo and Zn.
- Se deficiency in goats caused infertility in Nepal.

Recommendations

- In general, soil application of Zn and B, and foliar sprays of Mo and Fe, at recommended rates and timed effectively to compensate for the deficiency are recommended.
- Use of enriched seeds either by seed priming or use of mother seed can be cost effective for resource-poor farmers.
- Micronutrient deficient cultivars having high-yield potential can be recommended wherever they have been identified.
- Use of organic manure is recommended wherever available to reduce micronutrient deficiency.
- Foliar application to a strip of crops in a farmer's field for a suspected micronutrient deficiency may be used as a diagnostic tool for identifying a nutrient deficiency disorder.

Future Studies

- Development or identification of micronutrient efficient and Fe and Al tolerant cultivars
- Synergistic and antagonistic interactions of nutrients in areas of multiple deficiencies in order to optimise rates of application
- Micronutrient requirements for important cropping systems as a whole
- Role of organics in supplementing micronutrients in important cropping systems
- Characterisation and publication of deficiency symptoms of micronutrients in important crops of the region
- Se deficiency status of soils, plants, and water in areas where deficiency is suspected
- Trace element deficiency and toxicity in the soil-plant-animal-human chain

Group C: Soil nutrient management/Soil mapping

Mapping

- Develop regional/country maps for micronutrient status, crop responses, indigenous knowledge, human and animal deficiencies, and other related factors
- Develop maps suitable for extension purposes and government/policy makers/planners
- Prioritise mapping according to economic importance and human health values for micronutrients and micronutrient impacts, particularly for Zn, B, Mo, and Se

Important issues identified

- Adaptive micronutrient research suitable for resource poor farmers, through research outreach programmes/extension and development stakeholders
- Adaptive research programmes should use participatory approaches with special emphasis on poor farmers
- Training for agricultural stakeholders based on adaptive research results; stakeholders include input suppliers, farmers, and development workers with the knowledge

Prioritise activities across research problems

- Human health should also be considered when making recommendations

- Recommendations should be specific for ecosystem diversities
- Prioritisation of adaptive research issues based on economic modelling that includes human health costs, crop returns, sustainability, probability of success, and others

Identify appropriate micronutrient management options

- Management of organic inputs/FYM, crop residues
- Inorganic inputs: soil application
- Foliar spray
- Seed treatment: seed priming, seed enrichment
- Agronomic management, e.g., water management in rice
- Use of efficient crop varieties, rotations, and *Rhizobium*

Communication strategy

- Develop mechanisms to link different aspects of micronutrient research in relation to crop, animal, and human health activities
- Develop communication systems for sharing knowledge and experiences between regions, countries, institutions, and research and development workers across disciplines
- Identify contact persons from each country and institution for future communication
- Identify a regional coordinator/facilitator or a leading institute for future programme development

Programme development strategy

- Quantify benefits of micronutrient research and development as the basis for justifying programmes to donors
- In the development funding strategies, emphasise the impact on human welfare and the consequences of failure, act now to address micronutrient deficiencies
- Document successful impacts on poor rural populations of micronutrient R&D programmes

Miscellaneous

- Develop and strengthen the supply chain with quality control of micronutrient products and technologies by working with the private sector
- Develop regional and national research capacities to address micronutrient research issues/problems efficiently

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Micronutrients are elements that are needed by plants, animals, and human beings in minute quantities, but their presence is essential for health. Increasingly, Asian soils and food are affected by micronutrient disorders, leading to reduced crop yields and malnutrition. In this book, international researchers present problems and solutions.

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ISBN 92-9115-210-2